Water Management

The Irrigator's Pocket Guide

NCAT NATIONAL CENTER FOR APPROPRIATE TECHNOLOGY

NCAT ATTRA SUSTAINABLE AGRICULTURE

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Key Organizations & Resources for Irrigators

Organizations

The Natural Resources Conservation Service (NRCS)

NRCS is the primary private lands conservation agency within the U.S. Department of Agriculture (USDA), committed to helping agricultural producers, conservation districts, and other partners protect and conserve natural resources.

One of the best sources of information for irrigators, NRCS offers conservation programs and technical assistance—including one-on-one personalized advice—through State and Regional Offices and local Service Centers. While irrigation-related services vary from state to state, NRCS offers:

- Technical assistance with planning, designing, and improving irrigation systems.
- Soil survey information.
- Snow survey and water supply forecasting.
- Cost-sharing through many programs such as the Environmental Quality Incentives Program (EQIP), Agricultural Conservation Easement Program (ACEP), Conservation Stewardship Program (CSP), and Regional Conservation Partnership Program (RCPP).

  Main website: **nrcs.usda.gov**

Find the USDA Service Center closest to you:
nrcs.usda.gov/contact/find-a-service-center

Or contact your state office:
nrcs.usda.gov/conservation-basics/conservation-by-state/state-offices

Conservation Districts

Conservation districts are units of local government, established under state law and each managed by an elected governing board, whose purpose is to coordinate assistance from all available sources—public and private, local, state, and federal—to develop locally-driven solutions to natural resources concerns. They work closely with the NRCS, and their offices are often co-located with an NRCS Field Office in a USDA Service Center.

Depending on your state, they may be called "natural resource conservation districts" (AZ), "resource conservation districts" (CA), "natural resources districts" (NE), "land conservation departments" (WI), "soil conservation districts" (ID, ND, UT, MD, NJ, PR, TN) or "soil & water conservation districts" (AL, AK, CT, DC, FL, GA, HI, IL, IN, IA, LA, ME, MN, MS, MO, NM, NY, NC, OH, OR, SC, TX, VA, and the Pacific Basin).

Across the United States, nearly 3,000 conservation districts work with landowners to conserve and promote healthy soils, water, forests, and wildlife.

It's worth getting to know your local conservation district and learning what they offer. Besides being great sources of information, conservation districts sponsor resource restoration projects, landowner workshops, demonstrations, tours, and other educational programs.

The National Association of Conservation Districts (NACD) is the nonprofit organization that represents America's conservation districts.

nacdnet.org

506 Capitol Court, NE

Washington, DC 20002-4937 (202) 547-6223

Cooperative Extension System

More than 100 colleges and universities in the Land Grant University System are committed to "extension" as part of their mission: bringing research-based information to agricultural producers, small business owners, consumers, and others who can use it.

Many of these colleges and universities, especially in major agricultural states, have research and technical assistance programs on irrigation and offer publications, training, real-time evapotranspiration estimates, and other resources.

Most counties and tribal areas in the United States have an Extension office—part of the USDA's Cooperative Extension System (CES)— that provides practical, research-based information. Extension offices are usually conveniently located in town courthouses, post offices, and other local government buildings.

For general information:

> **usda.gov/topics/rural/cooperative-research-and-extension-services**

To find Land-Grant colleges and universities in your state:

> **nifa.usda.gov/about-nifa/how-we-work/extension**

State Departments of Agriculture

In addition to their familiar role in regulation, inspections, marketing, certification, and promoting the state's agriculture, state departments of agriculture often offer technical and financial assistance programs of interest to irrigators.

To learn more about irrigation-related resources and services available from your state's department of agriculture:

> **nasda.org/about-nasda/state-agriculture-departments**

State Soil Health Programs

Most states have passed healthy soils legislation and are running state-level programs to encourage agricultural practices that promote soil health. While programs vary widely between states, they sometimes offer grants to implement on-the-ground soil health improvement projects.

To learn about soil health programs and the status of soil health policy in your state:

nerdsforearth.com/state-healthy-soils-policy

Other Selected Sources of Irrigation Information

ATTRA Sustainable Agriculture Information Service

Managed by NCAT, the National Center for Appropriate Technology, ATTRA offers hundreds of publications, videos, podcasts, and one-on-one technical assistance on soil health, water conservation, organic farming, and all other aspects of sustainable agriculture.

ATTRA.NCAT.ORG

Soil for Water Program

Another program of NCAT, Soil for Water is a peer-to-peer learning community, resource, and story collection devoted to learning and sharing information about all possible ways of catching and storing more water in soil.

SOILFORWATER.ORG

The American Society of Irrigation Consultants

A society of professional irrigation consultants, ASIC offers a membership directory that's helpful for finding an irrigation consultant in your area.

asic.org

The Center for Irrigation Technology

Located within California State University, Fresno, CIT offers equipment testing, seminars, workshops, publications, software, news announcements, and more.

jcast.fresnostate.edu/cit

The Irrigation Association

A national trade organization of irrigation professionals, equipment manufacturers and suppliers, the Irrigation Association offers books, self-study resources, training, and technical papers.

irrigation.org

The Irrigation Training and Research Center

Located at the California Polytechnic State University in San Luis Obispo, ITRC conducts research and provides publications, software programs, and training through short courses each year on irrigation system design, evaluation, and management.

itrc.org

National Drought Mitigation Center

The National Drought Mitigation Center helps people and organizations build resilience to drought, offering publications and other educational and planning resources and tools and maintaining the U.S. Drought Monitor.

drought.unl.edu

National Integrated Drought Information System

NIDIS is a multi-agency partnership that coordinates drought monitoring, forecasting, planning, and information at national, tribal, state, and local levels, including many resources for agriculture.

drought.gov

NRCS National Water and Climate Center

The National Water and Climate Center offers irrigation reports, guides, statistics, photos, and links, including snowpack data, climate monitoring and streamflow forecasts.

nrcs.usda.gov/wps/portal/wcc

OpenET

Developed by the USDA Agricultural Research Service and many partners, OpenET uses NASA satellite data (such as leaf temperature, leaf size, and solar radiation) along with meteorological, soil, and vegetation datasets, to provide free evapotranspiration estimates for the entire western United States. User-friendly maps allow you to zoom in on individual fields, even small ones, and check ET for the crops growing in those fields, down to one quarter acre resolution.

openetdata.org

U.S. Bureau of Reclamation (BOR)

Best known for managing dams, power plants, and canals across the western United States, the U.S. Bureau of Reclamation also offers many helpful resources for irrigators.

Main website: **usbr.gov**

Water Measurement Manual:

usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm

WaterSMART Water and Energy Efficiency grants:

usbr.gov/watersmart/weeg

USDA Climate Hubs

The 10 regional USDA Climate Hubs deliver science-based knowledge, practical information, management & conservation strategies, and decision tools to help farmers, ranchers, and forest landowners adapt to weather variability and changing climatic conditions.

climatehubs.usda.gov

The National Water Information System

Maintained by the U.S. Geological Service, the National Water Information System offers current and historical information about groundwater conditions as well as real-time data from over 13,000 stream flow, lake, reservoir, precipitation, and water quality stations.

waterdata.usgs.gov/nwis/gw

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Introduction

First and foremost, good irrigation water management is a matter of maintaining a suitable environment for growing crops by keeping soils from getting too wet or too dry. To achieve this goal, almost all irrigators should:

1. Maintain and improve their soil's health and ability to catch and hold water.
2. Check actual soil moisture levels in the field.
3. Know how much irrigation water they're applying.
4. Know and follow crop-specific watering guidelines for the crops they're growing.

Many irrigators take their management to a higher level of control and precision:

5. Closely tracking evapotranspiration and planning their irrigations to match crop water use.

The ***Water Management*** side of this book describes several ways of doing each of these five things. Specific actions you can take are marked with a checkmark (✓), and the exclamation mark **!** indicates safety hazards, potential equipment or crop damage, or other situations calling for extra caution.

This new edition incorporates many improvements, including a greater emphasis on the topic of ***soil health***. Since the book first appeared 20 years ago, there have been major advances in soil biology and a nationwide soil health awareness campaign led by the USDA Natural Resources Conservation Service. When soils get healthier, they often catch and hold more water and become more drought resilient. Although often neglected in irrigation manuals, soil health needs to be a high priority for all irrigators

Over the past two decades, the western United States has experienced some of the most persistent and severe drought conditions in its history. We hope this book enables you to run your irrigation system more efficiently and consider converting to more efficient irrigation methods.

Wherever possible, we have followed the terminology and general recommendations of the NRCS ***Irrigation Guide***. Readers looking for deeper and more technical discussions of the topics in this guidebook are strongly encouraged to consult that comprehensive and authoritative manual.

No one knows more than you do about your fields and irrigation system. So adjust or reject any suggestion in this book if it doesn't fit your situation or doesn't seem to be working. Proceed cautiously and test every recommendation with direct observations in the field

References

USDA Natural Resources Conservation Service. 1997. **Irrigation Guide:** Section 15 of the **National Engineering Handbook**. directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba

1. Know Your Soils

This chapter explains:

- How soil holds water
- Soil moisture terminology
- How to learn your soil's texture, type, and series

Soil Textures and Types

Soils are classified into about a dozen standard ***textures*** or ***texture classes***, based on the ratio of sand, silt, and clay particles. For example, a soil that's 20 percent clay, 60 percent silt, and 20 percent sand (by weight) is classified as silt loam. ***Coarse-textured*** soils have a high percentage of sand and ***fine-textured*** soils have a high percentage of clay.

Soils are also classified into ***soil types*** and ***series***, based on factors such as geology, chemistry, and age. There are over 20,000 named soils in the U.S. alone, with names often referring to a town or landmark near where the soil was first recognized. For example, the Houston Black series is a clay soil formed under prairie vegetation in Texas, and the Myakka series is a wet sandy soil found in Florida. The full description of a soil series includes its layers or ***horizons***, starting at the surface and moving downward.

How Soil Holds Water

Soil holds water in small pores, just like a sponge. A soil's ability to hold water depends heavily on its texture, with fine-textured soils usually (but not always) holding more water than coarse-textured soils.

During rainfall or irrigation, pore spaces largely created by soil life (i.e. plant roots, earthworms, bacteria, and fungi) fill with water. After the pores are saturated, water keeps draining while evaporation at the surface pulls water upward through *capillary forces,* like water climbing up a paper towel. Capillary forces also hold water in films around the soil particles.

SOILS

After a few hours (in sandy soils) or days or even weeks (in clay soils) a balance is achieved between gravitational and capillary forces. Water stops draining and soil reaches a condition known as ***field capacity***.

The water remaining, ***capillary water***, is the water that matters most to growing crops. However, only a fraction of capillary water—often less than half—is ***plant available***. As soils dry out, the films of water around the soil particles eventually get so thin that plants can no longer overcome the capillary forces holding water to soil particles. The plants start to wilt.

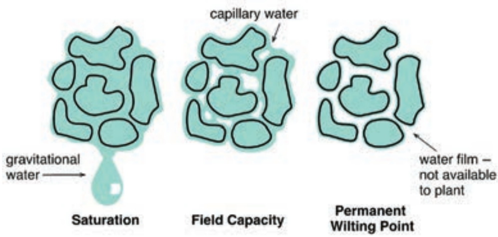

Figure 1. Saturation, Field Capacity, Permanent Wilting Point

Why Healthy Soil Holds More Water

In healthy soil, many of the pores are created by soil organisms: digging, tunneling, digesting, excreting, dying, and secreting various glues (such as glomalin) that make soil particles stick together in small clumps called ***aggregates*** that help maintain stability when soil is wet.

As soils get healthier, more numerous and diverse organisms create water-holding channels, pores, and aggregates, often greatly increasing infiltration rates and water-holding capacity.

Although you can't change your soil's texture class, you may very well be able to improve its health, using methods described in Chapter 2 of this book. That's why maintaining and improving soil health is "Job One" for irrigators. Everything about irrigation gets easier when you're working with healthy soil.

Soil Moisture Terminology

Saturation: The soil moisture condition where pores are completely filled with water. Saturated soil is too wet for good plant growth, starving plant roots and soil organisms of badly needed oxygen.

Field Capacity (also called ***soil water storage*** capacity): The condition where gravitational water has drained from soil and only capillary water remains—generally the upper limit of good irrigation management since additional water will drain and be unavailable to plants.

Crop Stress Point (also called the ***minimum balance***): The condition where plants can no longer extract enough water to meet their requirements and begin to experience serious damage to their growth and development.

Permanent Wilting Point (also called ***crop lower limit*** or similar names): The condition where plants can no longer extract the tightly held films of capillary water from soil at a rate fast enough to recover from wilting.

Available Water (also called ***plant-available water, usable water***, or similar names): Water that's readily available to the roots of growing crops.

Available Water Capacity (AWC) (also called ***plant-available water capacity*** or similar names): The difference between the volume of water stored in soil at field capacity and the volume at the permanent wilting point. AWC is commonly expressed in inches of water per foot or per inch of soil depth.

Root Zone (or ***rooting depth***): ***Potential rooting depth*** is the deepest rooting depth attainable by a crop. Because of physical and chemical barriers in the soil, the ***actual rooting depth*** may be less than the potential rooting depth.

Effective Root Zone: The upper portion of the root zone, where plants get most of their water—generally considered to be the upper half of rooting depth, where most (but not all) plants take up about 70 percent of their water.

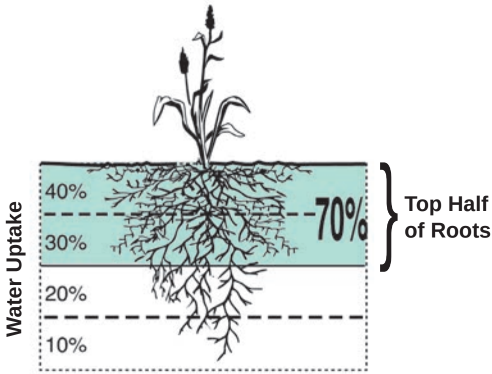

Figure 2. Effective Root Zone

The effective root zone changes as annual crops mature and is also affected by irrigation practices. For example, frequent and light irrigations generally encourage shallow root development while less frequent and heavier irrigations promote deep root growth.

Management Allowable Depletion (MAD) (also called ***allowable depletion, maximum allowed depletion, management allowable deficit,*** or similar names): The percentage of available water that can be depleted without seriously affecting plant growth and development. For many crop types and growth stages, MAD is in the range of 40 to 60 percent of AWC.

Allowable Depletion Balance (also called ***remaining usable water*** and similar names): The difference between the volume of water stored in soils at a given time and the volume at the crop stress point. The allowable depletion balance can be viewed as the irrigator's safety cushion.

Evapotranspiration (ET) (also called *crop water use*): The movement or loss of water from the soil to the atmosphere through the combined effects of evaporation from the soil surface and transpiration by plants. Note that ET does not normally include evaporation from wet plant leaves or evaporation from spray between a sprinkler and the ground.

Intake Rate (also called *infiltration rate*): The maximum rate at which soil can accept water, often expressed in inches of water per hour. If water application exceeds the intake rate, ponding or runoff will occur.

Summarizing much of the terminology above, soils normally dry out through a series of stages: from *saturation* to *field capacity* to the *crop stress point* to the *permanent wilting point.* Good irrigation management generally keeps soil moisture levels between *field capacity* and the *crop stress point*. At field capacity, *AWC* is the portion of water available to plants and *MAD* is the percentage of AWC that can be removed without causing serious plant stress.

Actions You Can Take

- ✓ Look up your soil's texture class, type, series, available water-holding capacity , and approximate infiltration rate in the online Web Soil Survey.

! Caution: Local soil conditions often vary from published averages, and onsite investigation is always recommended. AWC can be improved through good management and is generally higher in healthy soils.

References

Web Soil Survey: websoilsurvey.sc.egov.usda.gov
Maintained by NRCS as the authoritative source of U.S. soil survey information, with soil maps and data for over 95 percent of the nation's counties.

Further Resources

Soil section of the ATTRA website: attra.ncat.org/soil
Dozens of articles and videos on sustainable soil management.

Gardner, W.H. and J.C. Hsieh. 1959. **Water Movement in Soils** [Video]. Washington State University. *Classic 24-minute film, still one of the best, using time-lapse photography to show the surprising ways that water moves through soil.*

Anderson, Barb. 2021. **Smart Water Use on Your Farm or Ranch.** Sustainable Agriculture Research & Education program. sare.org/resources/smart-water-use-on-your-farm-or-ranch

LandPKS: landpotential.org
Free mobile phone app developed by the USDA Agricultural Research Service. Includes tools for soil health monitoring and allows you to check your soil's texture and classification using your phone's camera.

SARE Project Reports: projects.sare.org/search-projects
Searchable database of projects funded by the farmer-driven USDA Sustainable Agriculture Research and Education competitive grants program, including hundreds of projects related to soil health and water.

2. Catch More Water in Your Soil

This chapter explains several ways to:

- Improve soil health, water-holding capacity, and intake rates
- Reduce evaporation and compaction
- Slow, spread, and sink water

Improve Soil Health

The NRCS defines soil health as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans." Healthy soil carries out functions including regulating water, sustaining plant and animal life, filtering and buffering pollutants, cycling nutrients, and providing physical stability and support. The NRCS calls four main principles key to soil health:

1. Maximizing presence of living roots
2. Minimizing disturbance
3. Maximizing soil cover
4. Maximizing biodiversity

These practices feed microorganisms, protect soil from excessive heat and pounding raindrops, and create soil aggregates and water-holding channels and pores. Many agricultural soils are far below their biological potential. Through good soil health management, you may be able to improve your water-holding capacity and infiltration rates, even dramatically.

Table 1. Organic Matter Increases Water-Holding Capacity

	Typical inches of water per foot of soil		
% organic matter	Sand	Silt loam	Silty clay loam
1%	1.0	1.9	1.4
2%	1.4	2.4	1.8
3%	1.7	2.9	2.2
4%	2.1	3.5	2.6
5%	2.5	4.0	3.0

CATCH

Actions You Can Take

- ✓ Reduce tillage.
- ✓ Keep plant residues in the field and maintain post-grazing stubble heights.
- ✓ Integrate livestock to stimulate soil biology. Moderate levels of well-timed grazing can increase soil carbon.
- ✓ Grow diverse cover crops and incorporate into soil.
- ✓ Add organic materials: manure, biochar, mulch, compost, etc.
- ✓ Use diverse crop rotations to increase biodiversity.
- ✓ Inoculate with mycorrhizal fungi.
- ✓ Encourage earthworms.
- ✓ Regularly test your soils, including health indicators such as organic matter, respiration, and aggregate stability.

Reduce Evaporation

Keeping the soil covered and protected from heat and wind reduces evaporation.

Actions You Can Take

- ✓ Grow cover crops to keep the soil covered year-round.
- ✓ Establish rows of trees, shrubs, or grass as windbreaks.
- ✓ Leave tall stubbles.

Reduce Compaction

Reducing compaction decreases runoff and flooding, improves aeration, and allows plant roots to go deeper.

Actions You Can Take

- ✓ Minimize wheel traffic and hoof impact on wet fields.
- ✓ Grow deep-rooted cover crops like oats, cereal rye, radishes.
- ✓ Add organic matter.

Landforming

Shaping or leveling the soil surface can reduce runoff, slow and spread water, and give it a chance to sink in.

Actions You Can Take

- ✓ Use contour tillage, terraces, and swales.
- ✓ Create retention dams and beaver dam analogues along small and seasonal streams.
- ✓ Have your land levelled.

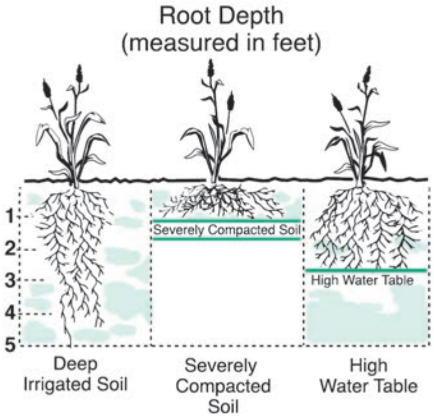

Figure 3. Restricted Root Depth

Stratified soil blocks water movement

Fine soil overlying a coarse soil, or vice versa, must become very wet before water will move downward and can hold up to three times as much water as it would normally.

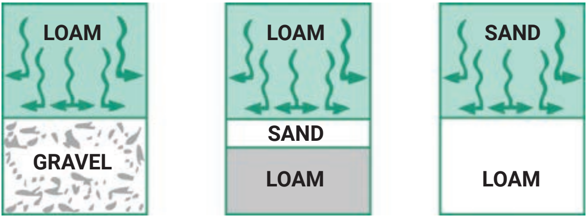

Figure 4. Water Movement in Stratified Soils

CATCH

References

Source for definitions on page 7: **NRCS Soil Health page**. nrcs.usda.gov/conservation-basics/natural-resource-concerns/soils/soil-health

Source for Figures 3 and 4: USDA Natural Resources Conservation Service. 1997. **Irrigation Guide:** Section 15 of the **National Engineering Handbook**. directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba

Source for Table 1: Hudson, Berman (March 1994). **Soil organic matter and available water capacity**. Journal of Soil and Water Conservation 49 (2) 189-194.

Further Resources

Soil for Water website: soilforwater.org
Peer-to-peer learning network and story collection managed by NCAT, devoted to finding and sharing better ways of catching and storing water in soil.

Bellows, Barbara et al. 2020. **Soil Health Indicators and Tests.** ATTRA publication IP603. attra.ncat.org/publication/soil-health-indicators-and-tests

Brown, Gabe. 2018. **Dirt to Soil: One Family's Journey into Regenerative Agriculture.** Chelsea Green Publishing.
How one farm restored soil health and increased its intake rates from less than one half inch per hour to over 10 inches per hour.

Guerena, Martin and Rex Dufour. 2019. **Managing Soils for Water.** ATTRA publication IP594. attra.ncat.org/publication/manage-soil-for-water. *Information on using the principles of soil health to improve water infiltration and storage.*

Stika, John. 2016. **A Soil Owner's Manual: How to Restore and Maintain Soil Health.** CreateSpace Independent Publishing.
Practical, no-nonsense guide to restoring the full potential and functional capacity of your soil.

Strickler, Dale. 2018. **The Drought Resilient Farm.** Storey Publishing. *Comprehensive guide to getting water into soil, keeping it in soil, and helping plants and livestock access it.*

3. Know Your Soil Moisture

This chapter explains:

- Three ways of measuring water in soil
- Several methods for checking soil moisture
- A way to check intake (infiltration) rates
- A way to estimate water-holding capacity in your root zone

Three Ways to Measure Water in Soil

Soil moisture can be measured based on the volume or mass of water in soil or based on ***soil water tension***.

The ***volumetric*** water content of soil is defined as the volume of water per unit volume of soil. You may see it expressed as:

- A ***ratio*** like cubic meters of water per cubic meters of soil
- A *number* like inches of water per inch or foot of soil depth or
- A ***percentage*** (volume of water / volume of soil) × 100

The ***gravimetric*** water content of soil is defined as the mass of water per unit mass of soil.

Soil water ***tension*** is the amount of energy holding water in soil. It's a measure of how tightly water is bound to soil surfaces or how hard the plant roots need to work to extract water. You may see it called soil water ***potential***, ***matric potential***, or other names.

Soil water tension is usually measured in ***centibars*** (cb), where a centibar is 1/100th of a bar and a bar is equivalent to about one atmosphere of pressure. However, you may also see it measured in ***kilopascals*** (kPa).

All three ways of measuring water in soil (by volume, mass, and soil water tension) have their advantages.

Knowing the **volume** of water in soil allows simple management decisions. For example, if your soil is holding one-half inch per foot of soil depth, and its field capacity is one inch per foot, you can bring it to field capacity by adding another half-inch.

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Measuring water by its **mass** is highly accurate and often used to calibrate tools, although it's too time-consuming for normal day-to-day decision-making. The method (easily found on the Internet) involves weighing soil samples, drying them in an oven, weighing them again, and using the difference in weight to calculate the amount of water that has been cooked out of the soil.

