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Rural Water Systems Planning and Engineering Guide

Commission on Rural Water Washington, D.C. 1973

Design: James True
Layout: Babs Clark McBride
Typesetting: Service Composition
Helvetica Light and Medium
Paper: Finch, Pruyn, and Company
Printed by Universal

Library of Congress Catalog
Card Number 73-77739
Printed in USA

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Foreword

The successful development of a rural water supply system requires continuous communication between local project directors and their engineering consultants. However, project directors and their staffs are often unfamiliar with details of system design, local and state regulations, and other technical aspects of water project development. This book has been written to meet the need for this information in the field and to enable project directors and their engineering consultants to work together more effectively to provide economically feasible and hygienically acceptable water supply systems for rural people. It should prove helpful both to engineering consultants in designing an adequate water supply system in a specific location and to project directors in evaluating these designs and relating them to overall project needs.

Since rural water systems are often funded in whole or in part by government agencies, it is important that government officials—federal, state, and local—have an understanding of some of the technical problems of water system development. This book is also intended as an information source for these officials, particularly health authorities.

Water systems in rural areas share, in principle, the general features of large urban systems. However, rural systems must fit the needs of the rural populations served. Often these populations are small, scattered over large areas, and low in income. Chapter One looks at the overall problem of rural water system planning and development, giving particular attention to the concept of the cluster-well system as a primary alternative to the traditional central system which, with its one water source and treatment facility,may not be feasible in many rural areas.

The water source for rural areas will usually be underground aquifers rather than surface sources. Sites for relatively deep wells must therefore be located and wells constructed using the best available technology (which is not necessarily the most expensive). Pumping and storage facilities can be smaller than those in urban areas because they will handle less volume. Distribution lines, when served by multiple wells, need not be as extensive as in the urban-type central system and will therefore be less costly. Treatment facilities, while usually necessary to some degree, need not be as complex as those in metropolitan areas because ground water usually requires less treatment than surface sources. Chapters Two through Five examine the essentials of water system development: well-site selection and well construction, requirements for pumping facilities, water treatment, and storage and distribution systems.

Cost estimates must consider both the users' low-income budgets and the initial quality of the system's construction. A compromise must be made between the original construction costs and the potential longevity of the system, in terms of operation and maintenance. Chapter Six presents cost analyses and comparisons for obtaining a water supply from both ground water and surface water sources and for the treatment necessary for each. Local conditions will determine whether the use of surface water or ground water is the more economically advantageous.

The final chapter provides general guidelines necessary for adequate well and water system maintenance, giving special attention to trouble shooting commonly used jet and submersible pump systems.

The authors wish to thank Stanley Zimmerman, Executive Director, National Demonstration Water Project, for his cooperation, aid, and understanding during the preparation of this book. They are also grateful to the following people for their valuable assistance during the writing of the manuscript: Judith A. Segal, U.S. Office of Economic Opportunity, Washington, D.C.; Edwin L. Hockman and William Long, U.S. Environmental Protection Agency, Washington, D.C.; Gene Mattern, U.S. Public Health Service, Washington, D.C.; Thomas P. Ahrens, U.S. Bureau of Reclamation, Denver; William H. Walker, Illinois State Water Survey, Urbana; John M. Heckard, Dames & Moore, Cincinnati; Truman W. Bennett, Pentron Industries, Inc., Columbus, Ohio; Joseph H. Van-Deventer and the staff of Demonstration Water Project, Inc., Roanoke, Virginia; Thomas C. Barnwell, Jr., Hyland L. Davis and the staff of Beaufort-Jasper Comprehensive Health Services, Inc., South Carolina; Roscoe Thornbury and the staff of Guyandotte Water and Sewer Development Association, Logan, West Virginia; Melvin L. Palmer, Department of Agricultural Engineering, Ohio State University, Columbus, Ohio; Steven N. Goldstein, System Sciences, Inc., Bethesda, Maryland; Maryon W. Ruckelman, David J. Smith, Lesley J. Powell, and Susan Hacker of the NWWA Research Facility and the remainder of its support staff. The authors wish to make a special mention of gratitude to Shirley True for her editorial work on this book and to James True for his contributions as both the designer and production manager.

The Commission on Rural Water has available a comprehensive library on well-construction technology and other materials on rural water and waste disposal systems development. Contact the Information Clearinghouse, National Demonstration Water Project, 221 North LaSalle Street, Suite 2026, Chicago, Illinois 60601 (area code 312/346-1862).

