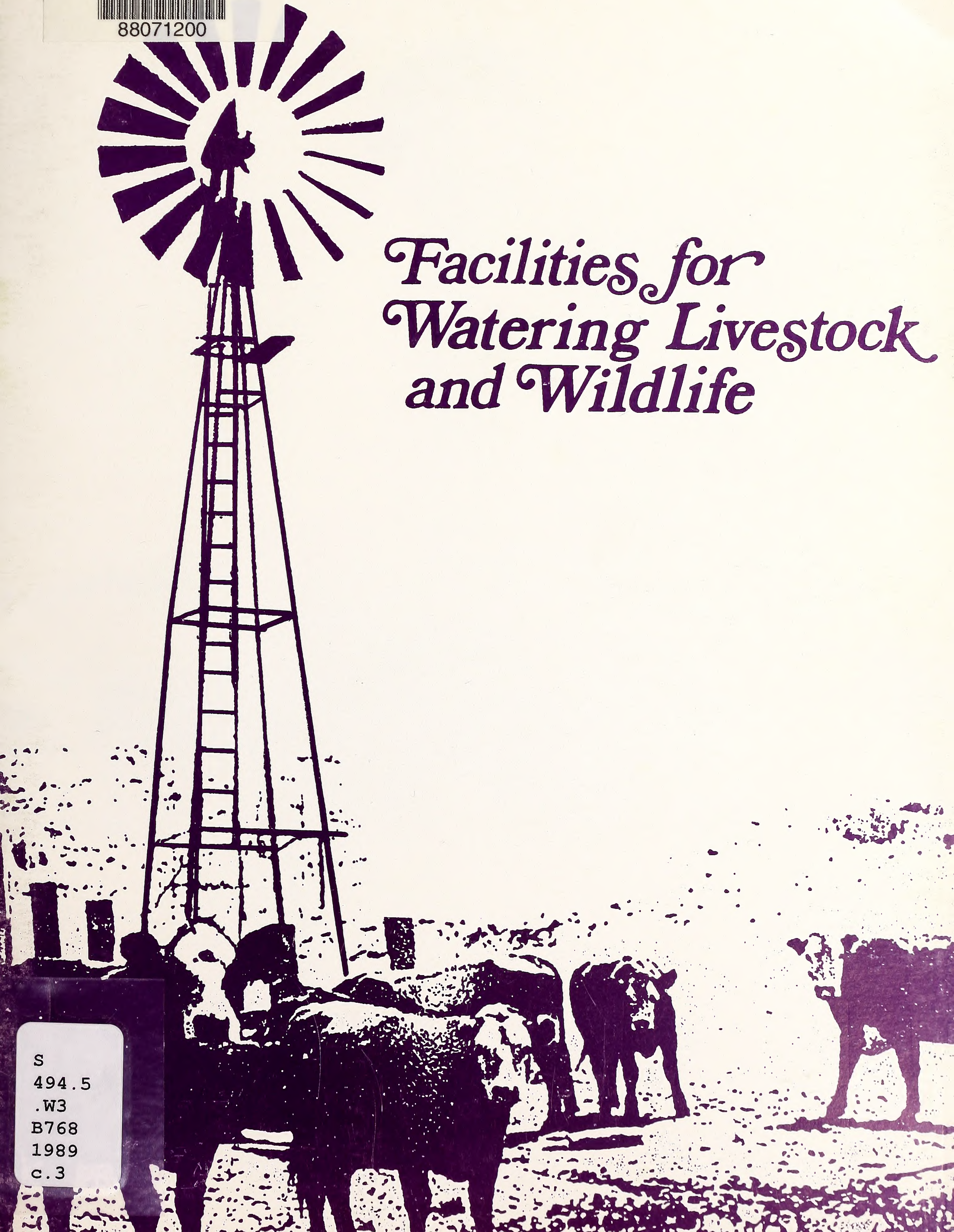
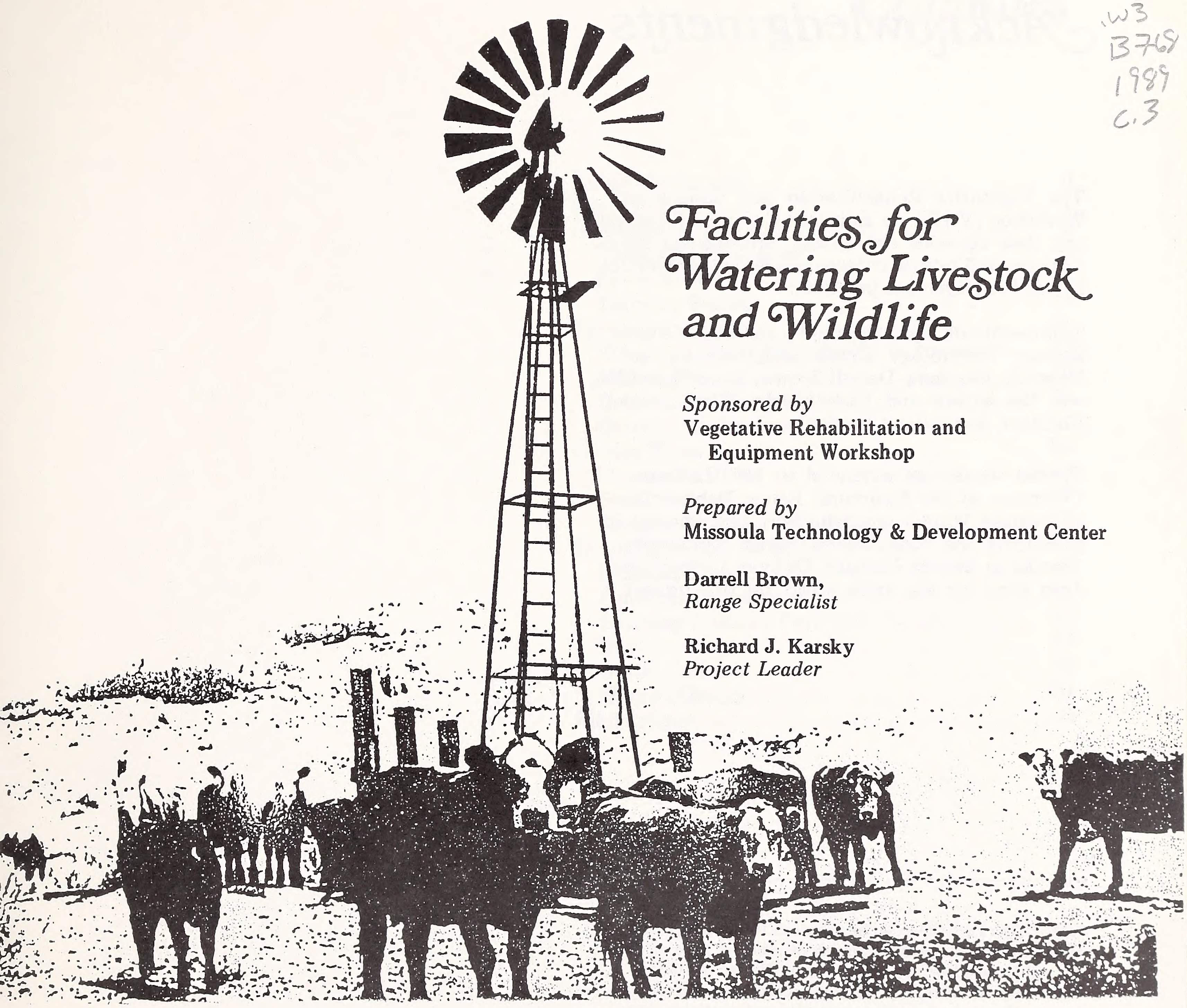
Facilities for Watering Livestock and Wildlife





Facilities for Watering Livestock and Wildlife

Sponsored by
Vegetative Rehabilitation and Equipment Workshop

Prepared by
Missoula Technology & Development Center

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5E42D31—Range Structural Equipment
Range Structural Equipment Handbook

Acknowledgments

The Vegetative Rehabilitation and Equipment Workshop (VREW) is an informal group of Federal and state agencies, universities, professional organizations, and private citizens concerned with effective land management practices.

This handbook was prepared by the USDA Forest Service Technology Development Center at Missoula, Montana. Darrell Brown, Range Specialist, was the author and Dick Karsky, Mechanical Engineer, was Project Leader.

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This manual was prepared at their request by the USDA Forest Service Equipment Development Center, Fort Missoula, Bldg. 1, Missoula, Montana 59801.

Contents

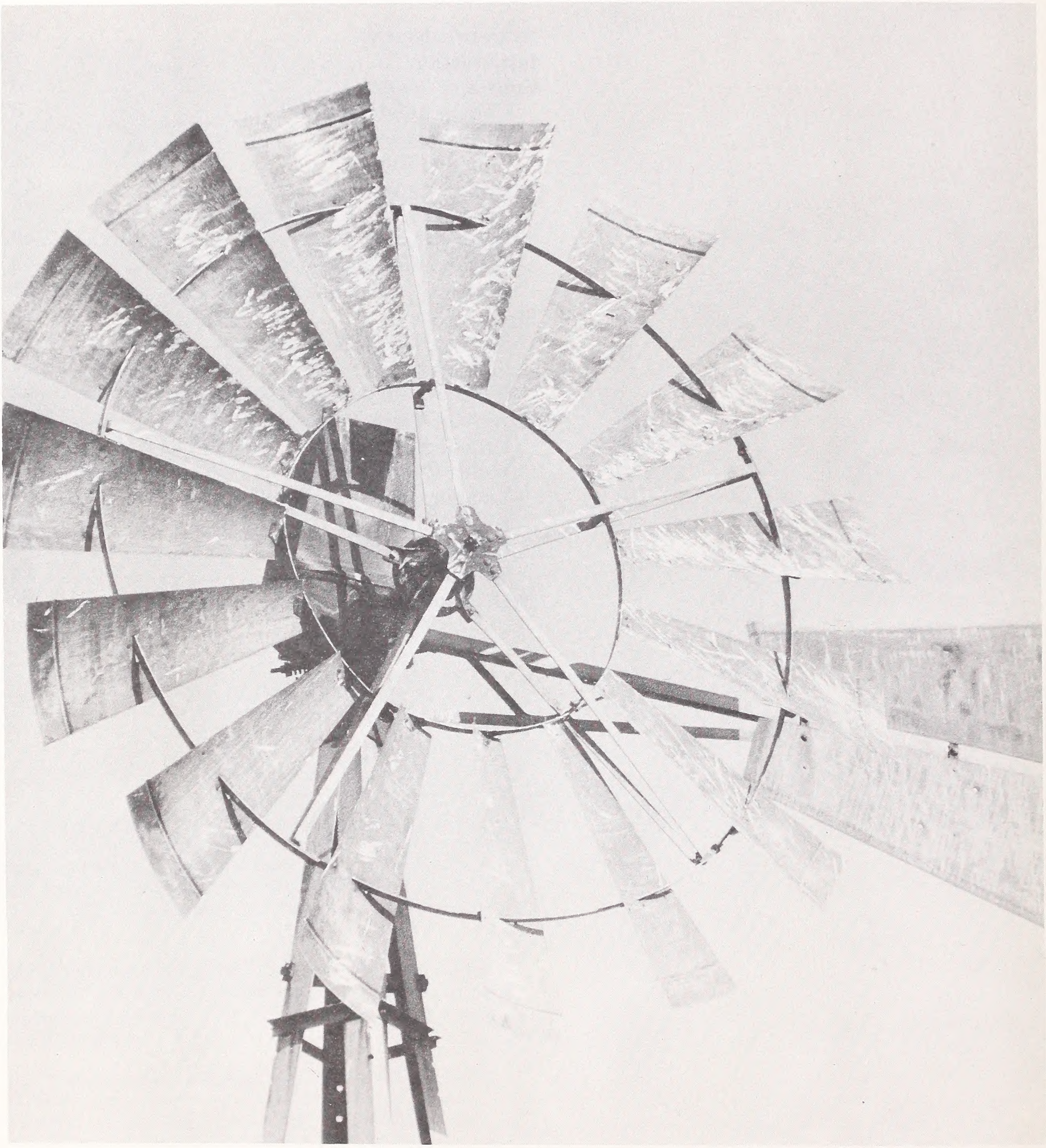


Photo courtesy Jean L. King

Introduction

As a part of the continuing effort to develop and test revegetation equipment and provide information about suitable equipment to land managers, the Vegetative Rehabilitation and Equipment Workshop (VREW) has consolidated structural improvement handbooks now scattered through various agencies into three volumes:

Fences
Facilities for Handling, Sheltering, and Trailing Livestock
Facilities for Watering Livestock and Wildlife

This volume describes facilities for watering livestock and wildlife. Watering facilities include all man-made improvements that collect, transport, or store water, or provide livestock or wildlife access to water. Facilities are grouped by function. Some facilities provide two or more of these functions. These are described in detail only once and cited in subsequent sections.

This volume discusses common facilities and their components, presents advantages and disadvantages of various facilities including relative costs and other relevant features, and briefly describes construction techniques. Pertinent books and articles are included in a bibliography. This volume is intended for use by private, federal, and state range land managers. It provides an overview of basic concepts, techniques, and equipment used to provide water for livestock and wildlife. To determine the most advantageous system, you must consult experts in constructing, operating, and maintaining water systems. Managers must analyze overall costs, legal requirements, and environmental impacts before beginning any water development project. This volume is designed to provide background information to allow land managers to seek the advice of experts in an educated fashion.

There are four major sections: collecting water, transporting water, storing water, and providing access to water. Collecting water includes information on wells, pumps, windmills, dams, and special man-made reservoirs. This section deals with ways of collecting water on sites that do not naturally have adequate, usable water. The section on transporting water includes pumps and piping. Some of the windmill information pertains to pumping, as well. The section on water storage includes reservoirs and storage tanks. The section dealing with access to water facilities describes methods of allowing wildlife and livestock to water without damaging the storage facility.

Photo courtesy Jean L. King

Collecting Water

On many range sites water is not naturally available for livestock or wildlife. Collecting water means finding water that occurs naturally on a site and developing methods of making the water available for use. Examples are building dams to collect rainwater or snowmelt that would otherwise run off the site or building windmills to lift subterranean water to the surface.

The two basic methods of collecting water on rangelands are trapping runoff and tapping into underground water sources.

Underground Sources

Collecting water from underground sources requires finding the water, developing a well to tap into the water, and lifting the water to the surface where it can be used. This handbook does not consider the problem of finding water.

Drilling a well is often the first step in creating a watering system for wildlife and livestock. However, before drilling begins, a number of questions must be answered:

1. Are water rights available? Each state has specific laws covering both water use and well location. Clarify the water rights before beginning any water development project.

2. Is a well feasible at the desired site? Get recommendations for your site from a competent ground water geologist. An expert from the Soil Conservation Service or a reputable well driller will have information on the efficiency, depth, and production of local wells. Ground water geologists can also predict the effect of a new well on currently established wells.

3. What is the cost of the project? Estimate the approximate cost of developing a variety of water systems capable of fulfilling your needs. Compare the cost of extending pipelines from existing water developments, developing springs or seeps, installing or building water storage facilities, hauling water, or drilling a well.

4. Is the drilling site appropriate? Locate the well where the risk of contamination is minor. If possible, locate the well on high ground. This not only reduces the possibility of contamination, but allows gravity to carry the water to watering sites.

5. What kind of power is available at the site? Available power determines the kind of pump you can use in your well.

6. Is maintenance feasible at the site? The types and frequency of maintenance may affect your choice of well and pump.

7. How will the proposed well be used? The kind of livestock, number of livestock, and the length of time the livestock use the well affect the well choice. The pump and pipeline must be sized properly to deliver adequate amounts of water at the needed time.

8. Is a competent well driller available? Secure a written contract with the driller before drilling begins. The contract should specify cost per foot of the finished well, the size of the well to be drilled, and the type of well casing to be used. The contract should include sealing the casing with grout to prevent contamination, developing the well by pumping, determining water yield of the well, disinfecting the well, and providing a copy of the drilling record to the owner. Be sure the driller has adequate insurance coverage.

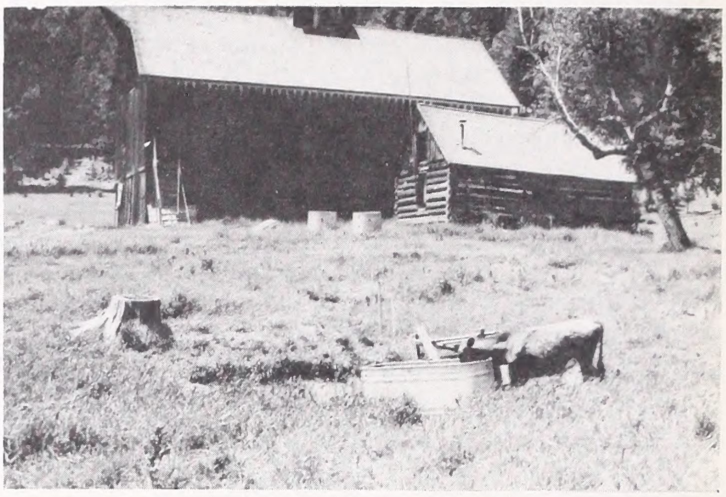
Determining Water Quantity Requirements

In addition to these questions, the land manager must consider the water system as a whole before developing the parts of the system. The first major consideration is the total water needed. The number and kind of livestock and wildlife to be supported by the water system are used to calculate total water needs. When the total needs are calculated and if a water source adequate to supply those needs can be developed, the water system must be designed.

Water requirements depend on the species of animal using the site, weather conditions, foods being eaten, age and sex of the animals, and time of year the site will be used. For example, cattle and horses require 10 to 15 gallons per day; a sheep requires 1 to 3 gallons per day. Cattle should not have to travel more than ½ mile to water in rough terrain or more than 1 mile in rolling or level terrain. Sheep should not have to travel more than 1 mile to water in rough terrain and 2 miles in rolling or level terrain.

	Water Consumption Per Day (gallons)
FARM (maximum needs)	
Dairy cows (14-15,000 pounds milk)	
Average drinking rate	20 per head
Dry cows or heifers	15 per head
Calves	7 per head
Beef, yearlings, full feed, 90°F	20 per head
Beef, brood cows	12 per head
Sheep or goats	2 per head
Horses or mules	12 per head
Swine finishing	4 per head
Brood sows, nursing	6 per head
Laying hens (90°F)	9 per 100 birds
Broilers (over 100°F)	6 per 100 birds
Turkeys—15-19 weeks (over 100°F)	20-25 per 100 birds
Ducks*	22 per 100 birds
Dairy sanitation—milk room & milking parlor	500 per day
Flushing floors	10 per 100 sq. ft.
Sanitary hog wallow	100 per day

*Studies on water consumption of ducks were not available. The figure is based on rule-of-thumb method of multiplying amount of feed consumed per day by two. This method is sometimes used for other fowls.



A typical galvanized-steel water reservoir, sufficient for a small number of animals.

To determine the capacity needed for watering livestock: (1) List all the watering devices currently used and those to be added to the system in the foreseeable future. Watering devices are storage tanks, reservoirs, streams or ditches, or any other location where livestock can drink. These must provide open access to the livestock. Do not consider sources such as streams where livestock use is being discouraged. Some water tanks have devices designed to limit the number of animals drinking at one time. (2) Determine the demand for each device. Table 1 provides estimated demands for various kinds of livestock and various types of watering devices. (3) Finally, add all the demands together. This summation shows the total water capacity needed for the watering system.

Table 1.—Water Demands for Determining Pump Size

Water Uses	Peak Demand Allowance for Pump	Individual Fixture Flow Rate
	Gallons per Minute	
Cattle—up to 40 head per watering space	.75 per space	1.5 per space
Horses—up to 10 head per watering space	.75 per space	1.5 per space
Sheep—up to 40 head per watering space	.25 per space	.5 per space
Watering Tank, Open—for cattle, sheep, and horses	2.5 per tank	5.0 per tank

The following example based on Table 1 illustrates how to calculate peak demand:

	Demand Allowance gpm
240 cattle require two open watering tanks at 2.5 gpm	5.0
20 horses require two watering spaces at .75 gpm	1.5
200 sheep require four watering spaces at .25 gpm	1.0
Total	7.5

A rule of thumb sometimes used by field managers is to simply double the requirements of the device with the greatest demand and add the other requirements. This provides a relatively liberal amount of water for a site. In this example, Table 1 shows the greatest demand for "Watering Tank, Open" at 5 gpm per tank. Multiply this figure by two and replace the 5 gpm under "Demand Allowance" with the new figure.

	Demand Allowance gpm
240 cattle require two open watering tanks at 2.5 gpm	10.0
20 horses require two watering spaces at .75 gpm	1.5
200 sheep require four watering spaces at .25 gpm	1.0
Total	12.5

This amount insures water for all foreseeable demands.

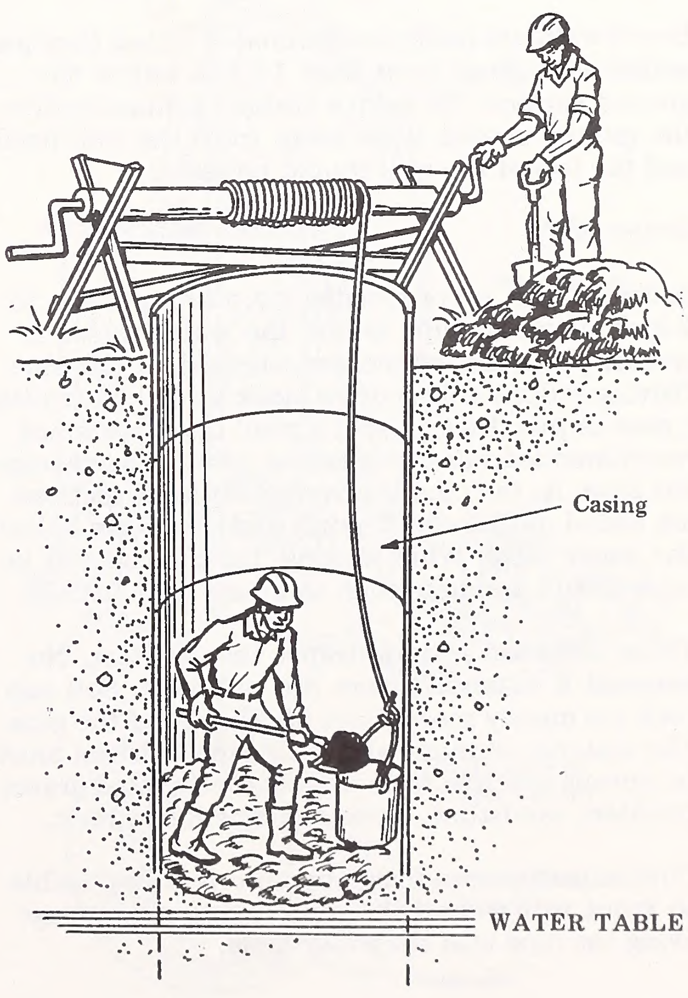
Wells

A well is a hole dug below the water table. Wells are dug by hand or machine to provide access to subsurface water. A variety of wells can be built; the methods used are based on the conditions at the site. A well driller familiar with the area should know the best method and well type for your site.

Pulling or pushing water from its source to the surface often exposes subsurface water to contamination from water seeping into the well through the well hole sides. During or after drilling, the driller places casing in the bore hole to stabilize the sides and to reduce seepage. Contamination can also occur if undesirable water flows down the outside of the casing into the well. Sealing the space between the bore hole and the outside of the casing with grout generally prevents this contamination.

Dug Wells

A dug well is a hole dug to below the water table. Dug wells are dug by hand or, more often, by equipment such as backhoes. Water collects in the bottom of the well, usually to the height of the water table. Dug wells can vary from 3 to 20 feet in diameter and are seldom more than 50 feet deep. The sides of the well are cased with tile, stone, brick masonry, concrete, or precast concrete pipe to prevent cave-ins. If a deep well is being dug by hand, extra ventilation must be provided for the person in the hole.



Dug well.

Dug wells are easily contaminated from surface runoff or subsurface seepage. Precautions to prevent surface contamination include sloping the ground around the well mouth away from the well. A completely sealed casing prevents subsurface leaking. Many dug wells fail during times of drought because the water table drops below the depth of the well.

Bored Wells

A bored well is constructed with an auger. A hand bored well is usually 2 to 14 inches in diameter, machine bored wells can be up to 36 inches in diameter. Bored wells are seldom deeper than 100 feet. The auger breaks the soil and small rocks loose so these materials can be lifted out of the bore hole. It is difficult to bore a well through boulders or dense rock. Boring is impossible in cemented limestone or sandstone. When the well is deep enough, it is cased with steel pipe or other suitable material.

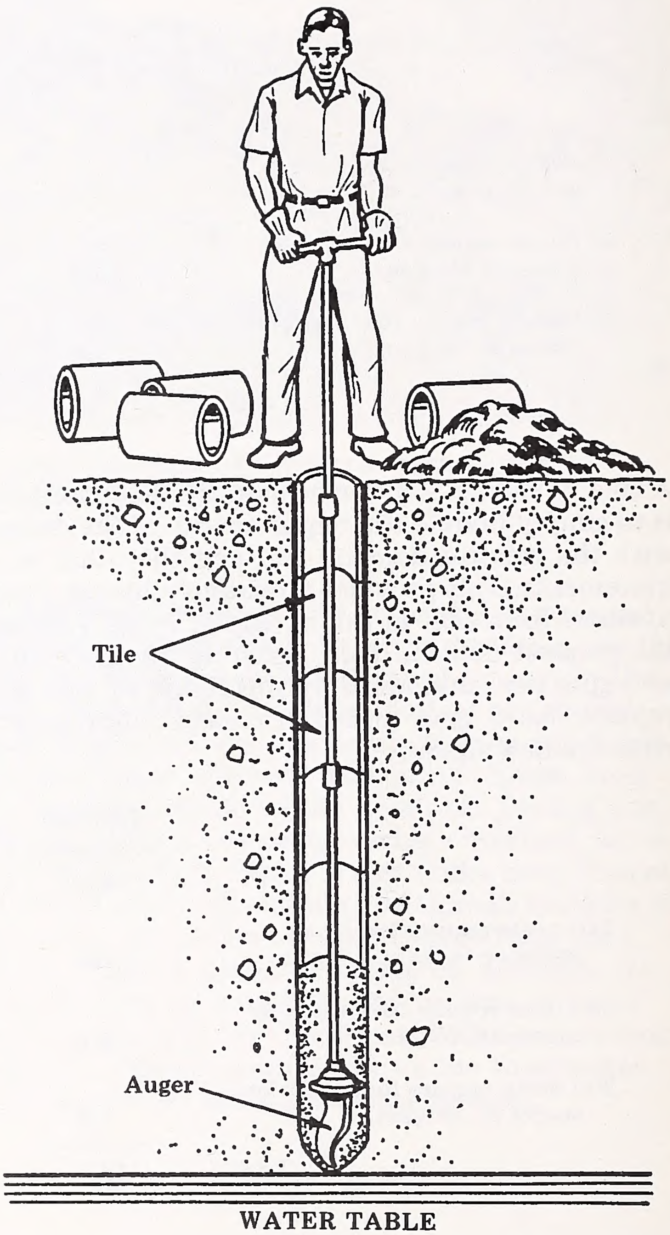
Bored wells are easily contaminated unless they are sealed with grout to at least 15 feet below the ground surface. To reduce surface contamination, the ground should slope away from the well head and the top of the well should be sealed.

Driven Wells

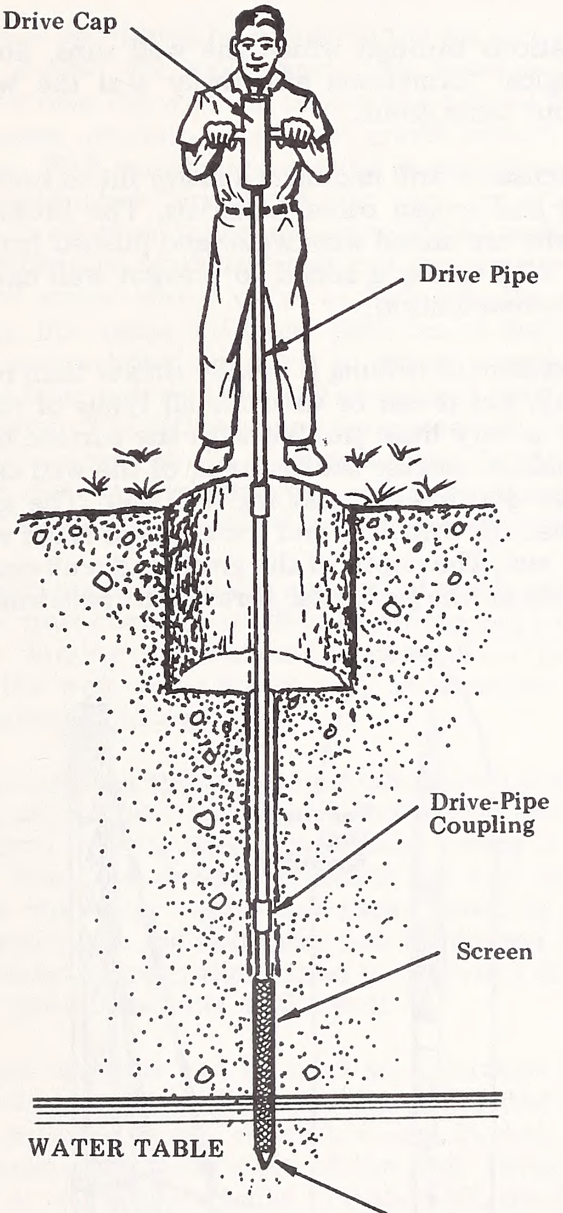
A driven well is constructed by pushing a 1¼- to 2-inch diameter pipe below the water table. A special point and screen are attached to the pipe. Driving is done with a drive block assembly or with a post or pile driver. Using a maul or sledge is not recommended because glancing blows can damage the pipe. As the pipe is driven, additional sections are added until the well point and screen are below the water table. While driving, the pipe should be turned with a pipe wrench to insure tight fittings.

These wells are seldom deeper than 60 feet. No material is extracted from the well hole. Soil and rock are merely pushed out of the way of the pipe. The material through which the pipe is driven must be porous and free from coarse or cemented gravel, boulders, sandstone, limestone, and dense rock.

Contamination can occur because it is impossible to grout seal around the pipe to prevent seepage along the pipe into the water table.



Bored well.