Finally, many irrigators prefer to measure **soil moisture tension** because it relates directly to plant well-being and stress. When you measure soil water tension, you're measuring the forces that make it hard or easy for plant roots to extract water. As an analogy, think about the work it takes to drink a thick milkshake through a straw.

What Method Is Right for You?

First, consider the limitations of your irrigation system. The more control you have over water applications, the more precise the soil moisture information you can use.

Also consider your soil, crops, and convenience. For example, some devices work best in coarse soils while others don't work at all in highly saline soils. Do you want a portable device you can carry around and push into the ground wherever you like? A permanent installation with buried blocks hard-wired in place? A system that takes automatic readings and sends them to your phone? Do you need to avoid burying cables that will interfere with tillage?

Finally, don't get too hung up on precision. Most methods and devices will track moisture trends similarly and give adequate information for practical farming purposes. The methods that follow are arranged roughly from least expensive to more expensive. All work just fine if used properly and diligently. We omit expensive high-tech tools like neutron probes, which are often used by crop consultants but not practical for most producers because of their high cost and special training and licensing requirements due to radiation safety hazards.

Direct Inspection

The least expensive methods rely on digging up soil samples in the field and then inspecting and feeling them.

Feel and Appearance Method

Take walnut-sized soil samples from various locations and depths in the field, appropriate to your crop's root zone. Then use Table 2 on page 16 to estimate the soil water content of your samples. A soil probe, auger, or core sampler works better than a shovel for retrieving deep soil samples.

Hand-Push Probe

A hand-push probe is one of the best $30 to $70 investments you'll ever make. Many irrigators find that a hand-push probe is all they really need.

Pushed into the ground, the probe stops abruptly when it hits dry soil. Check the mark on the shaft to find the depth of wetted soil. Most hand-push probes have an auger on the tip, allowing you to retrieve a soil sample by twisting the probe and pulling it out of the soil.

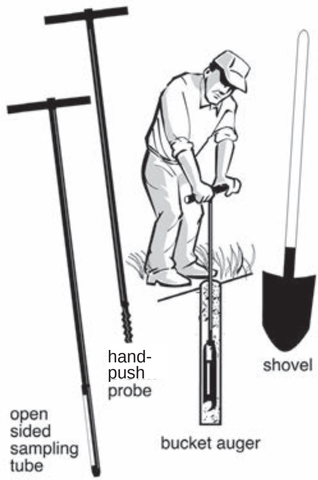


Figure 5. Soil sampling tools

Tensiometer

A tensiometer is an airtight, water-filled tube with a porous ceramic tip and a vacuum gauge near the top. As the name implies, tensiometers measure soil water tension. Water flows into or out of the ceramic tip, changing vacuum pressure inside the tube. When water stops moving and reaches equilibrium with its surrounding soil, the vacuum pressure equals soil tension and can be read from the gauge.

Table 2. Estimating Soil Water Content by Feel and Appearance

Soil Texture: Coarse (0.5 to 2.0 mm)	Moderately Coarse (0.25 to 0.50 mm)	Medium (0.25 to 0.50 mm)	Moderately Fine and Fine (< 0.01 to 0.05 mm)	% of Available Water Capacity (AWC)
Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles and free water forms on surface.	Exceeds field capacity – runoff & deep percolation.
Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand.				100% – At field capacity
Tends to stick together, forms a weak crumbly ball under pressure.	Forms weak ball that breaks easily; does not stick.	Forms a ball and is very pliable; sticks readily if relatively high in clay.	Ribbons out between thumb and finger; has a slick feeling.	70 – 80% of AWC
Tends to stick together. May form a very weak ball under pressure.	Tends to ball under pressure, but seldom holds together.	Forms a ball, somewhat plastic; sticks slightly under pressure.	Forms a ball; ribbons out between thumb and finger.	50 – 70% of AWC
For most crops, irrigation should begin at 40 to 60% of AWC.				
Appears to be dry; does not form a ball under pressure.	Appears to be dry; does not form a ball under pressure.	Somewhat crumbly but holds together under pressure.	Somewhat pliable; balls up under pressure.	25 – 50% of AWC
Dry, loose, single-grained flow through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily breaks down into powder.	Hard, baked, cracked; sometimes has loose crumbs on surface.	0 – 25% of AWC

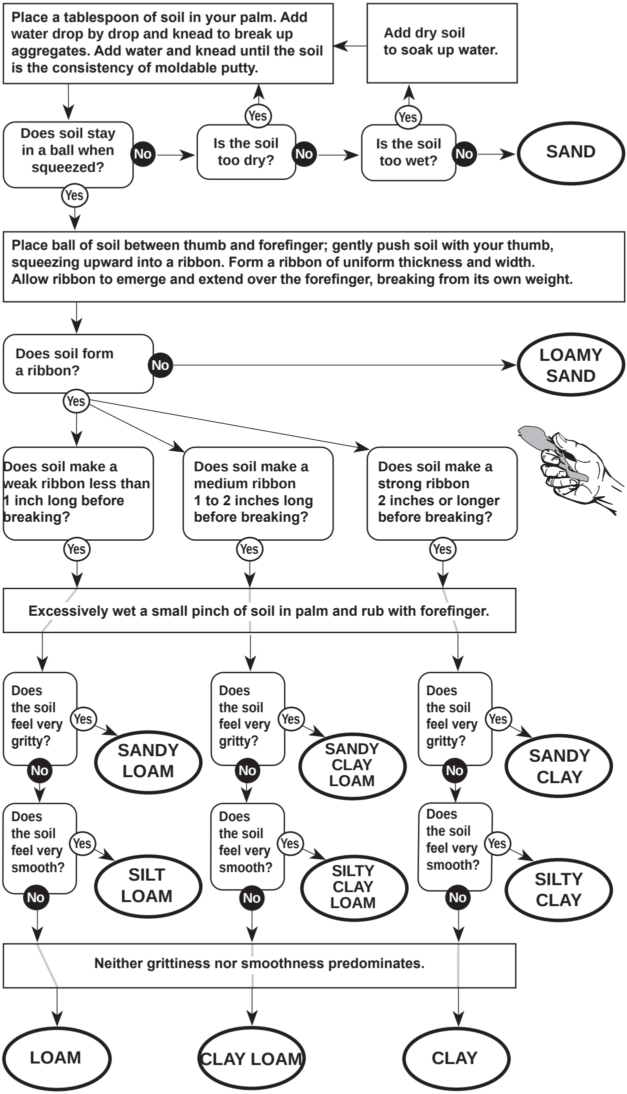


Figure 6. Determining Soil Texture by the "Feel Method"

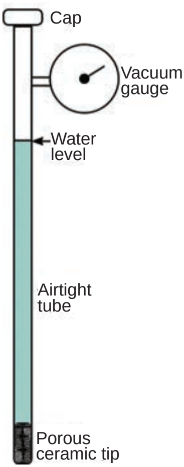


Figure 7. Tensiometer

Tensiometers are easy to use, last years with good care, and are not affected by soil temperature or salinity. While not as accurate as some electronic devices, they're plenty accurate for most practical farming situations. They cost $80 to $150 apiece, but you can find instructions on the Internet on making your own for less.

Because they're easy to install and remove, tensiometers are well-suited to cultivated fields, annual crops, orchards, and other situations where buried blocks or cable would be awkward. They work best in the range of 0 to 80 cb, making them better suited to coarse soils. (A fine-textured soil can retain more than half of its available water capacity at 80 cb.)

Electronic Meters & Sensors

Electrical Resistance Sensors

Electrical resistance sensors take advantage of the familiar idea that wet soil conducts electricity better than dry soil. They're made of porous material that absorbs water from the surrounding soil.

A meter runs an electric current through two electrodes implanted in the sensor, measuring electrical resistance, which is then translated into a soil moisture tension reading by either a portable hand-held meter or a data logger.

The most common types of electrical resistance sensors are ***gypsum blocks*** (with a short life of as little as one year but a low cost of $12 to $25 apiece) and ***granular matrix sensors*** (lasting three to seven years or more and costing $45 to $60 apiece.) Freezing will usually not hurt granular matrix sensors, whereas it can cause cracking and premature aging in gypsum blocks.

Electrical resistance sensors are more strongly affected by salinity than tensiometers. To give accurate readings, they also need to be buried carefully, with snug soil contact and no air pockets—something that's not always easy to do in coarse or gravelly soils.

Table 3. Irrigation Guidelines Based on Centibar Readings

Reading	Interpretation
0-10 cb	Saturated soil
10-20 cb	Most soils are at field capacity
30-40 cb	Typical range of irrigation in many coarse soils
40-60 cb	Typical range of irrigation in many medium soils
70-90 cb	Typical range of irrigation in heavy clay soils
> 100 cb	Crop water stress in most soils

Dielectric Sensors

Dielectric sensors measure the charge-storing capacity of soil: its tendency to become electrically polarized when exposed to an electric field, acting like a capacitor. Unlike tensiometers or electrical resistance blocks, dielectric sensors give ***volumetric*** measurements: the volume of water per volume of soil.

The two main types of dielectric sensors are ***capacitance sensors***—also known as ***frequency domain reflectometry*** (FDR) sensors—and ***time domain reflectometry*** (TDR) sensors. Once extremely expensive, TDR devices have become available that are close in price to high-quality FDR devices, making TDR an option worth considering for irrigators who need a high degree of accuracy.

Data Loggers

A ***data logger*** is an electronic device, usually powered by batteries or a solar panel, that records data at regular intervals. Electrical resistance blocks, tensiometers, and dielectric sensors can all be connected to data loggers.

Soil moisture data loggers are typically mounted on a post and connected by cable to one or more sensors. At regular intervals (from every few minutes to every few hours), the data logger sends a weak electric current to the sensors, taking measurements, and storing them in memory.

Data loggers store months or years of data that can be downloaded at your convenience or sent via Internet to your phone or laptop. They can send alerts if soil moisture gets above or below desired levels. They can even function as weather-based controllers that automatically modify your irrigation schedule based on soil moisture and weather conditions.

MONITOR

As a ballpark, you're going to spend $150 to $600 for a hand-held meter or a data logger. Total cost of a system will depend on the number and type of sensors you install. A wireless system with a single dielectric sensor can be set up for as little as $1,200, including annual fees for a data plan. On the other hand, a system with multiple sensors and a weather station that monitors multiple locations and depths could easily cost tens of thousands of dollars.

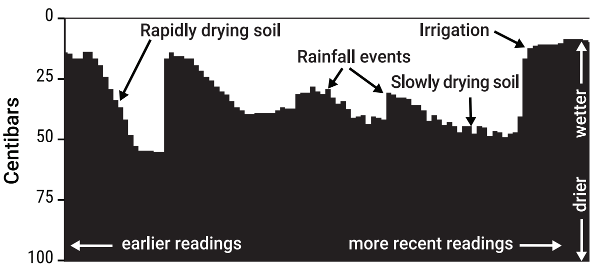


Figure 8. Data Logger Display, Showing 5 Weeks of Readings

Where to Place Moisture Sensors

When burying any soil moisture sensor, try to closely match conditions in the surrounding field. Be careful to minimize soil compaction and disturbance to the canopy cover.

- Put sensors in average soil and slope areas. Avoid field edges and unusually wet or dry spots.

MONITOR

Table 4. Available Water Holding Capacity and Intake Rates

Soil Texture	AWC Range (inches per foot depth)	Typical AWC (inches per foot depth)
Coarse Sand, Sand	0.1–0.4	0.25
Fine Sand, Very Fine Sand	0.6–0.8	0.75
Loamy Coarse Sand, Loamy Sand	0.7–1.0	0.85
Loamy Fine Sand, Loamy Very Fine Sand	1.0–1.4	1.25
Coarse Sandy Loam	1.2–1.4	1.3
Sandy Loam	1.3–1.6	1.45
Fine Sandy Loam	1.6–1.8	1.7
Sandy Clay Loam, Clay	1.7–1.9	1.8
Very Fine Sandy Loam, Sandy Clay, Silty Clay	1.8–2.0	1.9
Loam, Silt	1.9–2.2	2.0
Silt Loam, Clay Loam, Silty Clay Loam	2.3–2.5	2.4

	Intake Rate (inches per hour)		
Soil Texture	Sprinkler	Furrow	Border & Basin
Clay, Silty Clay	0.1–0.2	0.1–0.5	0.1–0.3
Sandy Clay, Silty Clay Loam	0.1–0.4	0.2–0.8	0.25–0.75
Clay Loam, Sandy Clay Loam	0.1–0.5	0.2–1.0	0.3–1.0
Silt Loam, Loam	0.5–0.7	0.3–1.2	0.5–1.5
Fine or Very Fine Sandy Loam	0.3–1.0	0.4–1.9	1.0–3.0
Sandy Loam, Loamy Very Fine Sand	0.3–01.25	0.5–2.4	1.5–4.0
Loamy Fine Sand, Loamy Sand	0.4-1.5	0.6–3.0	2.0–4.0
Fine Sand, Sand	0.5+	1.0+	3.0+
Coarse Sand, Sand	1.0+	4.0+	4.0+

! Caution: AWC and intake rate are affected by salinity, rock fragments, compaction, restrictive layers, vegetative cover, and other factors, and can often be increased over time by good soil management that improves soil health.

- For a shallow-rooted crop, you could place one sensor in the effective root zone and another below the root zone as a way of detecting deep percolation and overwatering.
- For deeper-rooted crops, place sensors in the top and bottom thirds of the root zone as "on-off" indicators. Start irrigating when the shallow sensor starts to get dry and stop irrigating when the deep sensor starts to get wet.
- For young trees and vines, place sensors close to the plant, in active roots. For mature trees, place sensors well away from the trunk but inside the drip line (canopy diameter).

MONITOR

! Sensors may have to be relocated in orchard and vine crops as the crop and its root system develop from seedlings to mature trees and vines.

- For drip tapes, place sensors at the edge of an emitter's wetted soil volume. Avoid getting too close or too far from emitters, where soil is continuously wet or dry.
- For center pivots, monitor a few sprinkler diameters from where you normally start and stop the pivot. Avoid the inner part of a pivot circle (inside the first tower), which tends to be wetter than the rest of the circle.

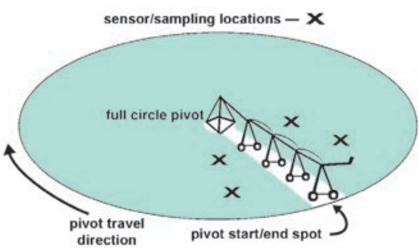


Figure 9. Soil Monitoring Sites under Pivot

Checking Infiltration (Intake) Rates

For a rough idea of your soil's intake rate, refer to Table 4 or look up approximate values for your soils in the Web Soil Survey. You can get a better idea by doing a *ring test*.

Pound a ring made of metal, PVC, or some other rigid material into the soil, pour a carefully measured amount of water into the ring, and record the time it takes for all the water to sink into the soil. Videos are available on the Internet showing the procedure.

Don't expect too much precision from ring tests and be careful about comparing different dates or times of year. Differences in soil moisture, temperature, and vegetation will greatly skew results. Here are some ways to make ring tests more accurate:

- Line the inside of the ring with a sheet of plastic wrap before adding water. Then carefully pull the plastic wrap out, releasing all the water exactly when you start timing.
- Add exactly one inch of water, so you can calculate your infiltration rate in inches per hour. (If you use a 6-inch diameter ring, this amount will be 444 mL.)
- Use a double-ring infiltrometer ($200 to $700), whose "ring within a ring" design forces water in the inner ring to infiltrate vertically and reduces error due to lateral spread of water.
- After the water is completely infiltrated, repeat the test. The second application (in wet soil) will give a more meaningful estimate of your infiltration rate.
- Use distilled water.

Estimating Available Water-Holding Capacity of Your Entire Root Zone

1. Look up your soil series on a map in the Web Soil Survey.
2. Look at the descriptive text to find the texture, depth, and available water-holding capacity (AWC) for each layer.
3. Calculate AWC for each layer, multiplying the thickness of the layer times its AWC per inch or per foot.
4. Add the numbers for each layer together to the root depth of the crop grown on that field.

The calculation will look like this:

Field No. ___2___ Crop Grown ___*Alfalfa*___

Effective Root Depth of Alfalfa at maturity ___*5 feet*___

Soil Series	Soil Texture	Texture Depth	Layer Thickness		AWC (inches of water per in.)		Total AWC
Bozeman	*Silt loam*	*0-8 in.*	*8 in.*	×	*0.17 in./in.*	=	*1.36 in.*
	Silty clay loam	*8-28 in.*	*20 in.*	×	*0.18 in./in.*	=	*3.6 in.*
	Silt loam, silty clay loam	*28-60 in.*	*32 in.*	×	*0.18 in./in.*	=	*5.76 in.*
	Effective Root Depth		***60 in. (5 ft.)***		***TOTAL***	**=**	***10.72 in.***

! Caution: Local conditions often vary from published averages. AWC can often be increased over time by good management that improves soil health.

Actions You Can Take

- ✓ Get in the habit of routinely checking your soil moisture, using one or more methods in this chapter.
- ✓ Look up intake rates for your soils in the NRCS Web Soil Survey and check intake rates with a ring test.
- ✓ Estimate water-holding capacity in your crop's root zone.

References

Source for Tables 2 and 4, Figures 5 and 9: USDA Natural Resources Conservation Service. 1997. **Irrigation Guide:** Section 15 of the **National Engineering Handbook.** directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba

Further Resources

Morris, Mike. 2022. **Soil Moisture Monitoring: Low-Cost Tools and Methods**. ATTRA publication IP 277. attra.ncat.org/publication/soil-moisture-monitoring-low-cost-tools-and-methods

Infiltration Ring with Ray Archuleta. ATTRA video. attra.ncat.org/infiltration-ring-with-ray-archuleta

Managing Soil and Irrigation for Drought. ATTRA video. attra.ncat.org/managing-soil-and-irrigation-for-drought

4. Know How Much Water You're Applying

This chapter explains:

- How to find net water application per set
- How to apply a desired amount of water with any irrigation system
- Several ways of measuring flow rates

"Set Time" and "Net Water Application"

Some sprinkler systems and most surface irrigation systems apply water in one location for a period of time before being turned off and moved to another area of the field. This period is called a ***set*** or ***set time***. In the case of center pivots and linear move systems, which move more or less continuously, set time is considered to be the period needed to cover the entire irrigated area.

In any irrigation system, some water fails to become available to the plant roots because of deep percolation, wind drift, runoff, evaporation, and other factors. ***Net water application*** is the amount of water that your irrigation system actually delivers to the crop root zone. To calculate net water application, you start with the gross amount of water applied and multiply it times a ***system efficiency***.

Gross water applied × system efficiency = net water applied

Table 5 (next page) gives approximate system efficiencies for common irrigation systems: the percentage of water that actually enters and stays in the root zone.

Note that these are only ballpark values for well-managed and maintained systems. In some cases, measuring ***distribution uniformity (DU)*** may give you a more accurate estimate for your system. DU measures how uniformly water is infiltrating into the soil in various parts of your field. Consult your local NRCS office or conservation district for help estimating your DU.

Table 5. Attainable Irrigation System Application Efficiencies

System Type	Efficiency (%)
Surface Systems	
Level border	60-80
Furrow	60-80
Surge	65-80
Graded border	55-75
Corrugate	40-55
Wild Flood	25-40
Sprinkler Systems	
Linear move	75-90
Center pivot (low pressure)	75-90
Fixed solid set	70-85
Center pivot (high pressure)	65-80
Hand move or side roll laterals	60-75
Traveling gun	60-70
Stationary gun	50-60
Microirrigation systems	
Surface/subsurface drip	85-95
Micro spray or mist	85-90

A Shortcut Method for Most Sprinkler Systems

To estimate net water application per set for most sprinkler systems (but not pivots or microirrigation systems), you can use the following two tables. Table 6 converts nozzle size and pressure to gpm. Table 7 converts gpm and the spacing between sprinklers and risers into gross water application in inches per hour. Then multiply this number by your system efficiency and set duration to find net water application.

Example:

A wheel line with new 9/64″ nozzles and 40 psi operating pressure, 40 foot × 40 foot sprinkler spacing, 11 hour set, 65% system efficiency

From Table 6, find the 9/64″ nozzle on the left and read across to the number under 40 psi. The number is 3.7 gpm.

Then using Table 7, find the 40 × 40 spacing on the left and read across to the 3 gpm and 4 gpm columns. Since 3.7 gpm is a little more than halfway between them, estimate gross water application at 0.22 inches per hour. Multiply 0.22 by 11 hours, the set duration, and by 0.65, the percent system efficiency.

Net water application = 0.22 × 11 × 0.65 =1.6 inches per set.

Table 6. Nozzle discharge (gpm)

Nozzle Size (inch)	Nozzle Pressure, psi				
	30	**40**	**50**	**60**	**70**
3/32	1.4	1.7	1.9	2.0	2.1
1.8	2.6	3.0	3.3	3.5	3.8
9/64	3.3	3.7	4.2	4.5	4.9
5/32	3.9	4.5	5.0	5.4	5.8
11/64	4.7	5.4	6.0	6.6	7.1
3/16	5.5	6.3	7.0	7.7	8.3
13/64	6.4	7.4	8.2	9.0	9.7
7/32	7.4	8.6	9.6	10.5	11.3

! Caution: Discharge rates are based on new nozzles. Flow from worn nozzles will vary significantly from these values.

The General Formula

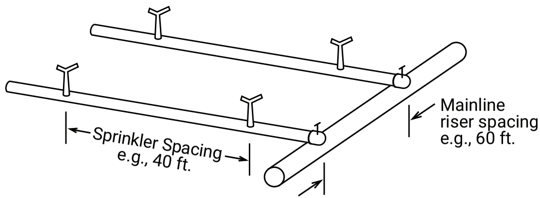
To calculate net water application in inches per set for any irrigation system, use the following general formula:

$$\text{Net water application per set (inches)} = \frac{\text{set time (hours)} \times \text{flow rate (gpm)} \times 96.3 \times \text{system efficiency}}{\text{irrigated area (sq ft)}}$$

You can use EITHER the flow rate for one nozzle/orifice divided by the area covered by that nozzle/orifice OR the flow rate for the entire system divided by the area covered by the whole system. The result is the same: inches per set.

Table 7. Water Application — Inches per Hour

Sprinkler Spacing	gpm/Sprinkler 2	3	4	5	6	7	8	9	10	11	12	15	18	20	25
30 × 30	0.21	0.32	0.43												
30 × 50			0.25	0.32	0.38	0.44	0.51	0.57	0.64	0.70	0.76				
40 × 40		0.18	0.24	0.30	0.36	0.42	0.48	0.54							
40 × 60				0.20	0.24	0.28	0.32	0.36	0.40	0.44	0.48	0.60	0.72	0.80	
50 × 60					0.19	0.22	0.26	0.29	0.32	0.35	0.39	0.48	0.58	0.64	
60 × 60							0.21	0.24	0.27	0.29	0.32	0.40	0.48	0.53	0.67
60 × 80									0.20	0.22	0.24	0.30	0.36	0.40	0.50



What's My Irrigated Area?

For most surface irrigation systems, the irrigated area is simply the entire area of the field. For furrow systems, you can use the length and spacing of the furrows to estimate irrigated area. (See example below.)

For most sprinkler systems, the area watered by one sprinkler is the distance between sprinklers on a line multiplied by the distance between mainline riser valves. (See the diagram in Table 7.) For pivots, you can multiply the entire swept area in acres by 43,560 to find square feet.