Michael D. Campbell
Jay H. Lehr
January, 1973
Columbus, Ohio

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Hydraulic Conversion Factors*

1 sec.-ft. = 7.48 gal. per second.
449 gal. per minute.
646,317 gal. per day.
60 cu. ft. per minute.
86,400 cu. ft. per day.
0.9917 acre-in. per hour.
1.98347 acre-ft. per day.
40 miner's inches in California.[1]
1 ft. of head = 0.43 lb. per square inch.
1 lb. per square inch = 2.309 ft. of head.

Conversion of Units of Volume

U.S. gallons to cubic feet: 1 gal. = 0.1337 cu. ft.
Cubic feet to gallons: 1 cu. ft. = 7.481 gal.
Millions of gallons to acre-feet: 1 million gallons = 3.07 acre-ft.
Acre-feet to millions U.S. gallons: 1 acre-ft. = 0.326 million gallons.
Millions U.S. gallons per day to second-feet: 1 million gallons per day = 1.547 sec.-ft.
Second-feet to millions U.S. gallons per day: 1 sec.-ft. = 0.646 million U.S. gallons per day.

Weight

Maximum density of water is at 39.3°F. At this temperature 1 cu. ft. of water weighs 62.4 lb., 1 gal. weighs 8⅓ lb.

Area

1 acre = 43,560 sq. ft.