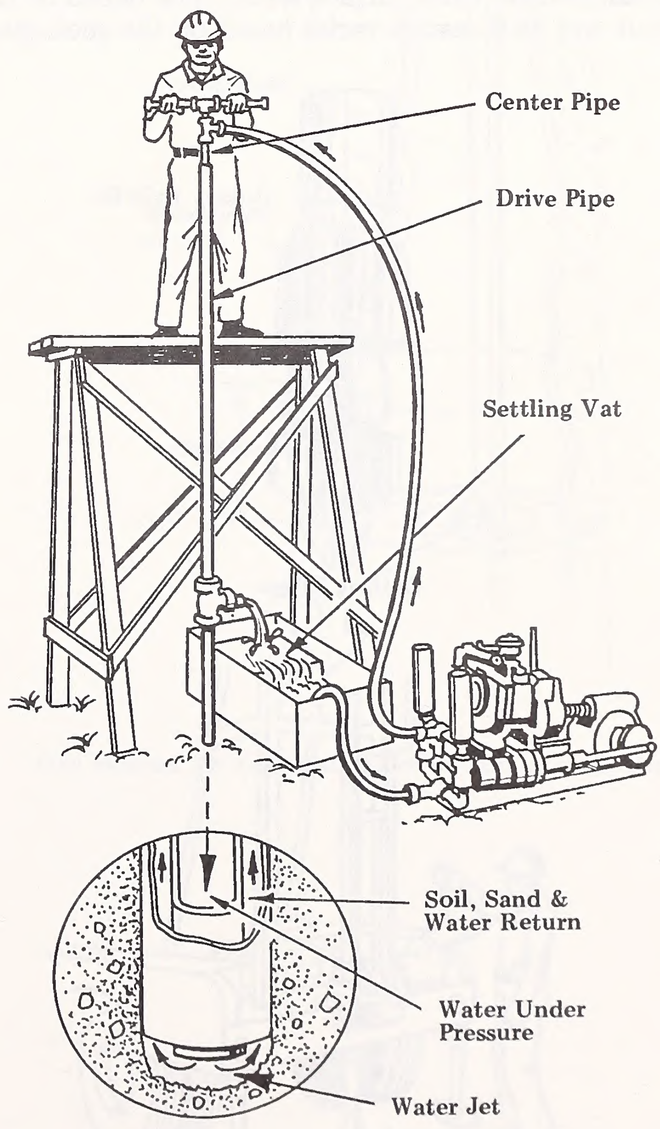
Driven well.

Jetted Wells

A jetted well uses water pressure to loosen and remove soil and rocks at the bottom of the bore hole. A pump pushes water down through a small pipe in the center of the hole. A larger diameter pipe, the riser pipe, surrounds the center pipe. The soil and rock are broken loose by the force of the water being pushed down the center pipe and are carried up to the surface through the space between the center pipe and the riser pipe, where they settle into a vat.

Jetted wells range from 2 to 14 inches in diameter. They are seldom more than 60 feet deep.

To protect against contamination from surface water, grout seal should be added around the well casing to at least 10 feet below the ground level.



Jetted well.

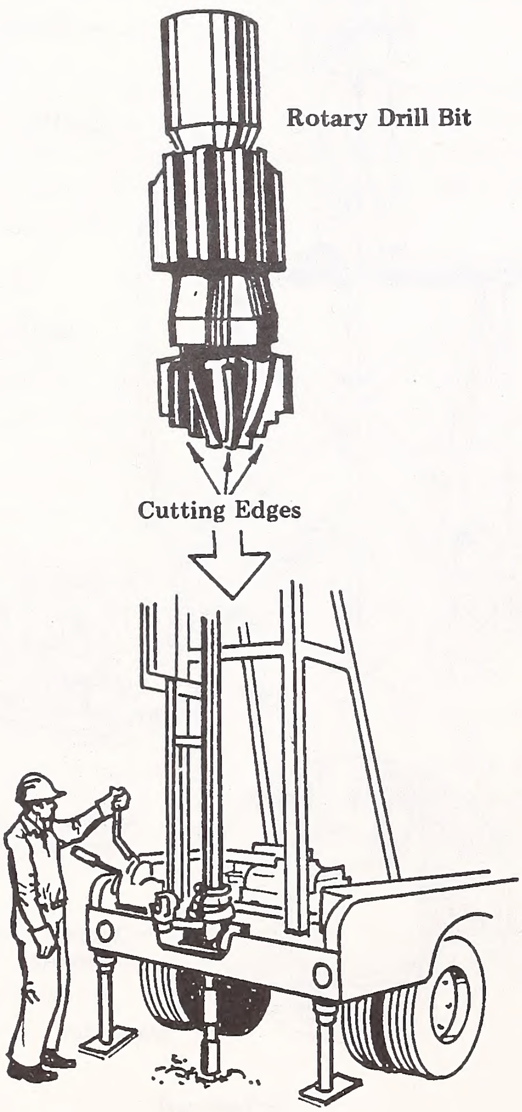
Drilled Wells

A rotary hydraulic drill uses a rotating bit attached to the end of a steel pipe (drill pipe). The rotating bit, 3 to 24 inches in diameter, breaks up material as it passes through. Drilling fluid, called drilling mud, is pumped into the drilled hole. The mud carries the broken pieces of rock and soil out of the hole, supports the wall of the bore hole to prevent caving, seals the bore wall to prevent fluid loss, and cools and cleans the drill bit. The drilling mud has a high percentage of very fine clays. Used mud should be stored in a confined area to minimize contamination of the surrounding soils.

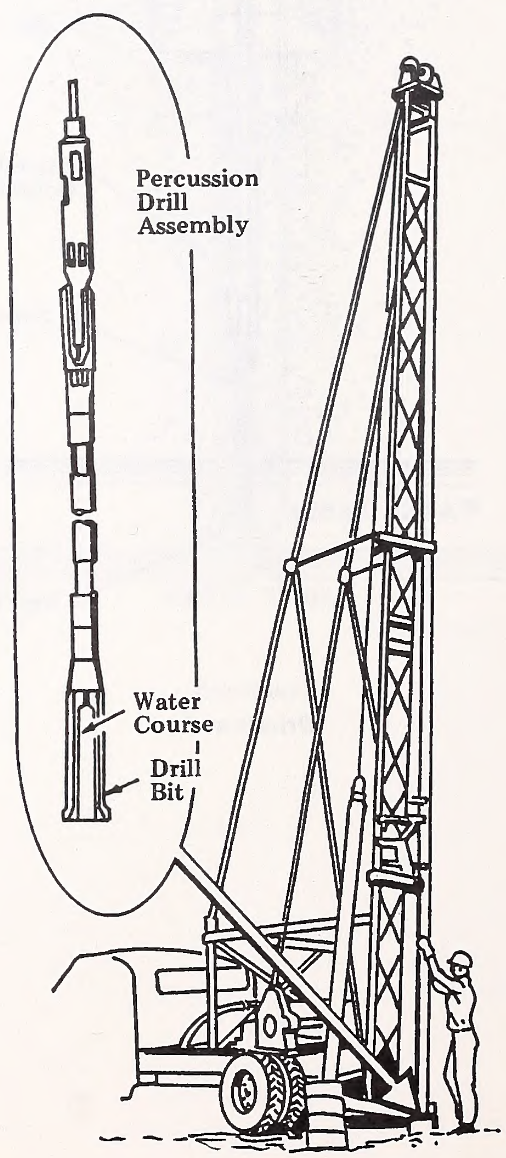
The drill hole is usually about 2 inches wider than the pipe casing. The space between the casing and the hole is filled with grout seal to prevent well contamination from surface water. The depth of the grout and well casings varies based on the geological formations through which the well runs. Some geological formations effectively seal the well without using grout.

A percussion drill hammers a heavy bit to break up rocks and loosen other materials. The broken particles are mixed with water and pushed from the hole. Well casing is added to prevent wall cave-ins and contamination.

This system of drilling is usually slower than rotary drilling, but it can be used for all types of rock. There is very little trouble with the surface contamination because the diameter of the well casing is often 4 inches less than the drill hole. The space between the drill hole and the casing is filled with grout seal. The depth of the grout and well casings depends on the geological formations penetrated.



Rotary hydraulic drill.



Percussion drilled well.

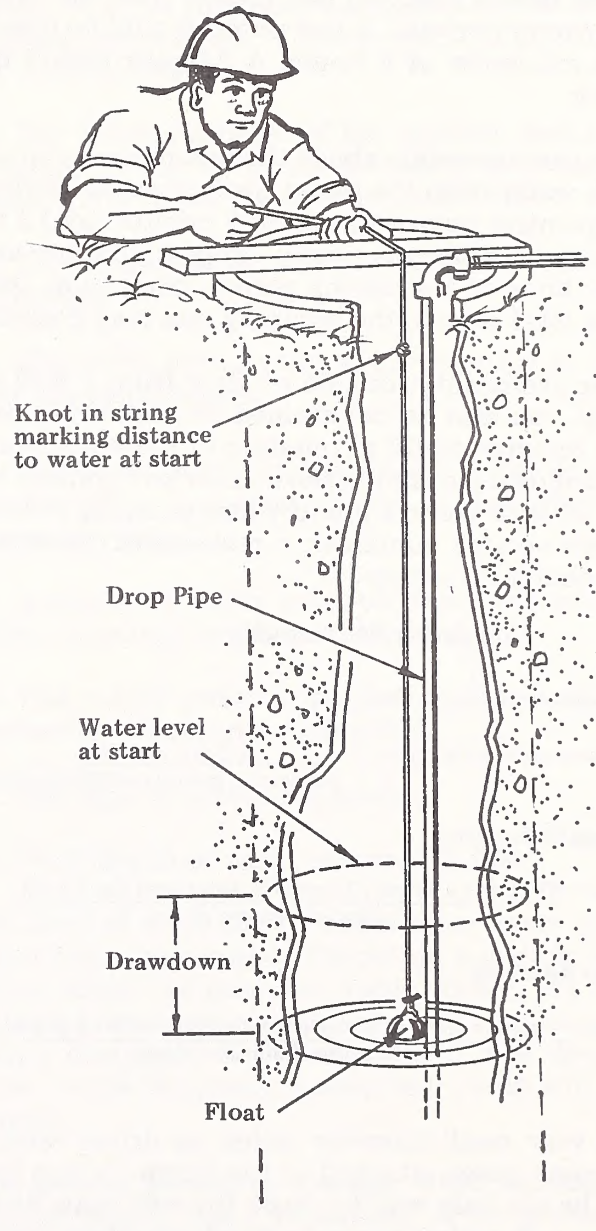
Developing The Well

A well is developed by removing the silt and small sand around the well screen. This unplugs the aquifer near the well and produces a natural filter of coarse, uniform sands and gravel around the screen. Well screens are needed in aquifers in unconsolidated formations like sand or gravel. Wells in aquifers of porous, consolidated rock like well-cemented sandstone may not require a screen. A well screen allows water to flow into the well casing, but keeps out larger particles of material. Well screen holes are sized to prevent sand or gravel from entering the well casing and destroying the pump. The efficiency of the screen will depend to some extent on the opening's shape, length, and width. Screen manufacturers will analyze samples from a well to determine the correct well screen.

Surging, moving water in and out of the formation, is the most common method of developing a natural filter. Surging carries the silts and small soil particles into the well casing where they are removed by pumping or bailing.

Gravel packing and other methods of well development are available to the well driller. One method of gravel packing uses a large outer casing in the drill hole. The developer inserts the well casing inside the outer casing and packs gravel in the space between the two casings to the desired depth. The outer casing is then raised to provide a gravel pack around the inlet to the well.

Several methods can be used to determine the amount of water available from a well. If the well was drilled, a bailer, which is a long bucket, can determine the water yield of the well. Using the drill rig to lower the bailer into the well, the driller marks the cable when the bailer first touches the water in the well; then the bailer is lowered until it fills with water; the driller quickly lifts it out and empties the water on the ground. By repeating this filling-and-emptying process over a period of time and counting the number of bails withdrawn, the driller can estimate how much water the well will produce. When the bailing process is ended, the driller lowers the bailer into the well once more and marks the cable when it hits the water. The distance between this mark and the first mark on the cable is the draw-down—the distance the water was lowered during the bailing time.



One method for determining the amount of water available.

The most accurate method of determing water amounts is to test pump the well. The test pump should have a pumping rate greater than the daily water requirements. A test pump should be operated for a minimum of 4 hours. A 24-hour period is better.

If you are uncertain about the test pump's capacity, catch water from the pump for 5 minutes. Multiply the quantity pumped in those 5 minutes by 12 to obtain the hourly capacity. Repeat this process every hour of the testing period, because as the water level lowers, the pumping rate may decrease.

Water availability, or rate of flow from a well or pump, can also be determined by measuring the time required to fill a container of known volume. The following example shows how to compute the rate of flow from a pump when pumping into a known volume container, a rectangular reservoir, or a circular reservoir:

Computing Well Capacities

Containers of Known Volume

$$\text{Gallons per minute (gpm)} = \frac{\text{Volume in gallons}}{\text{Number of minutes to fill container}}$$

Rectangular Reservoirs

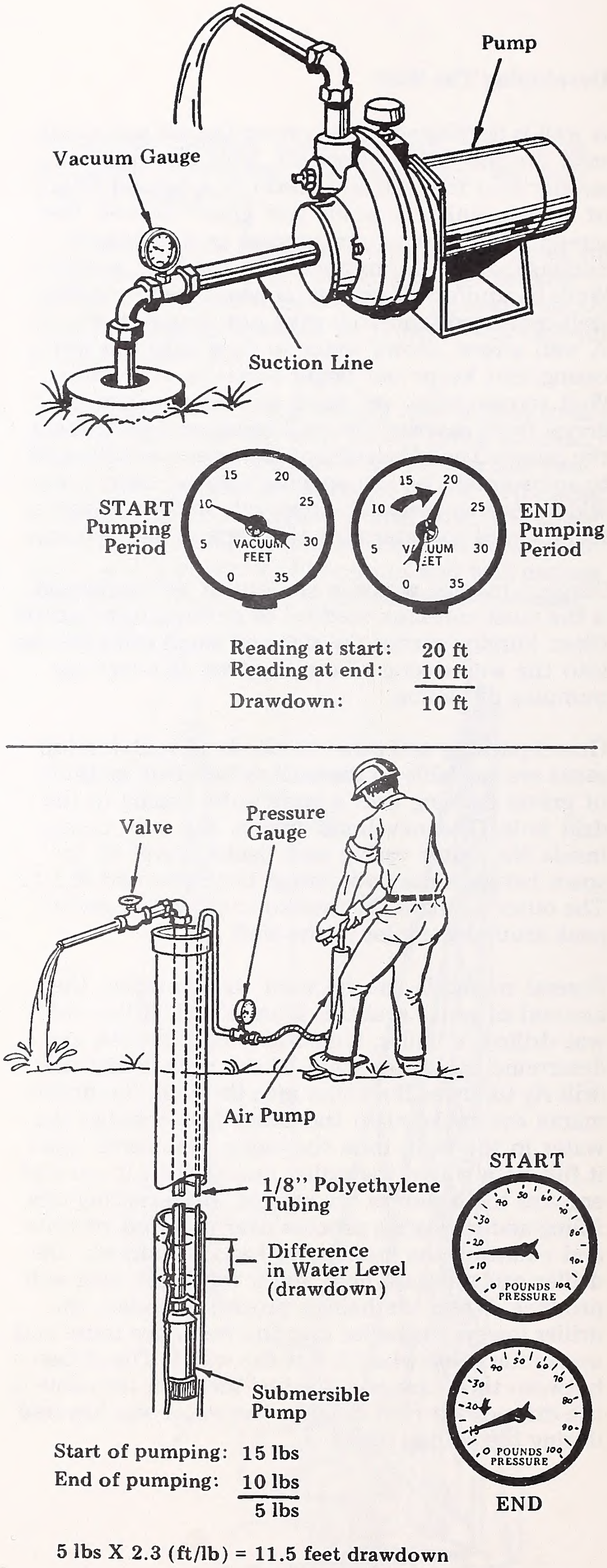
$$\text{gpm} = \frac{\text{Width (ft) x length (ft) x rise in water level (in) x 0.62}}{\text{Number of minutes of test}}$$

Circular Reservoirs

$$\text{gpm} = \frac{\text{Diameter (ft) x diameter (ft) x rise in water level (in) x 0.489}}{\text{Number of minutes of test}}$$

In a very small-diameter jetted or driven well, a vacuum gauge attached to the pump suction line may be the only way to check the well draw down (figure). A piston pump in good condition with all pipe connections completely airtight is needed. Insert a vacuum gauge into the suction line before connecting the pump to the well pipe. Start the pump and immediately record the vacuum gauge reading. At the end of the testing period and before the pump is turned off, record the gauge reading. Subtract the lower reading from the higher reading.

Vacuum gauges are calibrated in feet or inches of mercury. If the vacuum gauge is calibrated in feet, the feet of draw down is given by the difference in the two readings. If the vacuum gauge is calibrated in inches of mercury, multiply the difference in the starting and ending readings by 1.13 to obtain the feet of draw down.



Two methods of checking well drawdown.

Photo courtesy of Montana Historical Society, Helena

Pumps

After the well has been constructed, a pump is installed to move the water to the surface. A variety of pumps are available. Determining the one for your well depends on:

1. The inside diameter of the smallest part of the casing or hole in which the pump is to be installed. This should be exactly measured.

2. The desired water yield, measured in gallons per minute.

3. The water level in the well, measured in feet below the land surface.

4. The draw down or the lowest water level expected when pumping at the desired yield, measured in feet.

5. Amount of water available from the well (yield), measured in gallons per minute.

6. The water pressure needed at the well, measured in pounds per square inch.

7. The type of power available.

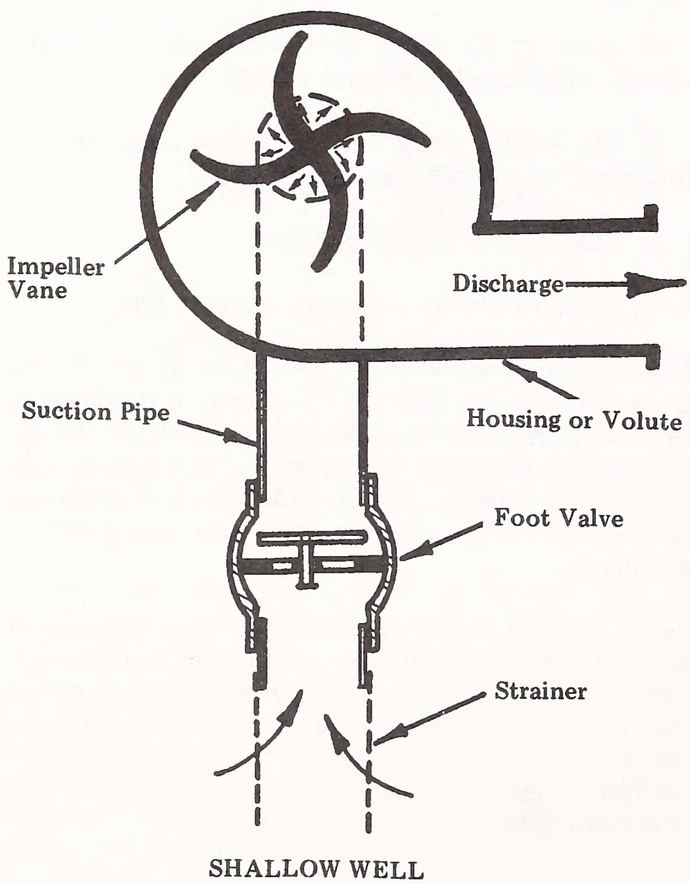
8. Total depth of well, measured in feet.

If the level of water in the well is never lower than 25 feet below the level of the pump, a shallow well suction pump can raise the water needed. At 25 feet below the level of the pump the rate of production decreases. If the water level ever drops 25 feet below the pump, a deep well pump will be required.

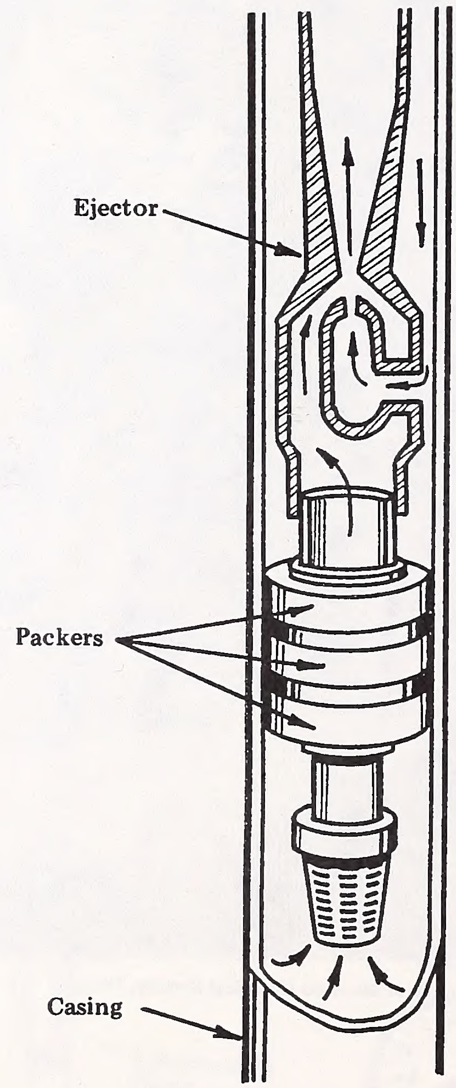
Some general factors to consider when chosing a pump are access (will it be located on the ground surface or in the well itself), pump efficiency at the required well depth, amount of sand and other particles in the water being pumped, pump performance based on the water pressure in the well, and acquisition and maintenance costs.

Centrifugal shallow well pumps use a rotating wheel or impeller to develop a vacuum in the intake pipe extending into the water. The entire pumping unit sits on the surface of the ground and is readily accessible for maintenance. These pumps are limited to shallow wells (15 feet or less). They produce a smooth, even flow and are very efficient for capacities over 50 gallons per minute and at pressures less than 65 pounds per square inch. Some models pump sandy water without damaging the pump. They are reliable and easily maintained. These pumps have low pumping capacities and can easily lose their prime. Their main disadvantage is that they are useful to only a limited depth. These pumps are often used as booster pumps to move water from a wellhead to a storage tank or through a pipeline.

Jet pumps consist of a pump and ejector assembly. The pump forces water into a suction pipe that holds the ejector assembly. The ejector assembly carries the water out of the well. Jet pumps can be either shallow or deep well pumps. The shallow well pump has all the components at the ground surface, which makes servicing easier. The deep well pump has the jet assembly in the well itself. These pumps have few moving parts and produce high capacities from relatively low pressure wells. They are easily damaged by sandy water. The jet ejectors become less efficient as well depth increases. Wells deeper than 85 to 100 feet generally use other kinds of pumps.

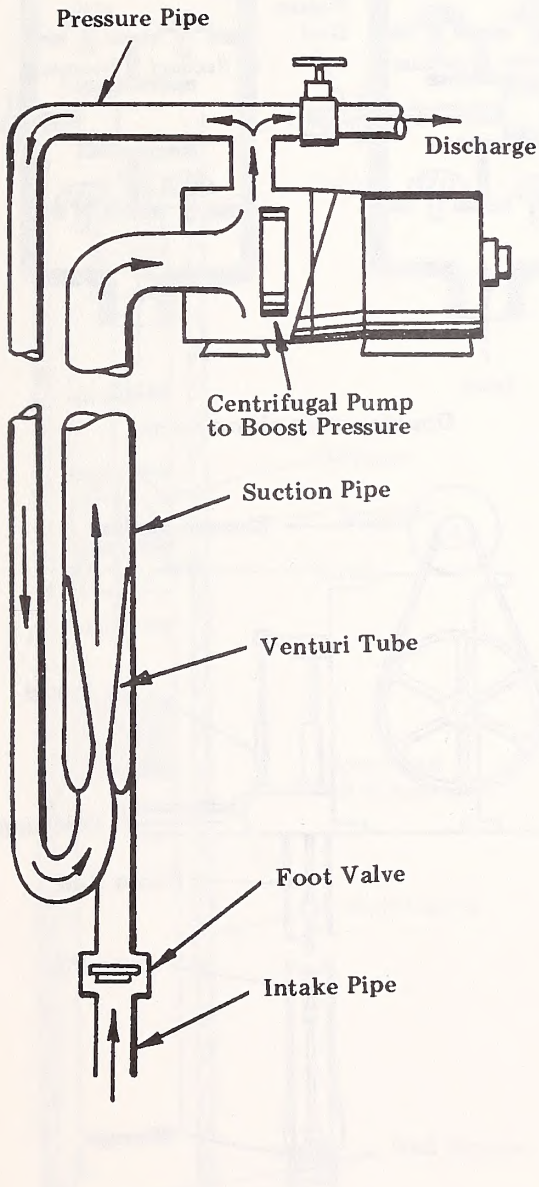


Centrifugal pump for a shallow well

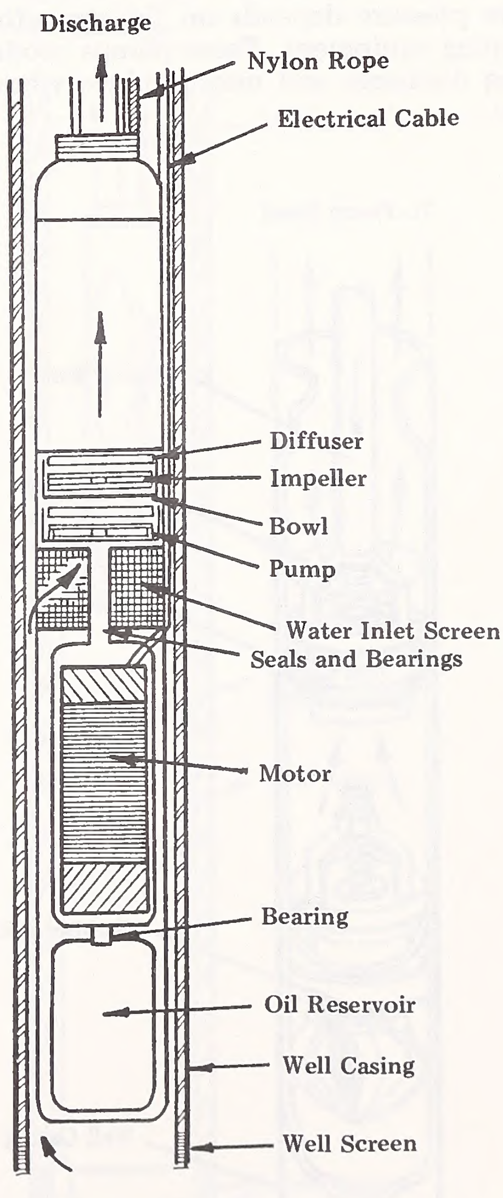


Packer jet pump used for extra-small wells (2 to 4 inches in diameter). It may also be used for larger wells where maximum pumping capacity is needed.

Submersible multistage pumps use rotating impellers to develop a vacuum similar to centrifugal shallow well pumps. Instead of being at the ground surface, however, the impeller housing rests in the well. The impellers force water up the pipe to the surface. These pumps work as deep as 1,000 feet and produce a smooth, even flow. They are easy to frostproof. Repairing the pump or motor requires pulling the pump from the well. Sandy water will damage the pump. Water pressure and pump capacity depend on the impeller design and the diameter, speed, and number of impellers.

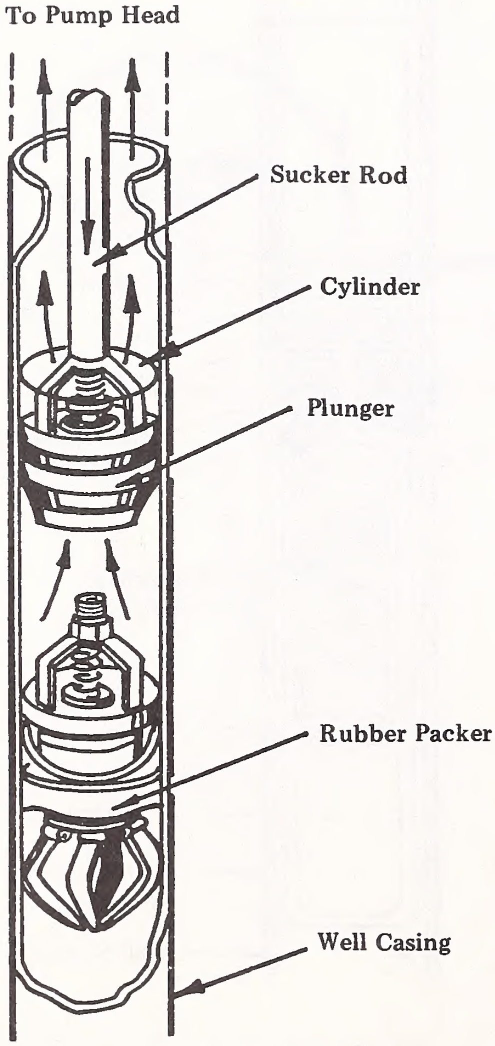


Deep well jet pump.



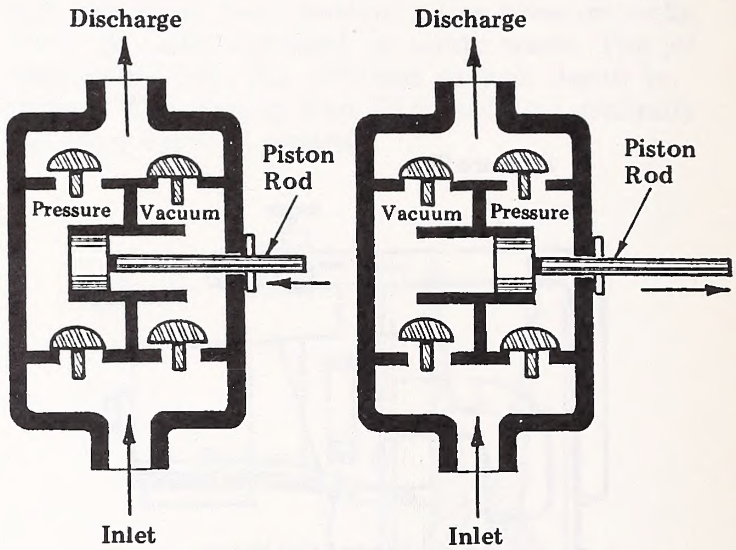
Submersible multistage pump.

Reciprocating or *piston pumps* develop a vacuum when the piston is pushed through the pipe. The vacuum draws water past a check valve so it cannot fall back down the well. On the next stroke, the piston draws more water, pushing the first amount further up the pipe. This continues until the water reaches the surface. Piston pumps are located either at the ground level where they can draw water from as deep as 20 feet, or in the well where they pump as deep as 600 feet. They work with small amounts of sand in the water. They produce a constant rate of yield. Pump capacity depends on the piston diameter and the number of strokes per minute. Water pressure depends on the strength of the pumping equipment. These pumps produce a pulsating discharge and may produce vibration and noise.

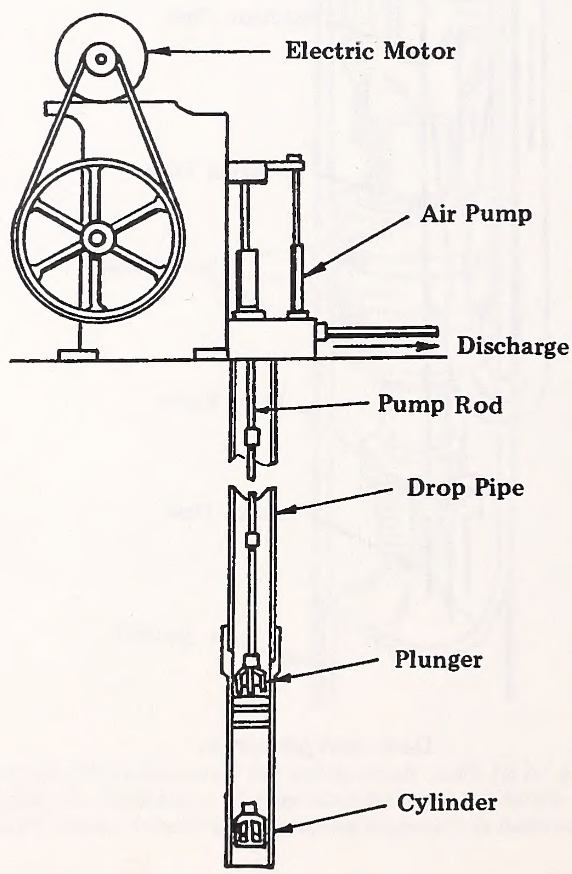


Piston-pump cylinders for extra small wells (2 to 4 inches in diameter).