Example Net Water Calculations

Wheel line, hand line, end tow: Assume average flow rate of 8 gpm per nozzle, 12-hour set, 40 foot × 60 foot sprinkler spacing, and 65% system efficiency

$$\frac{12 \times 8 \times 96.3 \times 0.65}{40 \times 60} = 2.5 \text{ inches net water application per set}$$

Center pivot: Assume 50-hour rotation, 900 gpm for the whole system, 130-acre field (= 5,662,800 ft^2), 75% system efficiency. (Flow varies along the length of the pipe, so you use the ***gpm for the entire pivot*** in your calculation.)

$$\frac{50 \times 900 \times 96.3 \times .75}{5{,}662{,}800} = 0.6 \text{ inches net water application per set}$$

Stationary big gun sprinkler: Assume 10-hour set, 78 gpm, 120 ft × 120 ft spacing, 50% system efficiency

$$\frac{10 \times 78 \times 96.3 \times .50}{120 \times 120} = 2.6 \text{ inches net water application per set}$$

Traveling big gun sprinkler: Use the following formula:

$$\text{Net water application} = \frac{\text{gpm} \times 1.6 \times \text{efficiency (\%)}}{S \times W}$$

where W = width between travel lanes in feet and
S = travel speed in feet per minute (fpm)

FLOWS

Example: 300 feet between travel lanes, 0.4 fpm travel speed, 400 gpm, 60% system efficiency

$$\frac{400 \times 1.6 \times 0.6}{0.4 \times 300} = 3.2 \text{ inches net water application}$$

Wild flood: Use total area flooded and total flow. Assume seven 24-hour days, 800 gpm flow, 40-acre field, 20% system efficiency

$$\frac{7 \times 24 \times 800 \times 96.3 \times 0.20}{40 \times 43{,}560} = 1.5 \text{ inches net water application}$$

Graded furrows: Use furrow length and spacing. Assume 11-hour set, 10 gpm assumed flow per furrow, 660-foot-long × 3-foot-wide furrows, 50% system efficiency

$$\frac{11 \times 10 \times 96.3 \times 0.50}{3 \times 660} = 2.7 \text{ inches net water application}$$

FLOWS

Applying a Desired Amount of Water

To determine how long it takes to apply a desired amount of water, rearrange the terms of the general formula:

$$\text{Set time hours} = \frac{\text{net water application (inches)} \times \text{irrigated area (sq ft)}}{\text{flow rate (gpm)} \times 96.3 \times \text{system efficiency}}$$

Wheel Line Example: Assume 8 gpm per sprinkler, you want to apply 1.2 inches, sprinkler spacing is 40 foot × 60 foot, and system efficiency is 65%.

$$\frac{1.2 \times 40 \times 60}{8 \times 96.3 \times .65} = 5.8 \text{ hours. Round up to 6 hours.}$$

A Simpler Calculation for Surface Irrigation

For surface irrigation systems, it may be easier to ignore system efficiency and use the following formula based on gross water application:

$$\text{Set time hours} = \frac{\text{gross water application (inches)} \times \text{irrigated area (acres)}}{\text{flow rate (cfs)}}$$

Graded border example: Assume 1.2 cfs flow rate, 10-acre field, and you want a gross water application of 1.5 inches.

$$\text{Correct set time (hours)} = \frac{1.5 \times 10}{1.2} = 12.5 \text{ hours}$$

What's My Flow Rate?

Sprinkler Systems (Including Pivots)

If your sprinkler system is relatively new, you can use the total design gpm of your system for a flow estimate. Divide the design gpm by the number of operating sprinklers on your system to find the average gpm per sprinkler. For pivots, use the design gpm for the entire pivot.

Be aware, however, that original design numbers don't take into account increased flow (sometimes significant) due to nozzle wear and pressure variations. A more accurate way to find the flow rate for your sprinkler system, especially if it's an older system, is to do a *bucket test*. (See the ***Conversions and Formulas*** section.)

Surface Irrigation Systems

It's sometimes difficult to estimate flow rates for **surface irrigation systems,** but several methods are possible.

Furrow Systems

- Portable furrow flow measuring devices are available.
- If you're using siphon tubes, look up the flow rate in a siphon tube head-discharge chart.
- Catch the flow to a single furrow in a bucket of known capacity, and measure the time it takes to fill the bucket.
- If you know total flow into the whole furrow system, divide it by the number of furrows to find the flow rate into each furrow.

Ditches or Open Channels

You can measure flow in a ditch or open channel with a ***weir, flume,*** or ***orifice*** that includes a vertical ***staff gage*** marked with numbers indicating water depth. Using a table for your size and type of structure, you simply look up the measured depth and convert it to a flow rate. Higher cost but more accurate electronic measuring devices are also available that offer continuous flow measurement and recording.

For accuracy, the ditch must have a shallow grade with a straight upstream segment, uniform cross-section, little turbulence, and quiet flow. Make sure you aren't causing sediment or debris buildup or flooding of surrounding areas. A few common devices suited to smaller canals, ditches, and farm turnouts are described below.

Weirs are easy to make and use but need enough ditch slope so water can fall freely to the downstream water surface. In ***rectangular*** and ***trapezoidal*** weirs, water flows through a rectangular or trapezoidal notch. In ***v-notch*** weirs, water flows through a 90-degree-angled notch. This weir is especially good at handling a wide range of flows.

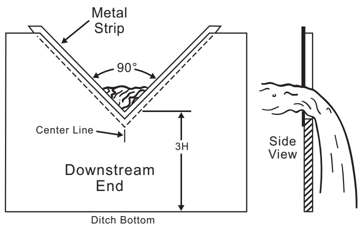


Figure 10. V-notch Weir

Flumes are more complex structures than weirs, including a constricted throat section that requires careful construction and installation. Flumes are used where ditch and canal grades are relatively flat. They're relatively accurate even when submerged.

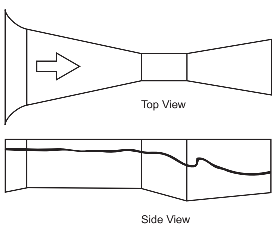


Figure 11. Parshall Flume

Parshall flumes, a common type, require only about a quarter of the ditch grade needed for weirs and can accommodate a wide range of flows.

FLOWS

Cutthroat flumes are a "throatless" variation on the Parshall flume and easier to make.

Ramp flumes (also known as ***modified broad-crested weirs***) are accurate, cost less to build than most other devices, and are simpler to construct.

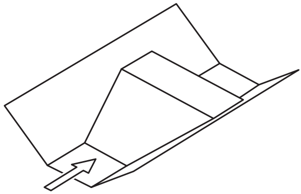


Figure 12. Ramp Flume

Submerged orifices are often used where ditch slope is insufficient for weirs. They generally cost less than weirs and can fit into limited spaces but are susceptible to trash build-up. Water flowing through an orifice is discharged below the downstream water surface. For these devices to be accurate, they must be submerged. The ***meter gate,*** a type of submerged orifice, can measure flow, be closed to shut off flow, or positioned at various settings to reduce or increase flow.

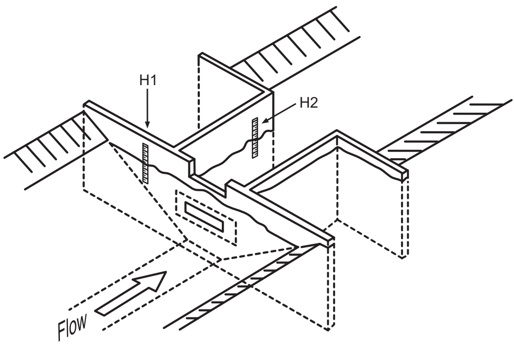


Figure 13. Submerged Orifice

Pipeline Flow

Pipeline flow is measured by either ***intrusive*** devices (located inside the pipe or inserted through the pipe wall) or ***external*** devices. ***Venturi, nozzle***, and ***orifice plate*** meters are installed in the pipeline and measure flow through a constriction within the pipe. They have no moving parts and need little maintenance in clean water.

Propeller meters are also installed inside the pipe. They can pass some debris, but even moderate amounts can foul the blades.

Pitot tubes are inserted into the side of a pipe. They require drilling a hole through the pipe, allowing insertion of the tube.

Non-intrusive flow meters are clamped onto the outside of the pipe wall, send ultrasonic or acoustic waves through the pipe, and measure Doppler shift or transit time to calculate flow rate. They require some training for accurate measurement and are costly: in the range of $1,500 to $10,000.

Actions You Can Take

- ✓ Determine your system's flow rate.
- ✓ Determine your irrigated acreage.
- ✓ Determine how much water you are applying (in inches) during each "set."

References

Source for Tables 5, 6, 7, and the formulas and calculations in this chapter: USDA Natural Resources Conservation Service. 1997. **Irrigation Guide:** Section 15 of the **National Engineering Handbook.** directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba

Further Resources

U.S. Bureau of Reclamation. **Water Measurement Manual.** usbr.gov/tsc/techreferences/mands/wmm
Maintained by the U.S. Bureau of Reclamation as a comprehensive and authoritative guide to measuring flowing water, originally published in 1997.

5. Know the Water Needs of Your Crops

This chapter explains:

- How to track crop water use or evapotranspiration
- General irrigation guidelines and management allowable depletion values for some crops

Tracking Evapotranspiration (ET)

Evapotranspiration (ET) is defined as the combined effect of evaporation from the soil surface and transpiration by plants. Many irrigators find it worthwhile to track ET as the season goes along, allowing them to predict when they'll need to irrigate and how much water they'll need to apply.

Publicly-Available ET Reports

In many parts of the country, weather stations provide publicly-available ET reports and forecasts, based on measurements of air temperature, relative humidity, wind speed, solar radiation, and other factors. Examples are the **AgriMet system** for the Pacific Northwest and the **CIMIS system** for California.

Also available in some parts of the country are ***satellite-based*** ET information systems and services like **OpenET**. Developed by the USDA Agricultural Research Service and many partners, OpenET uses NASA satellite data (such as leaf temperature, leaf size, and solar radiation) along with meteorological, soil, and vegetation datasets, to calculate and provide user-friendly ET estimates for the entire western United States. On OpenET maps, you can zoom down to field scale, looking at ET in your own fields and crops, or at the quarter-acre resolution of satellite data.

Many public sources of data provide "reference ET" values (commonly ET for alfalfa or grass) and include crop coefficient tables for translating these numbers into ET rates for your crops.

Do-It-Yourself ET Information

If no publicly-available ET data is available for your location, you might consider setting up your own weather station. Prices start around $1,000 and go up to several thousand dollars.

Atmometers, also known as ***evaporimeters*** or ***ET gauges***, estimate ET using a flat, porous ceramic disk that draws up water as evaporation dries the surface of the disk.

Evaporation pans are open-top water containers, often standard metal washtubs. As water evaporates, water level in the tub drops, and markings inside the tub allow you to estimate available water remaining in the root zone of your crops. You can find guidelines and crop coefficient tables for atmometers and evaporation pans on the Internet.

The Checkbook Method

In the ***checkbook*** method (also known as the ***water balance*** or ***water budget*** method), you track water inputs and withdrawals from the soil just as you balance a checkbook. Rainfall and irrigation ***deposit*** water while ET ***withdraws*** water. The soil is ***full*** when it's at field capacity and ***empty*** when the ***allowable depletion balance*** reaches zero and you're on the verge of seriously affecting crop growth and yield. To use the method, follow the steps below.

Step 1. Determine initial soil moisture in the root zone

Measure or estimate plant-available water in the root zone. If soil is at field capacity, it's holding its full available water-holding capacity (AWC).

Example:
Spring barley at boot stage is on Bozeman soils at field capacity with an effective root depth of 2 to 3 feet. From the Web Soil Survey (as shown in the example on page 24), we can estimate AWC in the top 30 inches of soil depth at 5.32 inches.

Step 2. Find Management Allowable Depletion at the crop's current growth stage

Recall that ***Management allowable depletion (MAD)*** is defined as the percentage of available water (AWC) that can safely be depleted without seriously affecting plant growth and development. The Crop Guidelines tables (pages 40–45) show MAD values for some commonly irrigated crops. Note that root depth for many crops will change significantly throughout the season.

Example:

From the Crop Guidelines table, we see that barley at the boot stage has MAD of 40% of AWC. So, in the effective root zone—the top 30 inches of soil depth—MAD is 2.13 inches of water.

$$0.40 \times 5.32 = 2.13$$

Step 3. Track ET and precipitation

Add rainfall and irrigation amounts and subtract daily ET amounts (in inches) from your initial MAD and record them in a table like the one below, tracking your safety cushion or ***allowable depletion balance.***

	ET	Rainfall	Net Irrigation	Allowable Depletion Balance
Date	–	+	+	2.13
21-Jun	0.25			1.88
22-Jun	0.12			1.76
23-Jun	0.25			1.51
24-Jun	0.25	0.3		1.56
25-Jun	0.3			1.26
26-Jun	0.3			0.96

On June 26 the allowable depletion balance is 0.96 inches in the effective root zone, meaning 0.96 inches can be safely depleted.

Step 4. Decide when and how much to irrigate

Plan to irrigate before your allowable depletion balance reaches zero. Continuing the example above, if we assume ET will continue at 0.3 inches per day, the 0.96 inches in the effective root zone on June 26 will be almost completely depleted by June 29. If you apply a net irrigation of 2.04 inches on June 30, the balance sheet would look like this:

	ET	Rainfall	Net Irrigation	Allowable Depletion Balance
Date	–	+	+	2.13
21-Jun	0.25			1.88
22-Jun	0.12			1.76
23-Jun	0.25			1.51
24-Jun	0.25	0.3		1.56
25-Jun	0.3			1.26
26-Jun	0.3			0.96
27-Jun	0.35			0.61
28-Jun	0.27			0.34
29-Jun	0.25			0.09
30-Jun	0.36		2.04	1.77

! Caution: Unless deliberately overwatering, e.g., to leach salinity, never bring soil moisture higher than field capacity. Amounts over field capacity are not available to the crop and will be lost through deep percolation or runoff.

Use the methods in Chapter 4 to determine how long you need to run your system to apply the desired amount of water. Then check Table 4 on page 21 to make sure the application rate doesn't exceed your soil's intake rate.

Crop Guidelines

Different crops can tolerate different soil moisture depletion levels, and most crops are especially sensitive to water shortages during a certain growth stage. Table 8 on the following pages shows MAD values and irrigation guidelines for some common crops.

Recommended MAD values are typically 25 to 40 percent for high-value, shallow-rooted crops; 50 percent for deep-rooted crops; and 60 to 65 percent for low-value deep-rooted crops. For deep-rooted crops, recommended MAD values are typically about 40 percent for fine-textured (clayey) soils, 50 percent for medium-textured (loamy) soils, and 60 percent for coarse-textured (sandy) soils.

! Caution: The following tables give average values and may need to be adjusted for your own situation. For example, check actual root depth and never assume that average levels are correct. Always proceed cautiously, watch how your crops are responding, and make adjustments as needed.

A Note on Overwatering

If you're living by the wasteful rule "When in doubt, irrigate," consider that over-irrigating can:

- drown root systems, reduce root growth, deplete essential oxygen, and encouraging disease.
- leach nitrogen and other nutrients below the root zone and into groundwater.
- cause waterlogging and salt buildup in the root zone
- reduce crop quality and yield.
- waste energy and money.

Drive Roots Deeper

In general, the longer-lived the crop, the deeper soil moisture should be maintained. Annual crops put their energy into above-ground development and seed production and usually don't build an extensive or deep root system. But perennials naturally prioritize root development and can be encouraged to grow deeper roots by irrigating more heavily and less often.

Table 8. Crop Guidelines

Crop	Effective Root Depth (ft)	MAD[1] (% of AWC)	Critical Growth Stage	General Guides
Alfalfa				
Established stands	4.0	50%	Early spring and immediately after cuttings	Adequate water is needed between cuttings. Avoid over-irritation. Irrigation to effective root depth should be done in spring and fall where precipitation is not adequate.
1st cut - 2nd cut				
2nd cut - 3rd cut				
New seedings				
Emergence to 1st cut	0.5-1.5	50-65%	Seedling	
Alfalfa-Grass				
Established stands	2.0-4.0	50%	Early spring and immediately after cuttings	Same as alfalfa.
1st cut - 2nd cut				
2nd cut - 3rd cut				
New seedings				
Seedling to 1st cut	0.5-1.0		Seedling	

[1]The percent of available water capacity that can be depleted without causing crop yield or quality loss due to moisture stress.

Crop	Effective Root Depth (ft)	MAD[1] (% of AWC)	Critical Growth Stage	General Guides
Beans, Dry				
4-leaf	0.8-1.0	40%	Early bloom, pod formation	Very sensitive to over-irrigation. Yield reduced if water is short at bloom and pod set. Last irrigation when earliest pods start maturing.
First flower	1.5			
First pod set	2.0-2.5			

Corn, Grain				
Emergence to tasseling	0.5-2.0	50-60%	Tasseling, silking, until grain becomes firm	Sensitive to over-irrigation. Needs adequate moisture from germination to dent stage. Restricted moisture shortly after emergence encourages tillering. Moisture shortage after hard dough stage does not affect yield.
12-leaf to silking	2.0-3.0*	50%		
Blister kernel to dough	3.0-3.5*	50-60%		

*Corn effective root depth will be shallower in humid climates.

Crop	Effective Root Depth (ft)	MAD[1] (% of AWC)	Critical Growth Stage	General Guides
Grapes				
Established vines	3.0-4.0	40%	During rapid shoot growth and cell division in berries, summer cell expansion in berries	Start season with soil profile full at effective root depth. Avoid over-irrigating.
Shoot growth				
Flowering				
Ripening		50%		
Grass For Pasture/Hay				
Established stands	1.5-3.5	50-60%	First 3 months of establishment	During establishment 50% of MAD must be maintained to the effective root depth. Use light, frequent irrigations.
New seedings				
Vegetative	0.0-0.5	40%		
Reproductive: flowering	0.5-1.5	50-60%		
Maturity	1.5-3.0			

Crop	Effective Root Depth (ft)	MAD[1] (% of AWC)	Critical Growth Stage	General Guides
Onions, Dry				
Establishment	1.0	40%	Transplanting, bulb enlargement	Apply frequent, light irrigations to keep soil moist. Cease irrigating once bulbs are full size and tops begin falling.
Bulb formation		30%		
Bulb growth				
Orchard, Fruits				
Tree size 3′ x 10′	2.0	50% at 2-ft level. 1st irrigation should fill root zone	Flowering to 4 weeks after bloom, fruit set, last 2-4 weeks before harvest	Some fruits are sensitive to stress during the last two weeks to harvest. Reduce orchard water use by controlling weeds and suppressing cover crop growth.
Tree size 6′ x 13′	3.0-3.5			
Tree size 12′ x 18′	4-5			

Crop	Effective Root Depth (ft)	MAD[1] (% of AWC)	Critical Growth Stage	General Guides
Potatoes				
Vegetative	0.5-1.0	35%	Flowering, tuber formation and growth	Sensitive to over-irrigation. Water should not stand around tubers. Light, frequent irrigation best. Reduced tuber quality if plants go into serious moisture stress. Last irrigation 3-4 weeks before harvest.
Reproductive: tuber initiation and growth	1.0-2.0			
Maturation	1.5-2.0	50%		
Small Grains				
Vegetative	0.5-2.0	60%	Boot, bloom, and early heading	Restrict moisture early in year to encourage stooling prior to boot stage. Irrigate to field capacity. Last irrigation at mild to dough stage. Irrigating after late dough may decrease yield.
Boot through flowering	2.0-3.0	40%		
Milk to soft dough	3.0-3.5	60%		

Crop	Effective Root Depth (ft)	MAD[1] (% of AWC)	Critical Growth Stage	General Guides
Soybeans				
Vegetative	0.8-1.0	60-65%	Early bloom, pod formation	Yield reduced if water is short at bloom and pod set. Last irrigation when earliest pods start maturing.
First flower to first pod	1.5	50-60%		
First pod to maturity	2.0	50-65%		
Sugar Beets				
Vegetative: first 5 weeks after emergence	0.0-1.0	50%	From seedling to root enlargement (post thinning)	Irrigate frequently and lightly during early season to ensure germination and seedling growth. Later in season avoid irrigating when crop simply shows signs of mid-afternoon wilt. Excessive irrigation lowers sugar content.
Vegetative: mid-May to mid-September	1.5-2.0			
Maturation: mid-August to harvest	2.0-3.0			

Table 9. Management Allowable Depletion (% of AWC) for Some Other Crops Assumed to be Growing in Loamy Soils

Crop	Crop growth stage			
	Establishment	Vegetative	Flowering yield formation	Ripening maturity
Alfalfa seed	50	60	50	80
Beans, green	40	40	40	40
Citrus	50	50	50	50
Corn, seed	50	50	50	50
Corn, sweet	50	40	40	40
Cranberries	40	50	40	40
Garlic	30	30	30	30
Grass seed	50	50	50	50
Lettuce	40	50	40	20
Milo	50	50	50	50
Mint	40	40	40	50
Nursery stock	50	50	50	50
Peas	50	50	50	50
Peanuts	40	50	50	50
Safflower	50	50	50	50
Spinach	25	25	25	25
Sunflower	50	50	50	50
Tobacco	40	40	40	50
Vegetables				
1 to 2 ft root depth	35	30	30	35
3 to 4 ft root depth	35	40	40	40

! Caution: Fine textured soils can reduce MAD values shown in this table. Use values for your specific soils. NRCS or Extension may be able to provide them.

Irrigating with Limited Water Supplies

Make your farm drought resilient *before* you get into a drought, using the methods in Chapter 2. Improving soil health, minimizing tillage, and adding organic matter can greatly increase water-holding capacity and intake rates.

When water supplies get short:

- *Focus irrigation on critical growth stages.* Depending on the crop, you'll usually see one of two responses to drought:

1. Seed crops and cereals are most sensitive to drought stress during flowering or seed formation and less sensitive during vegetative growth. Irrigate enough at the onset of seed formation to carry the crop through seed fill.
2. Perennial crops grown for forage and some root crops are relatively insensitive to moderate drought stress for short periods throughout the growing season and can recover with little reduction in yield. Focus on irrigating during periods of maximum growth.

- *Irrigate early in the season.* Fill the root zone to field capacity before hot weather starts.
- *Leave room for precipitation.* If there's any chance of rain, don't bring soils all the way to field capacity.
- *Plant drought-tolerant crops* or quick-maturing crops that require most of their water early in the season.
- *Reduce irrigated acreage* or *the amount of water you apply* over the whole irrigated area. As a rough guide, it's usually most economical to reduce acreage to the point where you can irrigate at about 80% of full irrigation.
- *Irrigate every other furrow,* switching furrows at each irrigation. You'll still get water to one side of each row using far less water.

Actions You Can Take

✓ Use the methods in Chapter 2 to improve soil health and make your farm more drought-resilient.

- ✓ See if publicly-available ET rates are available at your location. Learn how to use them.
- ✓ Look up management-allowable depletion (% of AWC) for the crops you're growing at their current stage.
- ✓ Try planning irrigations with the checkbook method.

References

Source for Tables 8 and 9: USDA Natural Resources Conservation Service. 1997. **Irrigation Guide:** Section 15 of the **National Engineering Handbook**. directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba

Further Resources

AgriMet. usbr.gov/pn/agrimet. *U.S. Bureau of Reclamation website providing ET estimates and related weather information to producers in the Columbia River Basin, from a network of over 70 weather stations in the Pacific Northwest.*

Burr, Chuck et. al. 2013. **Using an Atmometer or ETgage.** University of Nebraska-Lincoln Cropwatch. cropwatch.unl.edu/using-atmometer-or-etgage

California Irrigation Management Information System (CIMIS). cimis.water.ca.gov. *California Department of Water Resources website providing real-time and historical ET information from over 145 weather stations in California.*

National Drought Mitigation Center. drought.unl.edu. *Forecasts, publications, tools, and support for drought planning including the **Grass-Cast Grassland Productivity Forecast** for the Great Plains. https://grasscast.unl.edu*

Open ET. openetdata.org. *Website maintained by the USDA Agricultural Research Service and many partners offering free satellite-based ET estimates in Google Earth map format for the entire western United States.*

Smajstrla, A.G. et al. 2000. **Irrigation Scheduling with Evaporation Pans.** University of Florida IFAS Extension. edis.ifas.ufl.edu/AE118

6. Efficient Surface Irrigation

Limited control and erosion risks are inherent in many surface irrigation systems, but with skill and attention most systems can be managed quite efficiently. This chapter suggests several ways.