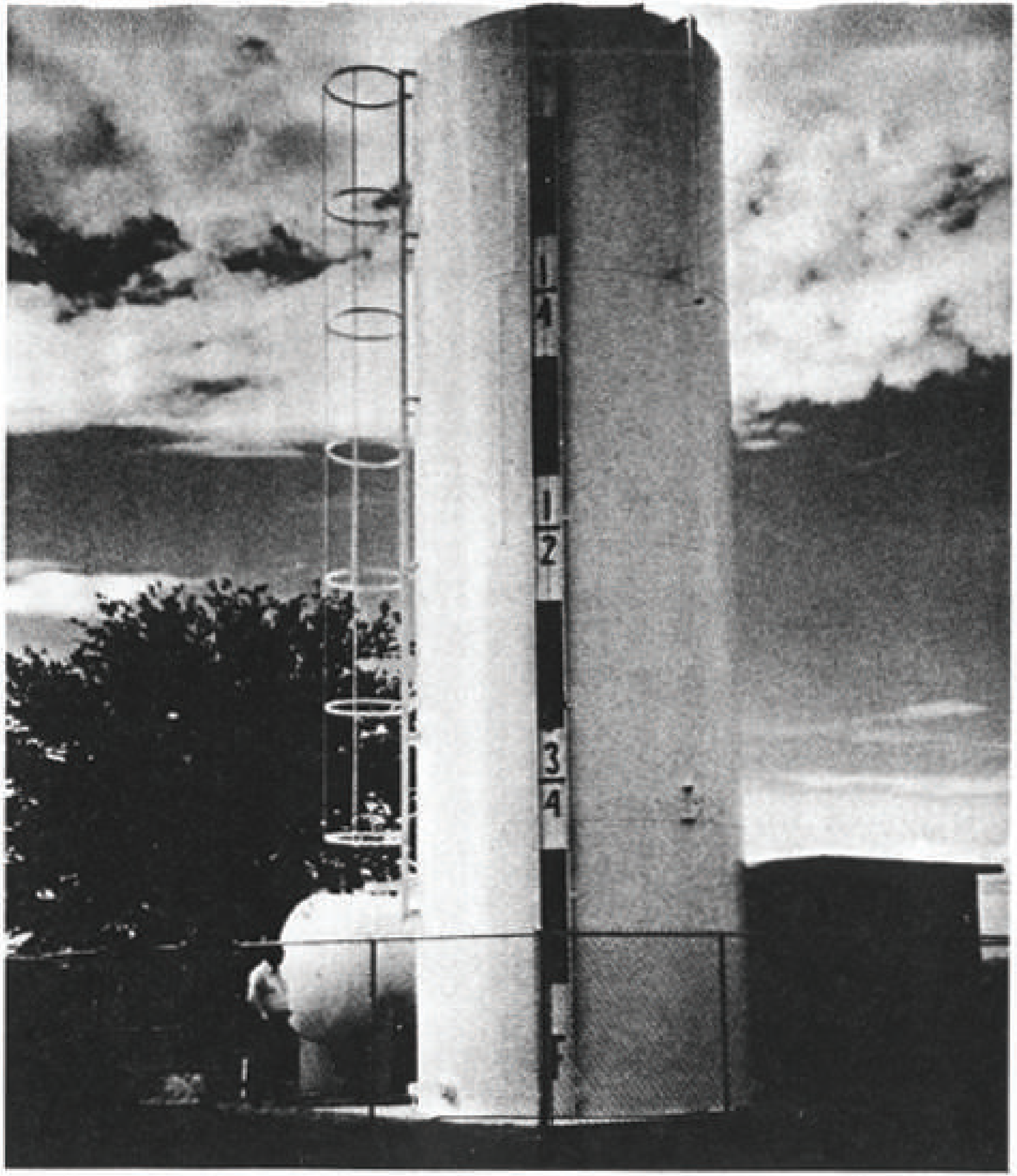
Approximate Equivalents

1 sec.-ft. (per day) = ⅔ million gallons = 2 acre-ft.
1 million gallons = 1½ sec.-ft. per day = 3 acre-ft.
1 acre-ft. = ½ sec.-ft. per day = ⅓ million gallons.
450 gal. per minute = approximately 1 sec.-ft. (1 sec.-ft. = 449 gal. per minute).
1 cu. ft. per second at 1 ft. head = approximately 0.1 horsepower (0.113).
1 lb. per square inch pressure = 2.3 ft. of head.

$$\text{horsepower} = \frac{\text{g.p.m.} \times \text{head in feet}}{4500}$$

[1] One California miner's inch has been defined as 1/40 sec.-ft. by law, or 11.2 gal. per minute. In southern California it is locally interpreted as 1/50 sec.-ft., or 9 gal. per minute.

[*For additional information on conversion factors and other engineering guidelines, see 24.]



1/4
1/2
3/4

Water System Planning and Development

The average American uses fifty to seventy-five gallons of water each day in purely household pursuits. He drinks it directly from the tap or uses it as a basic ingredient in other beverages such as tea or coffee. He uses it to wash his body, much of his clothing, his dishes, his car, and even his dog. Many of his foods are cooked in water. He uses water to scrub his floors and sometimes his furniture. He gives it to thirsty pets, sprinkles it on potted plants, and sprays it on dry lawns. He may even swim in water if he has a backyard pool.* Life is not possible without some water, and it is not very pleasant without a great deal of it.

Sources of Water

Americans are fortunate in that a plentiful supply of water is available in most parts of the country. It falls to the earth as precipitation — rain or snow. Some of it collects on the earth's surface to form lakes, rivers, and other *surface water*. The rest seeps downward through the earth until it accumulates in porous material at a subsurface level and becomes *ground water*. This ground water is not static but moves slowly through subsurface strata, some of it reappearing as surface water at lowland points: a swamp, the bed of a stream, the edge of a lake, a spring.