Wells less than 4 inches in diameter are difficult for deep well installations, especially if a large volume of water is needed. Special piston pumps designed for wells as narrow as 2 inches in diameter are available. Some of these use tight fitting rubber packers to seal the bottom of the well casing so the casing carries water to the surface. This makes a special pipe to discharge the water unnecessary.



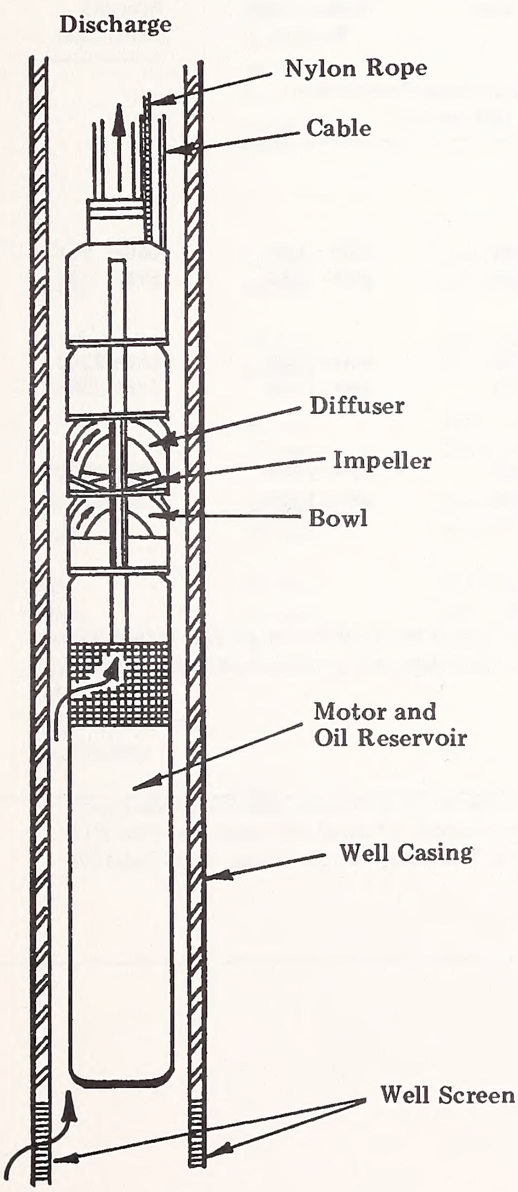
Double acting piston pump.



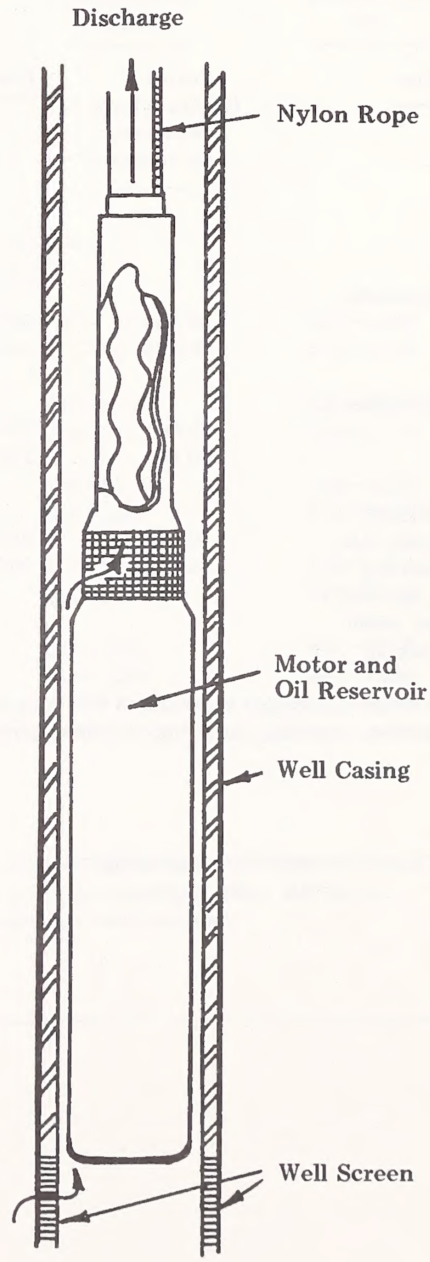
Deep well piston pump.

Deep well turbine multistage pumps operate like submersible centrifugal pumps. The impellers are modified to generate greater pressures and higher capacities. The impellers are located below the water level; the discharge pipe and power shaft extend to the power unit at the surface. These pumps provide a smooth, even flow. They are easy to frost-proof and pump from wells as deep as 1,500 feet. The long drive-shaft, extending from the water level to the surface, requires a straight and vertical well casing. Pump repair requires pulling the pump from the well. Sandy water damages the impeller. Capacity and pressure depend on the design, diameter, speed, and number of impellers.

Submersible helical rotor pumps use an auger-like blade located in the water source to push the water up the pipe. These pumps produce a smooth, even flow and are easy to frost-proof. Helical rotor pumps handle sandy water with less pump damage than any of the other pumps. The pump must be pulled from the well for repairs. These pumps can be used in 4-inch diameter and larger wells, and can pump as deep as 1,000 feet. The pump capacity depends on rotor design and size.



Turbine pump.



Helical pump.

The following selection chart should help determine the pump for your needs:

Pump Selection Chart—Shallow Wells, Low Pressure*

For pumps lifting water from depth of 25 feet or less and delivering to faucets not more than 20 feet above level of pump. Capacities based on delivery against pounds-per-square-inch tank pressure.

Well Size	Total Lift (Distance from lowest water level to pump)	Piston Pump	Shallow-well Jet	Shallow-well Turbine	Straight Centrifugal
			Range in Pump Capacities (gal. per hr.)		
1¼" Diameter					
	10 feet	250—500	400—1830	400— 565	450— 684
	20 feet	250—500	285—1440	380— 545	275— 646
1½" Diameter					
	10 feet	250—500	440—2800	400—1330	450—2300
	20 feet	250—500	285—2500	380—1290	275—2050
2" Diameter					
(or larger, also includes dug wells, cisterns, springs, ponds and lakes)	10 feet	250—500	440—3660	400—1330	450—3500
	20 feet	250—500	285—3420	380—1290	275—3100

* The range of pumping capacities in this table are not for any one pump, but rather for a number of pumps, with different capacities, operating under the conditions given. All figures are taken from manufacturers' published ratings on pumps.

Pump Selection Chart—Shallow Well, High Pressure*

For pumps lifting water from depths of 25 feet or less and delivering to faucets higher than 20 feet above pump level. Capacities based on 20 pounds per square inch of tank pressure at delivery level.

Well Size	Total Lift (Distance from lowest water level to pump)	Shallow-well Piston Pumps	Centrifugal Single and Multistage Straight Centrifugal	Shallow-well Turbine	Shallow-well Jet
		Range in Pump Capacities (gal. per hr.)			
1¼" Dia.	10 feet	260— 540	900—1400	0— 227	530—1450
	20 feet	260— 540	600—1000	0— 213	370—1080
1½" Dia.	10 feet	260—1020	2200—2500	227—1240	530—2610
	20 feet	260—1020	1800—2100	213—1200	370—1920
2" Dia.	10 feet	260—1680	2200—5600	227—1240	530—2610
	20 feet	260—1680	1800—2100	213—1200	370—1920
2½" Dia.	10 feet	260—2640	2200—5600	227—1240	530—2610
	20 feet	260—2640	1800—2100	213—1200	370—1920
3" Dia. (or larger, also includes dug wells, cisterns, ponds, and lakes)	10 feet	260—3960	2200—5600	227—1240	530—2610
	20 feet	260—3960	1800—2100	213—1200	370—1920

* The range of pumping capacities in this table are not those of any one pump, but rather for a wide range of pumps with different capacities made by different manufacturers but operating under the conditions given. All figures are taken from manufacturers' published ratings on pumps offered for individual water supplies.

Pumps for Lifting Water From More Than 25 Feet Depth

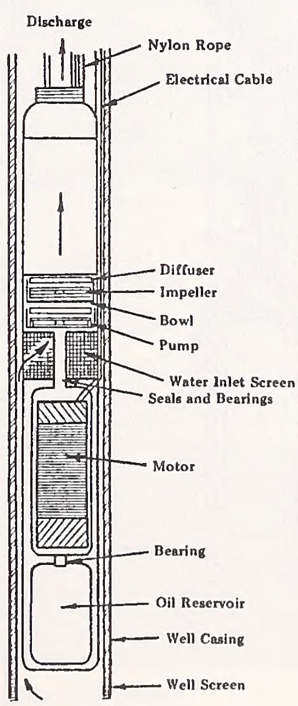
Water sources include driven, drilled, bored and dug wells.
Capacities based on 20 lbs. per square inch tank pressure at point of delivery.

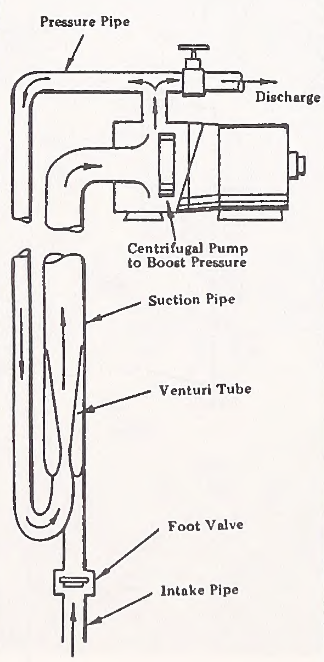
Well Size	Total Lift (Lowest water level to highest delivery point for jets)	Piston Pump Single-Acting Cylinder	Piston Pump Double-Acting Cylinder	Centrifugal Jet: Pump and delivery point on same level 1-pipe	Centrifugal Jet, Height—Pump to Delivery Point: 50 ft 1-pipe	Centrifugal Jet, Height—Pump to Delivery Point: 75 ft 1-pipe	Centrifugal Submersible	Deep-well Turbine
		Range in Pump capacities (gallons per hour)						
2" Diameter	30 feet	170—225	300—385	310— 900	270—1032	250—1000	Not	Not
	50 feet	170—225	300—385	245— 620	220— 690	190— 790	adaptable	adaptable
	100 feet	170—225	300—385	165— 350	0— 315	120— 490		
	150 feet	170—225	300—385	120— 180	0— 192	0— 360		
	200 feet	170—225	300—385	100— 125	0— 100	0— 100		
	300 feet	170—225	300—385					
	30 feet	180—250	300—445	400—1480	360—1380	320—1020	Not	Not
2½" Diameter	50 feet	180—250	300—445	360—1270	310—1070	290— 850	adaptable	adaptable
(2½" smallest	100 feet	180—250	300—445	200— 600	180— 540	160— 430		
well using	150 feet	180—250	300—445	170— 400	150— 260	130— 260		
open type	200 feet	180—250	300—445	160— 240	140— 220	120— 170		
cylinder)	300 feet	180—250	300—445	140— 150	120— 130	95— 100		
	30 feet	180—285	300—480	400—2250	360—2030	280—1800	Not	Not
3" Diameter	50 feet	180—285	300—480	360—1900	330—1700	260—1640	adaptable	adaptable
	100 feet	180—285	300—480	180—1200	160—1100	130— 880		
	150 feet	180—285	300—480	150— 750	130— 670	100— 520		
	200 feet	180—285	300—480	140— 500	0— 450	0— 360		
	300 feet	180—285	300—480	120— 230	0— 210	0— 170		
3½" Diameter	30 feet	180—360	300—720				Not	Not
	50 feet	180—360	300—720				adaptable	adaptable
	100 feet	180—360	300—720					
	150 feet	180—360	300—720					
	200 feet	180—360	300—720					
	300 feet	180—360	300—720					
4" Diameter	30 feet	180—585	300— 720	480—3000	450—1700	450—4000	640—4000	2160—7860
	50 feet	150—585	300— 720	450—1900	400—1700	410—3350	570—3600	1560—7560
	100 feet	180—585	300— 720	300—1100	310—1200	290—1530	320—3120	120—6720
	150 feet	180—585	300— 720	0— 750	220— 670	220— 670	0—2640	0—5880
	200 feet	180—585	300— 720	0— 500	180— 450	180— 450	0—2250	0—4320
	300 feet	180—585	300— 720	0— 230	160— 210	160— 200	0—1560	
	500 feet	180—585	300— 720				0— 820	
	700 feet	180—585	300— 720				0— 590	
	1000 feet						0— 270	
5" Diameter	30 feet	180—825	300—1620	Not	1500—4075	Not	640—4000	2160—7860
	50 feet	180—825	300—1620	adaptable	1085—3375	adaptable	570—3600	1560—7560
	100 feet	180—825	300—1620		610—2060		320—3120	120—6720
	150 feet	180—825	300—1620		0—1340		0—2640	0—5880
	200 feet	180—825	300—1620		0— 750		0—2250	0—4320
	300 feet	180—825	300—1620				0—1560	
	500 feet	180—825	300—1620				0— 820	
	700 feet	180—825	300—1620				0— 590	
	1000 feet						0— 270	
6" Diameter	30 feet	180—1290	300—2160	Not	Not	Not	640—4000	1560—7560
(and larger)	50 feet	180—1290	300—2160	adaptable	adaptable	adaptable	570—3600	2160—7860
	100 feet	180—1290	300—2160				320—3120	120—6720
	150 feet	180—1290	300—2160				0—2640	0—5880
	200 feet	180—1290	300—2160				0—2250	0—4320
	300 feet	180—1290	300—2160				0—1560	
	500 feet	180—1290	300—2160				0— 820	
	700 feet	180—1290	300—2160				0— 590	
	1000 feet						0— 270	

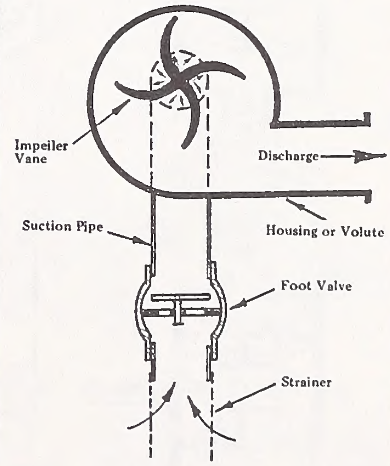
Minimum capacity based on 6" stroke at 50 strokes per minute. Maximum based on 9" stroke at 45 strokes per minute.
Larger units can be built to fit individual needs.

Well Pump Characteristics

	Submersible Multistage	Jet (or Ejector) Shallow-Well or Deep Well	Centrifugal Shallow-Well
Practical Lift	To 1,000	To 22' for shallow-well jet and to 85' for deep-well jet. Deeper deep-well jets are possible but less efficient.	To 15'
How It Works	Operates like a shallow-well centrifugal pump except there are several impellers mounted close together on a single shaft. The impellers and motor are in a housing immersed in the water source. Each impeller and its diffuser (a guide to the next impeller) is called a stage. A 4" or larger casing is usually required.	Jet pumps consist of a pump (usually centrifugal) and a jet or ejector assembly. The assembly is in the pump for shallow-well units or in the well on deep-well units. The pump forces some water through the nozzle and venturi tube of the assembly and forces the rest of the water to the distribution system.	A rotating wheel or impeller develops a vacuum in the intake pipe. Water fills the vacuum; the impeller increases its velocity and forces it into a surrounding casing shaped to slow down the flow and convert the velocity to pressure.
Advantages	Produces a smooth, even flow. Easy to frost-proof. Short pump shaft to motor.	Few moving parts. Both shallow-well and deep-well jets can be offset from the well. High capacity at low heads.	Produces a smooth, even flow. The open-impeller, but not the closed-impeller, type pumps water with some sand. Usually reliable and with good service life.
Disadvantages	Repair to pump or motor requires pulling from well. Easily damaged by sandy water.	Easily damaged by sandy water. The amount of water returned to ejector increases with increased lift; 50% of the total water pumped at 50' lift and 76% at 100' lift.	Loses prime easily. Efficiency depends on operating under design heads and speed.
Remarks	These pumps usually operate at 3500 rpm, the fastest practical speed for a 60-cycle electric motor. Pump capacity depends on impeller design. Pressure depends on diameter, speed, and number of impellers.	Capacity depends on design and number of impellers in the jet. Pressure depends on diameter, speed, and number of impellers.	Very efficient for capacities over 50 gpm and pressures less than 65 psi. Ideal for a booster pump. Can be offset from the well.

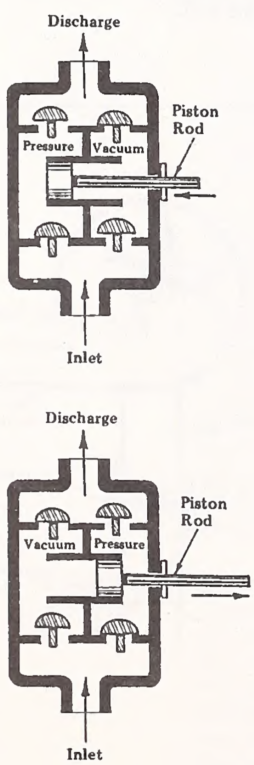


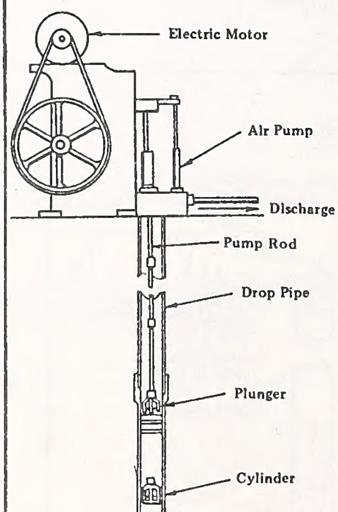


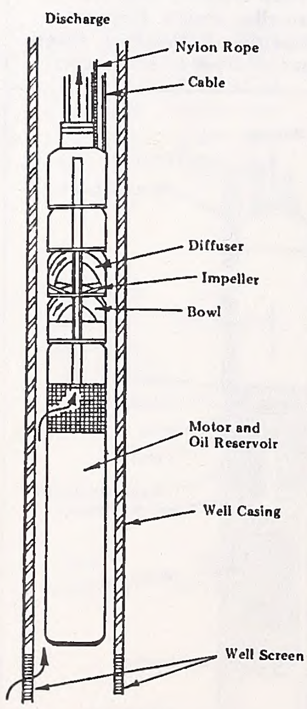


Well Pump Characteristics (continued)

Reciprocating or Piston Shallow Well	Deep Well	Deep Well Turbine Multistage	Submersible Helical Rotor
To 22'	To 600'	To 1,500'	To 1,000'
A Piston is driven from a chamber to develop a vacuum. Water fills the vacuum and is forced into the water system as the piston reverses direction.	A pump cylinder is attached to the bottom of the drop pipe. A piston is attached to a rod in the drop pipe. As the piston is forced up and down, it pumps water up through the drop pipe.	Operates like a centrifugal pump except there are one or more impellers mounted close together on a vertical shaft. The bowls (each bowl is one stage—an impeller and its diffuser) are below the pumping water level with the discharge pipe and shaft extending to the power unit at the surface.	A positive displacement pump mounted with a motor in a submersible housing.
Can pump small amounts of sand. Can be installed over small diameter wells. Positive displacement means a constant rate of yield. Adaptable to hand operation.	Same as for shallow-well. The open-type cylinder is easy to maintain.	Produces a smooth, even flow. Easy to frost-proof. Long drive shaft requires a straight and vertical well casing.	Produces a smooth, even flow. Easy to frost-proof. Short pump shaft to motor. Pumps sand with less pump damage than any other type.
Pulsating discharge. May cause vibration and noise.	Same as for shallow-well. The pump must be directly over the well.	Pump repair requires pulling from well.	Pump or motor repair requires pulling from well.
Pump capacity depends on cylinder size (displacement) and strokes per minute. Pressures are limited by the strength of the pumping equipment and the motor horsepower. Can be offset from the water source.	Double-acting barrels pump 65% more water with 15% more horsepower.	Usually operates at 1,760 or 3,500 rpm, depending on kind of power used. Usually used for high capacity from deep wells. Capacity depends on design, diameter, and speed of the impellers. Pressure depends on diameter, speed, and number of impellers.	Capacity depends on rotor design. Can be used in 4" or larger wells.







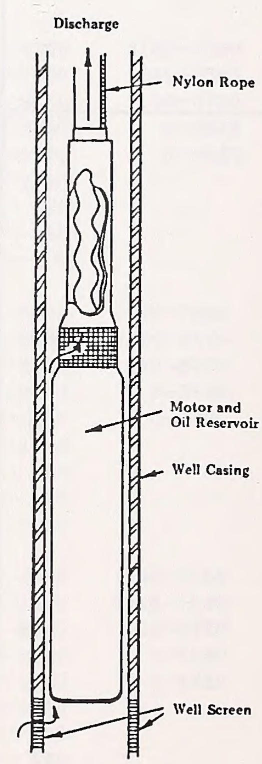


Photo courtesy of Montana Historical Society, Helena

Photo courtesy University of Montana, Mansfield Library

Power Sources

Electricity

Electricity is the primary source of power used to pump water. However, in many locations, main line electrical power is not available. Alternative sources of power include solar cells, windmills, and petroleum powered equipment.

Electrical motors for pumping water come in different types and sizes and must be matched to the pump and the water supply requirements. Electrical pumps are available to meet virtually any field condition. A qualified pump installer can determine the pump and motor that will best meet your requirements.

When installing an electrically powered pump:

1. Check the power supply voltage with a voltmeter and compare it with the motor requirements. If the motor can use different voltages, be sure it is set to match the power supply voltage.

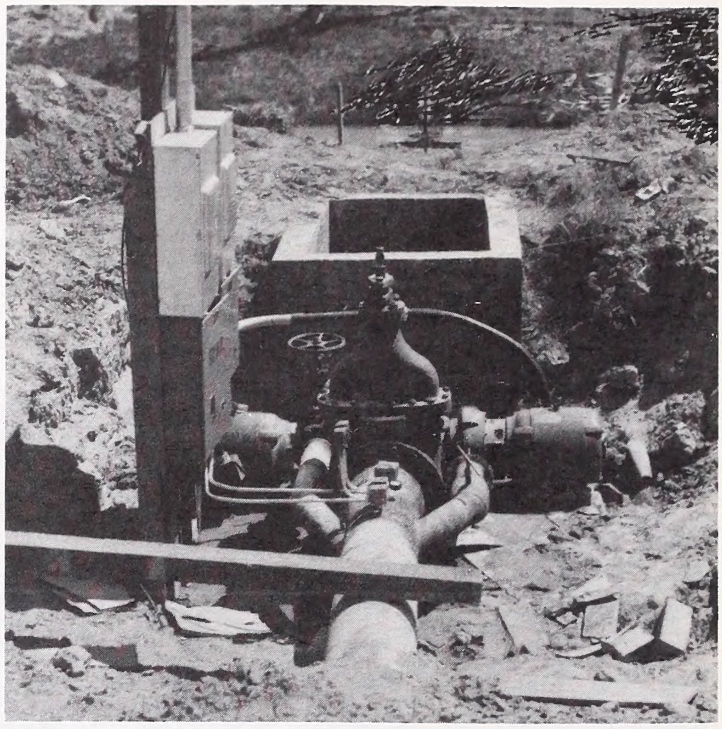
2. Most pump motors include overload. However, the motor should have its own branch circuit to protect the pump motor from a fire in other circuits. Dual element (motor) fuses or correctly sized circuit breakers should be used.

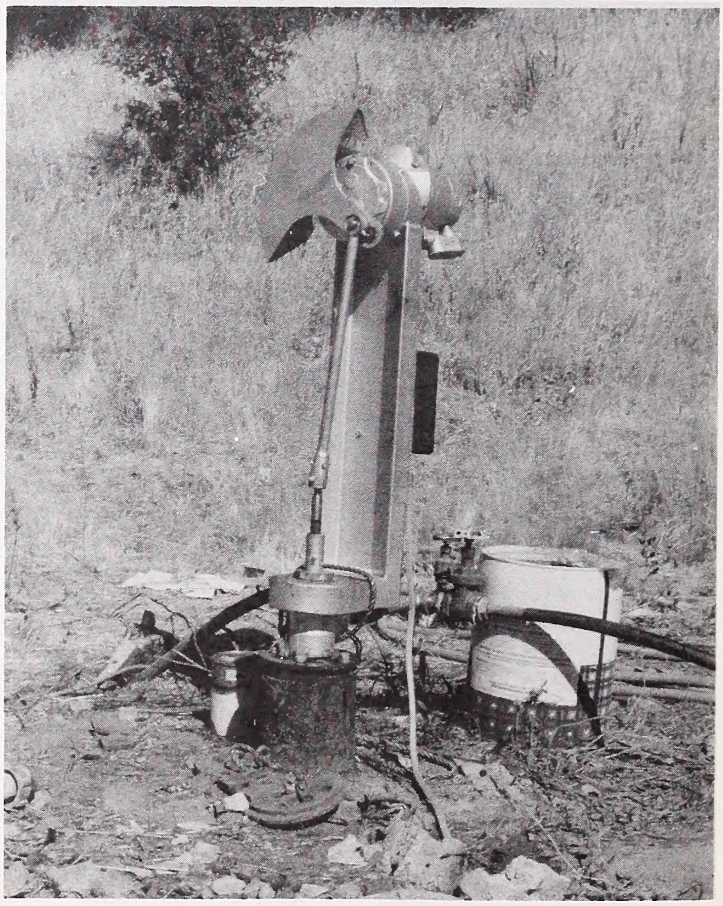
3. For safe and efficient operation, make sure all accessible pumps, controls, and metal plumbing are first connected together and then connected to the power supply ground. Install lightning arrestors to the service-entrance conductor or to a switchbox serving the pump.

4. Follow the manufacturer's recommendations about type, size, and length of wire required.

5. Be sure that belts on belt-driven pumps are not too tight or too loose and that the motor is mounted correctly, with no binding. Turn the belt by hand to be sure that everything is running smoothly before turning on the power.

6. After the pump motor has been started, recheck the voltage, amperes, and direction of rotation.



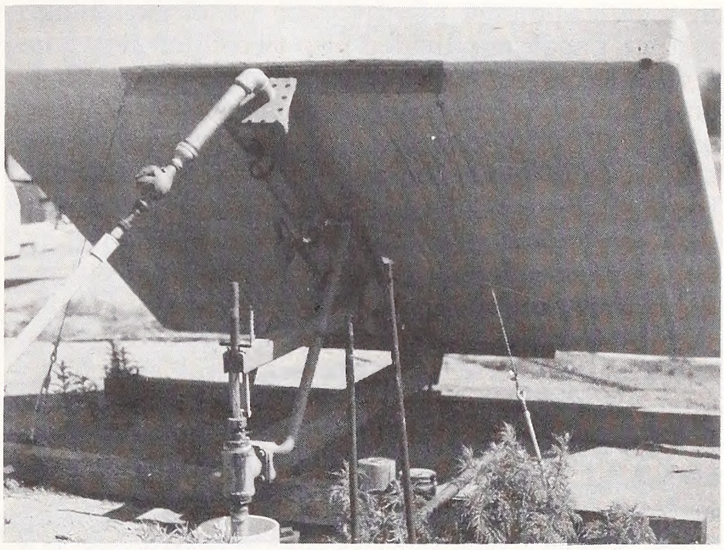


Typical electrical-powered pumps.

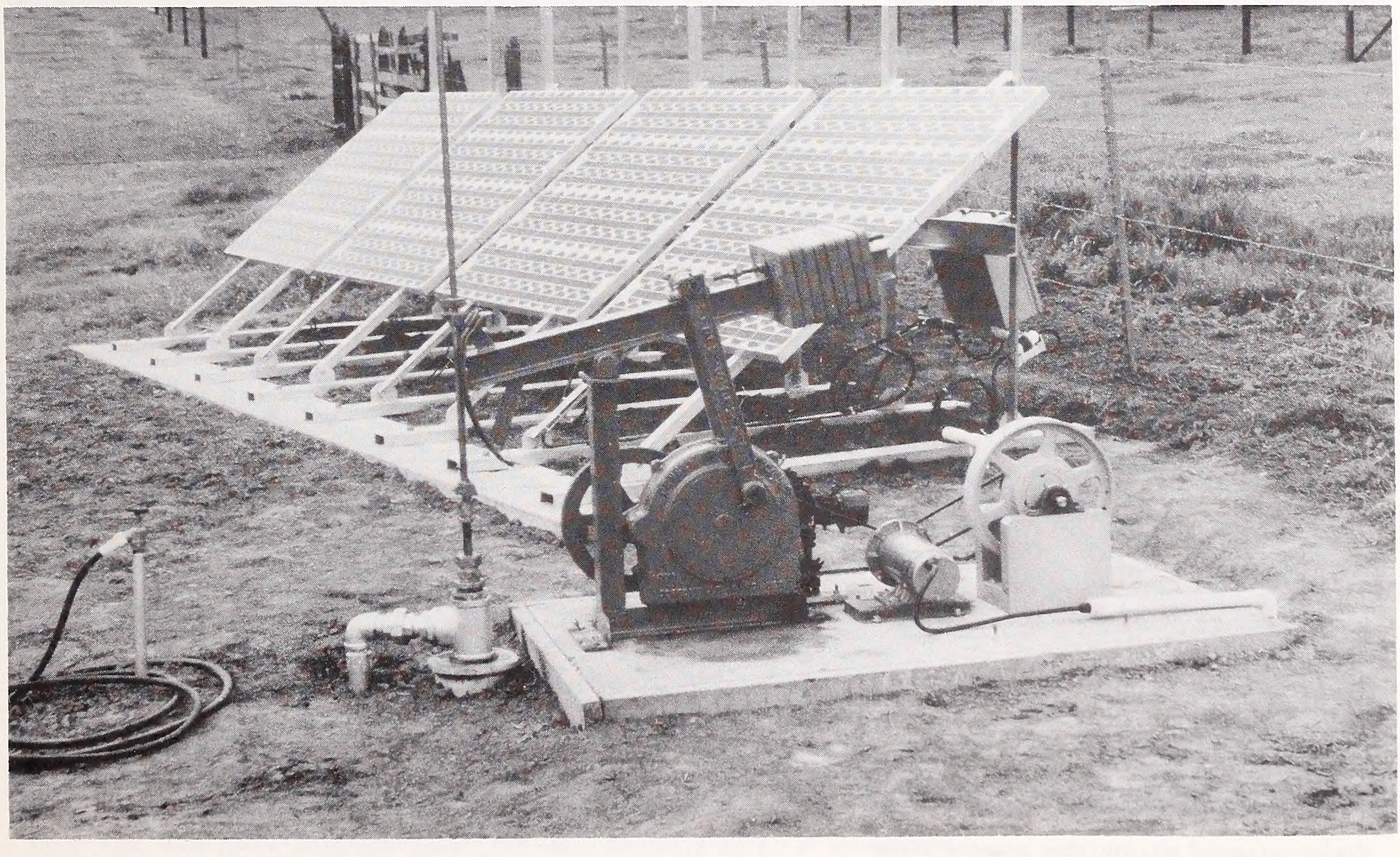
Solar Energy

Photovoltaic cells use solar energy to generate electricity when sunlight strikes the cells. Three solar systems require no batteries to operate the water pumping system: (1) large or oversized photovoltaic cell systems, (2) series-parallel photovoltaic panel switching, and (3) maximum power controller systems.