Some Surface Irrigation Methods

Most systems fall into one of four broad categories: ***wild flood, basin, border,*** and ***furrow***.

- ***Wild*** (or ***uncontrolled***) ***flooding*** allows water to flow over land without any structures to control or direct it.
- In ***basin systems***, water flows into level areas surrounded by dikes, berms, or levees used to pond the water.
- In ***border systems***, water flows across a slightly-sloping field divided by parallel dikes or ridges into ***border strips*** that are open at the end, allowing water to flow through.
- In ***furrow systems,*** water flows across the field through narrow furrows or trenches. Furrows can either be ***graded*** (slightly sloping) or ***level***—blocked at the ends, causing water to be ponded within the furrows.

There are countless variations. For example, ***contour ditches*** run along the contour of sloping land. Water overflows the ditch and flows down the slope in a uniform sheet.

SURFACE

Improving Efficiency

Actions You Can Take

✓ Use the methods in Chapter 2 to improve soil health. Over time, you may be able to improve infiltration rates and water-holding capacity of your soils.

✓ Decrease set time or irrigation frequency. Time your sets, watch for runoff, and experiment with different stream sizes and timing. Several hours after irrigation, probe various parts of the field to check soil moisture, infiltration uniformity, and deep percolation.

✓ Have your land levelled. Precision surface grading and land-leveling can greatly improve the uniformity and efficiency of many surface irrigation systems.

✓ Use ***gated pipe***, which has small adjustable gates, generally 18 to 24 inches apart, that can be opened individually. Gated pipe eliminates the leakage, percolation losses, and evaporation of open ditches and greatly increases control over water application.

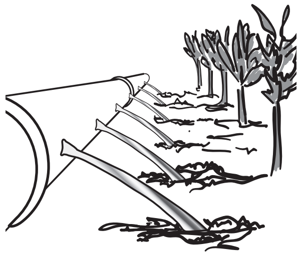


Figure 14. Gated Pipe

✓ Use ***surge irrigation***. Water is pulsed into furrows or border strips with pauses allowing water to soak in between pulses. The first surge lightly wets soils, and each subsequent surge causes deeper infiltration. Surge irrigation uses less water, improves uniformity, and reduces deep percolation, runoff, and erosion.

✓ In basin systems, use ***high-velocity flows*** to improve application uniformity, flooding the basin to the desired depth as quickly as possible.

✓ Plant a ***vegetative filter strip*** to reduce erosion and filter out sediments, fertilizers, and pesticides.

✓ Collect sediment and periodically redistribute eroded soil.

Making Furrow Systems More Efficient

Erosion and runoff are common concerns, and the upper end of the field must sometimes be overwatered to deliver enough water to the lower end. Soil intake rate, furrow spacing, and field length are all critical design variables.

Actions You Can Take

- ✓ Use high-velocity flows to improve uniformity and avoid overwatering the upper end of the field.
- ✓ Cutback inflow: When water has nearly reached the end of the furrow, reduce the inflow rate—increasing application uniformity along the furrow's length and reducing runoff.
- ✓ Modify length or slope: For more uniform infiltration and less erosion, shorten furrow length or gradually reduce furrow slope along the length of the furrow. In general, erosion increases with higher slope and longer furrow length.
- ✓ Install a tailwater reuse (pumpback) system that returns tailwater to the head of the field for reuse. These systems ordinarily include collection ditches, a pumping plant, pipelines, and a holding pond. Collecting and reusing tailwater reduces runoff and conserves water, but water may accumulate high levels of nutrients and pesticides.

Maximum Stream Size for Furrow Irrigation

Furrow erosion is a major problem on highly erodible soils with slopes as flat as one percent or even less. Soils may erode if the furrow velocity exceeds about 0.5 feet per second. Regardless of furrow slope, flow rate should generally not exceed 50 gallons per minute. Recommended maximum allowable stream sizes are:

$Q = 15 \div S$ erosion resistant soils

$Q = 12.5 \div S$ average soils

$Q = 10 \div S$ moderately erodible soils

$Q = 5 \div S$ highly erodible soils (This value can range from 3 to 9, depending on erodibility of soils.)

where Q = gpm per furrow and S = slope in percent

Example: Moderately erodible soils, 2% slope.
Stream size should not exceed $10 \div 2 = 5$ gpm per furrow.

SURFACE

References

Source for maximum stream size for furrow irrigation (p. 51): USDA Natural Resources Conservation Service. 1997. **Irrigation Guide:** Section 15 of the **National Engineering Handbook**. See Chapter 5, Furrow Irrigation. directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba

7. Efficient Sprinkler Irrigation

This chapter explains:

- Several sprinkler irrigation methods
- Several ways to improve sprinkler system efficiency

Sprinkler irrigation generally uses water more efficiently and allows more management options than surface irrigation. In many cases it's possible to calculate and regulate accurately the volumes of water being applied. On the other hand, distribution uniformity can be a problem with many systems, especially in windy areas.

Some sprinkler systems, such as wheel lines and hand lines, apply water in one location for a period of time. These ***periodic move*** systems apply fairly large volumes of water during each set. Because so much water is stored in the soil, periodic move sprinkler systems have a built-in margin for error. On the other hand, overwatering is an ever-present danger.

Linear move, center pivot, and other ***continuous move*** systems apply lower volumes of water during each set. The margin for error tends to be small, and soil moisture must be managed carefully throughout the season to avoid underwatering.

Some Sprinkler Irrigation Methods

- ***Hand move laterals***, also called ***hand line*** or ***hand move*** systems, consist of portable aluminum or plastic pipelines, usually 20 to 40 feet long, with risers and sprinkler heads. These lateral pipelines are connected manually to a mainline pipe, by quick couplers.
- ***Side roll laterals***, also called ***wheel line*** or ***wheel roll*** systems, have large wheels mounted on the lateral pipe, which functions as an axle. The wheels move the lateral across the field by rolling and are usually powered by a small gasoline engine.

- ***Hose-fed laterals***, also called ***pull laterals***, have sprinkler heads mounted on flexible plastic or rubber hose—sometimes mounted inside durable "pods"—that are pulled by hand or with an all-terrain vehicle to a desired location.
- ***Gun-type sprinklers***: ***Stationary guns***, also called ***big guns***, have a rotating, single-impact-type sprinkler head that discharges large volumes of water in a circular pattern. The sprinkler can be moved by hand or tractor. ***Traveling guns*** are self-moving: pulled or reeled across the field by a water piston, water turbine-powered winch, or small gasoline engine. With any gun-type sprinkler, application uniformity can be poor in windy areas. Compaction and surface sealing can also be concerns because of the large droplet size.
- ***Boom sprinklers*** have a boom with impact sprinklers or spray heads rotating around a central swivel joint. Like gun-type sprinklers, they can be either stationary or self-moving (***traveling booms***). Boom systems tend to be less expensive than some other sprinkler systems but have generally high maintenance requirements and often have poor application uniformity in windy areas.
- ***Fixed solid sets*** have lateral pipes installed in a pattern allowing the entire field to be watered without moving the pipes. Ordinarily, a control valve activates one group of sprinklers at a time until the entire field is irrigated. These systems eliminate the labor associated with moving pipe, and they are easily automated.
- ***Center pivots*** have a lateral supported by wheeled towers that rotates around a fixed pivot point. Application uniformity is usually high, labor requirements are low, and pressure requirements are often low, too, allowing the use of smaller pumps and motors. Erosion can be a problem in the outer part of the circle because of high application rates.

- ***Linear move systems***, also known as ***lateral move,*** are self-moving systems with the lateral pipe supported by wheeled towers, trusses, and cables. They move in a straight line and irrigate a rectangular area. Like pivots, they can be equipped with drop tubes and various spray heads to reduce wind drift and evaporative losses.
- ***Low energy precision application (LEPA)*** systems are center pivot or linear systems that apply water at low pressure (6 to 20 psi) directly onto the ground via flexible hoses and ***drag socks.*** LEPA systems use water extremely efficiently, require less energy than conventional systems, and can reduce wind drift and evaporative losses to near zero. Related ***Low Elevation Spray Application (LESA), Mid-Elevation Spray Application (MESA)***, and ***Low Pressure in Canopy (LPIC)*** systems apply water from sprinklers positioned anywhere from several inches to several feet above the ground.

Improving Efficiency

Actions You Can Take

✓ Follow your system's design specifications. When pressure or flow rates are lower or higher than the system was designed to handle, distribution uniformity is often compromised, forcing you to overwater or underwater some parts of the field.

✓ Decrease set time or irrigation frequency. Monitor soil moisture, follow crop-specific guidelines, and calculate the set time needed by your crops. You may be able to reduce set times or wait longer between irrigations.

✓ Maintain your equipment, following instructions in the ***Equipment Maintenance*** half of this book. *Worn nozzles* and *leaks* top the list of water- and energy-wasters. Both increase application rates and cause uniformity problems that may force you to resort to longer set times.

- ✓ Try an ***irrigation timer***. These inexpensive devices save energy and water by shutting off your sprinkler system after the correct amount of water has been applied.
- ✓ Install ***flow-control nozzles***. Especially useful on hilly terrain, these nozzles deliver a constant volume of water under varying pressures—improving application uniformity and sometimes allowing reduced set times.
- ✓ Install more efficient sprinkler heads on your pivot or linear move system: Among many options available are ***spinners*** or ***wobblers*** that produce larger droplets and reduce wind drift and ***dual spray heads*** allowing you to vary spray patterns according to season and crop stage.
- ✓ Consider moving ***every other*** riser as you go across the field with your hand move or side roll system. Then hit the missed risers when you come back across in the other direction. This will decrease runoff and deep percolation, get water to most of the field more often, and avoid the need to move the system all the way back across the field to start each set.
- ✓ Plant a ***circular buffer strip*** in your pivot field: a ring of native grasses that reduces wind damage and evaporation and improves the water cycle.

Further Resources

YouTube video: **Circular Buffer Strips of Native Perennial Grasses at NMSU Clovis.** youtube.com/watch?v=utKl1yq78CA

8. Efficient Microirrigation

This chapter explains:

- Several microirrigation methods
- Advantages and disadvantages of microirrigation systems
- Some ways to improve microirrigation system efficiency
- How to estimate required hours of operation

Microirrigation systems deliver water through low-volume, low-pressure devices such as drip emitters, micro spray and sprinkler heads, and bubblers. These systems generally apply water at very low rates and apply it frequently (often daily). Microirrigation is commonly used to irrigate windbreaks, vegetables, berries, grapes, fruit, citrus and nut orchards, nursery stock, and landscape and ornamental plantings.

Some Microirrigation Methods

Drip Emitters

Drip emitters (also known as ***point source*** emitters) drip or trickle water from a single point or opening. ***Orifice emitters*** discharge water through a narrow passageway. ***Turbulent flow emitters*** direct water through a wider and "tortuous" (crooked or zigzagging) path that creates turbulence to reduce pressure with less clogging. Some emitters are ***pressure-compensating***, discharging at a nearly constant rate over a range of pressures.

Line-Source Emitter Systems

Also known as ***drip tape, drip tubing,*** and similar names, ***line-source emitters*** are basically flexible tubing with uniformly-spaced emitter points. Some drip tapes emit water through small laser-drilled holes while other designs (***turbulent flow*** tape) include equally-spaced tortuous path emitter devices within the tubing. Some drip tape is designed for above-ground use, while other types may be buried.

Spray or Mini-Sprinklers

Also known as ***microspray*** or ***microsprinklers***, ***mini-sprinklers*** emit droplets from small, low-pressure heads. Some have spinners while others contain no moving parts. Compared to drip emitters, they wet a wider area and are less prone to clogging, since water moves through them at a high velocity.

Basin Bubblers

More commonly seen in urban and residential settings than in agriculture, ***basin bubblers*** apply water in a small fountain. A small basin or depression in the surrounding soil holds the water to allow infiltration.

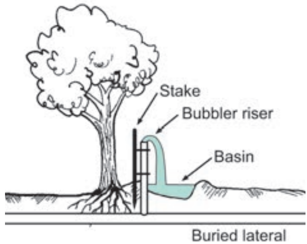


Figure 15. Basin Bubbler

Advantages of Microirrigation

- Frequent irrigation makes possible a high degree of control over the timing and amount of water applied.
- Well designed, installed, and maintained systems are highly efficient in their use of water, retaining as much as 85 to 95 percent of applied water in the root zone.
- Precise water delivery to the immediate vicinity of plant roots reduces erosion, runoff, deep percolation, and leaching of nutrients and pesticides to groundwater.
- Distribution can be highly uniform, reducing the need to overwater some parts of the field to avoid underwatering other parts.
- Yield and quality improvements have been shown for many crops.
- Fertilizer can be injected in precise amounts, directly to the root zone and at the right times for optimal growth.
- Smaller pumping plants are often required, using up to 50% less energy than conventional sprinkler systems.

- Fewer tractor trips across the field are needed, since chemicals can be injected through the irrigation system.
- The surface stays drier, reducing weed growth and muddy conditions that complicate using vehicles.
- Drip systems apply almost no water onto leaves, stems, or fruit—an advantage in avoiding plant diseases.
- Microirrigation systems are easily automated, starting and stopping at pre-set intervals or responding directly to soil moisture measuring devices.
- Microirrigation works well on irregularly shaped fields, steep slopes, and soils with low infiltration rates or low water-holding capacity.
- Salinity problems are reduced, for three reasons: (1) More continuously wet soil keeps salts diluted; (2) Salts move to the outer edges of the wetted soil area, away from plant roots; and (3) Salts have little or no chance of being absorbed through the leaves.

Disadvantages of Microirrigation

- Microirrigation systems require more intensive and technical management than conventional surface or sprinkler systems, as well as new skills and attitudes.
- Microirrigation systems are expensive to purchase and install: commonly $900 to $1300 per acre or more.
- High-quality irrigation water is needed to prevent clogging, since water is delivered through small openings. Filtration and regular flushing are required, and chemical injection is often needed to control biological and chemical sources of clogging.
- Animals, machinery, and foot traffic can cause leaks in above-ground tubing. Rodents, insects, and root intrusion can cause leaks in buried systems.
- Plants often have restricted roots, reducing their ability to withstand dry period without water.

- Your margin for error is reduced in hot dry conditions, since precise amounts of water are applied and stored in the soil. The water supply must be dependable, regular inspections and troubleshooting are a must, and equipment problems must be repaired promptly.
- Although some salinity problems are avoided, salt accumulation can still be a problem since water amounts are often insufficient to flush salts below the root zone.

Hours of Operation

Microirrigation systems are managed quite differently from other irrigation systems. Irrigation is frequent, maintaining a nearly constant, high level of soil moisture. You apply water in the root zone of individual plants instead of covering the entire field with a uniform layer of water. Typically, flowmeters measure the volume of water flowing through the system, and soil moisture monitoring is used to confirm moisture levels.

Despite these differences, management is generally based on the same methods described in the preceding chapters: monitoring soil moisture, following general crop-specific guidelines, and tracking ET.

Because irrigations are so frequent, checkbook-style calculations usually involve estimating ET for the next week or two, then planning the hours of operation you'll need to meet crop requirements.

For drip emitters and microsprinklers

The discussion below assumes that you know the ET rate of the crop you're growing. Then follow the steps below:

Step 1. Convert ET rates to gallons per day using Table 10 or this formula:

Water use (gal/day) = Crop spacing (ft^2) × ET (in/day) × 0.623

Example: ET rate is 0.35 inch per day, tree crop spacing 20 feet × 20 feet = 400 square feet.

Water use = 400 × 0.35 × 0.623 = 87.2 gallons per day

Table 10. Converting ET Rates to Gallons per Day

Crop Spacing (ft²) = row spacing × plant spacing	Evapotranspiration (inches per day) 0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4
100	3	6	9	12	16	19	22	25
200	6	12	19	25	31	37	44	50
400	12	25	37	50	62	75	87	100
600	19	37	56	75	93	112	131	150
800	25	50	75	100	125	150	174	199
1000	31	62	93	125	156	187	218	249
1200	37	75	112	150	187	224	262	299
1400	44	87	131	174	218	262	305	349
1600	50	100	150	199	249	299	349	399
1800	56	112	168	224	280	336	392	449
2000	62	125	187	249	311	374	436	498
2200	69	137	206	274	343	411	480	548
2400	75	150	224	299	374	449	523	598

Step 2. Determine your system's application rate in gallons per hour using this formula:

Number of emission devices × discharge rate per emission device (gal/hr/emitter) = application rate (gal/hr)

Example: Four drip emitters per tree with discharge rate of 0.75 gallon per hour = 3 gallons per hour per tree.

Step 3. Determine the required system operation time in hours per day using this formula:

$$\frac{\text{ET (gal/day)}}{\text{net application rate (gal/hr)}} = \text{hours of operation per day}$$

Example: ET is 62 gallons per day, drip emitters apply 4 gallons per hour, system efficiency 90%. Net application rate is 4 × 0.9 or 3.6 gallons per hour.

62 gallons per day ÷ 3.6 gallons per hour = 17.2 hours per day

For drip tapes and tubings

Step 1. Use Table 11 below to determine application rate of drip tape or tubing in inches per hour.

Step 2. Determine needed operation time in hours per day.

$$\frac{\text{plant water use (in/day)}}{\text{net application rate (in/hr)}} = \text{hours of operation per day}$$

Example: ET is 0.3 inch per day, drip tape applies 0.1 inch per hour, system efficiency 90%. Net application rate is 0.01 × .9 or 0.09 inch per hour.

0.3 inches per day ÷ 0.09 inches per hour = 3.3 hours per day

Table 11. Application Rate of Drip Tape and Tubing (Inches per Hour)

Row Spacing (inches)	Flow Rate (gallons per minute per 100 ft.)								
	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
12	0.1	0.14	0.19	0.24	0.29	0.34	0.39	0.43	0.48
14	0.08	0.12	0.17	0.21	0.25	0.29	0.33	0.37	0.41
16	0.07	0.11	0.14	0.18	0.22	0.25	0.29	0.32	0.36
18	0.06	0.10	0.13	0.16	0.19	0.22	0.26	0.29	0.32
20	0.06	0.09	0.12	0.14	0.17	0.20	0.23	0.26	0.29
22	0.05	0.08	0.11	0.13	0.16	0.18	0.21	0.24	0.26
24	0.05	0.07	0.10	0.12	0.14	0.17	0.19	0.22	0.24
26	0.04	0.07	0.09	0.11	0.13	0.16	0.18	0.20	0.22
28	0.04	0.06	0.08	0.10	0.12	0.14	0.17	0.19	0.21
30	0.04	0.06	0.08	0.10	0.12	0.13	0.15	0.17	0.19
32	0.04	0.05	0.07	0.09	0.11	0.13	0.14	0.16	0.18
34	0.03	0.05	0.07	0.08	0.10	0.12	0.14	0.15	0.17
36	0.03	0.05	0.06	0.08	0.10	0.11	0.13	0.14	0.16
38	0.03	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15
40	0.03	0.04	0.06	0.07	0.09	0.10	0.12	0.13	0.14
42	0.03	0.04	0.06	0.07	0.08	0.10	0.11	0.12	0.14
44	0.03	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.13
46	0.03	0.04	0.05	0.06	0.08	0.09	0.10	0.11	0.13
48	0.02	0.04	0.05	0.06	0.07	0.08	0.10	0.11	0.12
50	0.02	0.03	0.05	0.06	0.07	0.08	0.09	0.10	0.12
52	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.10	0.11
54	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.10	0.11
56	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
58	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
60	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10

Actions You Can Take to Increase the Efficiency of Microirrigation Systems

- ✓ Check frequently for leaks. These are usually easy to spot in surface drip and microsprinkler systems but harder to detect in subsurface systems. Watch your flowmeters: leaks cause increased flow and decreased pressure.
- ✓ Find and address causes of clogging. If you just install new emitters as a quick fix, clogging problems inevitably recur. Watch your flowmeters: clogging causes decreased flow downstream from clogs and increased pressure upstream.
- ✓ Check for plugged filter screens. Backflush as needed, and undo and clean any screens that are plugged.
- ✓ Flush lateral lines regularly—about every two weeks is a common interval.
- ✓ Inject chlorine or acid as needed to control mineral precipitation and biological contamination. See the ***Equipment Maintenance*** half of this book for specific recommendations.
- ✓ Avoid excessive backflushing that wastes water and energy and creates water disposal problems.

References

Source for Tables 10 and 11: Larry Schwankl, Blaine Hanson, and Terry Prichard. **Low-Volume Irrigation**. 1993. University of California, Davis.

Further Resources

Morris, Mike and Larry Schwankl. 2023. **The California Microirrigation Pocket Guide**. National Center for Appropriate Technology.

The **Irrigation Training and Research Center** at the California Polytechnic State University in San Luis Obispo. itrc.org
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MICRO

9. Water Quality and Salinity

This chapter explains:

- Several water quality concerns for irrigators
- Salinity concerns for irrigators
- Management suggestions for addressing these concerns

Water Quality Problems Caused by Irrigation

Irrigation runoff often carries sediments, nutrients (especially nitrogen and phosphorus), salts, pesticides, pathogens, and other contaminants. When this water returns to streams or groundwater, it may be harmful to other irrigators, municipal water users, fish, and wildlife.

Ground and surface water depletion causes wells to go dry, salinity and pollution problems in aquifers, and damage to rivers and streams: changing water temperature, concentrating pollution, and damaging fish habitat.

Actions You Can Take to Protect Water Quality

- ✓ Build organic matter and soil health. Improve your soil's water-holding capacity and ability to filter pollutants.
- ✓ Don't overwater. Keep application rates below your soil's maximum intake rate.
- ✓ Adjust flows or reduce furrow grades to prevent erosion.
- ✓ Follow a nutrient management plan to reduce fertilizer use.
- ✓ Follow an integrated pest management plan to reduce pesticide use.
- ✓ Plant vegetative filter strips to filter out sediments and chemicals.

Poor Quality Water and Salinity

Leach water, tailwater, and runoff from animal agriculture, septic systems, and urban areas can all contaminate water used by irrigators. Human pathogens (such as fecal coliform) are a special concern when applied to crops commonly eaten uncooked. And poor quality irrigation water can cause salts to build up in soils, such as the negative ions chloride, nitrate, and sulfate and the positive ions calcium and sodium.

Salt buildup often begins when water dissolves salts from fertilizers, manure decomposes, or soil minerals weather. Rain and irrigation move some salts down into subsoil while others are taken up as plant nutrients. High temperatures and wind also evaporate water from the surface and capillary forces draw water upward through the soil, leaving behind dissolved salts.

Sodic soils have a high concentration of sodium. Soil particles saturated with sodium ions repel one another, breaking down the chemical forces that hold soil particles together as aggregates and causing impermeable soil structure associated with poor tilth.

Salt accumulation in the root zone can interfere with a plant's ability to take up water, and some plants are especially sensitive. For example, at the same level of salinity, beans exhibit a 50 percent reduction in yields while yields of wheat, barley, and sugar beets are unaffected. In general, crops are most vulnerable to salt during germination or emergence. Most seedlings are highly sensitive to salt.

Sodium, chloride, and boron, all essential nutrients at low concentrations, can be toxic to plants at higher concentrations. If applied through sprinkler systems, salts can produce leaf burn or white spots on foliage. Water high in sodium ions can corrode metal irrigation lines. Water high in carbonates can clog nozzles.

Actions You Can Take

- ✓ Have your water quality analyzed regularly to check for contaminants, electrical conductivity, and specific ions. High electrical conductivity indicates a high concentration of salts.
- ✓ If a high water table is moving salts up into the root zone, you may be able to install drainage that lowers

the water table. You can also sometimes lower the water table by planting a deep-rooted crop, such as alfalfa.

- ✓ If high temperatures are evaporating salt-laden water from the soil surface, try mulching or leaving crop residues on the surface to reduce evaporation.
- ✓ Often the only solution is to saturate soil with water, leaching salts downward below the root zone. This only works if soil has good internal drainage, and you may need to repeat it on a regular basis. The percentage of irrigation water that drains below the root zone is known as the *leaching fraction*. Charts and tables are available showing the leaching fraction needed to keep salinity within acceptable levels for your crop.

! Caution: Leached drainage water can cause environmental problems downstream. Besides salts, leached drainage water may also contain pesticide residues, plant pathogens, and human pathogens.

- ✓ Plant crops that are less sensitive to saline conditions. You may also be able to grow plants that will take up and accumulate toxic ions such as chloride and boron.
- ✓ Plant seeds on the edges of raised beds to reduce their exposure to saline conditions. Salts tend to accumulate in the center of raised beds.
- ✓ Alternatively, run your irrigation system just before planting to move salts to the top and center of raised beds. Then knock down the top of the bed, removing accumulated salts.
- ✓ For sodic soils, broadcast and incorporate a soluble source of calcium such as gypsum (calcium sulfate). Then apply excess irrigation water, activating a chemical reaction that replaces sodium with calcium and leaches the exchanged sodium into the subsoil.

In Microirrigation Systems

Drip and micro-sprinkler systems generally cause less salinity problems because: (1) More continuously wet soil keeps salts diluted; (2) Salts move to the outer edges of the wetted area, away from plants; and (3) Salts have little or no chance of being absorbed through the leaves. However, the light water applications typical of microirrigation are also often inadequate to leach salts below the root zone.

Actions You Can Take

- ✓ Place emitters as close as possible to plants, so the wetted area extends farther away from the plant.
- ✓ Light, frequent irrigations can sometimes reduce the upward movement of saline water into the root zone.
- ✓ If you're depending on rainfall for leaching, run your drip system while it's raining for greater effectiveness.
- ✓ If high sodium, carbonate, or bicarbonate levels are reducing permeability and intake rates, acidify water to reduce carbonate and bicarbonate levels, while injecting gypsum to increase calcium levels.

! Caution: Gypsum can plug emitters and cause abrasion and damage to microsprinkler nozzles. Use very pure and finely ground gypsum and always perform a jar test to check for solubility before injecting gypsum.

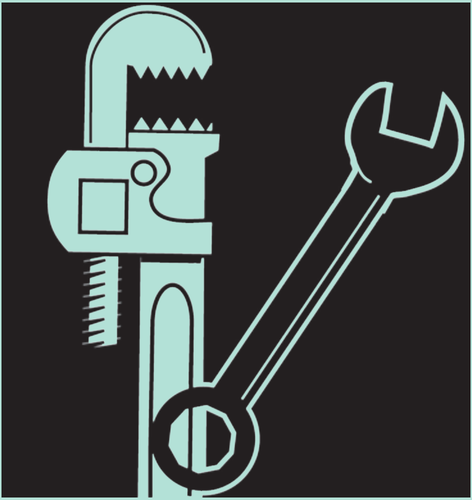
Further Resources

Water section of the ATTRA website. attra.ncat.org/topics/water

Nutrient Management Plan (590) for Organic Systems. National Center for Appropriate Technology. attra.ncat.org/publication/nutrient-management-plan-590-for-organic-systems

Rodriguez, Omar and Rex Dufour. 2020. **Saline and Sodic Soils: Identification, Mitigation, and Management Considerations**. ATTRA publication IP 602. attra.ncat.org/publication/saline-and-sodic-soils-identification-mitigation-and-management-considerations/and-methods

Equipment Maintenance



The Irrigator's Pocket Guide

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Preface

Over the two decades since it first appeared in 2003, this take-to-the-field guidebook has evolved through over a dozen editions with comments and advice from irrigation experts around the country. Besides the usual updates and corrections, this new version puts greater emphasis on the importance of soil health. Recent advances in soil science have taught us a great deal about how biologically dead or depleted soils can be brought back to life. When soils get healthier, they catch and hold more water—sometimes a lot more. Taking care of soil health should therefore be a high priority for all irrigators.

We appreciate all who have helped create and update this book over the years. We'd especially like to thank:

Greg Ames, David Amman, Ann Baldwin, Jim Bauder, David Bausch, Jim Beck, Linzy Browning, John Busch, Joel Cahoon, Greg Clouse, Lynn Cornia, John Dalton, John Doubek, David Fischer, Allen Gehring, Tim Grove, Joe Hamm, Mike Hansen, Jim Headlee, Stephen Henry, John Hester, Larry Hoffman, Carolyn Jones, Kristin Keith, Patricia Kelley, Larry King, Rob Krause, Ron Lee, Mark Lere, Barbara Lien, Doug Mawhinney, Brady McElroy, Mike McLane, Danielle Miska, Justin Morris, David Nelson, Leigh Nelson, Merlin Nelson, Troy Peters, Clare Prestwich, Stephen Rogers, Bruce Sandoval, Dave Scott, Marty Soffran, David Spengler, Alan Stahl, Mark Twyeffort, Daniel Vichorek, Gerald Westesen, Darol Wilson, Jesse Wilson, and Brian Wright.

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Introduction

The *Equipment Maintenance* half of this book gives specific instructions for keeping your irrigation system running properly, including:

- Descriptions and diagrams of recommended pumping plant installations.
- Suggestions for improving water and energy efficiency.
- A troubleshooting guide for pumps and motors.
- Dozens of frequently used conversions and formulas (in the center of the book).
- Detailed instructions for equipment maintenance, broken down by how frequently they need to be done.

This concise take-to-the-field guide is by no means intended to be a complete irrigation manual. For example, it does not tell you how to design an irrigation system and says little about maintaining diversion or conveyance structures (such as pipelines or ditches) for getting water to the farm or field. The discussion generally assumes that you already have an irrigation system in place, and the focus is on maintaining the pumping plant and distribution system.

The wrench symbol indicates maintenance tasks.

! The exclamation mark indicates safety hazards, potential equipment damage, possible harm to crops, or other situations calling for extra caution.

No one knows more than you do about your fields and irrigation system. So adjust or reject any suggestion in this book if it doesn't fit your situation or doesn't seem to be working. Proceed cautiously and test every recommendation with direct observations in the field.

1. Recommended Installations

Centrifugal Pumping Plant Installation with Electric Motor

The term ***pumping plant*** refers to the irrigation pump and motor or engine, considered together. If you have an older system, your pumping plant might look like the *Poor* setup in Figure 1 below on the discharge side. It's a false economy to cut costs by installing smaller valves and fittings since you'll have greater friction loss and higher pumping costs. The next time you rebuild your pump, replace fittings so your pumping plant looks like *Ideal.*

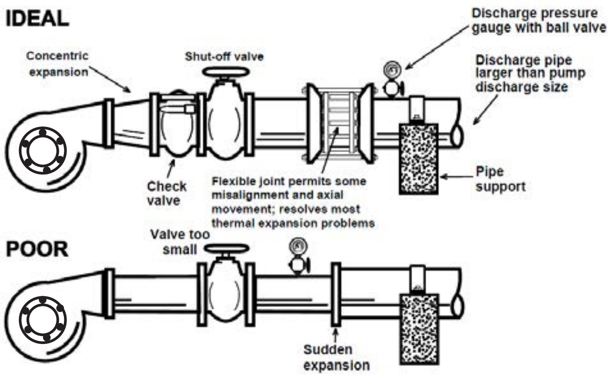


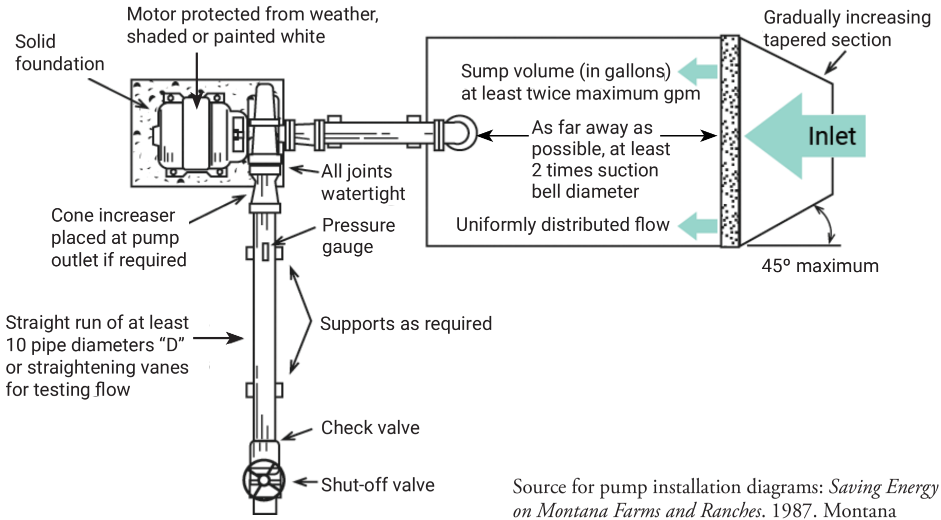
Figure 1. Ideal and Poor Installations

An ideal installation should have:

- A discharge concentric expansion instead of an abrupt change in pipe diameter to minimize head loss, turbulence, and air pockets.
- A discharge valve the same diameter as the mainline.

Figure 2, pages 4-5, shows what your pumping plant should look like when pumping from a surface source such as a river or canal.

Top View



Source for pump installation diagrams: *Saving Energy on Montana Farms and Ranches*. 1987. Montana Department of Natural Resource Conservation.

Side View

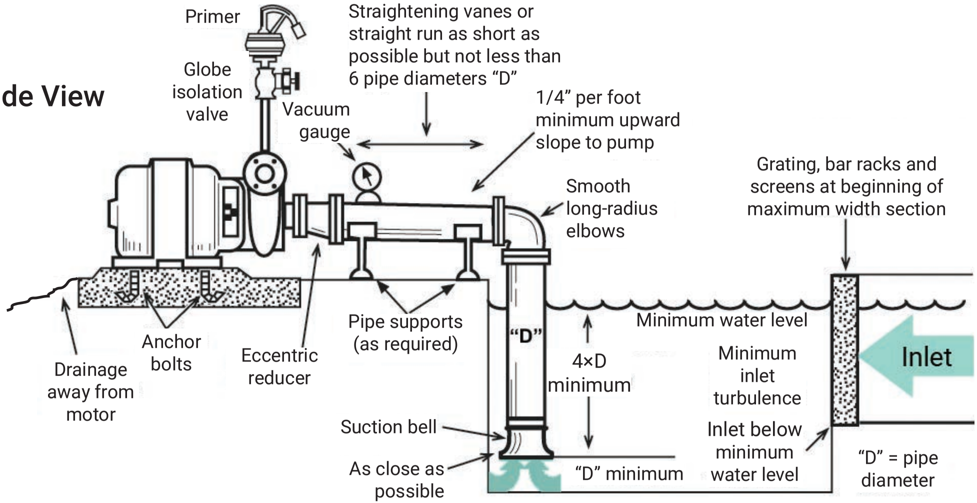


Figure 2. Recommended Pump Installation, Top and Side Views

A well-designed pumping plant should have:

Suction Side of Pump

- A screened sump that keeps trash away.
- Suction line joints that are airtight under a vacuum.
- No high spots where air can collect.
- A suction line water velocity of five feet per second or less. Two to three feet per second is best.
- A suction entrance at least two pipe bell diameters from sump inlet.
- A suction lift (vertical distance from water surface to pump impeller) less than 15 to 20 feet.
- An eccentric reducer to keep air from becoming trapped in the reducer fitting.
- A vacuum gauge to indicate whether the primer is pulling a vacuum or just moving air through the pump.

Discharge Side of Pump

- A valve the same size/diameter as the mainline.
- A non-slam check valve to prevent back spin of the pump when shutting pump off.
- An air relief device when a buried mainline is used.
- A discharge line water velocity of less than seven feet per second. Five feet per second is best.
- An energy-efficient 1800 rpm motor with 15% safety factor.
- A simple shade over the motor.

! Caution: Figures 1 and 2 show only components directly related to energy efficiency and don't show pressure relief valves, air vents, and other features necessary for safety and performance.

Turbine Pump Installation

Refer to the left half of Figure 3 on the next page for a properly installed turbine pump in a well. Many of these same principles apply to turbine pumps in sumps. A properly designed well should also:

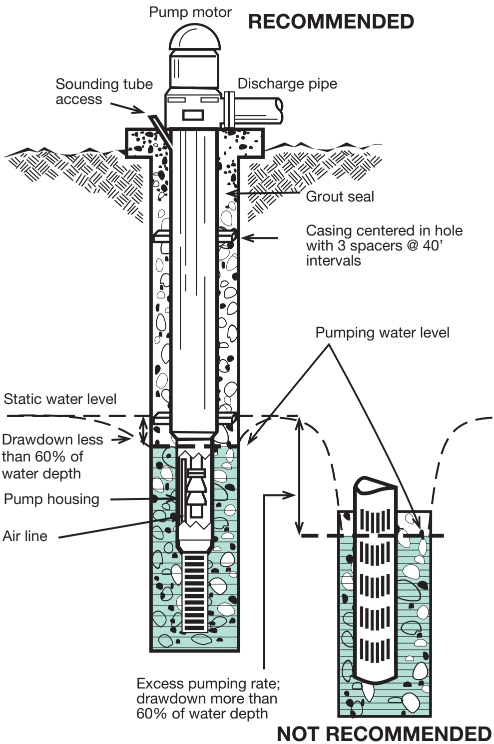


Figure 3. Deep Well Turbine Pump

- Be at least six inches in diameter larger than the outside diameter of the well casing when a gravel pack is required.
- Have horizontal well screen slots that continue below the pumping water level. The openings should hold back at least 85 percent of the surrounding material.

The poorly constructed well in the lower right side of Figure 3 shows a well casing that is not centered in the well. Vertical slotted pipe perforations are also above the minimum water level, creating cascading water.

About Pressure Gauges

A good quality oil- or glycerin-filled pressure gauge on the discharge side of the pump will tell you a lot about your system's condition. If the operational pressure stays close to the original design pressure, the pump is probably in good working order. Pressure changes can indicate clogged suction screens, leaks, pump wear, worn nozzles, or other problems. Use the gauge when filling the mainline to reduce demand and water hammer. Extend the life of your gauge by installing a ball valve on the riser. Keep the valve closed except when referring to the gauge. With a ball valve in place, you also have the option of removing the gauge during the winter.

Control Panel for Electric Motors

The importance of a properly installed control panel cannot be overemphasized for protecting your personal safety and your investment in your pump and motor.

Your control panel should:

- Have a shade over it to cool thermal breakers.
- Be mounted on secure poles or foundation.
- Have any missing knockout plugs and other holes in the starting switch box replaced and screened or puttied against rodents, insects, and dirt.
- Have a small hole (3/16-inch diameter) in the bottom of the panel to allow moisture to drain.
- Have circuit breaker(s) for overload currents.
- Have a lightning arrester.
- Have a surge protector.
- Have a phase failure relay, to protect the motor from phase reversal or failure and from low voltage.
- Have a pressure switch to shut off the motor if pumping pressure drops to undesirable levels.

2. Pumping Plant Maintenance

Plan and follow a regular maintenance schedule and see benefits in reduced repair costs, lower operating costs, longer system life, and less stress for you.

! Caution: The recommendations below are not comprehensive and may not be correct for all systems. Consult your owner's manual and always follow the manufacturer's instructions if they differ from the ones in this guidebook.

Electric Motors

An electric motor is an air-cooled piece of equipment and needs all the ventilation it can get. Excessive heat is the main cause of reduced motor life, and motors also like to be dry. Keep motor windings dry by keeping pump packing in good condition. Even if windings are protected from moisture, minerals in the water can attach to them, causing early failure.

Regular maintenance is especially critical for 3600 rpm motors and pumps. Motors that operate at 3600 rpm experience twice as much wear as motors operating at 1800 rpm.

General

✓ Make a habit of checking to be sure the motor is securely bolted to its platform. Mounting bolts can vibrate loose.

✓ Also make sure rotating parts aren't rubbing on stationary parts of the motor, causing damage.

Maintenance Tasks

At season startup:

✓ Remove tape on all openings. Clean out rodents, insects, and debris.

✓ Locate the motor drain hole on the base or support for the base and clean it out so water won't be trapped and held directly under the air intake.

- ✓ Change oil in reduced voltage starters using an oil recommended by the manufacturer. Be sure to clean the oil pan before refilling.
- ✓ Use vacuum suction or air pressure to remove dust and debris from moving parts of motor. (Don't exceed 50 psi of air pressure.)
- ✓ Especially on large motors, you may want your electrician to do an annual Megger check on the control panel, motor, conduits, and other electrical connections. The Megger device applies a small voltage to an electrical component and measures electrical resistance. Tracking changes in readings over time allows you to diagnose looming failures due to degrading insulation.

Periodically:

- ✓ Clean grass and debris from air ventilation openings on and around the motor to allow a full flow of cooling air.
- ✓ Check screens on motor ventilation openings. Replace with machine cloth (¼-inch mesh) as necessary.
- ✓ At end-of-season shutdown, cover the motor with a breathable, water-resistant tarp.

Motor Electrical System

Winter temperatures can cause electrical connections (especially in aluminum wire) to expand and contract, loosening connectors that were tight in the fall and causing heat buildup and arcing at electrical terminals. The voltage drop across loose connections also causes the motor to operate at less than its rated voltage, increasing internal motor temperature and breaking down motor winding insulation, resulting in electrical shorts and motor failures. A loose or broken connection can also unbalance the phases of three-phase power and damage the motor windings.

! Caution: Before conducting any of these tasks, be sure power is off at the utility disconnect switch. It may be necessary to have the utility company shut the power off.

Maintenance Tasks

At season startup:

- ✓ Inspect motor winding insulation. If windings are excessively grease-covered, consult your motor repair shop for direction.
- ✓ Check all safety switches following manufacturer's directions.

Twice per year:

- ✓ Check electrical connections from meter loop to motor for corrosion and clean if necessary. Coat the wiring (especially aluminum) and connectors with an antioxidant that meets electrical code requirements.
- ✓ Check electrical connections from meter loop to motor for tightness. Tighten and re-tape if necessary.
- ✓ Replace overheated connections or wires with new material. Overheated connections will show heat damage such as burnt insulation on wires.

PUMPING PLANT

Motor Bearings

Lubricate the motor according to manufacturer's instructions. Lubrication intervals depend on motor speed, power draw, load, ambient temperatures, exposure to moisture, and seasonal or continuous operation. Electric motors should not be greased daily. Bearings can be ruined by either over- or under-greasing.

Fill a grease gun with electric motor bearing grease and label it so it won't be confused with other types of grease.

! Caution: Follow instructions in owner's manual if different from the ones given here. Newer motors may have sealed bearings that cannot be lubricated.

Recommended Re-greasing Periods for Motors

	Horsepower Range		
Type of Service	**1 - 9**	**10 - 40**	**50 - 150**
Normal Duty (8-hour day)	8 months	6 months	4 months
Heavy Duty (24-hour day)	4 months	3 months	2 months

Maintenance Tasks

At recommended intervals:

✓ Change grease to remove any accumulated moisture:

- Remove the bottom relief plug and clean hardened grease out of passage way.
- Using a grease gun, fill housing with approved high-temperature electric motor bearing grease (refer to the manufacturer's manual for API number of grease) until old grease is expelled.
- Run motor until all surplus grease is thrown out through the bottom grease port (may require 5 to 10 minutes).
- Shut off motor and use a screwdriver or similar device to remove a small amount of grease from the grease port to allow for grease expansion during full load operation.
- Replace grease plug.

! Caution: Do not overgrease your motor. If old grease is not expelled as new grease is pumped in, stop adding grease and have your motor checked by a qualified repair person. Adding new grease without old grease being removed could blow seals and push grease into the motor. Grease forced into motor windings will cause the motor to overheat and reduce service life.

Control Panel

Control Panel Safety Precautions

! Caution: Never use the main disconnect to start or stop your motor. It's not meant for this purpose and abusing it in this way will cause excessive wear of the contacts and arcing. Use the start and stop button.

! Caution: If overhead lines to your control panel's service are obstructed by tree branches or other items, have your utility company clear the lines.

Have an electrician inspect your panel to ensure that:

- ✓ Control circuits are protected with the correct size and type of fuse.
- ✓ Lightning arresters are properly installed on meter and motor side of buss and breaker and mounted in a secure box to protect you if they blow up.
- ✓ The service panel is properly grounded, independently from the pumping plant.
- ✓ Service head grommets are in place and in good condition.

! Caution: After opening the control panel but before touching controls inside, use a voltmeter to BE SURE the incoming power is disconnected or turned off. If necessary, have your utility disconnect the power. If you have any doubts about the safety of your control panel, WALK AWAY and call a qualified electrician. Even a current of 15 milliamps (one milliamp is one one-thousandth of an amp) can cause serious injury or death. Always play it safe!

Maintenance Tasks

At season startup:

- ✓ Replace fuses after checking to be sure they aren't blown. Never use oversized fuses.
- ✓ Operate the disconnect switch slowly to check for alignment of blades and clips. Open and close the switch several times to clean oxide from contact points.
- ✓ Clean contacts of dust and dirt. Use very fine sandpaper or a fine file for copper contacts. Never file silver or silver-plated contacts! Replace pitted or burned contacts. Leave contacts clean and dry so dust won't collect.
- ✓ If accessible, check magnetic starter switch contact points.
- ✓ Clean out debris, rodent droppings, and nests and insects. Make sure the drain hole is open.

Periodically:

✓ Any time the main disconnect switch has been left open or off, operate it several times before leaving it closed or on. Copper oxide can form in a few hours and result in poor contact, overheating, poor grounding, and direct or high-resistance shorts.

At shutdown (end of season):

✓ Ensure that switches are in the off or open position. Lock panel in the off position and remove fuses to prevent accidental startup, vandalism, and corrosion.

✓ Protect exposed control boxes against moisture and dust with a waterproof tarp.

Engines: Diesel, Gasoline, Liquid Propane Gas (LPG), and Natural Gas

General

✓ Make a habit of checking to be sure the engine is securely bolted to its platform. Mounting bolts can vibrate loose.

✓ Regularly check coolant, oil levels, fuel, and fan belts. If coolant or oil level is down, check lines for leakage. On diesel engines, check injectors and fuel lines for leaks.

Maintenance Tasks

At season startup:

✓ Remove tape on all engine openings and distributor cap, and tighten belts.

✓ Charge batteries and connect them.

✓ Open fuel tank shutoff valve.

✓ Before starting the engine, override safety switches that protect against low water pressure, loss of oil pressure, and overheating. After engine has reached operating speed, activate the safety switches.

✓ Run the engine for 10 minutes, then turn it off and check oil and coolant levels.

✓ Check engine and pump for leaks caused by drying gaskets.

! Engines are affected by altitude and air temperature. Derate engine power output by 3.5% for every 1,000-foot increase in altitude over 500 feet above sea level and by 1% for each 10-degree increase in air temperature above 85 degrees F.

Engine Air System

Always replace disposable air filters with new ones. Cleaning will distort the filter and allow more dirt to enter.

Maintenance Tasks

At season startup:

✓ Clean and refill the filter bath in oil-bath air cleaners and reassemble air cleaner.

Periodically:

✓ Brush blockage off screen if the air-induction system is equipped with a pre-screener.

✓ Change the air filter only when the service indicator signals that it's time to change it:

- Turn off the engine before changing air filter.
- Wipe the outside of the cover and housing with a damp cloth and remove the cover.
- If cover is dented or warped, replace it.
- Use extreme care when removing the filter to prevent dirt from falling into the intake duct. Use a clean damp cloth to wipe inside of filter housing.
- Install new air filter.

Engine Electrical System

If you have a natural gas engine, note that natural gas has a higher octane value than gasoline. You can increase engine efficiency and reduce fuel consumption by setting the ignition timing to take advantage of the higher octane. Consult the engine manufacturer for recommendations on how to do this.

Maintenance Tasks

At season startup:

✓ Inspect breaker points for wear and replace if needed.

✓ Set the gap or dwell angle and lubricate rotor.

✓ Check timing and adjust if necessary.

✓ Clean all connecting terminals; cover with protectors.

✓ Spray silicone on electrically operated safety switches and ignition system to prevent corrosion.

Twice per year:

✓ In engines that have them, clean and re-gap spark plugs or replace with plugs in the recommended heat range.