With a large or oversized photovoltaic cell system the power generated during the prime sunlight times is much greater than the power required to run the pump motor. Since this system does not use batteries, the system is connected directly to the motor. Installations powering large motors generally require batteries to store energy generated during times of intense solar radiation. This system, without batteries and connected directly to the motor, is often inappropriate to run large motors. However, because of its simplicity, it may be a good method to run relatively low-power pumping systems.

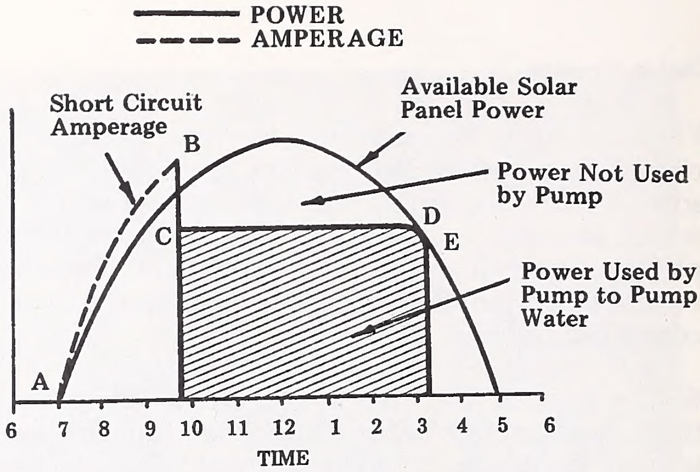


Solar-thermal water pumping system.



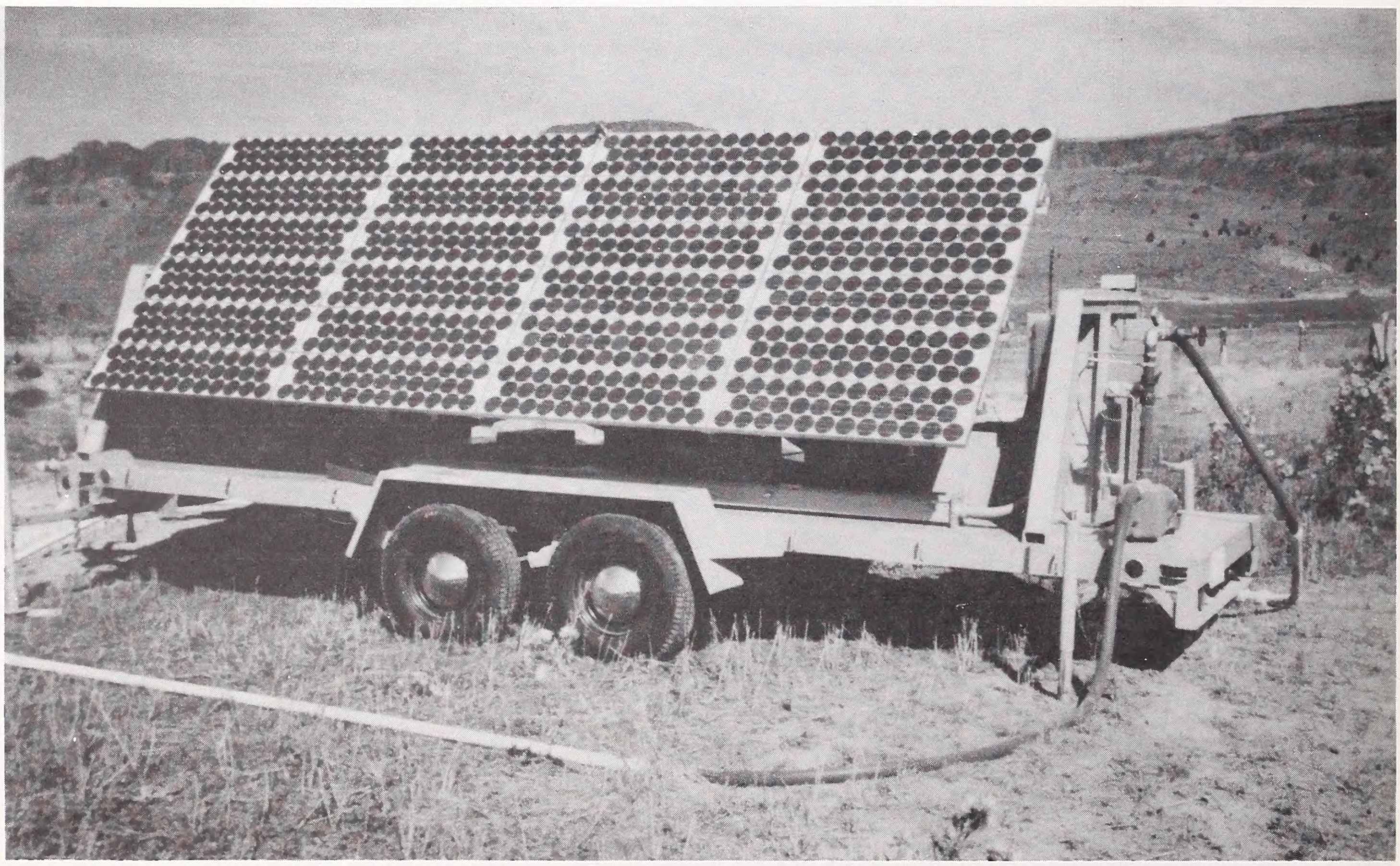
Pump powered by photovoltaic cells.

In a series-parallel photovoltaic panel switching system, panels are divided into two equal sets. The sets of panels are connected through a switching unit. The switching unit connects the two sets of panels either in parallel for combined amperage output or in series for combined voltage output. During periods of low solar radiation, such as early morning or during light cloud cover, the switching unit connects the set of panels in parallel, resulting in high amperage and low voltage output that will start or keep the motor running at a relatively slow speed. As solar radiation increases, the switching unit changes the connection between panels to a serial connection that allows the motor to increase its speed. The series-parallel switching system uses solar radiation more efficiently than the oversized array system. However, the switching system is more difficult to install and maintain because it is more complex.



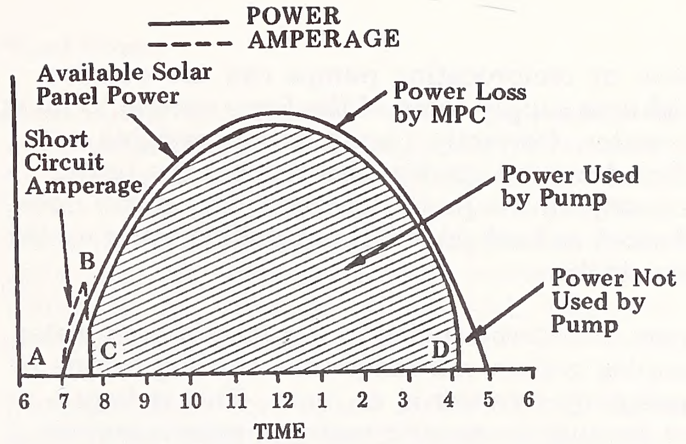
Explanation: The array is able to produce amperage as soon as the sun comes up at "A". Amperage increases until at "B" enough torque is developed to start the pump. Pump runs at power level "C", until solar power is limited at "D." At "D", available power becomes limited, until at "E" not enough amperage is available to run the pump. A large percent of the available electric power that the solar cells can produce is not used because the system does not run when the amperage is not high enough to start the unit, and when running cannot use all the available power.

Diagram showing daily operating cycle of large or oversized solar array.



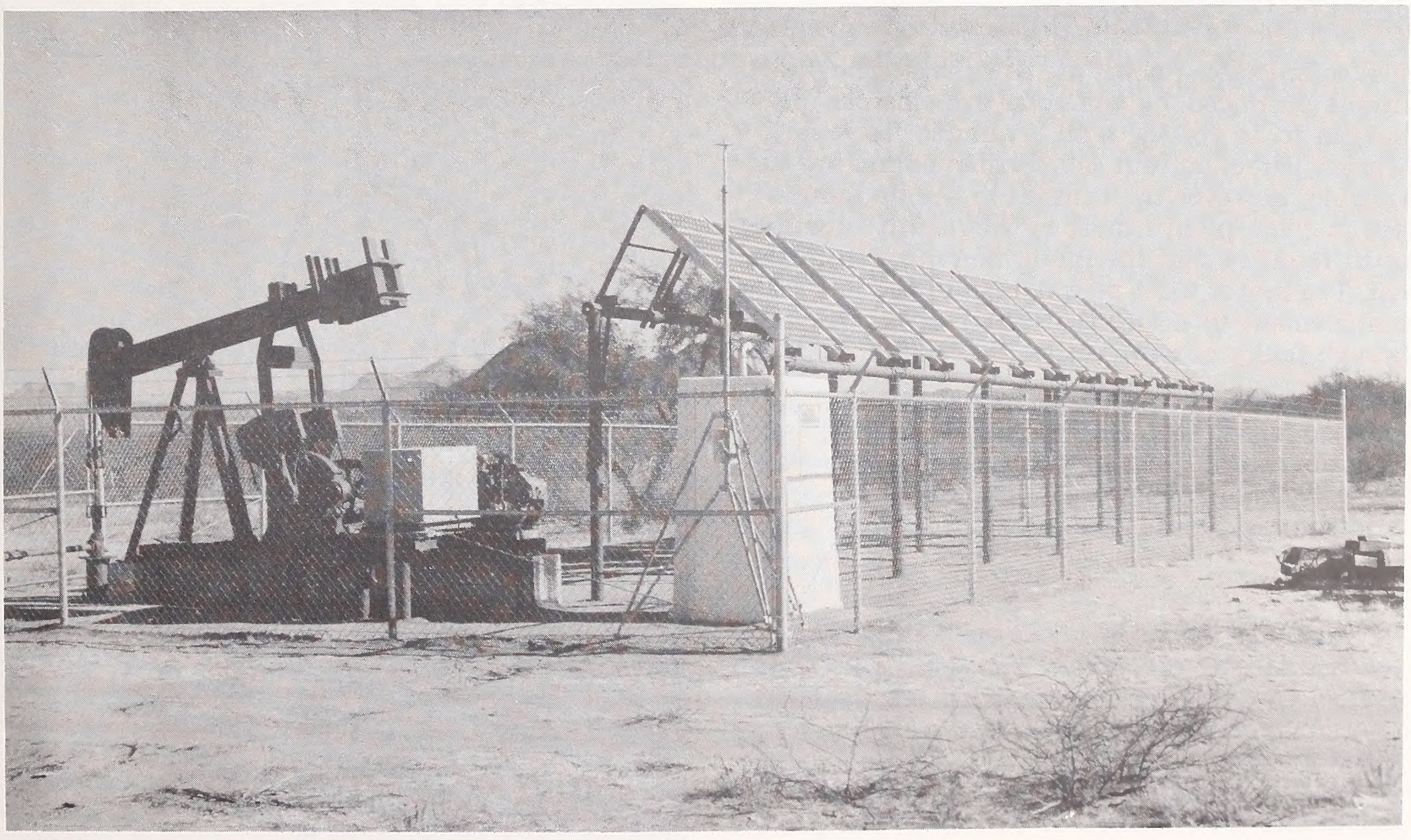
Trailer-mounted photovoltaic power system.

The maximum power controller system converts the low amperage and consistant voltage output of photovoltaic arrays just after sunrise to high amperage. The high amperage will start and run the pump and the lower voltage reduces pump speed. As sunlight increases, the photovoltaic arrays will produce higher amperage and constant voltage. The maximum power controller then converts this to higher voltage and lower amperage, which results in faster motor speed and more water pumped. Although this is the most complex and expensive of the three solar systems discussed, it uses solar energy more efficiently than the other two systems.



Explanation: The solar array is able to produce amperage as soon as the sun comes up at "A." Amperage produced by panels increases and is also increased by maximum power controller until at "B" enough torque is developed to start pump. Pump starts and runs slowly at "C." When more solar power is available, higher voltage is provided to the pump motor and it runs faster. After noon, when less solar power is available, the voltage is reduced and the motor runs slower until at "D" there is not enough power to operate the pump and the pump stops.

Diagram showing daily operating cycle of maximum power controller.



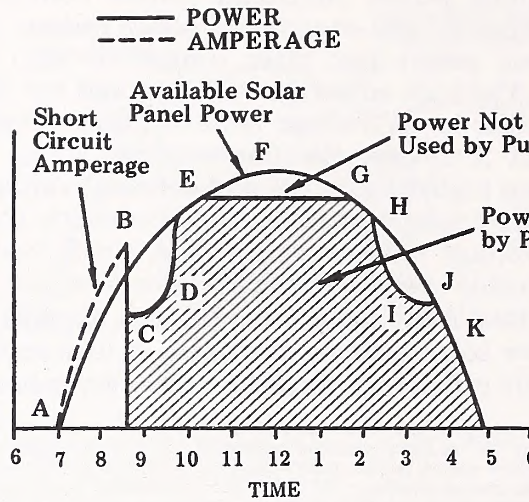
Large maximum power controller pump jack water pumping system at Queens Well on the Papago Indian Reservation, near Tucson, Arizona. This 2,700 peak watt photovoltaic-powered system pumps more than 3,200 gallons a day, from 525 feet, to supply water to a small Papago village. The system uses no batteries.

Piston or reciprocating pumps can use counterweights to supply some of the force needed to pump the water. Correctly placed counterweights are pulled down by gravity; this reduces the power necessary on the pump upstroke. The pump does not work as hard since it is not pulling water on the downstroke.

Proper counterbalancing in a solar powered water pumping system can reduce the starting torque of a pump by two-thirds or more. This is important because dc electric motor torque is approximately proportional to current or amperage. Amperage should be kept as low and steady as possible. Counterweights should be installed when the pump and motor system are installed. The manufacturer or pump installer will compute the counterweights needed to provide the most efficient solar power for your system.

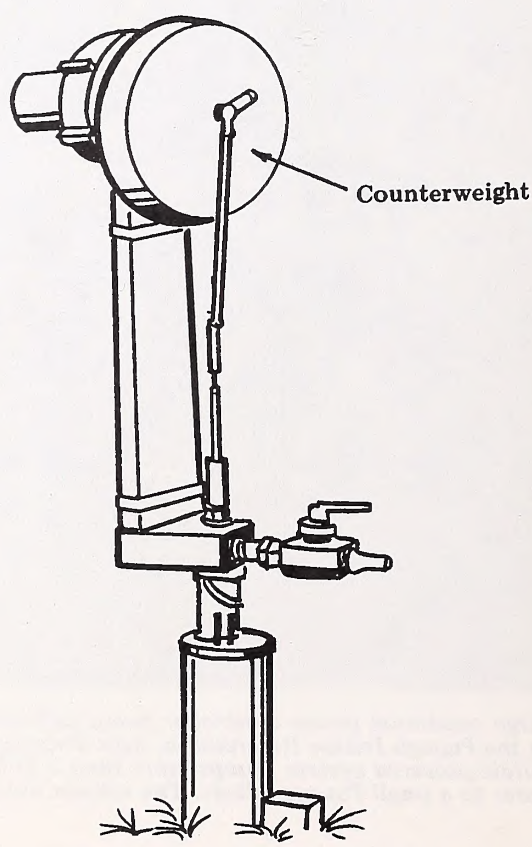
Solar systems produce direct current (dc) voltage. Motors powering most reciprocating pumps use direct current voltage, no conversion to alternating current (ac) voltage is needed.

Most submersible pumps use ac voltage. The direct current produced by the solar systems can be changed to ac voltage with a variable frequency inverter. Direct current submersible pumps are also available, however the brushes in the dc motors used in these pumps must be frequently changed, which requires that the pump be pulled from the well. The motor must be well-maintained in a sealed compartment to insure that water does not enter through faulty or worn seals.

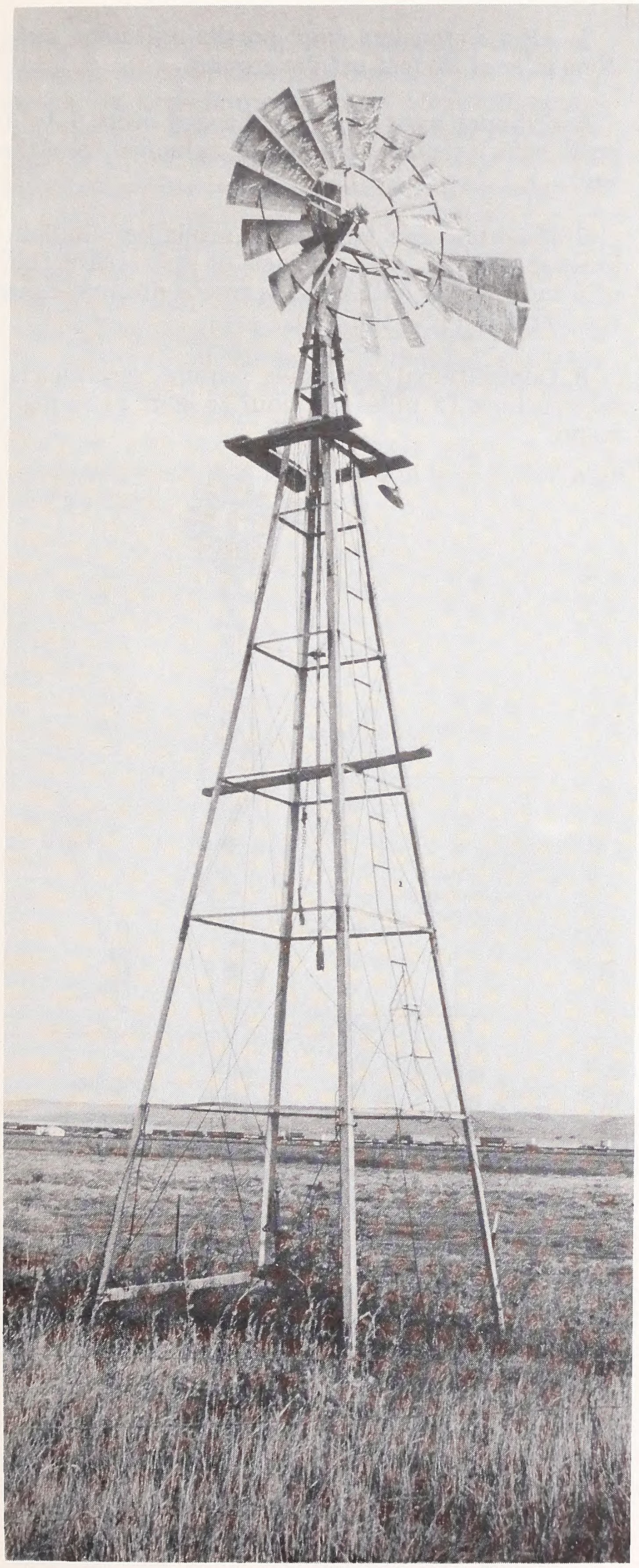


Explanation: The array is able to produce amperage as soon as the sun comes up at "A." Series-parallel switch is set for parallel (combined amperage). Amperage increases until at "B" enough torque is developed to start pump. Pump starts and runs at power level "C," at about half speed. When more solar power is available, series-parallel switch is changed to series (combined voltage) and pump speed is doubled, running at "E." As more power is available, pump runs at "F" for several hours. As less power is available, pump power decreases to "H" and then series-parallel switch changes to parallel (combined amperage) and pump runs at "I" power level. As available power is reduced, pump runs at "J" and then "K", at which time there is not enough amperage to run pump. Pump stops.

Diagram showing daily operating cycle of series-parallel photovoltaic panel switching.



Photovoltaic solar powered rod and well cylinder pump using no batteries, operating with series-parallel photovoltaic panel switching.



Typical windmill.

Wind Power

In locations with steady wind during seasons of water use, windmills can supply the power needed to pump water. Windmills are especially valuable where direct electrical power is not available or where pump location makes it impractical to manually start and stop pertroleum-powered pumps. Windmills are often an economical, long-term power source.

Windmills have been in use in the United States since 1629. Many old windmills are still in use. Windmill manufacturers produce a variety of models. However, all windmills work along the same principles. Properly installed and maintained windmills are dependable, long-lived machines.

Windmills have 2 to 36 sails (fan blades) forming a wheel from 6 to 60 feet in diameter. This wheel is mounted on a strong hub secured to a horizontal shaft. A set of gears converts the circular motion of the shaft to a usable up and down stroke. The gear mechanism is housed in a cast iron case containing oil that constantly lubricates all the moving parts. A tail vane attached to the case keeps the wheel facing into the wind like a weathervane. The vane is mounted on a swivel that can be moved parallel to the wheel, which causes the wheel to face away from the wind and in conjunction with a brake turns off the windmill. The tail vane is spring-loaded so when the wind becomes too strong, the pressure automatically forces the tail parallel to the wheel and shuts off the mill to prevent damage to the windmill mechanism.

The entire mill assembly—wheel, case, and tail—must rotate freely on a vertical axis. It is placed on top of a rotating mast pole that rests on the windmill tower. In some windmills the mast pipe doesn't rotate. Instead, the entire mill assembly turns on a turntable.

Windmill towers are from 30 to 50 feet high, depending on local wind conditions. Winds become stronger as the distance above ground level increases. Towers must be higher than an individual section of well pipe because the pipe-lifting equipment hangs in the tower. The windmill mechanism is attached to a pump rod connected to a sucker rod. The sucker rod—quite small in diameter—goes to the bottom of the well through a drop pipe and is connected to a plunger and an upper check valve. This plunger and valve are located inside a narrow cylinder at the bottom of the drop pipe. The plunger and upper check valve move with the up-and-down stroke of the windmill. A lower check valve, or stationary valve, is located in the bottom of the cylinder. The plunger and two valves lift water up the drop pipe. During the downstroke the lower check valve is forced closed and the upper check valve is forced open. Water trapped between the two valves has no place to go except above the plunger, through the upper check valve. When the stroke is reversed, the lower check valve is opened to allow water to be sucked into the void between plunger and lower check valve. During the upstroke the upper valve is forced closed, and the plunger lifts a column of water a distance equal to the stroke of the windmill. This amount of water—whatever fits into a space that is the distance of the stroke multiplied by the diameter of the drop pipe—is lifted into a storage tank with each stroke of the windmill. Windmill stroke distance can be changed. Deep wells use a short stroke; shallow wells use a longer stroke. Shorter, more powerful strokes can lift a deeper, heavier column of water than can pumps using longer strokes. Naturally, deeper wells will pump less water in a given time than shallow wells.

Some of the advantages of windmills are:

1. They work in remote areas where there is no electricity and where there are fairly strong, consistant winds.

2. Windmills are difficult to dismantle and steal.

3. If regularly maintained, windmills are dependable.

4. Operating costs are relatively low.

5. Windmills generally have companion storage tanks so if failure occurs, there is often a few days of water in reserve.

Some of the disadvantages are:

1. If the wind does not blow, water will not be pumped.

2. Windmills pump water at a relatively low volume.

3. Water storage facilities must be provided to insure water needs during the absence of wind.

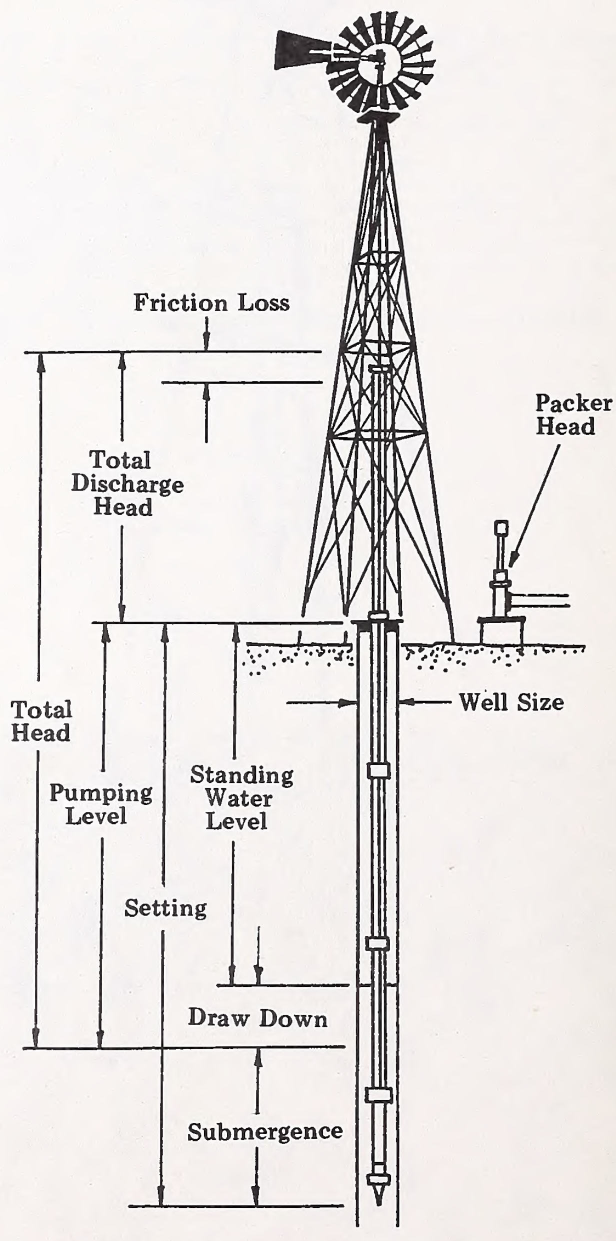
4. Windmills are expensive to purchase and install.

5. All maintenance work on the mill must be done at least 30 feet off the ground.

6. Cylinder parts must be changed every 1 to 5 years, which requires pulling the cylinders from the well.

7. Windmills are targets for vandalism. Bullet holes in the tail, vane, helmet, or sails, affect the efficiency of the mill. Objects can be dropped down the standpipe into the well.

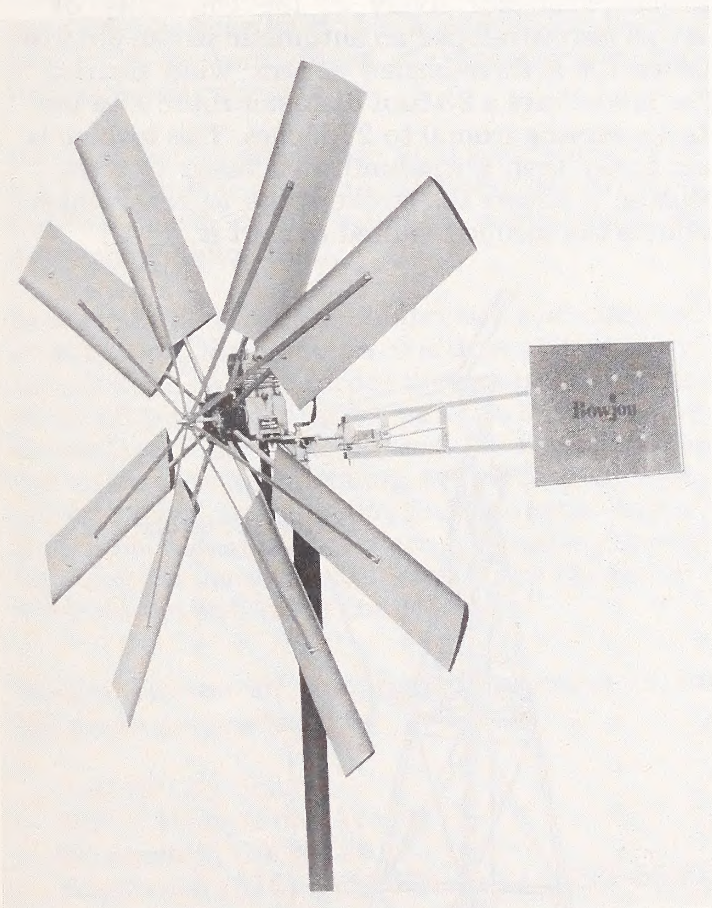
8. Conventional windmills require windspeeds approaching 12 miles per hour to start pumping water.



Windmill schematic.

In a *fully counterbalanced windmill*, water is pumped on both the upstroke and the downstroke. A non-counterbalanced windmill pumps only on the upstroke. A counterbalanced windmill allows the windmill to start pumping at lower windspeeds than a non-counterbalanced windmill.

In a counterbalanced windmill, the weight of the pump rods, one-half the water weight, and one-half the friction forces in the pump are counterbalanced by weights to reduce the starting torque. The power produced by a windmill is approximately proportional to the square of the windspeed. For example, a fully counterbalanced windmill will start in a 7 mph wind; a non-counterbalanced windmill will take a 12.2 mph wind to start.



Weights and weight arms of fully counterbalanced windmill.

In an extensive test comparing a fully counterbalanced windmill and a non-counterbalanced windmill set side-by-side (75 feet apart) on the Navajo Indian Reservation near Window Rock, Arizona, the fully counterbalanced windmill pumped substantially more water (13 times) at windspeeds below 10 mph than the non-counterbalanced windmill. At windspeeds above 10 mph, 32 percent more water was pumped by the fully counterbalanced windmill.

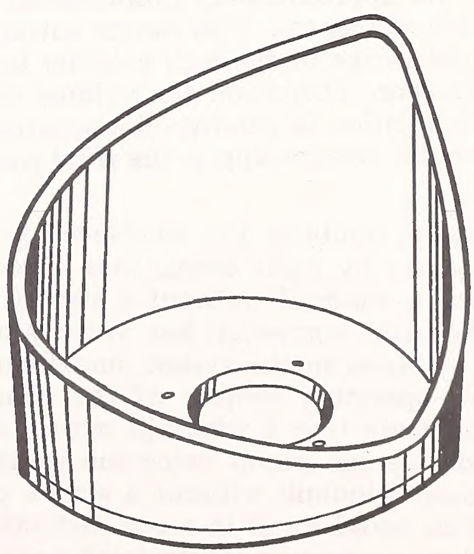
One supplier of counterbalanced windmills is the Wind Baron Corporation, 3702 West Buckeye Road, Phoenix, AZ 85009, telephone (602) 269-6900.

The Bureau of Land Management Vale District in Oregon, developed a *spring counterbalanced windmill* that starts and runs at relatively low windspeeds. One to four extension springs are attached at the top of the tower and the pump pole. The springs are stretched on the downstroke of the pump and contract to help with the upstroke.

A potential problem with spring counterbalancing is that the windmill is not designed to take loading on the downstroke and this may cause unusual wear.

In a *cam-operated windmill*, the lift cam is designed so the time of the lift stroke is longer than the time of the downstroke. When a cam mechanism is used in a windmill, the starting torque is reduced to allow the windmill to start pumping water at lower windspeeds than with a conventional windmill.

At windspeeds above starting windspeed where both the cam and conventional windmill are operating well, performance will be about equal. Limited production models of cam-operated windmills have been produced by WindEnergy Unlimited, Incorporated, 2527 North Carson Street, Suite 205, Carson City, NV 89702, telephone (702) 883-9303 or (805) 248-6023.



Cam of cam-operated windmill with a three-quarters lift time and a one-quarter return of downstroke time.

A Texas firm is developing a *hydraulic system* to replace the pumping rods in a conventional windmill. The windmill is connected to a well located at ground level. The water from this well is pumped down the windmill well to operate a cylinder pump. The advantages of this hydraulic system are:

1. This windmill starts and pumps in lighter wind than will conventional windmills.

2. The water source does not have to be directly below the windmill.

3. It is lightweight and can be quickly removed from a 100- to 200-foot well by hand.

4. Wind-powered water pumping can be either assisted by or entirely powered by solar cells.

For more information, contact W.L. Hydraulics, 10203 Kotzebue, Suite 112, San Antonio, TX 78217, telephone (512) 654-1412.

Automatic stroke control for conventional windmills—Wind power is approximately proportional to the cube of the windspeed. However, conventional rod and cylinder pumps can only use power approximately proportional to the windspeed when in the windmill's operating range. If the pumping mechanisms could use all the power available, the windmill would pump more water.

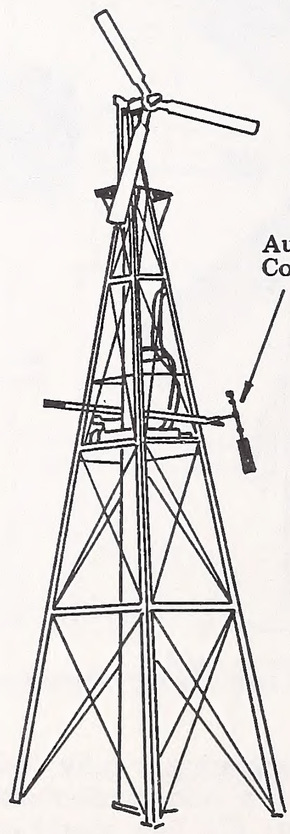
Professor Don Avery of the University of Hawaii developed an automatic stroke control device for conventional windmills that allows the pump to use power approximately proportional to the cube of the windspeed. This device automatically changes the stroke of the well cylinder to match the windpower. Therefore, the volume of water pumped in relation to windspeed is approximately the same cubic relationship as the wind energy.

Theoretically, doubling the windspeed increases pumped water by eight times, four times more water than a windmill without a stroke-control device. Actually, somewhat less water is pumped because of losses in the system and limits on maximum operating torques of the windmill. Studies indicate that a windmill with a stroke control device can pump twice the water as a similar sized windmill without a stroke control device. This could result in a cost reduction of one-third or more when constructing a windmill.

Also, a windmill equipped with a stroke-control device will start and pump water at lower windspeeds than a windmill without a stroke-control device. Discussions are underway for the manufacture of the device as a kit for conventional windmills. For more information, contact Don Avery, 45-437 Akimala Street, Kaneohe, HI 96744, telephone (808) 247-1909.

The Advanced Energy Corporation of Van Nuys, California, is working to determine economical matching and operation of wind generators driving submersible pumps. Contact them at 14933 Calvert Street, Van Nuys, CA 91411, telephone (213) 732-2191.

Automatic stroke control for a three-bladed wind turbine—Professor Avery of the University of Hawaii also developed an automatic stroke control device for a three-bladed electric wind turbine. The model uses a 23-foot diameter rotor with the stroke varying from 0 to 27 inches. This turbine is less costly than a windmill. It is easier to start because it allows the stroke to go to zero, which reduces the torque required to start it.



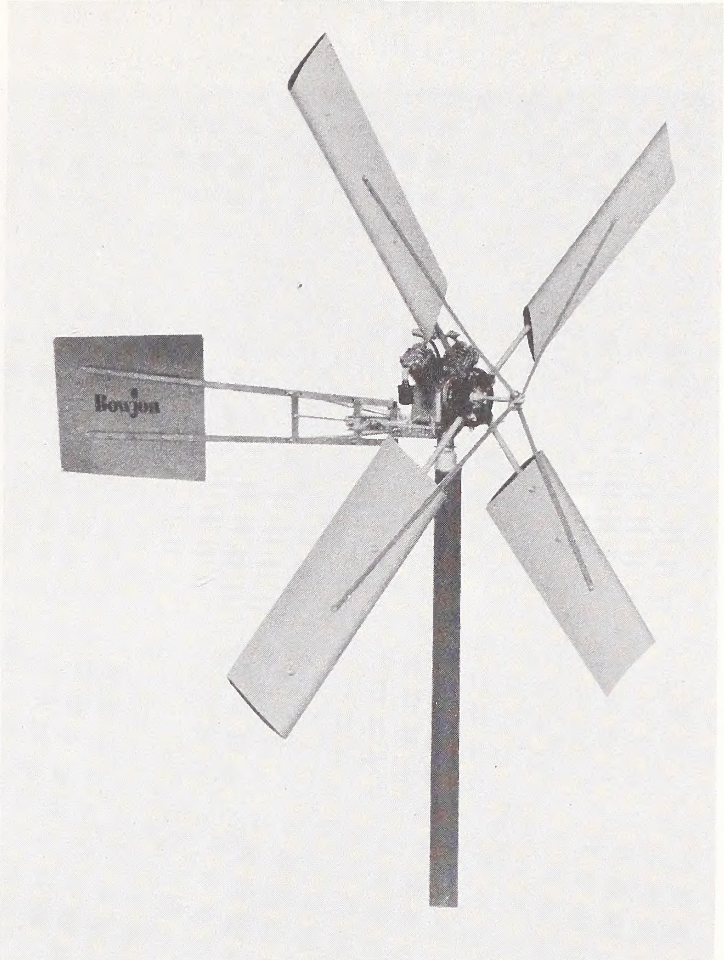
Three-bladed wind turbine equipped with automatic stroke control device.

Wind generator with a submersible pump—The USDA Agricultural Research Station at the Conservation and Production Research Laboratory in Bushland, Texas, is investigating commercializing a submersible centrifugal pump with a wind generator that produces alternating current and operates as a stand-alone water pumping system. Laboratory tests show the system to be promising. This water pumping system would have a relatively low initial cost and reduced maintenance. Wind generators are lighter, smaller, and less complex than conventional windmills that produce alternating or direct current.

The proposed pump system used with the wind turbine may be able to extract more power from the wind turbine than systems pumping with the multiblade windmill. The new system requires less maintenance because it uses a submersible pump located in the wall instead of conventional pump rods and well cylinders.

Components for an electric wind generator powering a submersible pump are commercially available, however, methods for matching components are not widely understood.

In a *windmill-driven air compressor operating an air lift pump*, the compressor is driven directly by the windmill. A hose carries the compressed air to an air lift pump. The air lift pump is located below the surface of the water, at least the same depth as the water. The air lift pump is a perforated foot piece attached at the end of the drop pipe. As air is pumped into the foot piece, the water column becomes less dense and is forced up by the denser water on the outside of the drop pipe.



Compressed air producing windmill.

Windmill-driven air compressors operating an air lift pump are produced by:

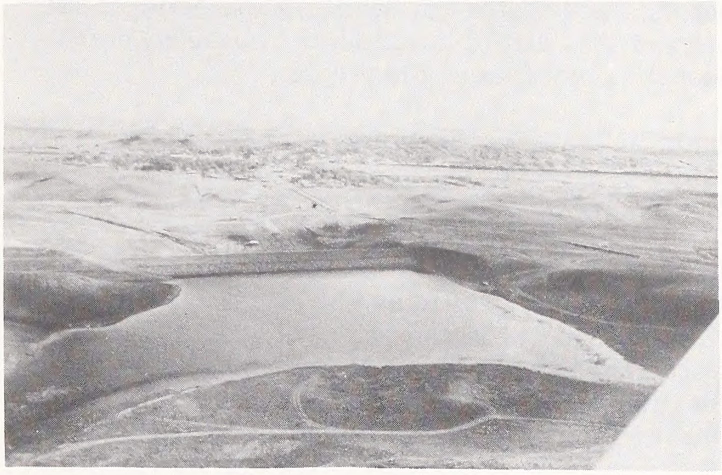
PAC III (Bowjon)
700 N. Henry Ford Avenue
Wilmington, CA 90744
Telephone: (818) 846-2620 or (213) 830-5520

Massey Enterprises
P.O. Box 1299
RR No. 1 — Springpoint Road
Fort MacLeod, Alberta
Canada TOL 020
Telephone (403) 553-3552

Photo courtesy of Montana Historical Society, Helena

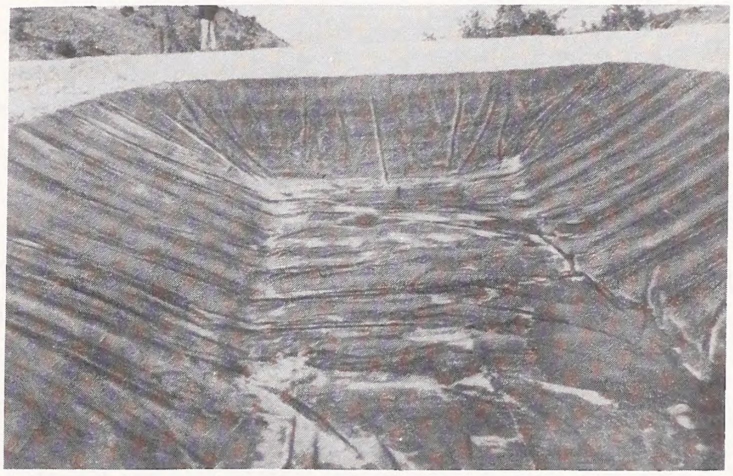
Trapping Runoff

Another way to provide adequate water to a range site is to trap runoff that occurs naturally on the site. This runoff is snowmelt or precipitation from a storm that normally flows over the surface of the site and is lost into the streamflows in the area. By trapping this runoff, the water is kept at an appropriate location until it can be used by wildlife or livestock. The most common method of trapping the runoff is by the use of dams.



Typical western dam and reservoir.

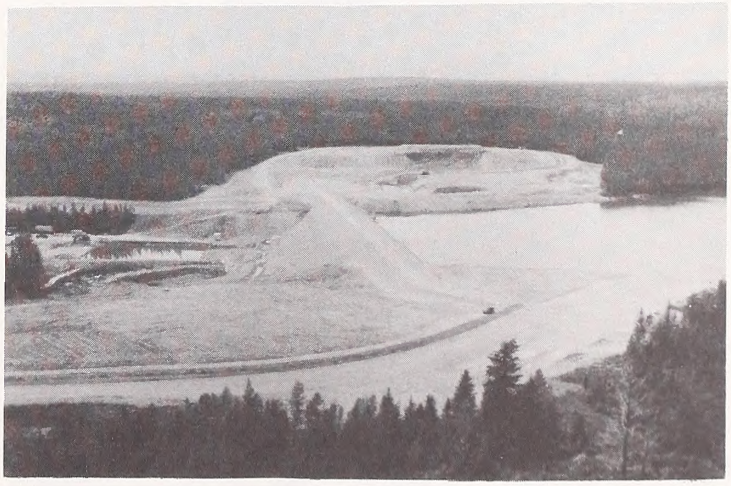
Dams and the reservoirs they produce are important water developments across much of the West. Reservoirs hold water, either from snowmelt or from rainfall, that would naturally flow off the site. Snowmelt and rain in the West are lost through evaporation, infiltration into the soil, or runoff over the ground surface. Dams collect and hold some of the water in reservoirs. Dams cannot trap water that naturally evaporates or infiltrates the ground. Acutally some of the water in reservoirs evaporates and infiltrates, which adds to overall losses. Appropriately built dams and reservoirs increase the amount of usable water on a site by concentrating the runoff and by holding the water until needed.



Small reservoir constructed with plastic liner.

Dams can be classified by the material used in construction. These materials range from plastic (for very small, temporary dams) to earth or cement. Although any relatively impervious material can be used to create a dam, most rangeland dams are built from earth. The cost of building a cement dam is generally too high for range applications. Plastic dams have low capacity and short life-spans. The use of plastics and butyl rubber for reservoir liners is discussed later in the section dealing with water storage.

Building earthen dams involves either excavating a shallow area or building an embankment across a natural watercourse. Excavating a shallow reservoir hole in a relatively level area provides water-holding capacity equal to the amount of excavation done. This is seldom done for rangeland applications. Usually excavation complements building an earthen embankment to provide a dam across a natural watercourse with the reservoir hole enlarged to hold more water.



Earthen dam and reservoir.

Site Selection

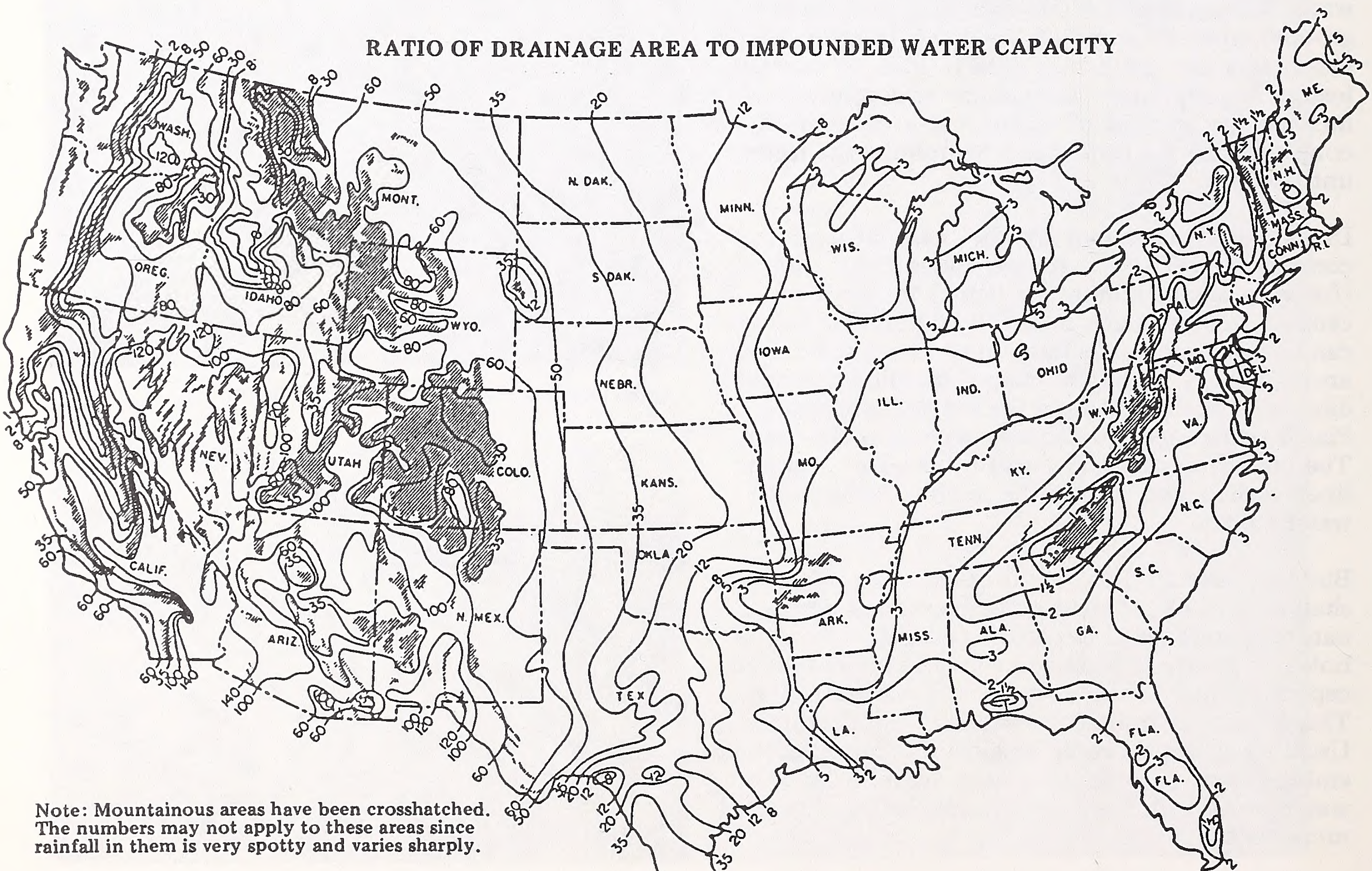
Site selection requires careful analysis of many factors. Each factor contributes to selecting a site that provides sufficient amounts of usable water to meet the objectives of the project.

Major factors to consider are:

1. WaterAvailability

Dams trap and hold water from runoff. Before bulding a dam, determine the water quantities required from the development. Then, calculate the expected water production from the drainage area. The drainage area is the land area that will provide runoff to the proposed reservoir.

A variety of factors determine the annual water availability from a given drainage area. According to the USDA Soil Conservation Service Agricultural Handbook Number 590, the runoff "depends on so many interrelated factors that no set rule can be given for its determination".[1] However, several rules of thumb relating to the climate and physical condition of the site can provide range managers with guidelines in choosing sites with adequate water availability. The following figure is a guide for estimating the number of acres of a drainage area required for an acre-foot of storage in a reservoir. The figure shows that a reservoir in western Nebraska requires 50 to 60 acres of drainage area for 1 acre-foot of water. In central Nevada the drainage area would have to be 100 to 120 acres to provide the same amount of water. The figure is only a general reference. Local guidelines are necessary to make final determinations of drainage area size. Specific site factors such as soil type, vegetative cover, slope gradient, rainfall patterns, and snowpack conditions must all be considered in the final determination of drainage area size.

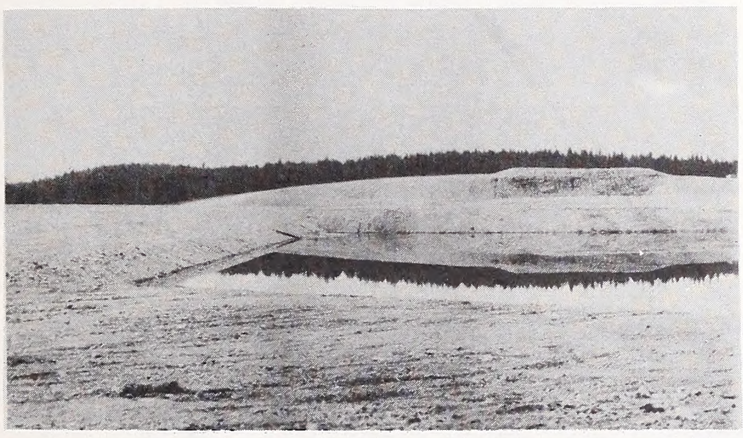


A general guide for estimating the approximate size of drainage area required for a desired storage capacity of 1 acre-foot in farm ponds and reservoirs. (From USDA Farmer's Bulletin.)

1 USDA Soil Conservation Service. 1982. *Ponds—Planning Design, Construction,* Agriculture Handbook Number 590, p.8.

Soils that absorb water in large amounts will reduce runoff. The specific soil type at a proposed site must be determined. Some soils absorb water quickly, but expand rapidly and therefore produce large amounts of runoff when rainfall continues for longer than 10 or 15 minutes. Other soils absorb water less quickly, but require large amounts of water to become saturated. These soils will produce large amounts of runoff in an intense storm, but not during a steady, low intensity rainfall.

The vegetative cover on the drainage area will also affect the area required to produce the desired amount of water. Thick vegetation generally traps and holds potential runoff; mats of moss or other ground covers may absorb rainfall; bare areas increase runoff. Although vegetation is often related to soil type, other factors, such as prior grazing use, can have a major effect on current vegetation.



Sparse ground cover increases runoff.

The slope of the drainage area contributes to the runoff potential and if all other factors are equal, a steep drainage area will produce more runoff than a level area.

The intensity, duration, and frequency of storms are important factors in determining the proper drainage area. High intensity rainstorms generally produce faster runoff than low intensity storms. Long duration storms tend to saturate the site and increase runoff. Frequent storms supply a constant source of runoff and reduce the amount of water that must be collected at any one time.

On many range sites, snowmelt is an important source of water for filling reservoirs. Snowfall patterns, drifting patterns, and melting patterns contribute to the water available from snowmelt.

For most range situations having more water than necessary is better than having too little water. Dams usually have methods of releasing excess water, but there is seldom any way of increasing water when the drainage area is too small.

When determining water availability, the range manager must consider both water quantity and water quality. Water quantity is assured by collecting from an appropriately sized drainage area. Water quality requirements are met by ensuring the water collected is not contaminated. Dams on rageland seldom collect contaminated water, however, local authorities can generally identify special problem areas or conditions that may endanger a project. Small dumps, mine tailings, or open scars in the land surface in the drainage area can contaminate runoff water. If they are included in the drainage area, be sure the water is not adversely affected by them.

When determining water needed in a reservoir, include expected losses from evaporation and infiltration or seepage. Evaporation contributes to much of the water losses from reservoirs in the West. Dams and reservoirs made of porous material, as most dams for rangeland management are, lose water from infiltration into the soil under the reservoir and from seepage through and around the dam.

A last consideration for water availability is timing. The reservoir must hold enough water to meet the project objectives at the time the water is needed. For example, on a pasture that will be used by livestock in early August but has all the runoff in late June, the reservoir will have to hold enough water to account for July evaporation, infiltration/seepage, and wildlife use, yet still insure livestock needs in August.

A reservoir designed to meet year-round use.

The factors discussed above must be considered simultaneously to determine the required drainage area. They often have conflicting effects on amount and timing of runoff. For example, an area with deep snowpack and rapid melting in the spring will result in different amounts of runoff if the site is steep with little vegetation than it will if it is level with thick vegetation. Consult local guides[2] and use the expertise of people familiar with local conditions whenever possible. The United States Department of Agriculture Soil Conservation Service, the United States Weather Bureau, various state agencies, and county extension services all provide information on determining water availability.

2. Soil Conditions

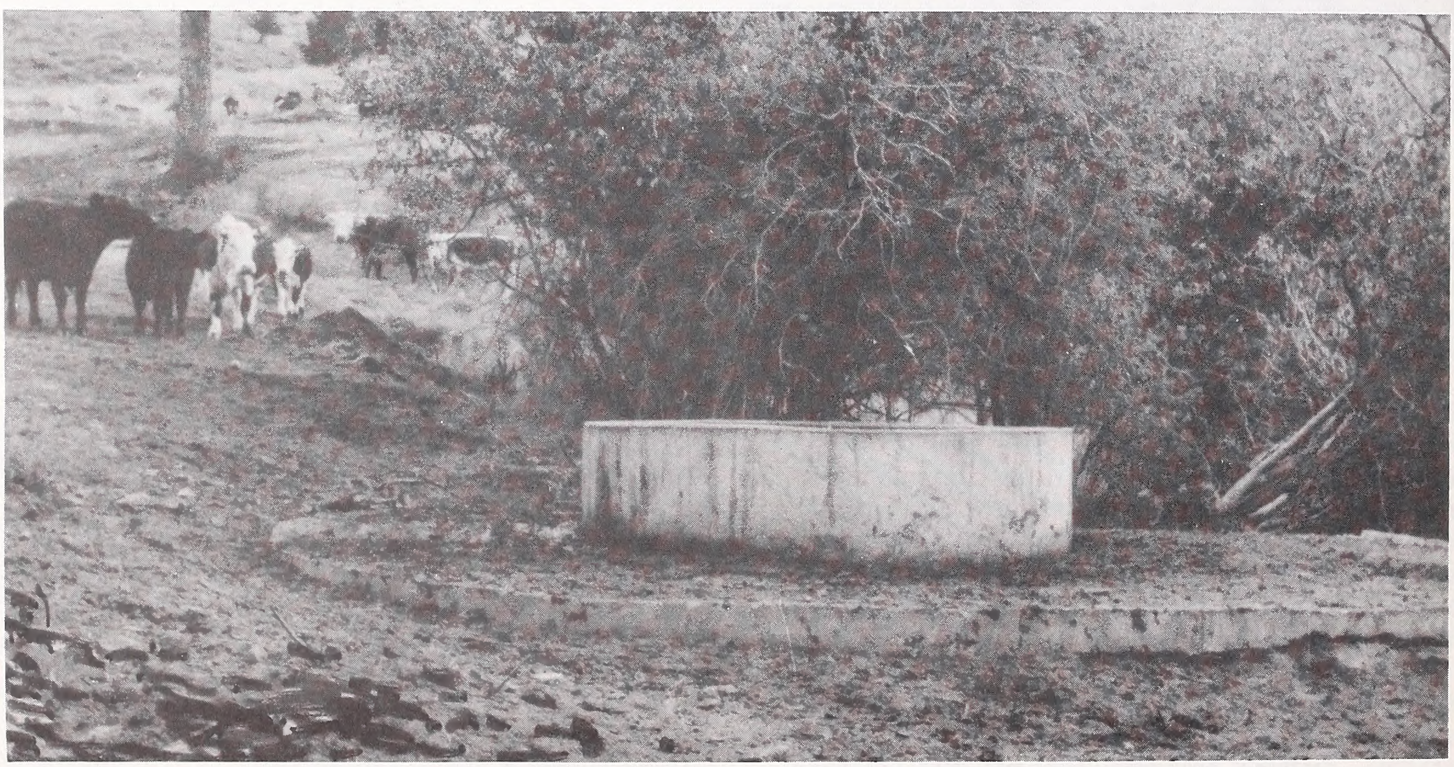
A soil scientist's analysis of the proposed site is vital. Soil conditions affect construction of the dam, durability of the dam, life of the reservoir, quality of the water, amount of water collected, access to the reservoir, and effects of increased use on surrounding lands.

Soil conditions affect water availability. Clay soils generally absorb small amounts of rainfall or snowmelt and then become impervious to additional water. This causes rapid runoff during long duration or high intensity storms. Silt absorbs water more slowly, but requires greater amounts of water to become saturated, which decreases the amount of runoff. Gravel is quite porous and water easily infiltrates, which reduces runoff water available for collections.

Water developments change livestock and wildlife use patterns with a corresponding change in vegetation and soil on the affected sites. Soil scientists, in conjuction with range and wildlife experts, can predict the consequences of these changes. Easily compacted soils, easily eroded soil, and unstable soils require special attention to prevent destruction of the site.

For example, easily compacted soils around a new reservoir can be destroyed by the increased trampling from livestock and wildlife going to the new water source. Fencing the reservoir and piping water to a storage tank on less fragile soil protects the soil around the reservoir while still providing the necessary water for animal use.

Soil conditions indicating excessive erosion over the drainage area usually mean that the reservoir will fill with soil in a relatively short period of time. In these areas dams and reservoirs must be designed to reduce the effect of sedimentation.

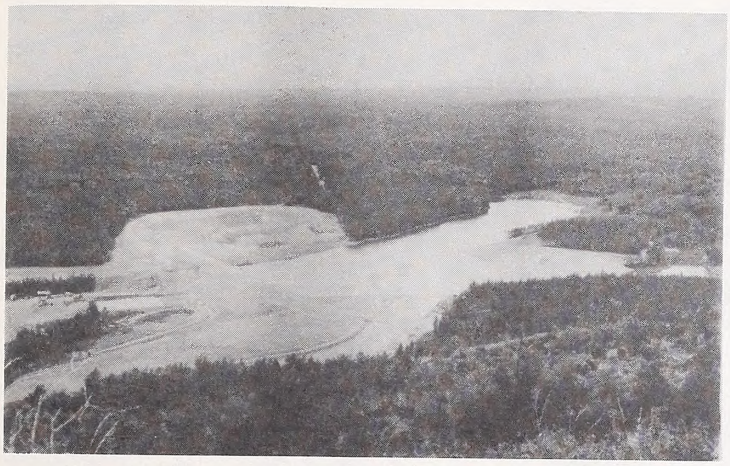


Example of cattle trampling soil around a water reservoir.

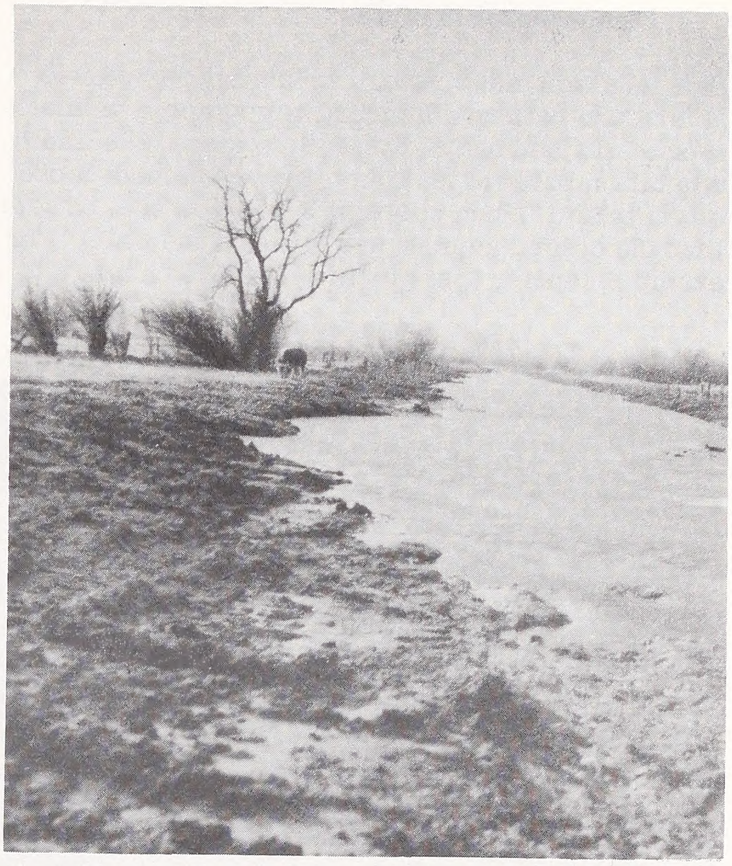
[2] Charts 1 & 6 from pages 45 & 47 of Surface Resource Facilities Handbook, Engineering, Montana State Office, BLM-MT-GI-83-006-4340.

3. Access to the Site

A suitable site provides adequate access for equipment needed to build a dam, for maintenance equipment and maintenance workers, and for livestock and/or wildlife. Heavy equipment needed to build the dam can often also build a road to the dam site. The lasting effects of such road building must be considered before committing to a site. Most dams and reservoirs need little maintenance, and access for maintenance workers is seldom a major problem.

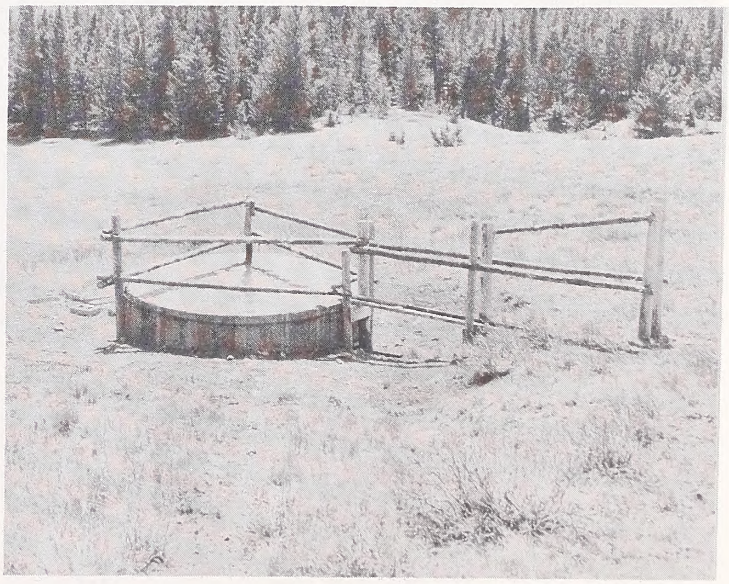


A reservoir that has access for maintenance equipment.