✓ Check all terminals and electrical connections for tightness and corrosion and spray with corrosion inhibitor (NOT grease).

✓ Remove the distributor cap and lubricate governor weights with silicone (NOT oil).

Engine Oil and Lubrication

Have a sample of engine oil analyzed for contaminants, which signal abnormal wear. Intervals between analyses depend on your engine, and these tests may only be cost-effective for larger engines. Equipment dealers should know where oil can be analyzed and how often this should be done.

Use only oil recommended by the manufacturer. Tag each engine with a label identifying the proper oil.

Maintenance Tasks

Twice per year:

✓ If engine was not protected during shutdown, or if oil has not been changed within the last year, change the crankcase oil and oil filter.

✓ Lubricate all engine accessories such as the driveshaft and U-joints.

Engine Fuel and Coolant

Maintenance Tasks

Twice per year:

✓ Remove and clean or replace the fuel filter.

Periodically:

✓ Check to be sure the fuel tank cap and oil filter cap are on tight and gaskets aren't cracked.

✓ Check to be sure fluid level and degree of coolant protection are adequate, the radiator cap is on tight, and gaskets aren't cracked.

At shutdown (end of season):

✓ Drain all fuel from the tank and lines and shut off the fuel valve. If LP gas is used, drain vaporizer-regulator. (Drain both fuel and water lines.)

✓ Remove spark plugs. Pour a tablespoon of clean motor oil into each spark plug hole. Position spark plug wire away from cylinder opening and rotate crankshaft by hand to lubricate piston and rings. Replace spark plug.

✓ Seal distributor cap with a sealant appropriate to your climate, where the cap joins the distributor housing.

✓ Seal all the openings in the engine with a sealant appropriate to your climate, including air cleaner inlet, exhaust outlet, and crankcase breather tube.

✓ If the engine coolant is water, drain and refill the cooling system with water, a rust inhibitor, and antifreeze.

✓ Remove tension from belts.

✓ Remove and store batteries in a cool but not freezing location. Never store batteries directly on concrete.

✓ If engine is outdoors, cover with a water-resistant tarp.

Centrifugal Pumps

General

To avoid water leaks, make sure all gaskets are the correct ones for the coupling or flange. (See sidebar on gaskets on page 36.) Eliminate air leaks in your pump's suction line by coating threaded connections with pipe cement or white lead and drawing them tight. Also examine suction line welds for cracks that allow air leaks.

If the pump isn't delivering water, verify that the shaft is turning in the direction of the arrow on the casing. As viewed from the motor end, rotation is usually clockwise, but check instructions that came with the pump. On three-phase motors, swap any two power leads to change rotation. It is recommended that a qualified electrician perform this task.

If the pump doesn't prime, check for air leaks on discharge valves. Many all-metal gate-type valves won't seal properly to create a vacuum. Sand or other debris between the rubber flap and the valve seat will also prevent check valves from sealing and forming a tight joint. If the rubber face is cracked or chipped and not seating, replace the gate valve or check valve. Check connections between pump and primer. On a hand primer, if grass or other debris is lodged in the check valve, air is pulled back into the pump at every stroke and the pump won't prime. After proper priming, fill the system slowly.

Maintenance Tasks

At season startup:

- ✓ Using new gaskets and pipe dope, reconnect to the pump any piping removed during shutdown.
- ✓ Re-install the primer and priming valve if they were removed during shutdown.
- ✓ Check pump for leaks caused by drying gaskets.

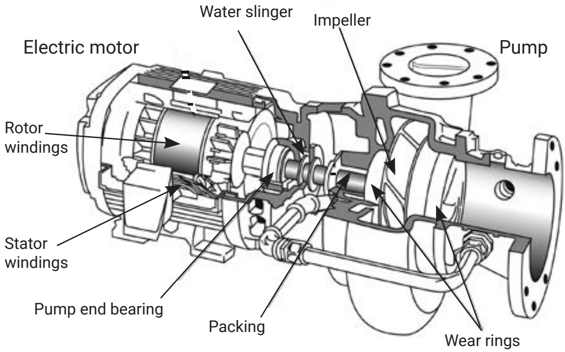


Figure 4. Centrifugal Pump and Electric Motor

✓ Check to be sure the pump shaft turns freely and is free of foreign objects. Applying power could break the impeller if it's rusted to the case.

✓ Check intake and discharge piping for support. Make sure pump is securely bolted to platform.

✓ Clean drain hole on the underside of the pump.

Twice per year:

✓ Thoroughly clean suction and discharge piping and connections of moss and debris.

✓ Tighten all drain and fill plugs in the pump volute case to avoid air and water leaks. Use a pipe thread compound on all pipe threads.

✓ Check for cracks or holes in the pump case.

✓ Clean trash screening device and screens on suction pipe.

At shutdown (end of season):

✓ All water MUST be drained prior to freezing weather.

✓ Remove suction and discharge piping in areas where ice is a problem. Make sure drain valves aren't plugged and drain water from the pump.

✓ Cover any exposed metal, such as the shaft, with protective lubricant to prevent corrosion.

✓ Cover all oil- or grease-lubricated bearings with lubricant so moisture won't rust and pit them.

✓ Remove tension from any belts.

✓ Open petcock and drain diaphragm-type hand primer.

✓ If discharge primer valve is equipped with a rubber seat, coat it with rubber preservative.

✓ Any rubber parts in a flexible coupling connecting the pump to the driver should also receive a coating of preservative.

✓ Make sure the ball valve on pressure gauge riser is closed. Remove the gauge and store it indoors.

✓ Seal all openings, including suction, discharge, and primer, to keep out rodents and foreign material.

✓ Cover the pump with a waterproof tarp.

Servicing Impeller and Wear Rings

If you suspect your impeller is clogged with foreign matter, damaged, or has worn wear rings, you can dismantle the pump. This is not easy and best done in the shop. Or have a qualified pump repair shop undertake this procedure. Follow the directions in the manufacturer's manual, if available, instead of the simplified directions below.

- Remove suction cover or volute case.
- Remove debris from impeller and volute. Remove pebbles lodged between vanes.
- Check wear at impeller eye and vanes. If worn, repair or replace the impeller.
- Re-machine or replace wear ring if clearance is more than 1/32 inch per side.

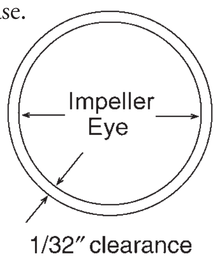


Figure 5. Impeller Eye and Wear Ring

- Replace suction cover or volute. Use a new gasket.

Net Positive Suction Head (NPSH) and Cavitation

A centrifugal pump doesn't pull water from a source; it can only pump water that is delivered to it. When air is removed from a suction pipe, as for example by a primer pump, the weight of the earth's atmosphere forces water to rise into the pipe. The maximum height that water can rise in a pipe under a given set of conditions is known as *Net Positive Suction Head,* or NPSH.

Under a perfect vacuum and at sea level, atmospheric pressure can theoretically force water to rise as much as 34 feet into a pipe, but this number drops with any increase in elevation, water temperature, or pipe friction. Practically speaking, centrifugal pumps more than 20 feet above a source water are likely to experience problems.

Insufficient NPSH often occurs when starting irrigation pumps. Since the pump is working against low pressure, it moves a larger-than-normal volume of water, increasing friction losses in the suction line and reducing NPSH. Insufficient NPSH leads to water vaporizing in the eye of the impeller, causing *cavitation*—a noisy condition where vapor bubbles collapse violently in the pump.

If cavitation is allowed to continue, the pump impeller and pump casing can become pitted and damaged. To stop cavitation that is occurring, close the discharge valve. To eliminate pump cavitation and water hammer, and to prevent high amperage draw on demand meters, open the discharge valve SLOWLY to fill the mainline every time you start the pump.

! Caution: Never let the pump run more than two minutes with the discharge valve closed.

Servicing Pump Packing

A properly adjusted pump with shaft sleeve and packing in good condition shouldn't require constant readjustment but should be checked daily. If proper leakage (about 8 to 10 drops per minute) isn't running through the packing box, the packing will get overheated and dry out, eventually burning and scoring the shaft sleeve. Excessive dirt, silt, or sand in the water can also score the sleeve.

Check for an improperly greased or worn rotary shaft seal by running the pump and squirting oil on the shaft just outside the seal. Oil drawn into the seal indicates a leak.

If the pump has been out of service, the packing may be dried and hardened. Air can leak into the pump through the packing box and the pump can lose prime..

Pump Packing Maintenance Tasks

Annually:

✓ Grease packing box with a proper pump packing grease. Less frequent maintenance causes grease to harden, making this task very difficult.

- If packing box is equipped with a grease cup or zerk, apply a couple pumps of grease to the box to force out the remaining water and protect the packing.
- For a packing box without a grease cup or zerk, remove the last two packing rings and pack packing grease into the packing box until full. Add two new rings and tighten the packing gland slightly to force the grease into the subsequent packing rings. Then loosen the gland.

Replacing the Packing

Old packing should be replaced completely if you can't reduce leakage by adding new packing rings to the old ones or if packing is dried up, scorched, or leaking excessively.

! Caution: This task is difficult. Have a qualified pump repair shop do it. Or if attempting to do it yourself, do it in the shop rather than in the field. Helpful videos are available on the Internet showing the procedure.

- Remove packing box gland nut with a wrench. Remove gland and packing, twisting two packing pullers 180 degrees apart into the exposed packing ring to pull each ring out of the packing box until all are removed. The lantern ring has two holes 180 degrees apart and can be removed with packing pullers.
- Replace shaft sleeve if worn or grooved. This usually requires pump disassembly. Once packing is burned and the shaft sleeve is scored, no amount of adjustment will maintain proper leakage for any length of time.
- Before replacing packing, insert the packing gland to make sure it enters freely to the gland's full depth. If it doesn't, clean out fragments of old packing and debris that may be obstructing it.
- Install new packing rings as far forward as you can reach. Install only the type and size of packing recommended by the manufacturer.
- Insert each ring separately. Push it securely into the box and seat it firmly. A small amount of packing grease applied to the packing will make this job a little easier. Never use sharp points to push the packing into the box. Use the packing gland, a wooden dowel, pliers handle, fingers, or other blunt object. Successive rings of packing should be installed so the joints are 120 degrees apart.
- Reinstall lantern ring (if required) in proper position to the packing rings as shown on your manual's parts page.
- Install packing gland so it enters the stuffing box straight and with all packing under uniform pressure.
- Seal gland with clip, stud, and nut.
- If packing box is equipped with a grease fitting, add a shot of grease. If there's no grease fitting, pack grease into the packing box until it's full, before inserting the last two packing rings. Add the last two rings and tighten the packing gland slightly to force the grease into the subsequent rings of packing. Then loosen the gland.

- Start pump with the packing gland loose so there is initial leakage. Tighten the packing gland only enough to draw the necessary vacuum for priming.
- Tighten gland nuts slightly and evenly every 15 to 20 minutes until leakage is reduced to 8 to 10 drops per minute or until water leaking from the box is cool.

! **Caution: Don't stop leakage entirely.**

Vertical Turbine Pumps

Vertical turbine pumps are centrifugal pumps whose impellers are connected by a vertical drive shaft to an above-ground motor or engine. They may have more than one impeller (***multi-stage***), and the drive shaft is either enclosed in a tube and oil-lubricated or else exposed and lubricated by water. Pumps less than about 50 feet in length are often called ***short-set*** while longer pumps are often called ***deep well, deep-set,*** or ***long-set***.

General Points

✓ Make a habit of periodically checking that discharge piping is firmly supported in the area near the pump. Make sure the pump is securely bolted to its platform.

✓ If your pump is installed over a well, and you've experienced water supply problems, check static level and drawdown in the well. A deeper pump setting might be required.

Maintenance

Maintenance procedures vary depending on pump length, whether it's water- or oil-lubricated, and other factors.

At season startup:

✓ For water-lubricated pumps, pre-lubricate line shaft bearings with light oil.

✓ For oil-lubricated pumps, change oil in the oil bath or reservoir for the upper bearings. Fill with approved turbine oil almost to the top of the sight of glass so bearings are covered. Make sure excess oil doesn't get on or in the motor.

- ✓ For oil-lubricated short-set pumps, start oil flowing to the pump one hour before starting the pump. Check to be sure the oil tube is filled before running the pump. The pump needs about 10 drops per minute.
- ✓ For oil-lubricated deep well pumps, start lubricating the shaft up to a week before starting the pump, or until the line shaft and column are full of oil and the oil begins to run out at the top near the stretch assembly. During this first week, allow 4 to 5 drops of oil per minute. After starting, increase to 10 to 15 drops of oil per minute. Check manufacturer's instructions to be sure of the requirement. (Oil will drip slower at night when it cools down.) The viscosity rating of the oil should be 9 or 10.

Annually (or according to manufacturer's instructions):

- ✓ Change bearing oil in vertical hollow shaft motors. Follow your motor manufacturer's instructions for the correct oil.

Periodically:

- ✓ Grease lower bearings. Refer to electric motor bearing greasing instructions on pages 11-12 and check your manufacturer's operation and maintenance literature for specifics to your equipment.
- ✓ Maintain packing as described on pages 22–24.
- ✓ Maintain bearing oil at the proper level. Overfilling the reservoir can cause oil to overflow when the motor heats up during operation. Excess oil will adhere to the motor and ventilation screens, collecting dirt and debris and reducing the motor's ability to dispel heat.

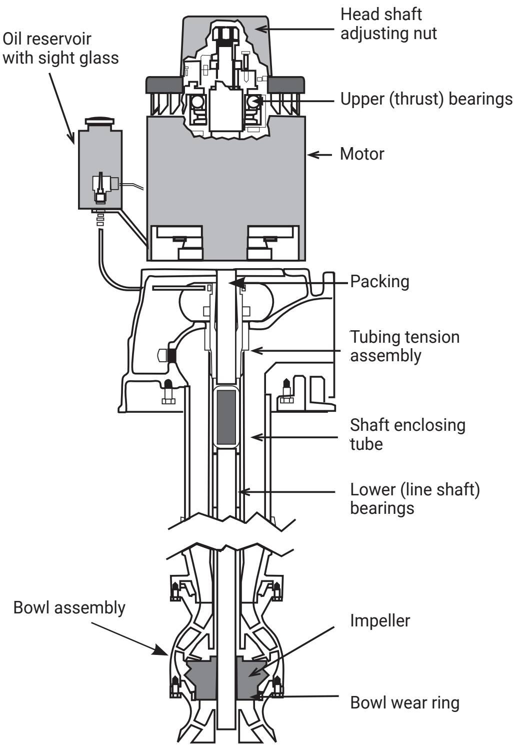


Figure 6. Oil-Lubricated Turbine Pump

Shaft Lift Adjustments

Impellers need to be positioned so they can spin freely, without rubbing on the top or bottom of the bowl. Raising or lowering impellers within their bowls can also improve pump efficiency and performance and is critically important for pumps with ***open impellers***, ones whose vanes are exposed on the suction side.

This is not something you should need to do often, but impellers should be checked and adjusted about every three to five years, or more often if you are pumping sand. On some vertical turbines, especially short-set pumps with ***closed impellers***, the adjustment is relatively straightforward and you may be able to do it yourself, using the head shaft adjusting nut, which is accessed by removing the top motor cover.

The adjustment procedure varies depending on the pump but usually involves raising the impellers an exact distance (or number of turns of the adjusting nut) from the bottom of the bowl. (Sometimes the procedure involves lowering the impellers an exact distance from the top of the bowl.) Follow your manufacturer's instructions or consult your pump dealer. Helpful videos are also available on the Internet showing the procedure.

! Caution: Pumps more than about 100 feet long experience shaft stretch or elongation, and only qualified service personnel should try to adjust the shaft lift on deep well turbines. Deep well pumps require advanced maintenance skills and adjustment must be very precise. Even a small miscalculation can cause severe pump damage.

! Caution: If, after adjusting, you can't turn the shaft easily by hand, remove the pump, disassemble, and inspect for damage or debris. If you have any questions about this procedure consult your pump dealer.

For Further Reading

A.W. Chesteron Company pump maintenance videos
youtube.com/@AWChestertonCompany/videos
Includes a five-part series on pumping packing installation

Cornell Pump. **Packing and Lantern Ring: Installation, Removal, and Grease Cup** (video). youtube.com/watch?v=uZRg4RAgdFQ

The **Hydraulic Institute** website. pumps.org/
Largest association of pump manufacturers in North America, offering application guidebooks, online tools, and calculators.

Intro to Pumps website. introtopumps.com/
Introduction to pump fundamentals, offering education and engineering training through online courses and other resources.

Scherer, Thomas. 2022. **Irrigation Water Pumps**. North Dakota State University publication AE1057. ndsu.edu/agriculture/sites/default/files/2022-02/ae1057.pdf
Overview of operating characteristics, power requirements, design considerations, and maintenance for all types of irrigation pumps.

USDA Natural Resources Conservation Service. 1997. **Irrigation Guide:** Section 15 of the **National Engineering Handbook**. directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba
*Comprehensive guide to all aspects of irrigation system design and management. See especially the discussion of pumps and motors in **Chapter 12, Energy Use and Conservation**.*

Vogel, Eugene. 2020. Pumps & Systems website. **Making Shaft Lift Adjustments in Vertical Turbine Pumps**. pumpsandsystems.com/making-shaft-lift-adjustments-vertical-turbine-pumps

Submersible Pumps

Submersible pumps have motors that are below the pump and submerged in water. Compared to vertical turbines they are somewhat less efficient and more susceptible to certain types of failure, but also silent, easier to handle, and have fewer moving parts.

Most submersibles need relatively little maintenance, but motor repairs require pulling the system out of the well. Inadequate water circulation may cause the motor to overheat and burn out. The riser pipe must be long enough to keep the bowl assembly and motor completely submerged at all times. The well casing must be large enough for water to flow easily past the motor. Electrical wiring from the pump to the surface must also be watertight, with sealed connections.

Troubleshooting

Find your symptoms and then look across the table to see possible causes. Most often, suction problems are the cause. Contact your pump repair shop for additional help.

! This troubleshooting guide is general and does not cover all possible system configurations or problems.

Symptoms

Cause of Suction Problems	Pump does not deliver water	Pump has insufficient capacity (gpm)	Pump loses prime after starting	Pump has insufficient pressure	Pump requires excessive power	Packing box leaks water excessively	Packing box has short life	Pump vibrates or is noisy	Bearings have short life	Pump overheats and seizes
Pump not primed	•	•								•
Insufficiently submerged suction pipe inlet	•	•	•							
Pump or suction pipe not completely filled with water	•	•	•					•		
Insufficient Net Positive Suction Head (NPSH — See page 21 for explanation)	•	•						•		•
Suction line, strainer, or centrifugal pump balance line plugged		•					•			
Air leaks into suction line		•	•							
Air leaks into pump through packing box		•	•							
Excessive air or gas in the water		•	•	•						
Foot valve too small, insufficiently submerged, or partly clogged				•				•		

Cause of System Problems

Cause of System Problems	Pump does not deliver water	Pump has insufficient capacity (gpm)	Pump loses prime after starting	Pump has insufficient pressure	Pump requires excessive power	Packing box leaks water excessively	Packing box has short life	Pump vibrates or is noisy	Bearings have short life	Pump overheats and seizes
Speed (rpm) too low	●	●		●						
Parallel operation of pumps unsuitable	●	●		●						●
Total system head higher than pump design head	●	●		●	●					
Wrong direction of pump rotation	●			●	●					
Speed (rpm) too high					●					
Total system head lower than pump design head					●					

Cause of Pump Problems

Cause of Pump Problems	Pump does not deliver water	Pump has insufficient capacity (gpm)	Pump loses prime after starting	Pump has insufficient pressure	Pump requires excessive power	Packing box leaks water excessively	Packing box has short life	Pump vibrates or is noisy	Bearings have short life	Pump overheats and seizes
Rotary shaft seals (packing) leak air	●									
Foreign matter in impeller	●	●			●			●		
Wear rings worn				●	●					
Impeller damaged				●				●		
Defective pump casing gasket allowing internal leakage				●						
Misaligned pump & driving unit					●	●	●	●	●	●
Bent shaft between pump & motor / engine					●	●	●	●	●	
Rotating part rubbing stationary motor part					●			●	●	●
Packing gland too tight. No flow to lubricate packing and shaft.					●		●			
Packing worn, improperly installed, or wrong for operating conditions					●	●	●			
Cooling water not getting to water-cooled packing boxes							●			
Packing forced into pump interior						●	●			
Shaft or shaft sleeves worn or scored at the packing						●	●			

Cause of Pump Problems, continued

Cause	Symptoms: Pump does not deliver water	Pump has insufficient capacity (gpm)	Pump loses prime after starting	Pump has insufficient pressure	Pump requires excessive power	Packing box leaks water excessively	Packing box has short life	Pump vibrates or is noisy	Bearings have short life	Pump overheats and seizes
Shaft running off-center						●	●	●	●	●
Impeller or rotor (electric motors) out of balance						●	●	●	●	●
Bearings worn							●	●	●	●
Foundation or platform not rigid or mounting is loose								●		
Pipe not supported								●	●	
Under- or over-greasing of bearings or greasing sealed motor bearings								●	●	
Condensation of atmospheric moisture in bearing housing								●	●	
Lack of or improper lubrication								●	●	
Scoring or rusted bearings (turbine pump)								●	●	
Improperly installed bearing, incorrectly assembled stacked bearings, unmatched bearings used as a pair (turbine pump)								●	●	
Excessive thrust, seen as shaft movement from mechanical failure or failure of hydraulic balancing device								●	●	●

Pumping Plant Maintenance Form

Field # ____ Year ____ Begin date ________ End date ________

Date pump start-up ________ Beginning PSI ________

Midseason PSI ________ Date ________

End of season PSI ________ Date ________

Motor amps ________ Test date ________

Motor amps ________ Test date ________

Pump:	**Motor:**
Installation Date ________	Installation date ________
Dealer ________	Dealer ________
Mfr. ________	Mfr. ________
Model ________	Model ________
Serial no. ________	Serial no. ________
Rated head ________	Rated horsepower ________
Rated flow ________	Service factor ________
Repair date ________	Repair date ________
By ________	By ________
Desc. of repair ________	Desc. of repair ________
________	________

Date Replaced / Serviced	System 1	System 2
Gauges	________	________
Motor bearings	________	________
Pump packing	________	________
Oil change	________	________
Filters	________	________
Hoses	________	________
Cooling system	________	________
Lube	________	________
Adjust turbine bowls	________	________
Primer pump	________	________
________	________	________
________	________	________

PUMPING PLANT

3. Distribution System Maintenance

Sprinkler Systems

General

Ideally, aluminum mainlines should be raised off the ground with short boards or old tires to allow air circulation and prevent corrosion.

Lay out mainline and handline pipe as straight as possible to minimize friction loss through couplers. Install air relief valves and vacuum relief as needed on high points of mainline and air relief at end of the mainline. Set mainline pressure relief valve at 10 psi above normal operating pressure or at the pressure specified to protect piping.

! Caution: Irrigation pipes are one of the most common sources of human contact with power lines. To avoid serious injury or electrocution, always look up for power lines BEFORE you start work. Treat all overhead power lines as though they were bare and uninsulated. Keep vehicles, equipment, tools, and people at least 10 feet away from power lines. When lifting, pipe sections, never raise the end of a pipe higher than your head. ***Never stand a pipe on its end, or you could hit a power line.***

Sprinkler Heads

To make sprinkler system maintenance less of a chore:

- Always keep a few extra nozzles and sprinkler heads on hand for quick repairs.
- Use a box-end wrench to remove and replace sprinkler nozzles. Open-end or pipe wrenches will damage nozzles.
- When reinstalling sprinkler heads, wrap threads with Teflon plumber's tape. Petroleum-based pipe-dope compounds cause early deterioration of rubber washers. Also, don't lubricate sprinkler heads for either storage or operation.