A muddy, trampled shoreline can cause problems.

Access for wildlife and/or livestock is an important factor in choosing a suitable site. Since most small reservoirs on rangelands provide water for animals, adequate access is imperative. Where soil, vegetation, and shoreline conditions are acceptable no special problems exist. Animals using the reservoir can simply walk to the shoreline and drink the water. Problems occur when the soils or vegetation are fragile and need to be protected. Other complications result when water levels are low and animals are trapped while walking through muddy or boggy areas to get to open water. Livestock often contaminate water by stirring up the soil from reservoir beds. When water levels are low, lifestock walking into the reservoir disturb soil on the bottom of the pond, which then mixes with the water making it less palatable to the livestock.

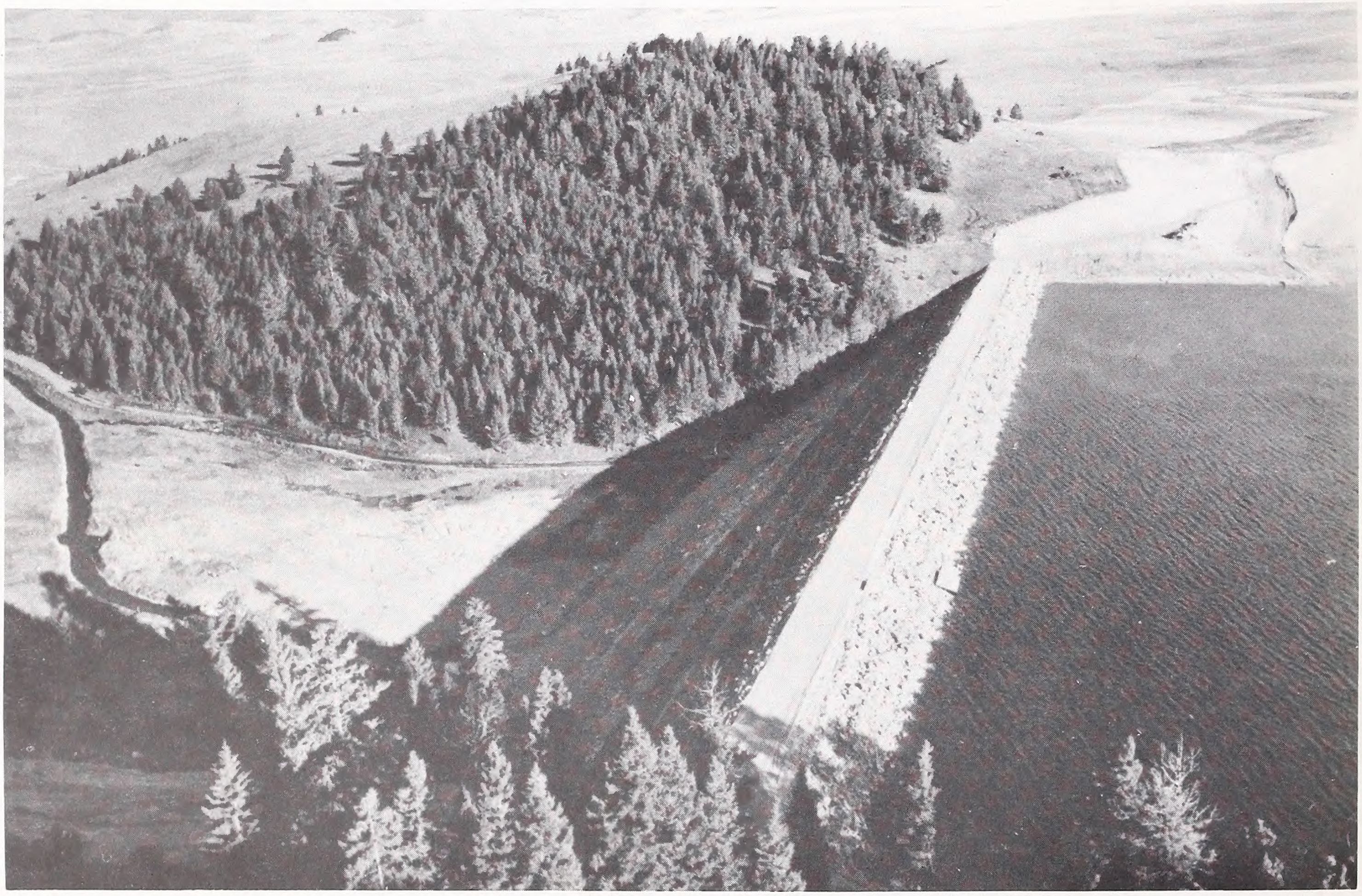


An example of a fenced reservoir.

Fencing reservoirs and piping water to desirable watering sites is a common solution to access problems. Some reservoirs have outlet streams left open for animals to get water. Another solution is to fence part of the reservoir so animals can water at the reservoir until the water level decreases below a certain point. Then, piping the water or opening an outlet stream provides any further water for animal use.

4. Usefulness of the Site

Site selection must recognize limitations due to animal use patterns. Fencing, topography, animal species, sex and age of livestock, season of use, and vegetation patterns all affect the way animals move on rangeland. When choosing a reservoir site, be sure that the desired animals will move to the water. For example, fencing that obstructs travel to a new site may result in animals continuing to use earlier water sources. One common reason for developing new water sources is to spread livestock use over the range. Placing a reservoir near other watering sites will not spread range use to new areas. Before selecting a site, determine the objectives of the water development. Determine what kinds of animals will be using the development and when they will use it to assess the usefulness of the site.



An example of a well-constructed reservoir. Watering livestock, wildlife, and irrigation were considerations in this design.

Dam Construction

Dam construction includes designing the dam, surveying the dam site, preparing the reservoir foundation, and building the dam itself.

1. Designing the dam

Designing the dam requires the services of a soil scientist, an engineer, a range conservationist, and if possible, a hydrologist. Design criteria are based on the specific site chosen, the expected life of the dam and reservoir, the size of reservoir needed, and the characteristics of the soils at the site. Well designed dams require a coordinated effort to ensure that the many factors relating to dam life and usefulness are considered before building the dam. The extra effort provides a reliable source of water that benefits users for many years.

Stockwater reservoirs must be watertight and stable, in addition to meeting the site selection criteria described above.[3] The reservoir foundation, which is the soil surface on which the water will be stored, must resist seeping and leaking. A soil scientist or hydrologist should be consulted to determine whether the soils at the site are adequate for the reservoir foundation. In general, new reservoir foundations will not hold water well until they have been saturated for several months.[4] A soil scientist or hydrologist can determine whether the soils at the site will seal the reservoir adequately when the soils become wet. Soils that allow too much water seepage must be modified or covered with a substance to seal the reservoir.

2. Surveying the dam site

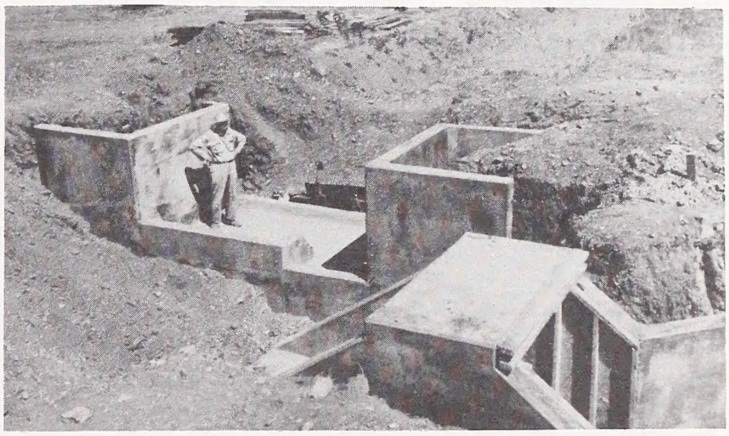
Surveying the dam site requires an engineer to inspect the site and lay out the actual dam. The engineer must know the objectives of the project including the water-holding capacity required, the type of livestock to use the site, and the overall water system plan. An experienced engineer will then be able to stake out the dam so contractors can actually build the dam.

3. Preparing the reservoir foundation

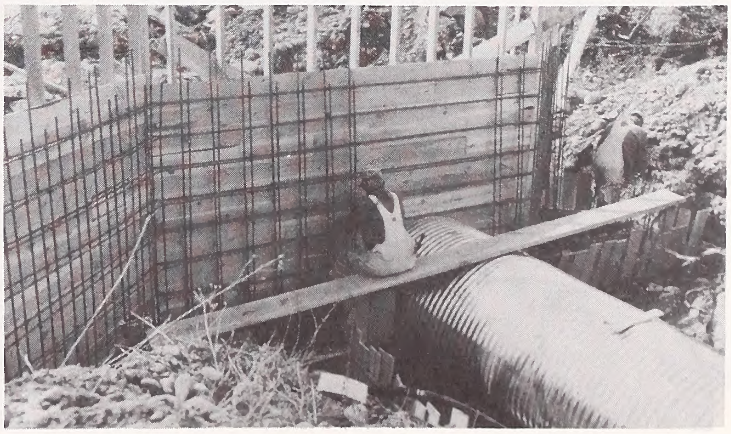
The foundation of the reservoir must be adequately prepared to hold water when the dam is finished. An adequately designed dam on a good site has a reservoir bottom that is impermeable. Some sites need compaction or removal of permeable layers before the dam is built. In addition, some dams require a core trench filled with impermeable materials to make the dam watertight. The core trench is dug beneath the ground level of the dam, under the site where the dam is to be built. The trench is filled with a compacted clay that prevents water seepage through the dam.

4. Building the dam

The engineer's plans are used by heavy equipment operators to build the dam. The dam should be built by a contractor experienced in rangeland improvements. The details of building the dam are beyond the scope of this volume.



A dam foundation under construction.



Placing reinforcing steel bars in a small diversion dam.

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[3] USDI Bureau of Land Management *Surface Resource Facilities Handbook*, Montana State Office, BLM-MT-GI-83-006-4340, no date, p. 3.

[4] USDA Forest Service Southwestern Region *Range Improvement Standards Handbook*, FSH2 2209.22 R3, January 1972, p. 61.

Photo courtesy Montana Museum of the Rockies, Bozeman, MT

Transporting Water

Collected water must be delivered to animals at the right time and in adequate amounts. In some cases the well or dam is at the correct site for watering the animals. Usually, however, transporting the water to one or more watering sites is required.

Water transport systems for rangelands almost always involve piping systems. Other options are trucking, which is generally prohibitively expensive, and ditches, which require considerable amounts of maintenance and are susceptible to water loss from seepage and evaporation. Piping water is usually the most cost-efficient and resource-efficient method of moving water from its source to the watering site.

Factors important in designing a pipeline include range conditions, topography, livestock use-patterns, soil condition, fencing, water needs, and water supplies. After the water source has been developed, the water supply can be estimated from testing the well or calculating runoff that will be collected. The first step after determining the water available is to draw a diagram of the piping system that best utilizes the range. This piping system must consist of the water source, the pipeline to move the water to the watering or storage areas, and the watering or storage tanks. When the source and the storage/watering sites are located, the pipeline can be drawn.

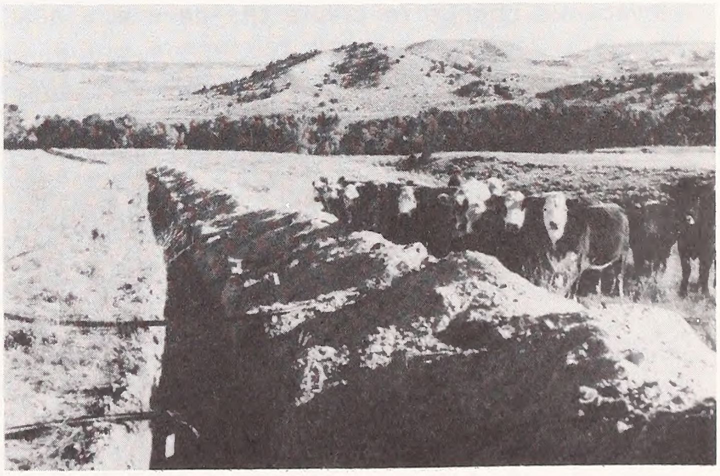
The proposed pipeline must be surveyed. The topography of the site will determine the extent of the survey. If the topography is relatively level or rolling, a field survey may be required. On sites where the pipeline runs down a relatively constant slope, a loosely controlled photogrammetric survey may suffice. In either case, those laying the pipe must be familiar with the terrain and must be experienced in the type of pipeline being laid.

Once the pipeline route has been chosen, choose the type of pipe to use.

Choosing the pipe to best supply the desired flow of water to the watering sites requires an understanding of how pipes affect the flow of water. Water flow is affected by water pressure, pipe diameter, rating, pipe material, inner surface smoothness, and length of pipe.

Ditch used for transporting water.

A concrete ditch minimizes water loss from seepage, but is expensive to construct.



Water pipeline under construction.

Water has weight and exerts pressure. It requires power to move it from one place to another and as it moves, friction absorbs some of the power, resulting in a loss of pressure. The amount of water pressure depends on the elevation of the water and not on the volume or size of the water column. The change in elevation between the water entering the pipeline and the water exiting the pipeline is referred to as the "head." The head is generally measured in pounds per square inch (psi).

Friction loss in a pipe increases as flow rate increases, causing water pressure to drop rapidly. Pipe fittings increase friction loss by adding turbulence to the water flow. The power required to move water depends on the desired rate of flow and the desired pressure at the outlet. Power absorbed by friction is unavailable for moving water or developing greater pressure.

The flow of water is measured as volume moved in a certain length of time. Usually, this flow is expressed in gallons per minute (gpm). For very small flows it is expressed in gallons per hour (gph).

Effects of Water Flow on Water Pressure

A fixed rate of water flow is needed at the watering or storage site. This rate is determined by calculating water needs for the livestock and the number of livestock to be served by the water supply. Flow rate, in quantity of water delivered in a set period of time, affects friction loss in a pipeline. Therefore, desired flow rate at the storage or watering site is a factor in the static discharge head needed to deliver adequate supplies of water. The head must have enough force to absorb the friction losses over the length of the pipeline, plus the friction losses from the pipe fixtures that the water must pass through, and still carry sufficient water to the site. Pipeline systems using only gravity to pull water to the desired sites must have enough elevational change to create the necessary head. Designing pipeline systems relying on pumps to move the water requires consideration of all forces that consume the static discharge head, and requires pumps powerful enough to overcome those forces.

Types of Heads

Static Heads have no water flowing.

Static Suction Lift is the elevation difference between the intake on the pump and the draw-down level of the water in the well. Due to friction loss in the suction pipe and the inability of pumps to create a perfect vacuum, the normal lift limit is 25 feet. For each 1,000 feet in elevation above sea level, this lift limit is lowered by 1 foot. Therefore, at an elevation of 5,000 feet, the lift limit would be 20 feet. This lift is the maximum height that a suction pump can draw up water. If the well is deeper than this lift, a static suction pump cannot be used.

Static Discharge Head is the pressure developed when the water enters the pipeline at a higher level than the discharge point. Since this is a static measurement, there is no loss of pressure from friction.

Different pipe material causes different friction loss. For example, friction losses from steel pipe are higher than those from plastic pipe. The pipe material determines the inner surface smoothness of the pipe, which changes over time as the pipe corrodes or collects deposits from running water. Some friction loss charts indicate the change in friction through corrosion or deposit by a multiplication factor that approximates the added roughness of the inner surface of the pipe as it ages. As the pipe diameter becomes larger, the friction loss is reduced. As the psi rating of the pipe changes for the same diameter of pipe, the friction loss can also change. If the increase in pipe wall thickness is added to the inside of the pipe, the pipe's inside diameter will be decreased and the friction loss factor increased. Friction loss data furnished by the manufacturer for specific pipe will determine pressure demand used by the pipe.

Types of Pipe

The flow rate and psi rate at the wellhead will determine the type and size of pipe to be used. Various kinds of pipe are available (Table 2).

Polyvinyl chloride (PVC) pipe is semi-rigid, plastic pipe. It comes in 20-foot long sections and a variety of common diameters. PVC pipe is commonly joined with a coupling and solvent, but threaded types are also available.

PVC pipe has several advantages:

1. It is very durable under most soil conditions.

2. It resists corrosion inside the pipe.

3. It works well at a wide range of water pressures (up to 600 psi).

4. It resists deterioration by sunlight.

The disadvantages of PVC pipe are:

1. It is susceptible to impact damage.

2. It can be damaged by hard freezes.

Polyethylene (PE) pipe is a black, flexible or semi-rigid plastic pipe. It is available in continuous rolls of 100, 300, and 500 feet and all common diameters. PE pipe is generally joined with a nylon insert and two stainless steel band clamps, although socket fusion and heat fusion are other methods of joining ends.

Advantages of PE pipe are:

1. It is very durable under most soil conditions.

2. It resists corrosion inside the pipe.

3. It works well at relatively low water pressure levels (80 to 160 psi).

4. It can be ripped into the ground with a ripper tooth.

5. Joints can be fused together instead of clamped.

Disadvantages are:

1. Freezing pipeline water may damage the pipe.

2. It is susceptible to puncture damage and rodents.

3. It weakens after prolonged exposure to sunlight.

These three types of plastic pipe are seldom used for rangeland systems.

Acrylonitrite Butadene Styrene (AB5)—This is a semi-rigid sewer pipe with pressure ratings between 30 and 160 psi.

Chlorinated Polyvinyl Chloride (CPUC)—This is similar to PVC, but is better for handling corrosive water at high temperatures. It is suitable for both hot and cold water lines.

Polybutylene (PB)—This is a flexible plastic pipe for hot or cold potable water lines. Gasoline penetrates it.

Galvanized steel pipe has a protective coating of zinc that greatly increases the life of the pipe. Galvanized steel pipe is available in sections up to 20 feet long and in all common diameters. It is joined by threaded couplings.

Advantages of galvanized pipe are:

1. It lasts 30 or more years under most soil conditions.

2. It works well at a wide range of small water system pressures.

3. It resists puncturing and rodent damage.

4. It is not affected by sunlight.

Disadvantages of galvanized pipe are:

1. Swampy ground reduces the service life of the pipe to between 12 and 16 years.

2. The pipe corrodes in acid or alkaline water.

3. It collects lime deposits in hard waters.

4. It bursts if water freezes in the pipe.

5. It is very expensive for long lines.

Copper Pipe is designed to withstand heavy outside pressure. Hard tempered copper is rigid and comes in lengths of 12 and 20 feet. Soft tempered copper is flexible tubing and is good for normal underground use. Soft tempered copper comes in 60- to 100-foot coils up to 1-inch in diameter and in 60-foot coils in diameters above 1 inch.

Advantages of copper pipe are:

1. Under most soil conditions, life expectancy is 40 to 100 years.

2. It is very resistant to inside pipe corrosion.

3. It withstands mild freezing.

4. It is adequate for small water system pressures.

5. It resists both puncturing and rodent damage.

6. It is not affected by sunlight.

Disadvantages of copper pipe are:

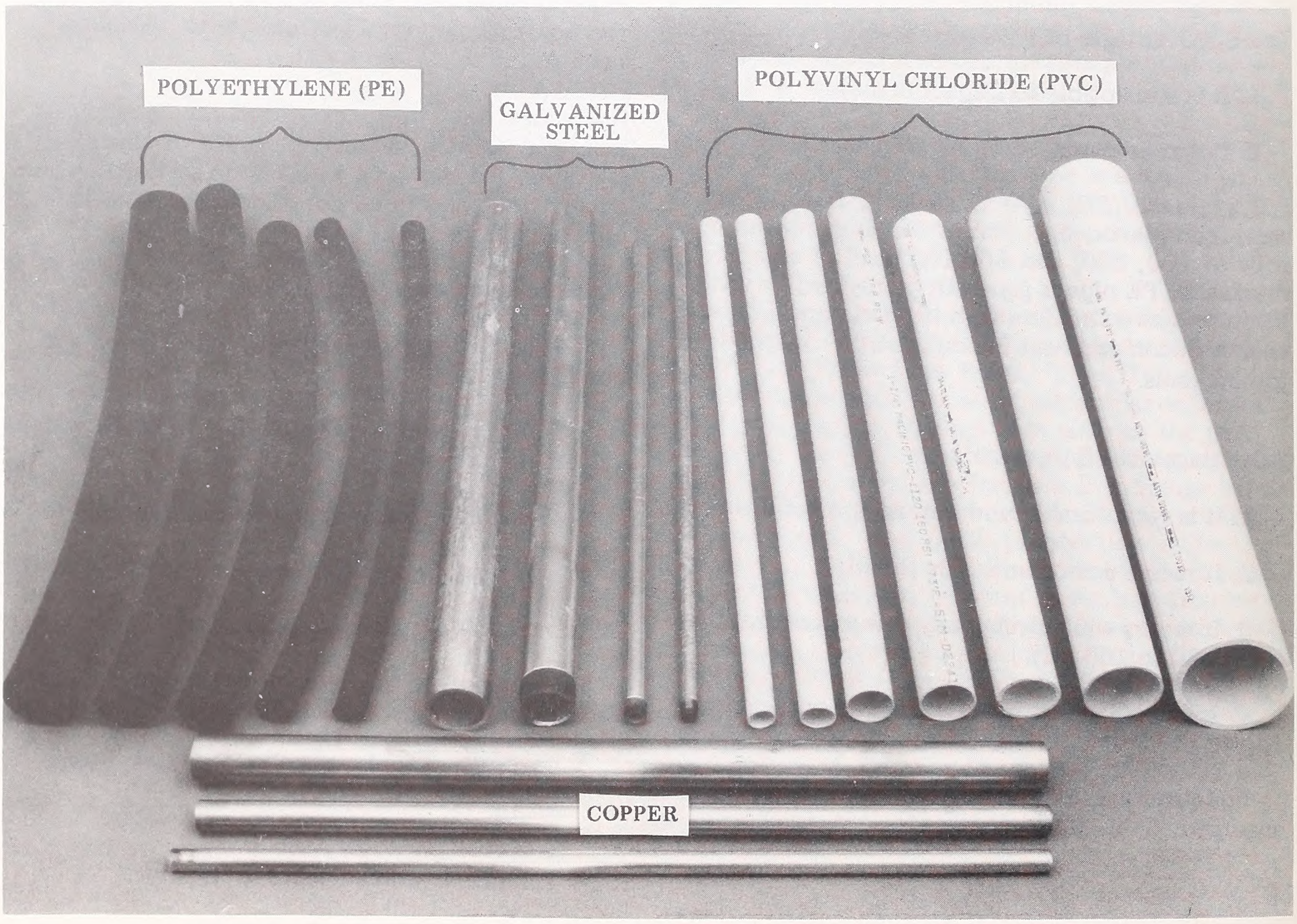
1. In high sulfide soil it will last 14 to 20 years, and less than 10 years in cinders.

2. Copper pipe may corrode with water containing free carbon dioxide.

3. Deposits on the inside of the pipe may form from lime and suspended particles in the water.

4. Acidic water dissolves copper and causes an off flavor.

5. It is normally too expensive to use for rangeland applications.



Examples of polyvinyl chloride (PVC), polyethylene (PE), galvanized steel, and copper pipes.

Table 2.—Comparison of steel, copper, and plastic pipe

Factors to Consider	Galvanized Steel (3 oz. coating min.)	Copper: Type K (heavy duty)	Copper: Type L (standard)	Plastic
Underground soil corrosion—Probable life expectancy (1)	30 plus yrs. under most soil conditions. (If no corrosion inside pipe, life could extend to 100 yrs. or more.) Waterlogged soils under most conditions—12-16 years. May be less than 10 yrs. in very high acid soils.	40-100 yrs. under most conditions. 14-20 yrs. in high sulfide conditions. May be less than 10 yrs. in cinders.	30-80 yrs. under most conditions 12-14 yrs. in high sulfide conditions. May be less than 10 yrs. in cinders.	Experience indicates durability is satisfactory under most soil conditions.
Resistance to corrosion inside pipe	Will corrode in acid, alkaline and hard waters or with electrolytic action.(2)	Normally very resistant. May corrode rapidly in water containing free carbon dioxide.		Very resistant
Resistance to deposits forming inside pipe	Will accumulate lime deposits from hard water. (2)	Subject to lime scale and encrustation from suspended materials.		Resistant, but occasional deposits will form. (3)
Effect of freezing	Bursts if frozen solidly.	Will stand mild freezes.		PE—will stand some freezing. PVC—will stand mild freezes.
Safe working pressures (lbs per sq. in.)	Adequate for pressures developed by small water systems.	Adequate for pressures developed by small water systems.		Working pressures at 73°F. PE 80 to 160; PVC 180 to 600
Resistance to puncturing and rodents.	Highly resistant to both.	Resistant to both.		PE—Very limited resistance to puncture and rodents. PVC—resistant
Effect of sun-light	No effect	No effect		PE—weakens with prolonged exposure PVC—Highly resistant
Lengths available	21 ft. lengths	Soft temper: 60-ft—100-ft coils up to 1" diameter 60-ft coils above 1" diameter Hard temper: 12- and 20-ft. lengths		PE usually in 100-ft coils or longer; PVC usually in 20-ft lengths
Ease of bending	Difficult to bend except for slight bends over long lengths.	Soft temper bends readily, will collapse on short bends. Hard temper difficult to bend except for slight bends over long lengths.		PE Bends readily, will collapse on short bends; PVC Rigid Bends on long radius
Conductor of electricity	Yes	Yes		No

(1) Derived from studies reported by Dennison, Irving A. and Romanoff, Melvin, "Soil-corrosion Studies, 1946 and 1948: Copper alloys, Lead and Zinc," Research paper RP2077, Vol. 44, March 1950 and "Corrosion of Galvanized Steel in Soils," Research paper 2366, Vol. 49, No. 5, 1952, National Bureau of Standards, U.S. Dept . of Commerce.

(2) It is possible to greatly reduce corrosion and prevent lime scale in steel pipe by adding a phosphate material. It coats the inside of pipes, as well as the lining of all connected equipment. Prevents further lime scale and greatly reduces corrosion.

(3) Jones, Elmer E. Jr., "New Concepts in Farmstead Water System Design," Am. Society of Agricultural Eng., paper No. 67-216, 1967.

Joining Pipe

There are several methods of joining pipe to create a pipeline.

The following figure shows common methods of joining various types of pipe. Steel pipe is cut to appropriate lengths and threaded so that it will screw into standard sized connectors. A compound that will make the connection watertight is applied to the threads, and the pipe is screwed together. Copper pipe is cut to the appropriate length; flux is applied to the ends of the copper pipe; the flux covered end of the pipe is slid into a copper connector; and the joint is heated to solder the connection together. Steel and copper pipe joints are watertight and usually permanent, but if they are not corroded and are accessible to workers they can sometimes be taken apart.

Plastic pipe is cut to the required length, then joined using either clamps, solvent, or heat fusion. PE plastic pipe is usually joined using clamps. The pipe ends to be joined are slid over connectors that are placed inside the pipe. Clamps around the pipe are tightened so that the pipe is compressed firmly around the connector. This makes a watertight joint. However, if the clamps become loose, there may be some leaking. This is seldom a serious problem. PVC plastic pipe is usually joined by putting solvent on the outside of the pipe and slipping the pipe ends into connecting sleeves. The solvent essentially melts the outside of the pipe and the inside of the sleeve. When the solvent and the plastic on the pipe and the sleeve harden, the joint is watertight and permanent. This joint is virtually impossible to take apart. When separating the pipes, the joint is usually cut out and scrapped.

Butt fusion of plastic pipes is accomplished by:

1. Cutting pipe ends with a pipe cutting tool to insure that the mating surfaces are flat. Cut surfaces are wiped clean of burrs and cuttings.

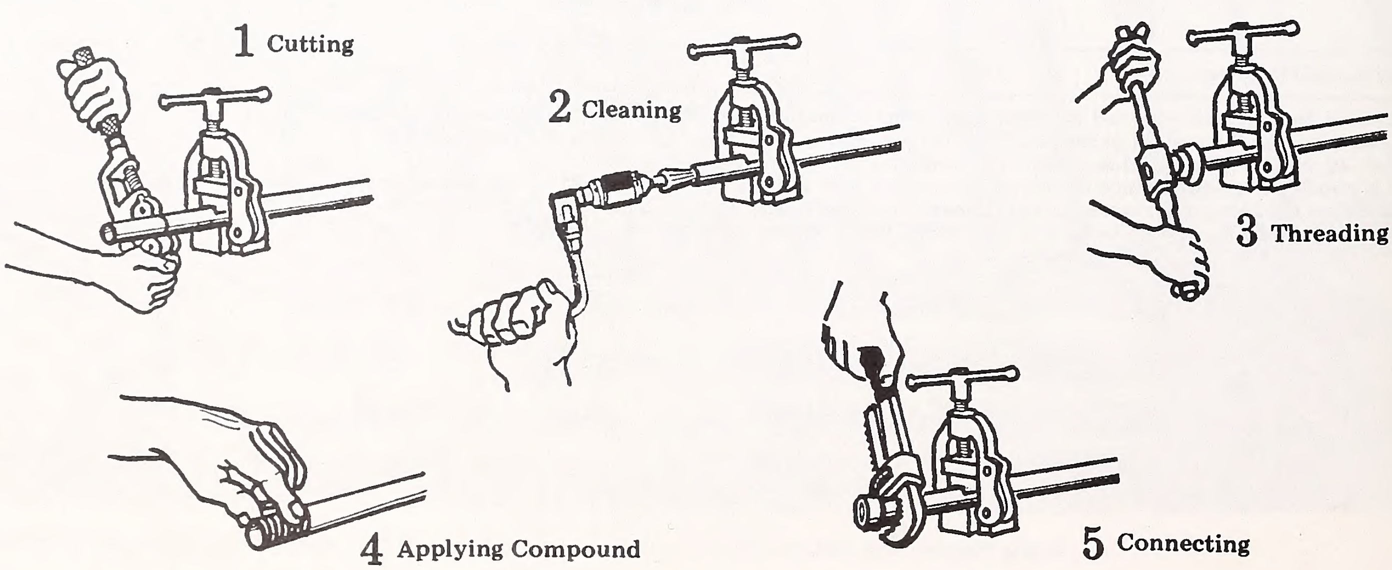
2. Clamping pipe ends in the fusion unit with about 1½ inches of pipe extending past the clamps. A tight fit is important to insure properly aligned pipe ends and a strong joint. Pipe rated at 100 psi and larger can be clamped tightly in place. Outside diameter of pipe below 100 psi is too small to be firmly clamped. In these cases, a shim can be placed inside the insert to insure a tight fit.

3. Bringing the ends together to check alignment once the pipe ends are firmly in place. A heater plate is then inserted between the aligned pipe ends.

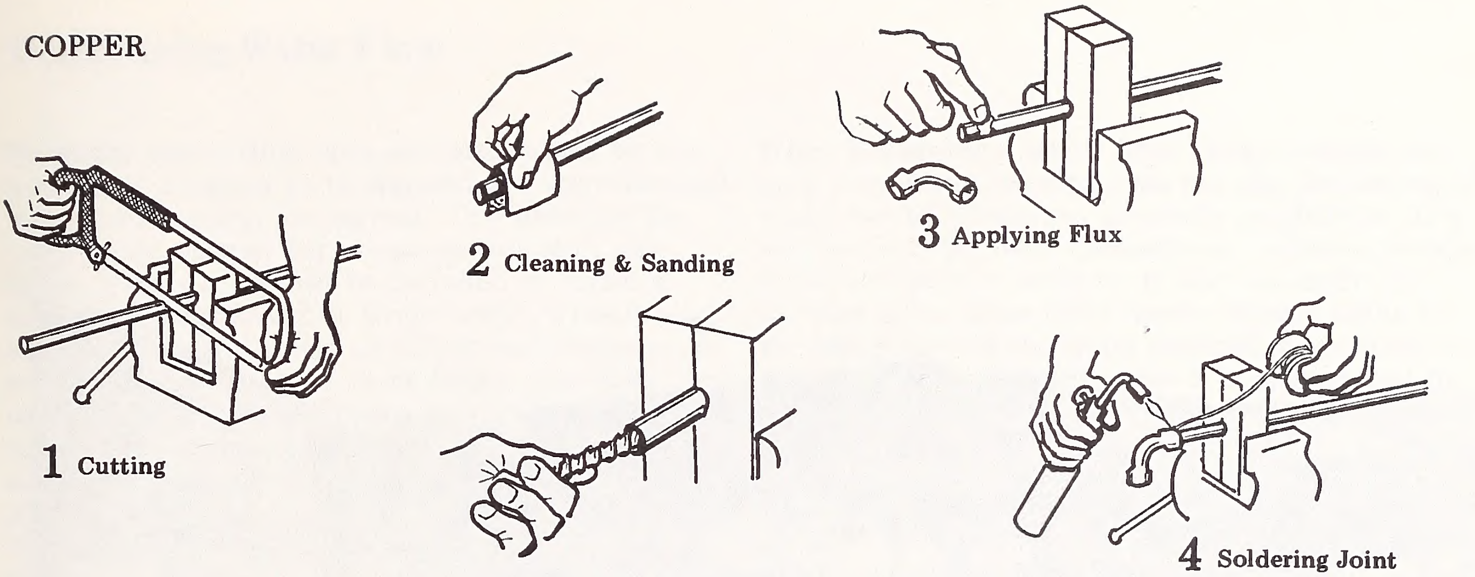
4. Pushing pipe ends against the heater and applying moderate pressure. Pressure is maintained until the softened plastic rolls up into a bead with a thickness of about 1/16 of an inch. If too much pressure is applied, the joint area will not soften properly and a poor joint will be made.

5. Moving pipe ends away from the heater plate and removing the plate from the joining frame. The softened ends are brought together with firm pressure for about 30 seconds as the joint cools.

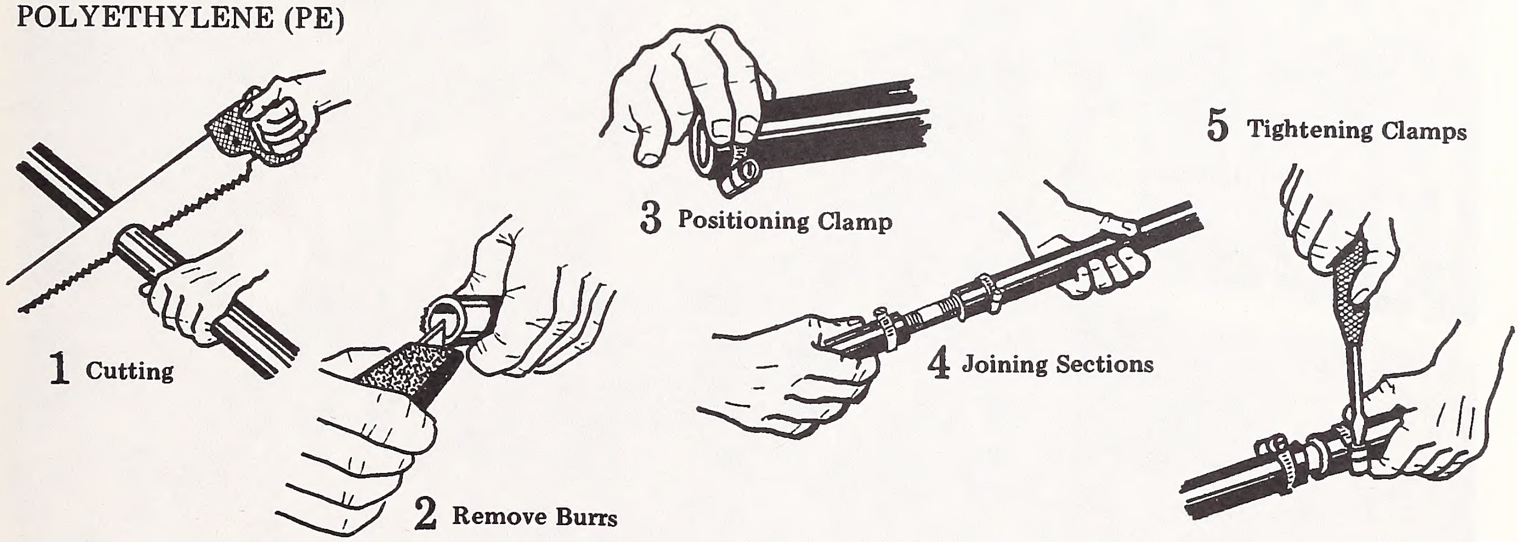
STEEL



COPPER



POLYETHYLENE (PE)



POLYVINYL CHLORIDE (PVC)

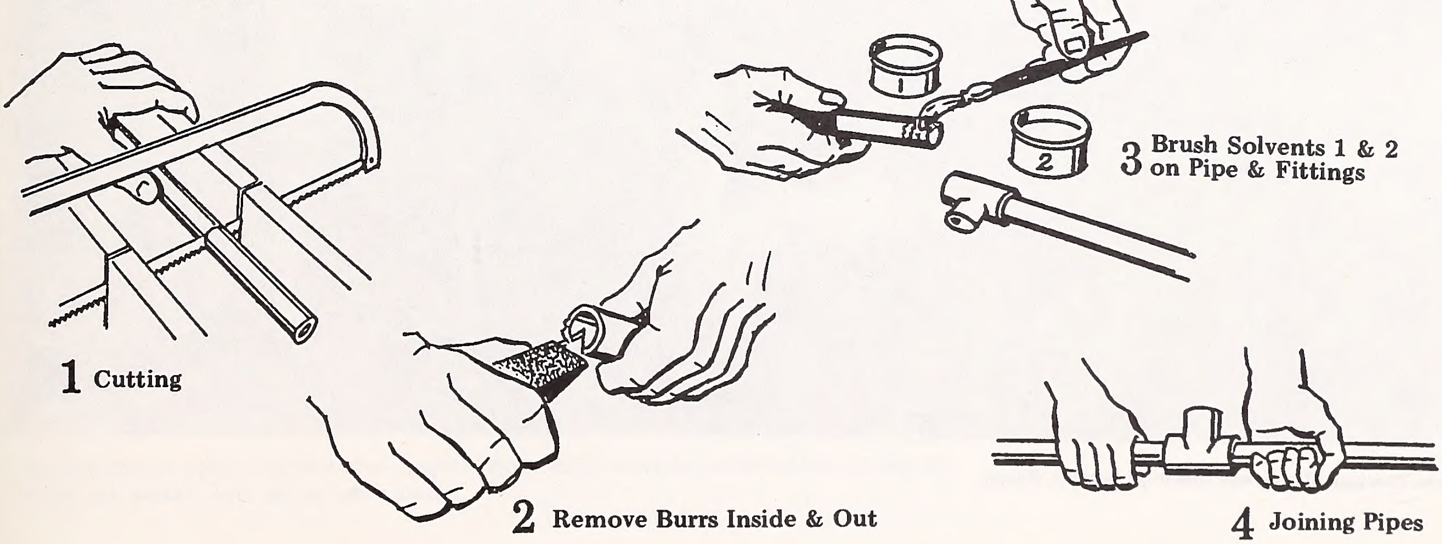


Photo courtesy of Montana Historical Society, Helena

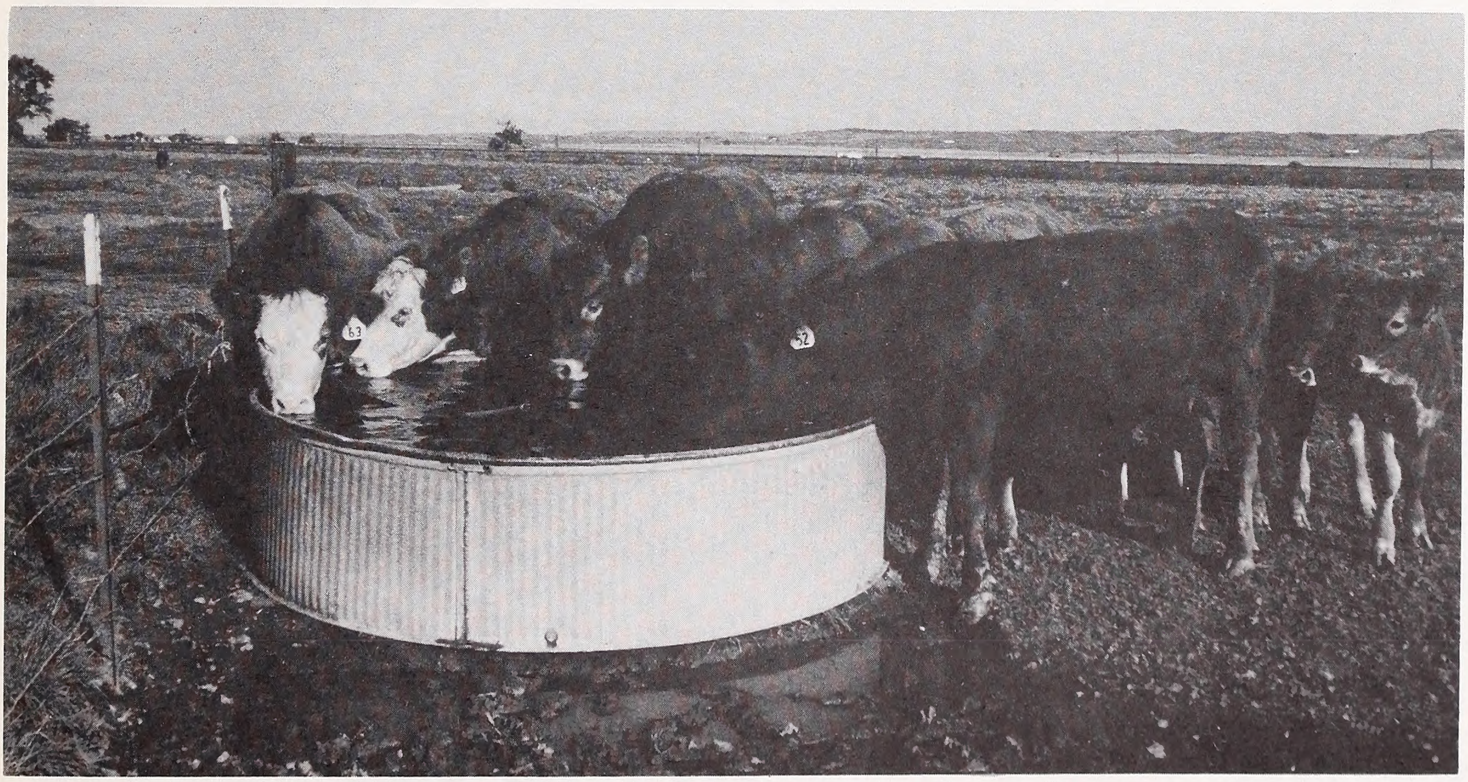
Determining Water Flow

Necessary water flow rates are determined by the number of livestock to be watered and the estimated daily consumption per animal. This provides the total water needed for consumption each day. Other factors must also be included to arrive at total water requirements. Evaporation, wildlife use, and peak demand times all affect water requirements. Water stored in open tanks, reservoirs, or ponds evaporates at rates determined by air temperature, relative humidity, and water temperature. The water lost to evaporation must be replaced. Water consumed by wildlife must also be replaced to ensure an adequate supply for livestock needs.

Animals tend to drink at certain times of the day. A large number of animals will generally drink at the same time, while at other times of the day, no animals will be drinking. This causes an uneven requirement for water throughout the day. The water flow rates must provide adequate water at peak times.

When determining water flow rates, consider not only total water requirements but also the timing of water needs. Where the two-hour production of a well exceeds the daily demands on a system, storage tanks are seldom needed. If the two-hour production is less than daily needs, storage tanks are necessary to hold the water pumped throughout the day. Currently pumped water is supplemented by stored water to meet the two-hour peak demand on the system.

The friction loss in the system depends on the type of pipe, the length of the pipeline, the type and number of connectors in the pipeline, and the type and number of fixtures (valves, faucets, tees or wyes) in the pipeline. Using the friction loss tables, determine the pressure that is needed to deliver the water. The necessary pressure must be sufficient to meet the pressure needs at the storage or watering site where the water will be delivered and make up for the pressure losses in the pipeline system. As a rule of thumb, the pressure at the storage or watering site should not be less than 15 psi. Use friction loss tables provided by pipe manufacturers to determine the pressure rating of the pipe used.



Animal water consumption and evaporation rates must be determined to supply adequate water flow to an open tank.

Photo courtesy University of Montana Mansfield Library, MIssoula, MT

Designing A Pipeline System

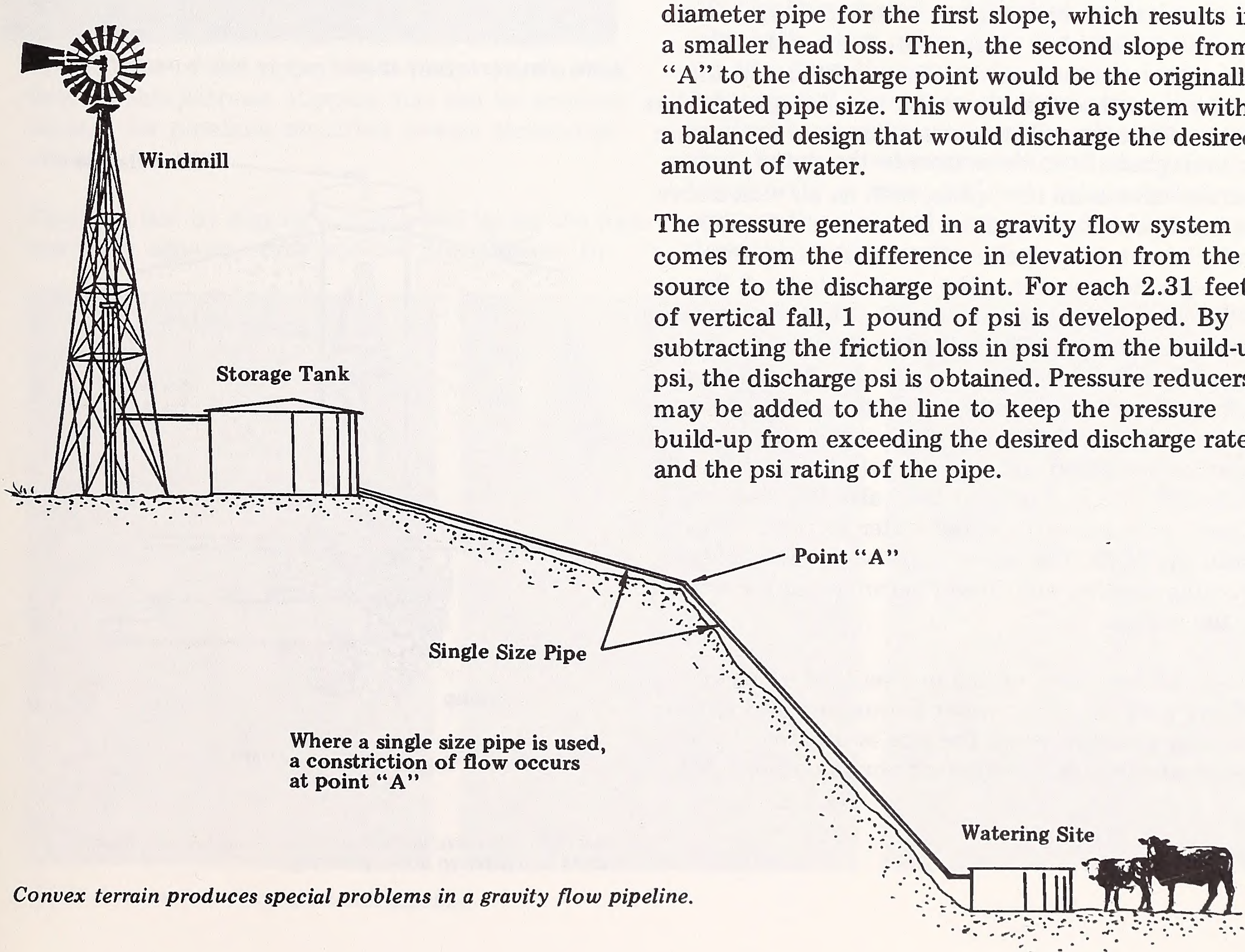
The pipelines delivering the volume of water should be sized appropriately to provide adequate water in the appropriate period of time.

If a water source is developed on high ground and piped to the watering areas by gravity, a pumping system can be avoided. To determine the needs for a gravity system, a ground profile survey is required. Surveys range from highly controlled field surveys to loosely controlled photogrammetric surveys. The topography of the land will determine the type of survey needed. For example, a long route with small changes in elevation or many topographic changes requires a sophisticated survey using a transit. If the route has a generally concave aspect, a more loosely controlled photogrammetric survey is sufficient.

Convex terrain produces special problems in a gravity flow pipeline. Where a single size pipe is used, a constriction of flow would occur at point "A" in the illustration below, because the hydraulic head is greater in the lower portion of the line, where the slope is steeper. Therefore, the water will flow faster in the lower portion of the pipeline than in the upper portion and create a vacuum that draws air into the pipeline. This creates a siphon. Since the pipe is above the hydraulic grade line, air bubbles will collect and the pipe will not discharge its full capacity.

To change this situation, the pipeline must be relocated by equalizing the slope of the upper and lower portions or by changing the available head at "A". Changing the available head at "A" can be done most economically by installing a large diameter pipe for the first slope, which results in a smaller head loss. Then, the second slope from "A" to the discharge point would be the originally indicated pipe size. This would give a system with a balanced design that would discharge the desired amount of water.

The pressure generated in a gravity flow system comes from the difference in elevation from the source to the discharge point. For each 2.31 feet of vertical fall, 1 pound of psi is developed. By subtracting the friction loss in psi from the build-up psi, the discharge psi is obtained. Pressure reducers may be added to the line to keep the pressure build-up from exceeding the desired discharge rate and the psi rating of the pipe.



Convex terrain produces special problems in a gravity flow pipeline.

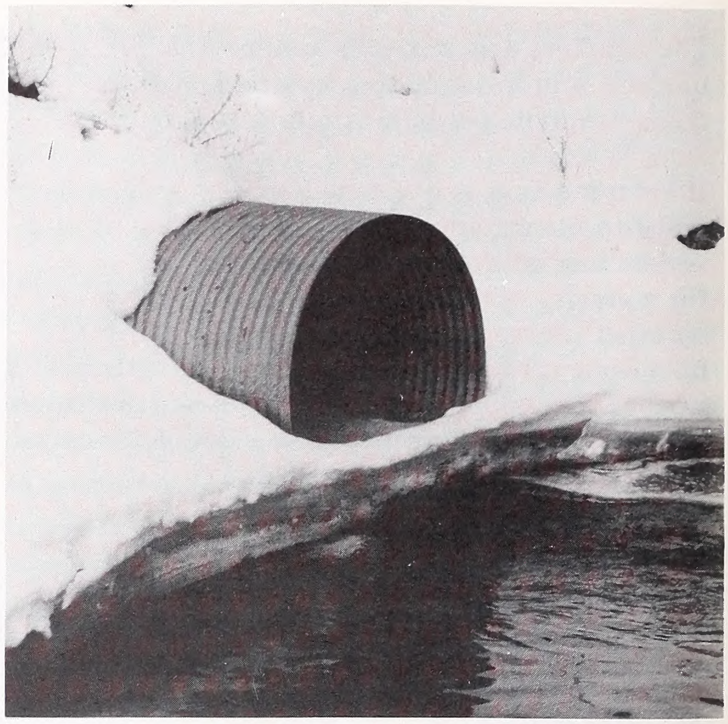
Freezing

All water pipes can be damaged by freezing. Frost penetration depths vary throughout the country.

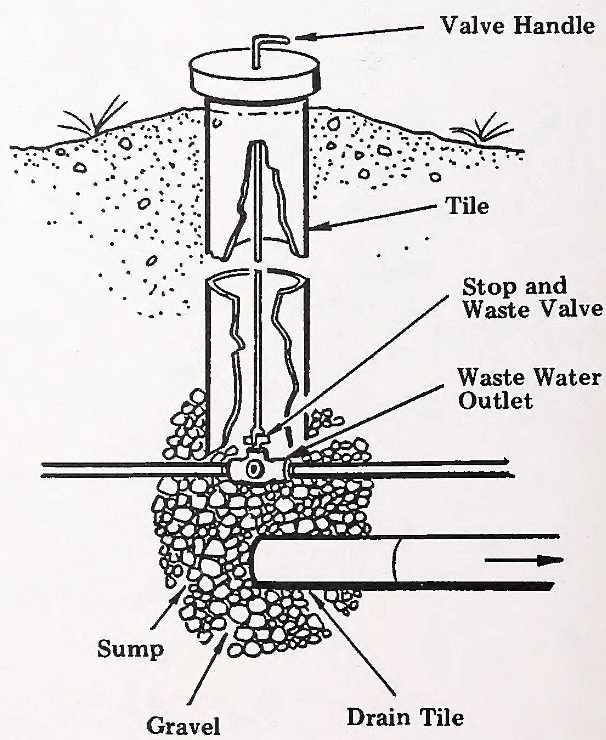
To insure adequate protection from freezing, check with local water dealers, the county extension office, neighbors, or others in the area who would know how deep to bury water pipe. Frost penetration depths depend on surface-cover, soil moisture, temperature, and duration of below-freezing temperatures. Penetration depths will vary from year-to-year. Bury the pipe deep enough to withstand maximum frost penetration, not average frost penetration. In some circumstances the cost of burying pipe this deep is greater than the cost of replacing or adequately draining the pipe every year.

Water pipes not used where freezing occurs need not be buried below the predicted frost level. However, they must be provided with drains and air vents to insure complete water drainage. Compressed air can blow all the water out of the lines. The water source must be disconnected and the outlet opened so that the water remaining in the line will be forced out. If the water line does not run on an even grade from the source to the outlet, locate a drain valve at all low spots, with an air vent above each valve. Air vents allow air to enter the lines and prevent the pipeline from collapsing from atmospheric pressure as the water is drained. Pipes with larger inside diameters are less likely to collapse than smaller pipes. The following illustration shows a useful method for opening valves in buried pipe. A valve handle is inserted through a tube of tile down to the buried pipe. The waste valve in the pipeline is located and opened with the valve handle. Note that the soil around the valve has been replaced with gravel to allow water to drain away from the valve. The valves must be opened before freezing weather and closed before pumping water in the spring.

There are no valves on the market that let air out of the pipeline when water is pumped and relieve vacuum pressure when the line is drained. Valves are available that do either one or the other.

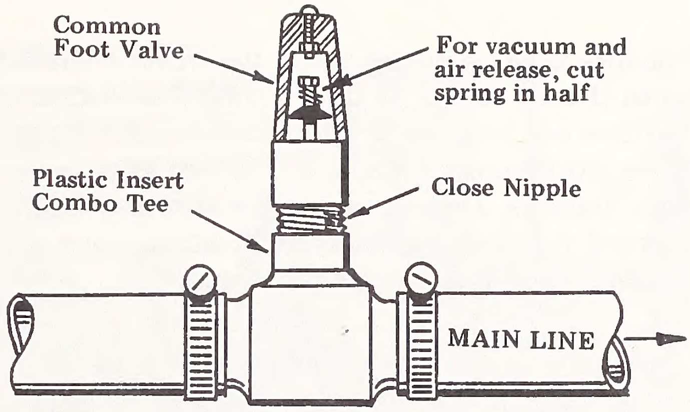


Cold climates require special care to insure water flow.



A stop-and-waste cock is used to drain unused pipe lines in winter to avoid freezing.

Steven Johnson on the Humboldt National Forest in Nevada found that installing a simple foot valve between a "tee" and stand pipe and removing one-half of the spring that normally held the valve closed allowed the valve to remain partially open. This permitted air to escape when water was turned into the system. When water arrives at the valve at approximately 3 psi, the valve closes and forces water on through the system. When the system is drained, the valve opens to allow air back into the line.



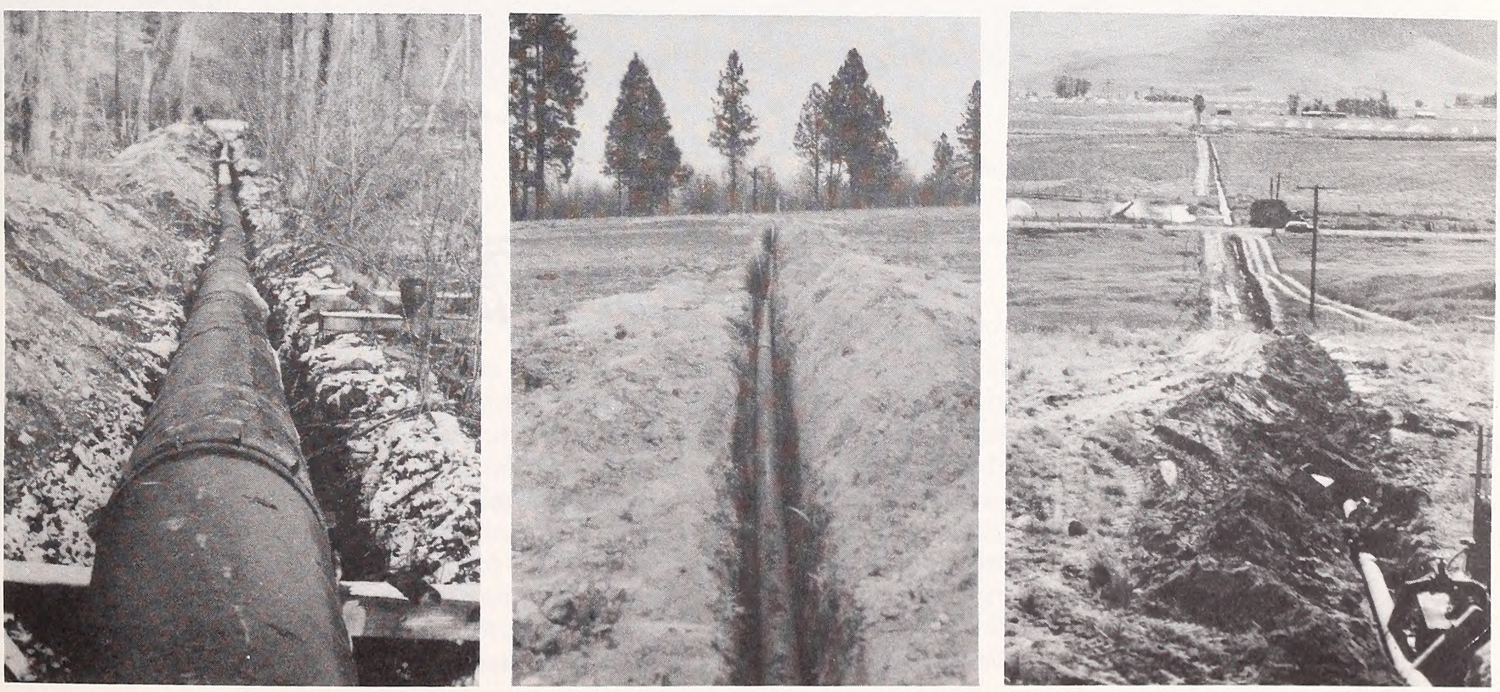
Using a modified foot valve to allow air in and out when filling and draining water lines.

Laying Pipe

Laying pipe can be accomplished with specialized equipment ripping the pipe into the ground or by digging the pipeline ditch and manually laying the pipe. Ripping pipe into the ground is limited by several conditions. Only flexible pipe, such as PE plastic pipe, can be laid in this way. Rocky soils may not be suitable for ripping. The pipe must be joined by a method that will feed through the feeder tube of the ripper. Butt-fusion joints work best for this purpose. Ripping may not be accurate enough for pipelines requiring precise elevational changes.

Pipelines laid by digging a trench and laying the pipe manually require some special precautions. In rocky ground, at least 4 inches of backfill material should surround the pipe to prevent puncturing the pipe. In any type of soil, avoid dropping rocks on the pipe.

All pipelines should be checked for leaks. Fill the pipe with water, allow time for settling and contraction from the cool water, then check for leaks. Pipes should have water in them when the trench is filled to prevent crushing the pipe. Plastic pipe should not be covered when temperatures are below 50°F or above 95°F. At relatively low temperatures the pipe will contract and at high temperatures the pipe expands.



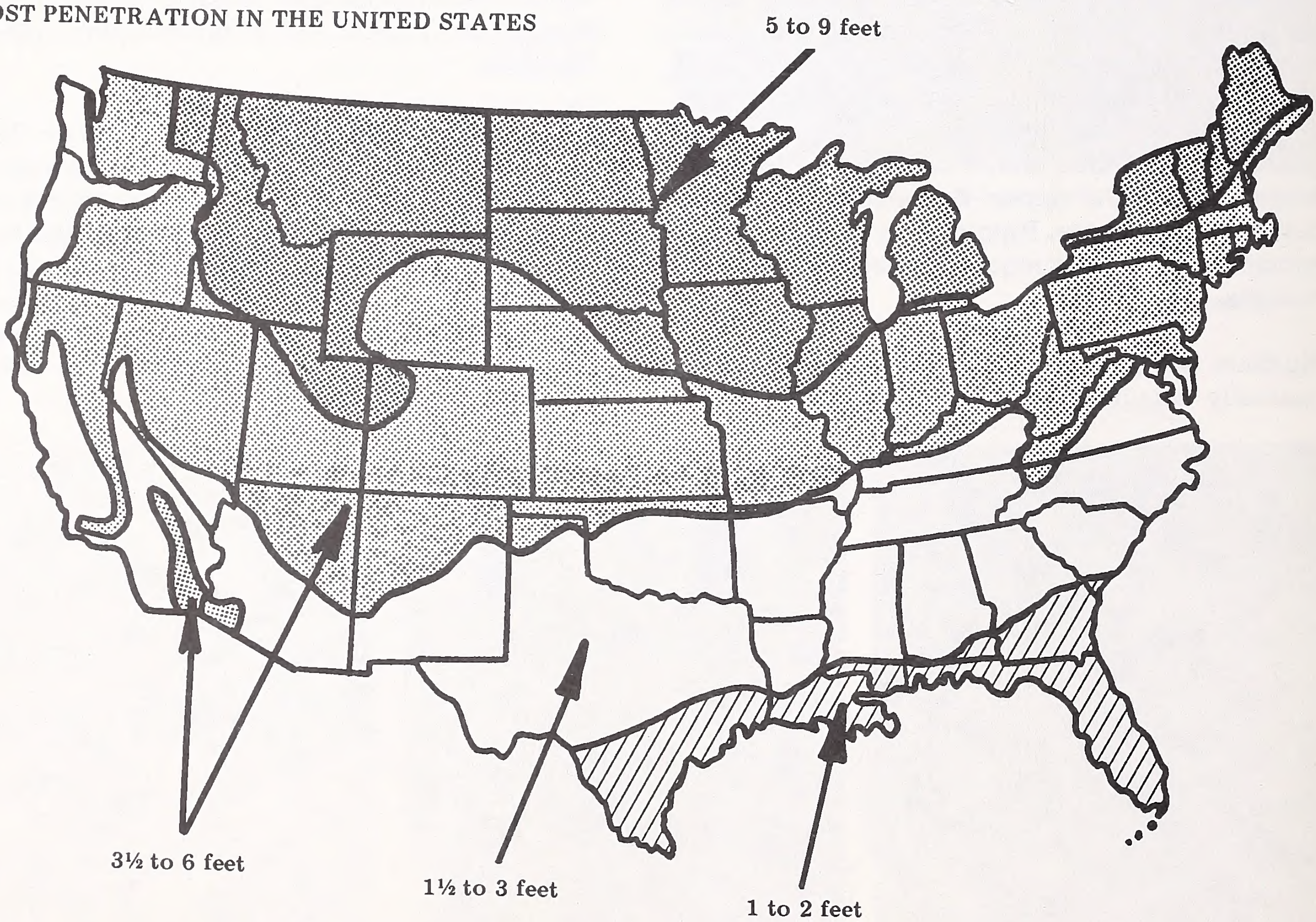
Typical examples of laying a water pipeline.