- When installing new sprinkler heads, spray a dab of paint on the new heads. Avoid getting overspray on rubber or moving parts. Spray the same color on your shop wall and note the year, using a different color for each year. Since sprinkler heads last one to five years, four or five colors are enough.

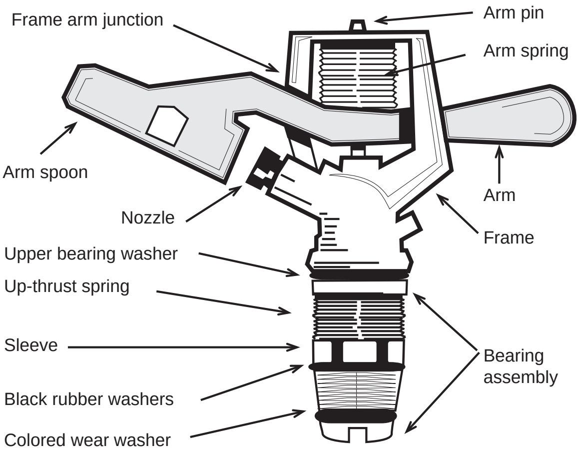


Figure 7. Sprinkler Head

Remember that broken or weak springs cause uneven spray patterns and reduced production due to uneven water distribution.

If your cropland is rolling, with significant elevation changes, consider ***flow control nozzles***. These nozzles will compensate for pressure differences caused by elevation changes. Most models are only effective, however, at pressures between 25 psi and 55 psi.

Maintenance Tasks

Daily:

✓ Check that nozzles aren't plugged. Unplug nozzles with something softer than the material they are made of. *Never hammer a head to dislodge a plug!*

Nozzle Wear and Sizing

Over the years, or even within a season, irrigation systems often acquire a variety of nozzle sizes, resulting in widely varying amounts of water put on the crop.
For example, at 50 psi a 9/64″ nozzle puts out 4.1 gpm, an 11/64″ nozzle puts out 6 gpm, and a 13/64″ nozzle puts out 8.5 gpm. If you mix 9/64” and 13/64” nozzles, you could be applying 0.2″ water per hour on one part of the field and over 0.4″ of water per hour on another part. Worn nozzles would show an even wider variation.

Normally, sprinkler nozzle size should be the same along the length of a lateral. (Center pivots are an exception.) If you're unsure of the correct nozzle size for your system, contact your irrigation equipment dealer.

✓ For other problems, such as bent arms, broken springs, or broken arm pins, replace the head with one of your extras.

At shutdown (end of season):

✓ Remove a few two- or three-year-old sprinkler heads. If some show wear, remove all sprinkler heads of the same age and check for nozzle wear and worn washers and springs. Replace worn nozzles and heads as needed.

Mainlines and Lateral Pipes

Maintenance Tasks

At season startup:

✓ Clean pipe of animal nests.

✓ Inspect for bent or flattened piping, split seams, and punctures. Use a slightly tapered wooden plug of proper diameter to round out any damaged ends.

✓ Reassemble couplers, gaskets, risers, and sprinkler heads. Replace damaged gaskets. Gaskets shrink and admit air. Tighten flanges or connections, or replace gaskets.

✓ If mainline valves leak, replace valve plates or lids.

Choosing Gaskets

Using a gasket in a coupling that it was not made for is a common cause of leaky gaskets.

Flat gaskets: Most are made of neoprene and are used on flanged, bolt-together fittings. They are usually not expensive. They normally fail by "creeping" out of their fitting. Look for new neoprene gaskets that contain a cotton backing sandwiched in the gasket to reduce the creeping action.

Shaped gaskets: The three most common materials are styrene-butadiene (SBR), ethylene-propylene (EPDM), and polyethylene (poly). SBR and EPDM have much better resistance to cracking, abrasion, ozone, and weathering resistance than poly gaskets. They're more expensive than poly but will last longer. When buying shaped gaskets, look for gaskets that are dull. This indicates that little or no plasticizer has been added to the gasket. Plasticizers significantly reduce gasket life.

✓ If your mainline valves have grease zerks, lubricate according to manufacturer's instructions.

✓ Tap exposed steel pipe with a rubber hammer before startup to release rust.

✓ Flush entire system thoroughly with end plugs and wheel line drains removed to prevent plugging nozzles and pressure regulators with dirt, rust, or other foreign material that may be in the system. Replace end plugs and drains.

✓ With water supplied to the lines, check all nozzles and impact sprinklers for plugging, mismatched sizes, breakage, corrosion, or other damage caused by wear or winter weather. Check couplers, connections, levelers, and drains for leaks.

Periodically:

- ✓ In spring and fall, inspect piping for corrosion. If any is found, consult the supplier for protection methods.
- ✓ Check pipe, valves, drains, and risers for plugging from grass and other debris.
- ✓ Flush sediment from ends of laterals.

At shutdown (end of season):

- ✓ Dismantle hand lines into sections and store on inclined racks above the ground to allow drainage and air circulation. Avoid storing pipe near acids, caustic or other chemical fumes or dusts, or animal waste.

Wheel Line (Side Roll) Mover and Wheels

! Caution: The cover on the power mover should be closed unless the mover is not being worked on and especially before turning the irrigation water on. Wheel lines should never be moved with water in the pipeline.

Maintenance Tasks

At season startup:

- ✓ If fuel was left in the carburetor through the winter, fuel passages may have become clogged by sediment, residue, or additives. If gas is not entering the engine cylinder, the carburetor may require adjustment or cleaning before the engine will start and operate properly.
- ✓ Remove dirt and debris from mover chain and gears of the drive mechanism. Lubricate teeth and chains with SAE 30 weight oil or grease by wearing rubber gloves and using a bucket full of grease. (Consult manufacturer or equipment dealer for the correct lubricant.) Realign drive chains if necessary.
- ✓ Open hydraulic fluid valve and check hydraulic fluid. Refill if necessary.
- ✓ Inspect the entire length of the line, checking wheels and power mover for loose bolts, equipment wear, or winter damage. Repair as necessary.

- ✓ Before starting wheel line mover for the first time in the spring, make sure drive mechanism is disengaged.
- ✓ Make sure fuel tank is free of debris. Fill with fresh fuel. If fuel tank was not emptied at shutdown, or stabilizer was not added, drain tank before filling with fresh fuel.
- ✓ Remove spark plug. Clean and set the gap. If spark plug is damaged or shows excessive heat erosion, replace it.
- ✓ To check operation of power mover, engage transmission and slowly power unit forward or backward to make sure all wheels, chains, and gears are working properly. Make sure wheel line is straight or the ends are slightly lagging behind the power mover's direction of travel.

Periodically throughout the season:

- ✓ Remove dirt, oil, and debris from exterior engine surfaces, paying special attention to cooling fins, surfaces near air intake, and carburetor linkages.
- ✓ Lubricate mover teeth and chains with SAE 30 weight oil or grease.
- ✓ Check air filter weekly. Clean or replace it after every 25 hours of operation or more frequently under dusty or dirty operating conditions. Follow manufacturer's guidelines for cleaning and replacement.
- ✓ Check engine oil once per week or every five operating hours. Change oil after every 25 hours of engine operation, using a high quality oil, or more frequently if air cleaner shows evidence of dusty or dirty operating conditions. When adding or changing engine oil, do not under- or overfill the crankcase.
- ✓ Check fluid reservoir of hydraulic transmission every 25 operating hours. Fill to proper level. Drain any water that has seeped into the reservoir.

- ✓ If fluid appears dirty, drain and replace with hydraulic fluid recommended by manufacturer. Replace inline filter in pickup line of transmission.
- ✓ Grease wheel axles and main drive hub bearings every two weeks with water-resistant multipurpose grease. Follow manufacturer's recommendations for lubrication selection and application.

At shutdown (end of season):

- ✓ Evaluate system components. Mark problems for repair: worn impact sprinklers, nozzles, leaky pipes, gaskets, levelers, and drains. Buy replacement equipment for installation in the spring.
- ✓ Flush automatic drains so they are free of sand.
- ✓ Where freezing is a concern, drain water from all pipelines and completely open valves.
- ✓ Remove end plugs from wheel lines and empty water, debris, or sediment in pipe ends. Replace plugs.
- ✓ Remove gaskets, clean off silt, sand, or other debris, and store in a dry place—ideally in a plastic bag and sprinkled with talcum powder to prevent cracking.
- ✓ After gaskets have been removed, clean couplers with water to remove foreign matter.
- ✓ Wire covers onto the ends of wheel line sections to prevent debris and rodents from entering pipe during the winter. (Coffee cans work well.)
- ✓ If livestock will be in the field, move wheel line to the end of the field and surround it with electric fence.
- ✓ To prevent wind damage to wheel lines, secure line to posts driven at every third or fourth wheel.
- ✓ Start engine and let run for a few minutes. Shut off fuel tank switch and let the carburetor run out of fuel. Drain or siphon out all remaining fuel in the tank and flush

out any debris. If you want to leave fuel in the tank, add fuel stabilizer.

✓ Remove spark plug and pour a tablespoon of clean motor oil into spark plug hole. Position spark plug wire away from cylinder opening and rotate crankshaft by hand to lubricate piston and the rings. Replace spark plug.

✓ Remove mover chain and store in a bucket of used motor oil for the winter.

✓ Secure engine cover by latching or tying it in place to keep wind from blowing it open.

✓ Avoid placing wheels in a ditch where expansion and contraction of piping can twist the wheels.

Center Pivot & Linear Move

Most newer pivots and linear move systems operate at low pressure and include pressure or flow regulation devices that are susceptible to plugging. Even small amounts of nozzle fouling will noticeably reduce water application uniformity. The water supply for center pivot and linear move systems must be clean.

Maintenance Tasks

At season startup:

✓ Clean pipe of animal nests.

✓ Disconnect electrical power and check that mover motor lead connections are tight and not burned or corroded.

✓ Make sure all equipment is properly grounded.

✓ Check and lubricate all valves according to manufacturer's instructions.

✓ Grease center pivot swivel with one full tube of grease.

✓ Grease the driveline if equipped with grease-type U-joints, and check for excessive wear.

- ✓ Grease all zerks liberally at least annually.
- ✓ Check tower boxes for damage and seal to keep water out if they show signs of moisture.
- ✓ Check for proper tire inflation. Uneven tire pressure is hard on gear boxes. Inflate tires (22-25 psi for 11.9-inch tires, 16-18 psi for 14.9-inch tires) and tighten lug nuts.
- ✓ Flush system thoroughly with drains removed to prevent plugging nozzles and pressure regulators. Replace drains.

Annually:

- ✓ Check gear box lubricant to ensure that it's filled to the proper level. Change oil in gear boxes at least every three years. If you operate your system more than 1,000 hours per year, change oil every other year. Follow the manufacturer's recommendations for oil type, weight, and service schedule specific to your equipment.

Regularly throughout the season:

- ✓ Inspect pipe for corrosion. If you find corrosion, consult the supplier for protection methods.
- ✓ Check pressure regulators at each sprinkler head. If water leaks out the side air hole during operation, replace it.
- ✓ Check all nozzles for wear and make sure they are spraying properly.
- ✓ Check that drains are free and working properly.

At shutdown (end of season):

- ✓ Park pivot for the winter on level ground if possible, or slightly uphill from pivot center.
- ✓ Flush automatic drains so they are free of sand.
- ✓ Where freezing is a concern, drain water from all pipelines and completely open valves.
- ✓ Where freezing is a concern, remove drain plugs from gear boxes to let water out. Then replenish with oil. Fill to ¼ inch above the uppermost bearing, or to within ¼ inch of the top if it has an expansion chamber.

✓ Booster pumps may have a mechanical seal in the packing box. If the seal wears out, replace it. Follow shutdown procedures for pumps and motors described in the *Pumping Plant Maintenance* section.

✓ If possible, raise tires and place boards under them, perpendicular to the line of travel, to allow movement as the system contracts and expands over winter.

✓ Disconnect power to center pivot or linear move system.

Surface Systems: Ditches, Siphon Tubes & Gated Pipe

Maintenance Tasks

At season startup:

✓ In the spring, clean ditches of mud and weeds.

✓ For gated pipe, replace broken gates and clean gaskets.

At season shutdown:

✓ Where freezing is a concern, clear ditches and repair cracks in concrete liners to prevent damage.

✓ Store siphon tubes and system controllers under cover.

✓ Store gated pipe with gasket end facing north to lessen damage from sunlight, with gates closed and turned up to discourage rodents from gnawing the seals.

Microirrigation Systems

Water quality is critical to maintaining microirrigation systems. Emitter clogging is the biggest problem you face.

Maintenance Tasks

Regularly:

✓ Check for leaks daily or weekly. These are generally easy to spot in surface systems. In subsurface systems, watch flowmeters and pressure gauges closely. *Leaks cause increased flow rate and decreased pressure.*

- ✓ Inspect filters. Clean and replace as necessary. Backflush manually or with automatic cycle. In media filters, replace filter media (such as sand) when it begins to cake.
- ✓ Check pressure upstream and downstream from filters. Dirty filters increase pressure differential. Follow manufacturer's guidelines for acceptable pressure drop.
- ✓ Flush lines about every two weeks. If it takes more than about a minute to flush the lines clean, you may need to flush more often.
- ✓ Inspect emitters for clogging daily or weekly. Completely clogged drip emitters should be cleaned or replaced, although most are sealed and can't be taken apart for cleaning. Check flowmeters and pressure gauges as an indication of partial clogging. *Clogging decreases flow downstream from clogs and increases pressure upstream.*
- ✓ Check application rate (inches per hour) once or twice per year. For surface systems, catch flow from several emitters in a rain gauge for exactly one minute. For subsurface systems, take pressure measurements and use conversion tables provided by the manufacturer. Sudden changes indicate partly clogged emitters, leaks, or other problems.
- ✓ Chlorinate monthly with 10-20 ppm if you have moderate clogging due to biological contamination.
- ✓ For drip emitters completely clogged with biological contaminants, try injecting 50-100 ppm of chlorine. Wait 24 hours, then thoroughly flush the system.

! Caution: Organic growers are not allowed to have residual chlorine levels above the maximum residual disinfectant limit under Safe Drinking Water Act limit, currently 4.0 ppm. Allowed alternatives to chlorine include hydrogen peroxide, alcohols, and soap-based algicide/demisters.

✓ Clogging due to mineral desposits such as lime or iron precipitates can be prevented and often remediated by injecting acid to lower pH to 6 to 6.5 every 2 to 4 weeks. (Measure with pH strips or a pool/spa test kit.)

✓ For emitters that are completely clogged with mineral deposits, try injecting enough acid to lower pH to 5.0. Wait 24 hours and then thoroughly flush the system.

! Caution: Acid can damage emitters and other irrigation components, with the greatest risk below pH 5.5. The flexible orifice in some pressure-compensating emitters is especially susceptible to acid damage.

! Caution: Organic growers are generally not allowed to use synthetic acids. Many organic growers use vinegar, which contains acetic acid, if it is from a natural source.

! Caution: Be careful when mixing chemicals. Wear eye protection and gloves and follow instructions. Any carelessness on your part could cause an explosion of caustic chemicals, a release of toxic gases, or a chemical reaction that will severely clog emitters.

! Caution: Your system must include appropriate valves, drains, and controls to prevent backflow, which could cause chemicals to contaminate your water source or spill onto the ground.

! Caution: Do not mix chlorine and acids (or acidifed fertilizer) together, or store them in the same room, since they will form chlorine gas which is toxic and can cause eye and skin burns, lung damage, and even death.

At season shutdown:

- ✓ Treat entire system with 40 ppm residual chlorine concentration for at least four hours and completely flush the system.
- ✓ Drain water from all pipelines. The system may have to be blown out lateral by lateral with an air compressor. Don't exceed 15 to 20 psi of air pressure, or you'll blow off the emitters. Polyethylene pipes can withstand some freezing without breaking, so it isn't critical that all water be removed. In cases where remaining water may be a problem, add a gallon of non-toxic antifreeze (the type used in RVs) to the piping system and distribute it throughout with compressed air. More antifreeze may be necessary for larger systems.

! Caution: Organic growers are prohibited from using synthetic substances such as RV antifreeze.

Sprinkler System Maintenance Form

Field # ____ Year ____ Begin date ________ End date ________

System: ______________________________

Installation date __________ Dealer ______________

Mfr. ________________ Model ______________

Repair date ____________ Repaired by ____________

Description of repair ______________________

____

System: ______________________________

Installation date __________ Dealer ______________

Mfr. ________________ Model ______________

Repair date ____________ Repaired by ____________

Description of repair ______________________

____

Date Replaced or Serviced

	System 1	System 2
Nozzles		
Heads		
Levelers		
Gaskets		
Drains		
Mainline valve plates/lids		
Pressure regulators		
Wheel line mover		
Engine oil		
Hydraulic fluid		
Filters		
Lube system		
Hoses		
Pivot drives		
End gun booster pump		

4. Saving Energy

You don't have control over rising electricity costs or low commodity prices, but you can stop throwing money away on inefficiencies in your system. Read the tips here on cost-effective improvements to your system. Then study the *Water Management* half of this guidebook to use your efficiently pumped water most effectively.

Electrical Use and the Charges on Your Power Bill

Electricity is measured in watts or kilowatts (equal to 1,000 watts). The number of watts is the product of operating voltage times the current (or amps) flowing to the load. A kilowatt-hour (kWh) is an amount of energy equivalent to using one kilowatt (kW) over a one-hour period. To visualize one kilowatt-hour, it may be helpful to imagine ten 100-watt lightbulbs burning for one hour.

Although billing procedures vary among electric providers and in different regions of the country, irrigation bills typically include three basic charges for electricity:

1. **Base Rate or Meter Charge.** This is either a monthly or seasonal charge. Some utilities roll this charge into the electric consumption or energy rate.
2. **Electric Consumption or Energy Charge.** This charge is based on the amount of electricity used over time as recorded on the kilowatt-hour meter, with a rate charged for each kWh consumed.
3. **Electric Demand Charge.** Many utilities charge their larger customers an amount over and above the charge for kilowatt-hour energy consumption, to maintain enough capacity to serve these large customers' needs. (Customers with small motors may not have a demand charge.)

Electric providers generally calculate the demand charge in one of two ways, each intended to give an approximation of the customer's size:

- The demand charge may be based on connected load or horsepower, with a fixed rate charged per horsepower during each billing period. This charge is usually based on "nameplate" horsepower. For example, if your demand charge is $10 per horsepower your demand charge for a 40-horsepower system would be $400.

- The demand charge may be based on maximum wattage during the billing period. In this method, a special demand meter might measure a wattage for each 15-minute interval during the billing period. (Strictly speaking, the demand meter measures wattage every few seconds and then averages these measurements at the end of the 15-minute interval to calculate an average wattage for the interval.) The demand charge is based on the 15-minute interval during the billing period with highest wattage.

For example, suppose your demand charge is $10 per kilowatt and your demand meter records wattage of 29 kilowatts for some 15-minute intervals in the billing period, 30 kilowatts for other 15-minute intervals, and 31 kilowatts for other intervals. You would be billed $310. Demand charges are based on the size of your system—not how many hours you run the system. You would incur a demand charge even if you ran your system for just one 15-minute interval during the entire billing period.

You can save a lot of money by understanding how and when you're charged for electricity. Talk to a customer service representative at your utility and ask for an explanation of the rate structure. Make sure you know when your meter reading date is each month, since this can influence your management decisions. If your power bill includes a demand charge, remember that this charge will be about the same whether you operate your system one day or 31 days during a billing period.

Every kWh Counts

Some irrigators mistakenly assume that since they're charged for demand, they won't save money by turning off their pumps and reducing hours of operation. It's true the demand charge is often a substantial percentage of your total electric bill. But all electric providers bill for every single kWh that is consumed. You'll always save money by reducing your hours of operation.

Common Causes of Wasted Energy

Lack of system maintenance:

✓ Develop a regular maintenance schedule. Impellers that are out of adjustment, plugged screens, worn nozzles, engine drive units that need a tune-up, worn shaft sleeves, leaking gaskets and drains, and dried out bearings and pump packing are only a few of the problems that you can avoid with regular maintenance.

The wrong pump for the system:

✓ If your pump is oversized, undersized, or just not matched to your system, it will never operate efficiently. While it may be possible to trim the pump impeller, re-nozzle the sprinklers, or redesign the layout of the mainline and laterals, a new pump with different characteristics is most likely necessary.

Pump wear from cavitation or abrasion:

✓ Cavitation damages pump impellers, reducing efficiency. If your pump is cavitating, determine if you have sufficient NPSH. (See page 21 for an explanation of NPSH.) You should also have a valve on the discharge side of your pump to allow filling the mainline slowly, avoiding cavitation.

✓ If your water source contains a lot of sediment, re-engineer your intake structure to allow sediment to settle out of the water before entering the suction line.

Causes of High Demand

Your demand meter can alert you to problems. Track the demand amount on your power bills and compare month to month and year to year.

- Is demand increasing gradually even though you haven't made changes to your system? This might indicate leaks that are growing or increasing wear in the pump or motor bearings.
- Did demand take a sudden jump? This could signal a large leak or major problem such as motor overloading, inadequate bearing lubrication, voltage imbalance, or other problems.
- Is average demand too high for the connected horsepower? The demand reading on your power bill in kW should be about ¾ of your connected horsepower. For example, a 40-hp pump should have a demand reading of about 30 kW if no other loads are on this meter. If a pivot mover or booster pump are on this meter, the kW will be ¾ of the whole connected load.

Improperly sized or designed fittings:

✓ Every minute that water is passing through undersized fittings such as valves, your profits are draining away. Replace those fittings with ones of the correct size.

Water source changes:

✓ If the water level in your well has dropped, you may have to reset the pump at a lower level. To compensate for the increased head, you may have to add more stages to turbine or submersible pumps. If you're using surface water and the level has dropped, centrifugal pumps may need to be relocated closer to the water source in order to supply sufficient NPSH.

✓ If turbine or submersible pump capacities don't fit the well characteristics, you may need to replace the bowls with new ones suited to your well capacity.

Time-of-Use Rate Schedules

In some parts of the country, irrigators can sign up for a time-of-use billing schedule. Under time-of-use billing, rates are higher at peak times (when demand is greatest) and lower at "off peak" times. Time-of-use billing allows some irrigators to adjust their work schedules so they irrigate when rates are low, reducing costs and avoiding power interruptions. If time-of-use billing is available in your area, call your utility to discuss this option and see if a time-of-use rate schedule may work for you.

Hardware Improvements

Electric Motors

✓ Rebuild your older motor and gain several percentage points in motor efficiency. This procedure typically involves replacing the bearings, rewinding, and "dipping and baking," and is done by qualified motor repair shops.

✓ Consider a premium efficiency motor instead of a standard efficiency motor in all new installations, if the cost of rewinding exceeds 65% of the price of a new motor, and when replacing over- or undersized motors. Premium efficiency motors are 2-4% more efficient than standard efficiency motors and usually have higher service factors, longer insulation and bearing lives, and less vibration than standard efficiency motors.

! **Caution: Some premium efficiency motors draw a higher startup current. Make sure your system can handle it.**

- ✓ If you're putting in a new system, be aware that an 1800 rpm motor is more efficient than a 3600 rpm motor. For example: an open drip-proof 3600 rpm, 40-hp motor is 91.7% efficient whereas an 1800 rpm, 40-hp motor is 93% efficient. Since an 1800 rpm motor makes half the revolutions of a 3600 rpm motor, maintenance needs are lower and motor life is longer.
- ✓ Consider a variable speed drive (also called a variable frequency drive, or VFD) or electronically commutated motor (for smaller motors) if you need to produce a wide range of flows and pressures to meet varying system needs. For example, a pump serving two pivots with a variable speed drive would run at a slower speed with one pivot turned on and a higher speed with both pivots operating. A variable speed drive can reduce electric demand charges on oversized pumps and during lower flow uses or seasons, while mitigating other problems caused by oversized pumps. Cost-effectiveness of a variable speed drive will depend on operating hours, pump size, and crop value.
- ✓ Constant-pressure valves or flow-control nozzles may be as effective as a variable speed drive. Contact your equipment supplier for more information.