Pipelines must be buried below the frost-penetration depth if they are to be used during the winter. Pipelines not being used year-round and not buried below frostline need drains and air vents for complete drainage. Do not ignore the cost and time required for draining the systems when doing a complete cost analysis of a pipeline.

Installing pipelines disturbs the surface of the pipeline site. Disturbed areas should be reseeded. Be sure the plant species seeded are desired on the site. When pipelines are laid by hand, workers can sometimes seed as they cover the pipeline. Getting workers to grab handfuls of seed from desirable plants along the pipeline is an efficient, relatively inexpensive method of seeding. If erosion is a potential problem, as is usually the case with disturbances that proceed downslope, use measures to mitigate the problem. Water bars, reseeding, or ripping the surface along the slope after the pipe has been laid can all help reduce erosion.

Livestock tend to use pipelines as trails. Barricades of brush, trees, or small fence sections often reduce this problem.

FROST PENETRATION IN THE UNITED STATES



Depth of frost penetration in the United States.

Storing Water

Photo courtesy of Montana Historical Society, Helena

Water collecting and transporting are often done on a continuous basis. The dams hold runoff; windmills and pumps draw water when the conditions are favorable. The time that the livestock or wildlife need the water is not considered when the collection occurs. Usually the water collected must be stored until the livestock or wildlife need to drink. Without water storage, the effectiveness of rangeland water development would be much less dramatic.

Water storage, as discussed in this section, includes both facilities where livestock and wildlife have access to the water and storage facilities where the water is held before delivery to facilities where they can drink. In some cases, the only difference between the two is whether or not the animals are physically prevented from getting to the storage facility. A few types of storage facilities are built so that access to the water is impossible until it is transported to watering troughs.

Storage Facilities

Storage facilities are structures that hold water until it is released to drinking facilities. Storage facilities range from ponds and reservoirs to metal storage tanks to large balloon-like rubber bags. They are protected from livestock by fencing or by burying the facilities. Storage facilities may be covered by a roof or some floating material to reduce loss from evaporation, and protect against contamination. Some storage facilities are covered with roofs that slope toward the center of the tank. A hole at the center of the roof allows water to drain into the tank.

A water storage tank with a well-anchored roof (to minimize evaporation).

Most storage tanks are metal with metal or concrete bottoms. Corrugated sheets or metal plates make up the sides of the tanks. Tanks with metal bottoms are placed on a sand or gravel base. These tanks should not be placed on a concrete foundation, because water condensing between the tank bottom and the concrete may rust out the bottom of the tank.

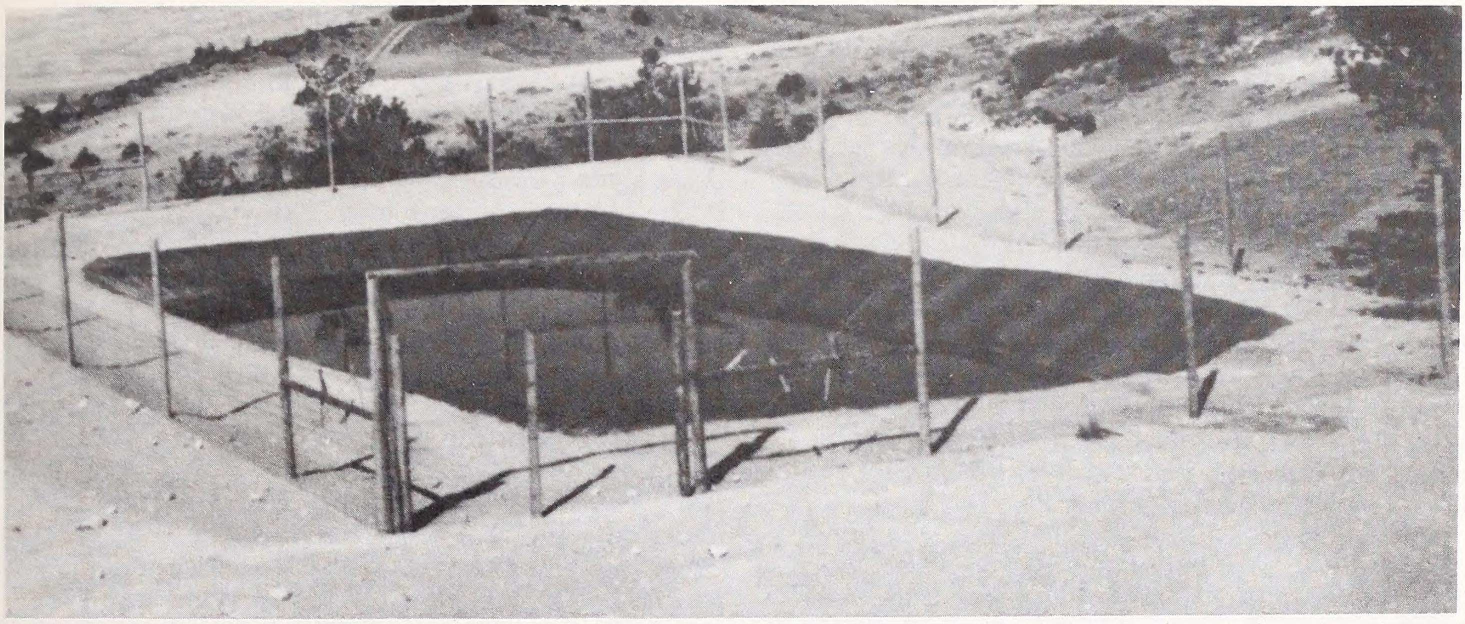
Metal tanks with metal bottoms are heavy and bulky. They make low maintenance, long-lasting storage facilities that are familiar to most range users. The tanks are occasional victims of vandalism by people shooting holes in the sides of the tanks. All metal tanks can be moved from site to site if necessary. Since they are often heavy and bulky, moving them can be a difficult task. This is complicated by the fact that many storage facilities are located in relatively rugged terrain.

Metal tanks with concrete bottoms are more permanent structures with higher costs of initial construction than all-metal tanks. They are very long-lasting, although they are also subject to vandalism. They are not movable once they have been built, so cannot be used for relatively temporary or short-term storage.

Concrete tanks have walls and bottoms of poured concrete. These tanks are low-maintenance, rarely susceptible to vandalism, and extremely long-lived when properly installed. However, they are quite expensive to build and often cannot be justified on economic grounds.

A typical concrete tank.

Butyl rubber tanks are collapsible rubber bags. The bags are often used with tarps or other ground covers to gather the water that is then funneled into the bag. The ground cover is made of impervious material and prevents any infiltration of precipitation that falls onto the cover. The precipitation runs downhill to an inlet tube in the rubber tank. The water collects in the tank until the water is needed for animal use.



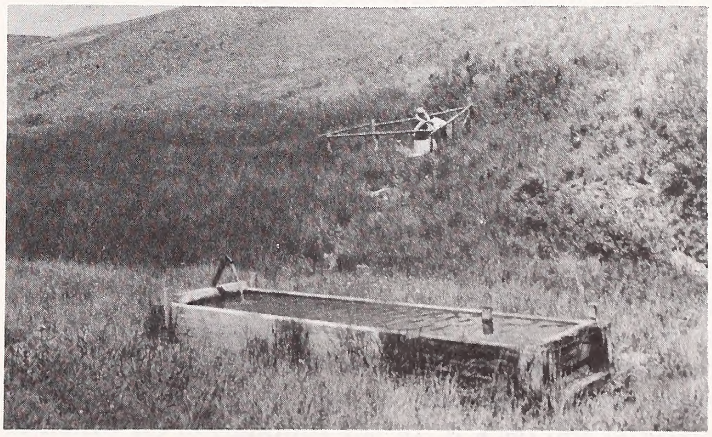
A butyl rubber reservoir.

The rubber bags are available commercially in sizes up to 100,000 gallons. The water collected, since it is completely covered, is not susceptible to evaporation. The bags are easy to transport; they can be used to hold water collected by any means (not just by ground covers), and they can be moved from site to site with some ease. They are relatively expensive, can be easily damaged by vandals. Their capacity is reduced if snow or water stands on the bag, and they require timely maintenance if they are damaged. Vandalism and other damage can be minimized by locating rubber bags in trenches.

Reservoirs and ponds qualify as storage facilities if they are fenced off to prevent use by livestock. They are inexpensive since no work beyond that of developing the reservoir is required. Properly constructed reservoirs have a long and predictable life-span. Disadvantages are the initial cost of fencing and the cost of maintaining the fencing. Another major disadvantage is evaporation from the surface of the reservoir.

Site Selection

Selecting storage sites involves a number of factors. The site must restrict access for livestock; it must be stable enough to bear the weight of the water being stored, and it must be located close to the water source. The stored water generally flows into drinking troughs placed at appropriate spots across the rangeland being grazed. For convenience and economy the storage site should be located where the water can flow down to the drinking sites.



A storage tank placed in a convenient site for livestock.

Construction and Installation

Storage tanks hold water for future use by livestock and wildlife. They must be large enough to hold all the water needed by the expected numbers of animals, plus additional amounts for evaporation and seepage. When building or installing the tanks, be sure that they can hold the necessary amount of water. The construction or installation must consider the source of the water. Water generated by runoff or snowmelt will collect very rapidly for a relatively short period of time. The tanks must be able to accept large amounts of water quickly. Water generated by springs or wells generally accumulates more gradually over a long period. Tanks for these sources have a more predictable pattern of collecting water and do not need to be able to accept water as quickly.

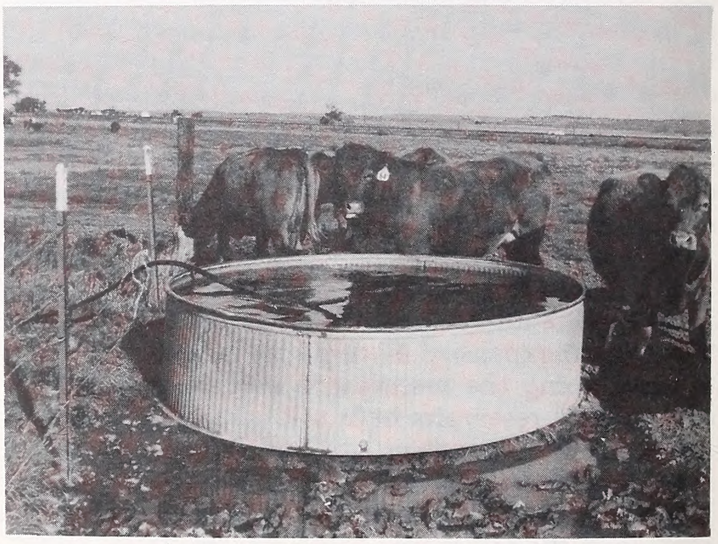
A lowcost storage tank collecting snowmelt.

Constructing and installing storage tanks requires adequate knowledge of the stability of the site, knowledge of the future uses of the rangelands being served, and experience dealing with the type of tank. The site's stability affects the amount of work needed to install a tank. Sites with a solid, stable foundation of rock or soil can support large tanks with little ground preparation. On less favorable sites, the installer must either dig to a firm bed for the tank or haul in appropriate fill material and pack it for the foundation on which to put the tank.

The uses for the rangeland being served also affect the construction and installation of storage tanks. Rangelands being used mainly in the spring and early summer often have less need for storage tanks with protection from evaporation. If the water being stored is collected in the spring and used late in the summer the tank may need to be covered to reduce evaporation. If the stored water is needed for wildlife the construction or installation may need to include specialized structures to meet the requirements of the target wildlife species. For example, specially designed ladders allow small animals to descend to the water level without getting trapped or falling into the water.

Range managers should seek the assistance of experienced water system builders when constructing or installing storage tanks. These experienced people can recognize problems early on and can provide solutions based on their prior work.

Methods of preventing animals from getting to the storage tanks are needed in areas where the storage tanks are not also used as watering tanks. This generally means building fences around the storage tanks. Keeping wildlife out often requires special types of fencing.



A solid, stable foundation prevents mudholes.

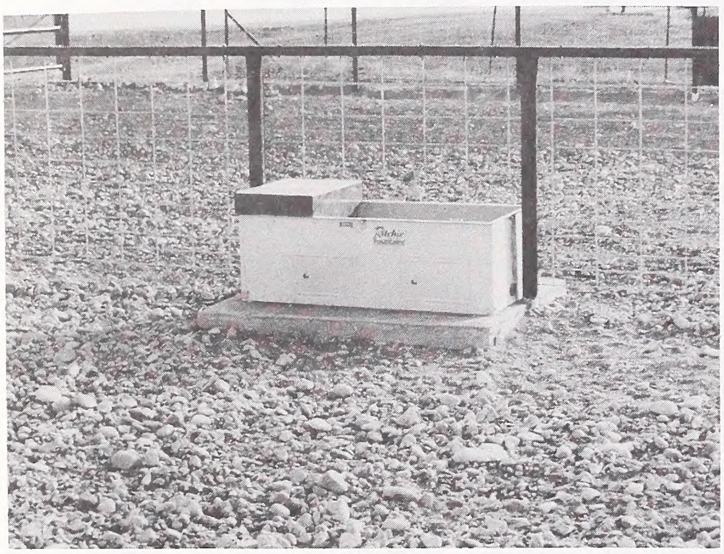
Providing Access to Water

Photo courtesy of Montana Historical Society, Helena

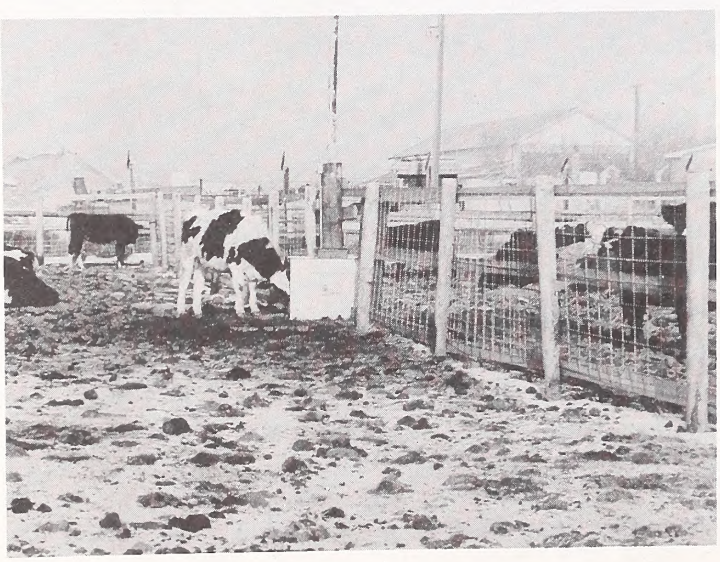
The final part of any water system is the facility for providing animals access for drinking. Protecting both the animal and the drinking facility are difficulties that must be overcome. Large animals such as cattle and deer can become trapped in mud or can injure themselves climbing up or down a steep embankment. Small animals and birds can fall into the water and drown. Trampling around drinking troughs promotes erosion; intense grazing along pond shores destroys shoreline vegetation, and trapped animals contaminate the water. All these can be minimized by proper design of the water system and by systematic maintenance of the drinking facilities.

Drinking Troughs

Drinking troughs are water-holding tanks that allow livestock and wildlife to drink from them. Troughs are usually made of galvanized steel, wood, or heavy rubber. Galvanized steel tanks are similar to metal storage tanks. They are heavy, bulky, long-lived, dependable, and readily available. Installing steel tanks requires access to the site by vehicles capable of carrying the tanks.



Galvanized steel drinking trough.

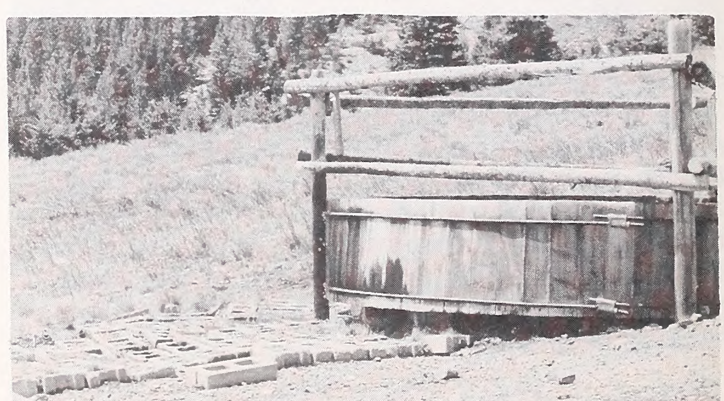


Drinking trough in use.

Wooden tanks are often used in areas where access is limited or where the aesthetics of the site would be enhanced. Redwood planks placed vertically side-by-side to form the exterior wall of the tank are held together by a metal band or cable wrapped around the outside of the circle. As water enters the tank the planks swell, forming a water-tight tank wall. The metal band or cable keeps the planks from being pushed out of the circular shape. The planks remain swollen as long as water is in the tank. When the tank empties, the planks dry and shrink. Wooden troughs can be placed in relatively remote sites, since they can be carried to the site in pieces. Assembling the tanks requires several people, but is not a difficult task. Since the planks shrink as they dry, some may occasionally fall out of place during the dry season. An additional problem is that the metal band may slip when the planks shrink. Therefore, normal maintenance requires inspecting the tanks prior to starting water into the tanks. If durable, weather-resistant woods such as redwood are used, the tanks have a relatively long life.

Heavy rubber troughs are used like metal troughs. They are more resistent to some types of damage, are long-lived, and are often lighter than metal troughs. Some rubber troughs are constructed from large tires. These are generally used for small animals and birds or in relatively isolated areas of a rangeland. They are too small to hold sufficient water for large numbers of livestock.

A round galvanized steel drinking trough.



A redwood drinking trough.

Ponds and Reservoirs

Photo courtesy University of Montana Mansfield Library, Missoula, MT

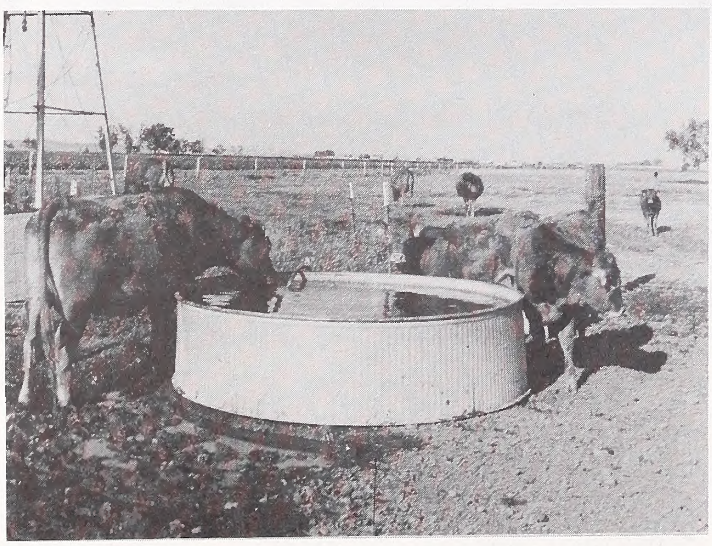
Many ponds and reservoirs are not only used for collecting and storing water but also provide access so livestock can drink. Since large animals, especially livestock that go to and from water in herds, can damage the shoreline it is advisable to restrict the watering areas. By fencing off portions of the shoreline, those portions are protected from the damage caused by trampling and grazing. Critical parts of ponds and reservoirs, especially earthfill dams, spillways, and inlet/outlet streams may need the extra protection provided by fencing. Fencing is an expensive initial task and requires occasional maintenance, therefore the benefits of protecting the shoreline must be weighed against the fencing costs. When water levels are quite low, some ponds become dangerous for livestock. The animals walk out into deep mud trying to get to the water and then get stuck in the mud. At times of low water levels, livestock managers need to be aware of the conditions of the ponds to prevent livestock losses.

Locating Drinking Facilities

Some factors to consider when locating drinking troughs include the location of the water source, the type of animal using the troughs, and the characteristics of the range in mind. Troughs should be in well-drained areas with easy access for the animals. Rocky and sandy areas often provide the necessary solid foundation and rapid infiltration desired around a watering tank. Locating tanks in clayey or loamy soils may result in water-logged soils around the tank. Livestock going to and from the tank destroy the soil structure and leave the area susceptible to severe erosion. Proper tank site selection is vital to preserve the soils and vegetation around the tank. Livestock use of the area around tanks will always be very high; by choosing a stable site the damage caused by the intense use can be minimized.

Whenever possible, locate drinking troughs below storage facilities to reduce the need for power sources to carry the water between storage and drinking facilities. Range conditions often affect the choice of trough sites. Water troughs placed widely apart encourage livestock to disperse their use of the range. If the troughs can be moved at various times the control over use of the range increases. The same effect can be achieved by having a large system of troughs and cutting off the flow to some at various times.

Locating the troughs must also consider the type of animals using the water. Different species, breeds, sexes, and ages of livestock all range differently. Knowledge of the type of animal and how that animal behaves on the topography of the watering site is vital for designing an effective system. Some animals also react differently in different environments; therefore it is important to discuss animal behavior with someone experienced in the geographical area.



A poor location for a water trough results in water-logged soils.

A portable water trough.

Inlet Controls

Watering troughs receive water from storage tanks or directly from water sources. The troughs have a limited capacity so the amounts in the tank must be controlled by limiting the amount sent to the tank or by removing the excess water.

Where the water coming into the tank is coming from a storage facility, inlet controls regulate the amount carried to the drinking trough. The most efficient and effective method of controlling the flow is by using a valve that starts flow when the water level decreases below a certain point and stops the flow when the water level rises above a certain point. Placing these valves away from the trough reduces the damage from livestock and vandalism. As evaporation and drinking lower the water level in the trough the float valve sinks with the water level. When the float reaches a critical level it opens the valve and allows more water to enter the trough. When the water level rises, carrying the float with it, the valve is closed.

The use of float valves with storage tanks separate from drinking troughs makes efficient use of the often limited water resources on rangelands. Water, from whatever source, is kept until needed in covered, protected storage facilities. The drinking tank holds only the amount of water allowed by the float valve. Livestock or other animals drink enough water to open the valve, and only then is water taken from the storage facility. Evaporation is minimized; runoff is eliminated, and any contamination of the water is done only on the amount held in the watering tank.

Inlet pipes for watering troughs must be adequately protected. The most desirable situation is to bury the pipe and have it come into the tank in the middle of the tank. The mouth of the inlet pipe should be lower than the mouth of the overflow pipe, but it need not be at the bottom of the trough. Many tanks have dried out because the inlet pipe was not well protected and animals have knocked the pipe out of the tank. This leads to a destructive stream of water flowing across the ground surface.

Outlet Controls

All watering troughs should have outlet controls. Even those whose inlet amounts are controlled should have overflow pipes in case the inlet controls malfunction. Water overflowing a trough often creates a mudhole and weakens the foundation of the trough.

Outlet controls are generally overflow pipes that carry excess water to an appropriate place. The overflow pipe must be at least as big as the inlet pipe. It must take the excess water far enough away from the trough that the animals using the trough will not trample through the excess. It should lead to a place where the drainage is good so it will not create a mudhole.

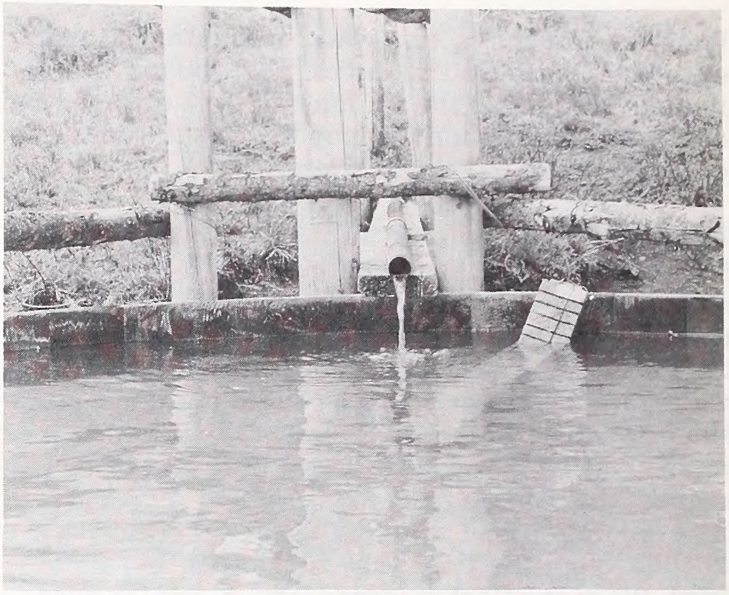
Wildlife Designs

Drinking troughs are often used by various types of wildlife. Larger animals, such as deer, elk, and pronghorn, seldom have problems with troughs built to serve the needs of livestock. Smaller animals and birds, however, need specialized devices to make the troughs safe for their use.

Escape ramps for birds and small animals make any uncovered water tank safer for use by these wildlife. A good escape ramp extends from the top lip of the tank to the bottom of the tank, along one edge of the tank. The ramp must be on the edge of the tank because small animals that fall into the water often swim along the tank edge looking for a way out. Ramps that extend from the lip to the center of the tank may not be found by swimming animals. The escape ramp may be made of any material that is rough enough to provide footing for the animals. Some common materials are wood, cement with small pieces of reinforced steel rods sticking out, and tight mesh woven wire.

Some range users put wooden covers that provide safe perches for birds and animals on the water surface. The wooden cover is built small enough to allow about two feet of open area around the edge of the trough. An opening is cut in the cover to go around the overflow pipe, so that when the water level goes down, the cover will not hang up on the pipe. The cover provides a place for birds, and occasionally small animals, to stand while they are drinking. The wooden cover does not replace an escape ramp; small animals may still need a way out of the trough.

In addition to methods for getting out of a tank, small animals may need a way to get access to the tank. A pile of rocks, a small ramp like the escape ramp, or a fence post leaning against the tank could all provide access. Be sure that any access technique is safe from destruction by livestock or large wildlife. Often placing the access structure inside a fenced-off portion of the tank eliminates damage by livestock.



Example of an escape ramp for small animals.

Posts leaning against a drinking trough provide access for small animals.

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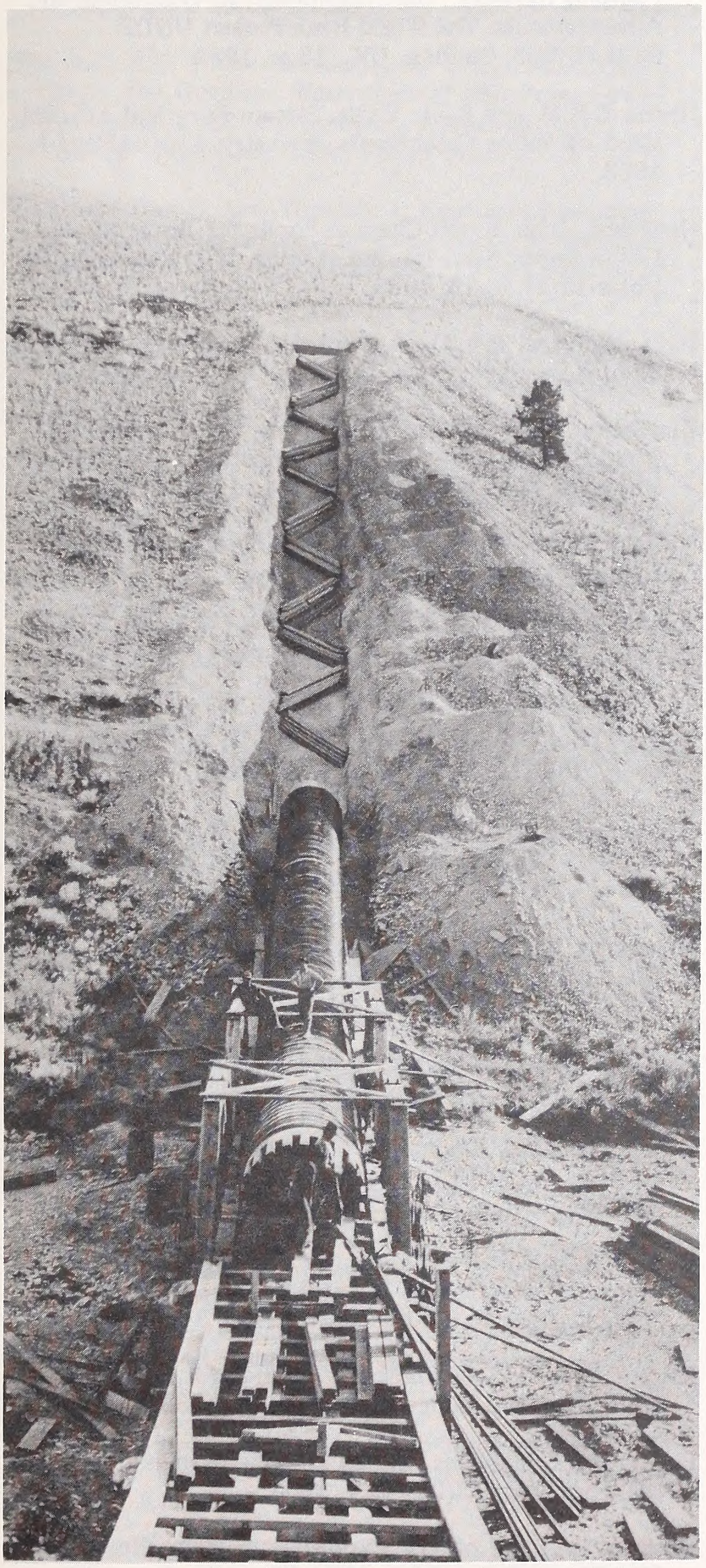

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Index

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2400—Range
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