Engines

- ✓ Keep your engine drive in peak operating condition to reduce fuel costs and downtime. Refer to the *Engine Maintenance* section for tune-up advice.
- ✓ If your radiator-cooled engine uses a cooling fan, its efficiency is reduced by 5-8%. In other words, 5-8% of the fuel going into the engine is used to run the fan, not pump water. You can install equipment that uses the irrigation water to cool the engine, eliminating the need for a fan. Check with an equipment dealer.
- ✓ Think about using the variable speed ability of your engine to your advantage. By varying the rpm of the engine you can vary the flow rate, total dynamic head,

and brake horsepower requirements of the pump to meet varying system needs and save fuel. Consult an engine equipment or irrigation equipment dealer for advice.

Centrifugal Pumps

- ✓ Rebuilding your older pump is often a cost-effective alternative to buying a new pump and usually involves replacing shaft sleeves, packing, and wear rings, and re-machining or replacing the impeller.
- ✓ For optimum efficiency, the pump must match requirements of your water source, water delivery system, and irrigation equipment. If your pump is under- or oversized and does not match the system needs, pump replacement is the best option. Running an oversized pump with a mainline valve half-closed is like driving your car with your foot on the brake and the accelerator at the same time.

Turbine Pumps

- ✓ Vertical shaft turbine pumps lose efficiency if they aren't regularly adjusted. See pages 25-27 for instructions on adjusting a short-coupled turbine pump. Deep well turbine pumps should only be adjusted by qualified pump service personnel.
- ✓ Rebuilding your older turbine pump is often a cost-effective alternative to purchasing a new pump and usually involves replacing shaft sleeves, packing, and bearings, and re-machining or replacing the bowls.

Mainlines

- ✓ Mainlines too small for the volume of water pumped through them contribute to high head requirements and lowered system efficiency. Water velocity through a mainline should never exceed 7 feet per second (fps), and velocity below 5 fps is best. Refer to the *Conversions and Formulas* section of this book for recommended maximum flow rates for different pipe sizes.

How Leaks Cost You Money

Many irrigators aren't too concerned about leaks because "the water ends up on the field anyway." What these folks don't realize is that leaks reduce system pressure, causing a poor distribution pattern and moving the pump operating point from where it is most efficient, thus increasing demand costs. Significant leaks can also cause motor overload and shorten motor life.

Sprinkler Systems

✓ Convert a high-pressure pivot with impact sprinklers to low pressure (20 to 35 pounds per square inch or psi) or very low pressure (10 psi), install drop tubes, and either reduce your pump size or have the impellers trimmed to reduce horsepower. Besides saving energy and money, you'll increase application uniformity and reduce wind drift since water will be discharged closer to the ground. Be aware, however, that a low pressure pivot could exceed your soil's infiltration rate, causing runoff.

✓ Sprinkler options have come a long way in recent years. *Spinners* produce larger droplets that are more rain-like and reduce wind drift. *Dual sprayheads* allow for different spray options for crop germination or irrigating later in the season. Spray plates can also be replaced to allow for different spray patterns. Check out sprinkler packages and options at your local irrigation equipment dealer.

✓ You can also convert your pivot to Low Energy Precision Application (LEPA), installing hoses and drag socks that apply water directly at the soil surface. These extremely low pressure systems reduce energy needs, virtually eliminate wind drift, and prevents deep wheel tracks since the ground is wet behind the wheels and not in front of them.

✓ Any uphill water sources? Use them! Reduce horsepower requirements or eliminate your pump completely by taking advantage of gravity if you have sufficient elevation drop. Two and three-tenths (2.3) foot elevation drop is equal to one psi of pressure. Your irrigation equipment dealer can help you determine if you can convert to a full or partial gravity system.

✓ If you're raising orchards or vegetable crops, consider converting to drip or micro sprinklers. They operate on very low pressure and allow precise placement of water to the plant (which also reduces weed problems).

Sprinkler Nozzle Wear

To check nozzle wear, remove the nozzle and clean out the interior. Then:

- Use a numbered drill index with bits measured in thousandths of an inch or a new high speed drill bit. If a drill bit is used, get a new nozzle to compare alongside the worn nozzle.
- Insert the index into the nozzle opening and compare the size to that printed on the nozzle.
- Or, insert the shank (smooth end) of the drill bit into the nozzle opening. The fit should be snug. If you can wobble the bit sideways even slightly, the nozzle is worn.

Surface Irrigation

✓ Consider replacing open ditches with ***gated pipe***. Gated pipe allows water to flow out through evenly-spaced "gates" or openings along the length of the pipe, giving you increased control over the way water is applied.

✓ If you're already using gated pipe, increase water application efficiency and reduce runoff by installing a ***surge valve***. Surge flow automatically alternates the water from one set of furrows or border strips to another, smoothing the soil and causing the water stream to advance much faster. Deep percolation at the upper end is reduced and water penetration at the lower end is increased for more even water distribution. Depending on crop value and labor costs, these systems often pay for themselves in a few years.

How Worn Nozzles Cost You Money

Just a tiny bit of nozzle wear (a few thousandths of an inch) can cause a big increase in sprinkler output and seriously decrease the system's application efficiency. Worn nozzles, like leaks, are one of the most common and underrated problems with irrigation systems and a primary cause of increased electrical demand costs. They also decrease pumping plant efficiency and overload motors, leading to substantially reduced motor life. Depending on your system's total dynamic head and efficiency and your electric costs, *each* worn sprinkler nozzle might be costing you anywhere from $0.25 to $5.00 or more annually.

Handy Conversions and Formulas

Source

Most conversions and formulas in this section come from the USDA Natural Resources Conservation Service. 1997. **NRCS Irrigation Guide:** Section 15 of the **National Engineering Handbook.** directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17837.wba

Flow Rate Conversions

Gallons Per Minute (gpm)	Cubic Meters Per Hour	Acre Feet Per 24 Hours	Cubic Feet Per Second (cfs)	Acre Inches Per 24 Hours
1	0.2270	0.004	0.00223	0.05
4.403	1		0.00981	
224.4		1	0.50	11.9
448.8	101.9	2	1	23.8
673.2		3	1.50	35.7
897.6		4	2.00	47.6
1,000.0		4.5	2.23	54.0
1,122.0		5	2.50	59.5
1,346.4		6	3.00	71.4
1,570.8		7	3.50	83.3
1,795.2		8	4.00	95.2
2,244.0		10	5.00	119.0
2,692.8		12	6.00	142.8
3,141.6		14	7.00	166.6
3,590.4		16	8.00	190.4
4,039.2		18	9.00	214.2
4,488.0		20	10.00	238.0

Volume Conversions

1 ft³/sec = 50 Miner's inches in ID, KS, ND, NE, NM, SD, UT, WA, Southern CA

1 ft³/sec = 40 Miner's inches in AZ, MT, OR, NV, Northern CA

1 ft³/sec = 38.4 Miner's inches in CO

One cubic foot per second (cfs) is a volume of water 1 foot wide, 1 foot long, and 1 foot high passing a given point every second. One acre-inch is a volume that would cover 1 acre of land 1 inch deep. One acre-foot would cover 1 acre 1 foot deep. One acre inch per 24-hour day takes 18.7 gpm continuous flow. A flow of 1 cfs for 1 hour = 0.99 acre-inch. Continuous flow of 1 gpm per acre = 0.053 inches per 24-hour day.

$$\text{gpm} = \text{cfs} \times 448.8 \qquad \text{cfs} = \text{gpm} \times 0.00223$$

$$\text{Gross application of water (in acre inches per acre)} = \frac{\text{gpm} \times \text{hours}}{450 \times \text{number of acres}}$$

Liters	Gallons	Cubic Feet	Cubic Meters	Acre Inches	Acre Feet
1	0.2642	0.0353			
3.785	1	0.1337	0.003785		
28.32	7.48	1	0.02832		
1000	264.2	35.314	1		
	27,154	3,630		1	0.0833
	325,850	43,560	1233.5	12	1
	1 million				3.07

Weight Conversions

1 kilogram = 2.20 pounds = 1,000 grams

1 gram = 28.4 ounces

1 pound = 7,000 grains

1 gallon water = 8.33 pounds

1 cubic foot water = 62.4 pounds

CONVERSIONS

Length Conversions

Inches	Links	Feet	Yards	Meters	Rods/ Poles	Chains	Kilo- meters	Miles
7.92	1							
12		1		0.3048				
36		3	1	0.9144				
39.37		3.28		1			0.001	0.000622
	25	16.5	5.5		1			
	100	66	22		4	1		
			1093.61	1000			1	0.62137
		5280	1760	1609	320	80	1.61	1

Area Conversions

Square Meters	Acres	Hectares	Square Feet	Square Yards	Square Rods	Square Chains
1	0.000247	.0001	10.76	1.196		
4049	1	0.405	43,560	4,840	160	10
10,000	2.471	1	107,639	11,960		

Square feet × 0.000023 = acres

Square yards × 0.00021 = acres

Square rods × 0.0062 = acres

Square chains × 0.10 = acres

Triangle area = ½ base × height

Rectangle area = length × width

Circle area = $\pi \times \text{radius}^2$ or $3.1416 \times \text{radius}^2$

Circle circumference = π × diameter or 3.1416 × diameter

Temperature Conversions

$$°F = (1.8 \times °C) + 32$$

$$°C = \frac{(°F - 32)}{1.8}$$

Power Conversions

Kilowatt	Horsepower	BTU/hour
1	1.341	3,413
0.746	1	2,545

Electrical Formulas

Single Phase Power Supply

Electric Demand = kW = $\frac{V \times I}{1000}$

Electric Consumption or Energy = kWh = kW × hours

$$= \frac{V \times I \times \text{hours}}{1000}$$

Where V = voltage I = current (amps) kW = kilowatts

Three Phase Power Supply

Electric Demand = kW = $\frac{V \times I \times 1.73}{1000}$

Electric Consumption or Energy = kWh = kW × hours

$$= \frac{V \times I \times 1.73 \times \text{hours}}{1000}$$

Kilowatt (kW) = Electric Demand = 1000 watts

Kilowatt-hours (kWh) = Electric Consumption

= 1000 watts × hours = kW × hours

To find approximate annual operating hours for an irrigation system, divide average monthly demand from your electric bills by total kWh over the whole irrigation season (found by adding together the kWh numbers in your power bills).

Example: Average monthly demand was 25 kW and you used a total of 27,650 kWh during the irrigation season.
27,650 kWh ÷ 25 kW = 1,106 operating hours.

Pressure Conversions

Pounds per Square Foot	Inches of Head	Kilo-Pascals	Feet of Head	Inches of Mercury	Pounds per Square Inch	Atmospheres
1	0.1926	0.0479	0.01605	0.01414	0.00695	0.0000473
5.1972	1	0.249	0.08333	0.07343	0.0361	0.0002454
20.886	4.022	1	0.331	0.296	0.143	0.0099
62.32	12	3.024	1	0.88	0.4335	0.0295
70.7262	13.6185	3.3864	1.1349	1	0.491	0.033421
144	27.73	6.985	2.31	2.03	1	0.068
2,116.22	407.5	101.32	33.93	29.92	14.7	1

Pressure Loss: pounds per square inch (psi) lost per 100 feet of pipe

	3/4-inch pipe			1-inch pipe			1.5-inch pipe			2-inch pipe			3-inch pipe		
gpm	S	PE	P	S	PE	P	S	PE	P	S	A	P	S	A	P
2	0.83	0.45	0.39	0.26	0.14	0.12	0.03								
5	4.55	2.43	2.14	1.40	0.75	0.66	0.17	0.09	0.08	0.05	0.06	0.02			
10		8.79	7.74	5.07	2.72	2.39	0.63	0.34	0.30	0.19	0.20	0.09	0.03	0.03	
15					5.75	5.06	1.34	0.72	0.63	0.40	0.43	0.19	0.06	0.05	0.03
20						8.63	2.28	1.22	1.07	0.68	0.72	0.32	0.10	0.09	0.05
30							4.83	2.58	2.27	1.43	1.54	0.67	0.21	0.19	0.10
40							8.22	4.40	3.87	2.44	2.62	1.15	0.36	0.33	0.17
50								6.65	5.86	3.68	3.96	1.74	0.54	0.50	0.25
60									8.21	5.16	5.54	2.43	0.76	0.70	0.36
70										6.87	7.38	3.24	1.01	0.93	0.47
80												4.15	1.29	1.19	0.61

S = Steel Pipe PE = Polyethylene Pipe A = Aluminum Pipe P = Plastic Pipe

Example: A flow of 20 gpm through 1.5-inch polyethylene pipe is losing 1.22 psi per 100 feet of pipe.

Note: Multiply psi lost × 2.31 to get feet of head lost.

Pressure Loss: pounds per square inch (psi) lost per 100 feet of pipe, continued

	4-inch pipe			6-inch pipe			8-inch pipe			10-inch pipe			12-inch pipe		
gpm	S	A	P	S	A	P	S	A	P	S	A	P	S	A	P
100	0.54	0.35	0.24	0.07	0.05	0.03									
150	1.30	0.75	0.51	0.16	0.10	0.07	0.04	0.03							
200	1.90	1.58	0.87	0.27	0.18	0.12	0.06	0.04	0.03	0.02					
300	4.10	2.75	1.85	0.57	0.40	0.26	0.14	0.09	0.06	0.05	0.03	0.02	0.02		
350		3.60	2.35	0.75	0.50	0.34	0.19	0.12	0.08	0.06	0.04	0.03	0.03		
400		4.65	3.20	1.00	0.65	0.44	0.24	0.16	0.11	0.08	0.05	0.04	0.03	0.02	
450			4.00	1.20	0.80	0.55	0.30	0.19	0.14	0.10	0.06	0.05	0.04	0.03	
500			5.00	1.50	1.00	0.67	0.36	0.24	0.17	0.12	0.08	0.06	0.05	0.03	0.02
600				2.10	1.38	0.95	0.51	0.34	0.23	0.17	0.11	0.08	0.07	0.05	0.03

S = Steel Pipe A = Aluminum Pipe P = Plastic Pipe

Pressure Loss: pounds per square inch (psi) lost per 100 feet of pipe, continued

	4-inch pipe			6-inch pipe			8-inch pipe			10-inch pipe			12-inch pipe		
gpm	S	A	P	S	A	P	S	A	P	S	A	P	S	A	P
700				2.80	1.85	1.25	0.70	0.45	0.31	0.23	0.15	0.10	0.10	0.06	0.04
800				3.60	2.40	1.60	0.87	0.55	0.39	0.29	0.18	0.13	0.12	0.08	0.06
900				4.40	3.00	2.00	1.10	0.72	0.50	0.36	0.24	0.17	0.15	0.10	0.07
1000					3.60	2.45	1.33	0.87	0.61	0.45	0.28	0.21	0.19	0.12	0.08
1200					5.00	3.50	1.90	1.18	0.85	0.63	0.41	0.29	0.26	0.17	0.12
1400						4.55	2.55	1.65	1.12	0.85	0.54	0.38	0.35	0.23	0.16
1600							3.20	2.15	1.42	1.10	0.69	0.48	0.45	0.29	0.20
1800							4.00	2.65	1.79	1.34	0.90	0.60	0.56	0.36	0.25
2000							4.90	3.20	2.20	1.65	1.10	0.74	0.69	0.45	0.30

S = Steel Pipe A = Aluminum Pipe P = Plastic Pipe

Example: A flow of 1,400 gpm through eight-inch steel pipe is losing 2.55 psi per 100 feet of pipe.

Water Velocity Formula

Water velocity in feet per second (fps) = 0.409 × flow in gallons per minute (gpm) divided by the pipe diameter (in inches) squared.

$$= \frac{0.409 \times \text{flow (gpm)}}{\text{pipe diameter (inches)}^2}$$

Example: 300 gpm through a 6-inch diameter pipe.

$$= \frac{0.409 \times 300}{6^2} = 3.4 \text{ fps}$$

Recommended Maximum Flow Rate by Pipe Size

Pipe diameter (inches)	2	3	4	5	6	8	10	12	16
Flow rate (gpm)	50	110	200	310	440	780	1225	1760	3140

Note: For maximum efficiency:

- Keep water velocity in suction line < 5 fps; 2-3 fps is best.
- Keep water velocity in mainline < 7 fps; < 5 fps is best.
- Increasing pipe size, reducing the flow rate, and changing pipe type can save energy by lowering water velocity.

CONVERSIONS

Other Pumping Plant Formulas

Total Dynamic Head (TDH) =
Total Lift (Suction + Discharge)
+ Pressure Head
+ Velocity Head
+ Pipe Friction Loss

Discharge Lift (feet) = Distance in feet from centerline of pump impeller to pressure gauge.

Suction Lift (feet) = Distance in feet from water level on suction side of pump to centerline of pump impeller.

Pressure Head (feet) = Pressure in psi from a gauge at or near the pump discharge flange × 2.31 (psi × 2.31).

Example: If the gauge reads 20 psi, the pressure head = 20 × 2.31 = 46.2 feet.

Velocity Head (feet) = Water velocity in feet per second squared divided by 64.35 $= \dfrac{(\text{fps})^2}{64.35}$

Note: *In most pumping systems, velocity head can be ignored.*

Pipe Friction Loss (feet): See tables on pages 62-64. Multiply psi losses times 2.31 to get feet of head loss.

Example: Using water velocity found on preceding page,

$$= \frac{(3.4 \text{ fps})^2}{64.35} = 0.18 \text{ feet}$$

Water Horsepower (WHP)

$$= \frac{\text{system gallons per minute (gpm)} \times \text{TDH (in feet)}}{3{,}960}$$

Example: 300 gpm flowing through 6-inch steel pipe is losing 0.57 psi or 1.32 feet of head per 100 feet of pipe. If the system is 200 feet long, Pipe Friction Loss = 2.64 feet.

CONVERSIONS

Input kW (for pumps with electric motors)

$$= \frac{3.6 \times \text{Revs} \times \text{Kh} \times \text{PTR} \times \text{CTR}}{\text{Time (seconds)}}$$

Where: *Revs* = *Number of meter revolutions (usually 10)*
Kh = *Meter Constant (noted on electric meter)*
PTR = *Transformer Ratio (usually 1)*
CTR = *Transformer Ratio (usually 1)*
Time = *Number of seconds it takes for the meter to make 10 revolutions*

Electric Horsepower (EHP) = Input kW × 1.34

Diesel Input Horsepower (IHP_{diesel})

$$= \frac{\text{gallons of Diesel used per hour}}{55}$$

Propane Input Horsepower ($IHP_{propane}$)

$$= \frac{\text{gallons of propane used per hour}}{36.15}$$

Natural Gas Input Horsepower ($IHP_{natural\ gas}$)

$$= \frac{\text{dKt of natural gas used per hour}}{392.9}$$

Note: *1 dKt = decatherm = 1,000,000 Btu. Contact your natural gas supplier for a conversion to decatherms, if needed.*

$$\text{Overall Pumping Plant Efficiency} = \frac{WHP}{EHP} \quad \text{OR} \quad \frac{WHP}{IHP^{*}}$$

*Diesel, propane or natural gas

Brake Horsepower (BHP) =

$$\frac{\text{motor efficiency} \times EHP}{100} \quad \text{OR} \quad \frac{\text{motor efficiency} \times IHP}{100}$$

$$\text{Pump Efficiency} = \frac{WHP}{BHP}$$

Net water application per irrigation period (inches) =

$$\frac{\text{set time (hrs)} \times \text{flow rate (gpm)} \times 96.3 \times \text{system efficiency}}{\text{irrigated area (square feet)}}$$

Set time (hours) =

$$\frac{\text{net water application (inches)} \times \text{irrigated area (sq ft)}}{\text{flow rate (gpm)} \times 96.3 \times \text{system efficiency}}$$

For **surface irrigation systems**, a handy formula is:

Set time (hours) =

$$\frac{\text{gross water application (inches)} \times \text{area irrigated (acres)}}{\text{flow rate (cfs)}}$$

A Simple Method to Estimate Your Pumping Plant Efficiency

Pumping plant efficiency measures the amount of power produced by the pump (known as *water horsepower*) per unit of input power (known as *input horsepower*).

When the system is operating under normal, stable conditions, follow the steps below:

Step1. Find total dynamic head (TDH) in feet.

Read pressure from gauge ______ psi × 2.31 = ______feet

Add height* if pump is above water surface + ______feet

OR

Subtract height* if pump is below water surface – ______feet

To get total dynamic head (feet). ______TDH

*Height = distance from water surface to centerline of discharge pipe.

Step 2. Find flow rate in gallons per minute.

If your system has a flow meter, read gallons per minute (gpm). If meter reads in cubic feet per second (cfs), multiply times 448.8 to get gpm.

______ gpm

If your system doesn't have a flow meter, do a *bucket test*:

2a. Bucket test for hand move, side roll, or linear move systems:

Measure flow of one sprinkler per lateral that is on relatively level ground. The selected sprinkler should be 1/3 down the length of the lateral from the mainline. Use a hose to direct the flow into a five-gallon bucket. Using a stopwatch, measure time in seconds to fill the bucket. For greater accuracy, take more than one reading per sprinkler and average the times. Repeat for other sprinklers on other laterals.

Number of seconds to fill bucket = ______ seconds

Average gpm/sprinkler = 300 divided by the number of seconds

300 ÷ _____seconds = __________ gpm

Total flow per hand line or wheel line
= Avg gpm per sprinkler × # of sprinklers = __________ gpm

2b. Bucket test for pivots:

First, measure the flow of one sprinkler in each set of nozzle diameters along the pivot using the method described in 2a.

	Seconds to fill bucket		Average gpm/ sprinkler		No. sprinklers in each set		Total gpm in each set	
300 ÷	_____	sec =	______	gpm ×	______	=	______	gpm
300 ÷	_____	sec =	______	gpm ×	______	=	______	gpm
300 ÷	_____	sec =	______	gpm ×	______	=	______	gpm

Total Flow = ______ gpm

Next, estimate flow from end gun using end gun pressure and nozzle diameter from table below. = ______ gpm

Estimated end gun flow in gpm
Diameter of end gun nozzle (inches)

PSI	½	¾	1	1½	2
10	23.6	53.2	94.4	212	378
20	33.4	75.3	134	300	534
30	40.9	92.2	164	368	654
40	47.2	106	189	425	755
50	52.8	119	211	485	845

Now add sprinkler flow to end gun flow to find total pivot flow.

= ______ gpm

Step 3. Find water horsepower (WHP) from Steps 1 and 2.

_____ (TDH) × _____ (gpm) ÷ 3,960 = _____ WHP

CONVERSIONS

Step 4. Find input horsepower (IHP).

4a. For electric motors, locate the meter constant on the electric meter faceplate: marked Kh and followed by a number such as 57.6 or 43.2. Using a stopwatch, time the number of seconds it takes for the disk in the meter to make 10 revolutions or for the little bar to move across the screen 10 times. If your meter shows kilowatt demand, simply multiply this number times 1.34 to get input horsepower.

48.1 × ______ (Kh) ÷ ______ (secs) = ______ IHP

______ (KW) × 1.34 = ______ IHP

4b. For diesel engines, divide gallons of fuel used per hour by 55 to get input horsepower. (Divide gallons per hour by 36.2 for propane or decatherms natural gas per hour by 392.9.)

______ (gallons per hour) ÷ 55 = ______ IHP

Step 5. Determine pumping plant efficiency, using results from steps 3 and 4.

______ (WHP) ÷ ______ (IHP) = ______ % Efficiency

CONVERSIONS

Step 6. Compare your efficiency to expected values below.

Rated Motor Size (HP)	Expected Efficiency (%)
3 to 5	66 %
7.5 to 10	68 %
15 to 30	69 %
40 to 60	72 %
75 +	75 %

Note: *Efficiencies are for older pumps in excellent condition. New pumps and pumps used under mild conditions or improved design will have higher efficiencies.*

Any system with pumping plant efficiency less than 65% has room for improvement. A result in the 50% range or lower indicates a significant problem requiring attention.

Note that unless hours of operation are reduced, improving pumping plant efficiency may simply increase flow rates without reducing energy consumption.