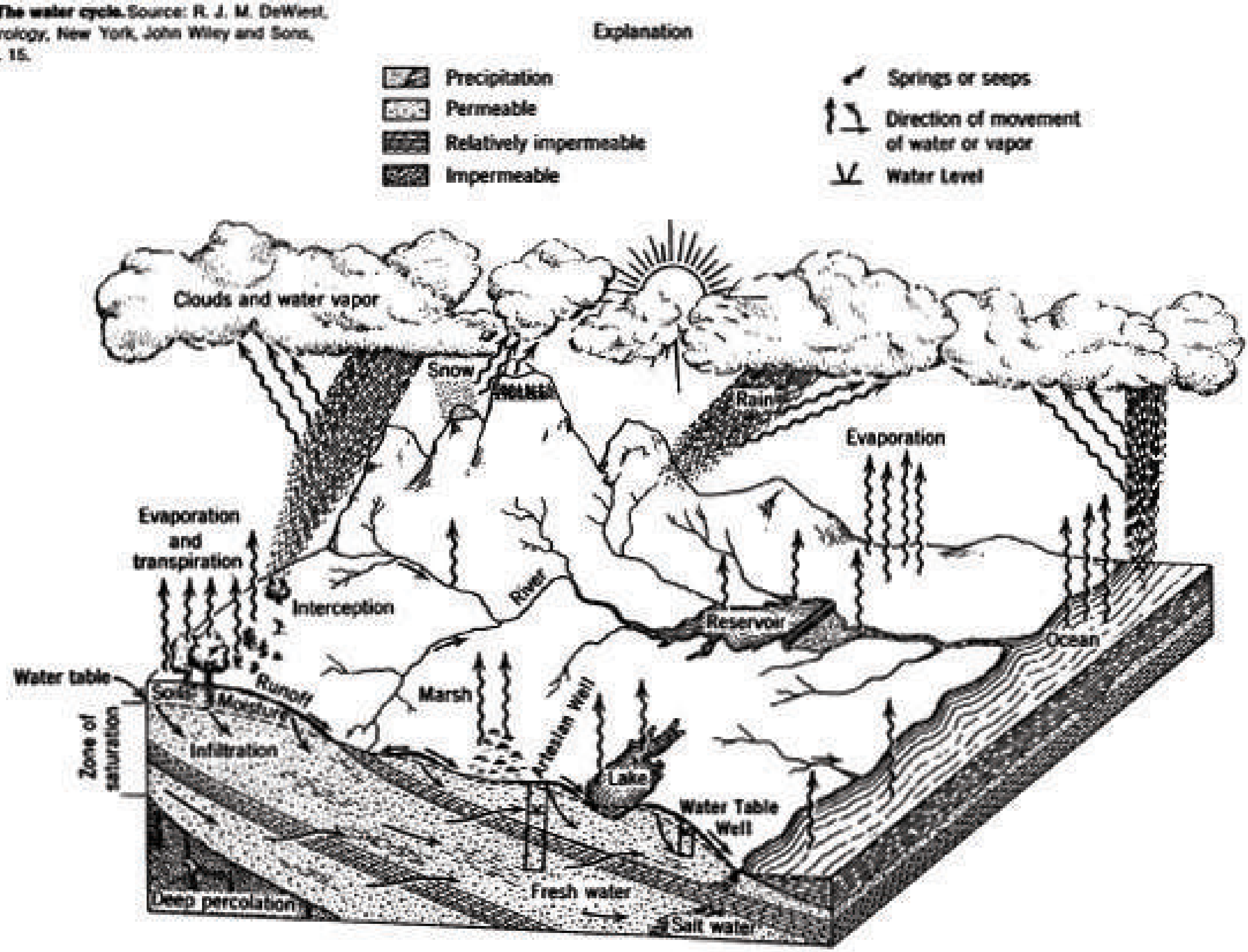
The water supply is constantly being replenished via *the water cycle*. Some surface water evaporates directly to the atmosphere and some returns by way of growing plants which transpire water vapor. These actions produce the clouds from which rain and snow fall. Water is thus constantly changing from moisture in the air to rainfall, to surface water, to ground water, back to surface water, and ultimately back to atmospheric moisture. (See Figure 1.)

Ground water is found in water-bearing formations known as aquifers. There are three basic types: (1) unconsolidated deposits of sand, gravel and clay; (2) consolidated de-

*Water is also used for flush toilets in houses that have indoor plumbing, so that the problems of water supply and wastewater disposal are intimately related. On wastewater systems, see Steven N. Goldstein and Walter J. Moberg, Jr., *Wastewater Treatment Systems for Rural Communities*, Washington, D.C., Commission on Rural Water, 1973.

posits of sand, gravel and clay (sandstone, conglomerate, and shale, for example); and (3) "hard rock" formations of granite and other crystalline materials (basalt, limestone, dolomite, and marble, for example). In both consolidated and unconsolidated sand and gravel formations, the space between individual particles is filled with water, while in "hard rock" formations, water is located in interconnected joints, cracks, or solution channels. The *water table* is a more-or-less continuous surface below which the rocks are saturated with water. Depending on the area, water table depth can vary from a few feet to hundreds of feet. It tends to follow the contours of the land, sloping downward from hilly areas to low points. Any device for tapping ground water must thus penetrate below the water table.

Fig. 1. The water cycle. Source: R. J. M. DeWiest, Geohydrology, New York, John Wiley and Sons, 1965, p. 15.



Water Supply and Water Facilities

Although surface water and ground water combined provide an ample general supply of water, specific supplies for household use will not usually be adequate without proper water facilities.* The term "adequate," when applied to water supply, means more than simply a *quantity* of water sufficient to meet the household needs mentioned earlier; the *quality* of the water is also important. It should be *pure*, i.e., free from bacterial or mineral contamination which make it unsafe or unpleasant to drink. In addition, the water supply should be convenient — located in close enough proximity to the user that he can take full advantage of it without great hardship and expense.

While there is general agreement that minimum standards for adequacy in a water supply are that it be ample and pure, there is more controversy about convenience.There are no standards regarding how much trouble a household should be asked to endure in order to secure water, or how much it may fairly be asked to pay. Of course, convenience and health are interrelated because an inconvenient water supply is likely to be utilized less, thus leading to health problems. At the very least, a convenient water supply would seem to be one located on the household site, if not actually piped into the house.

Today, standards of adequacy in a water supply cannot often be met without water facilities. The term facility implies a man-made device for tapping a water source and/or purifying the water (a well, a reservoir, a treatment plant). In pioneer days, such facilities were often unnecessary — a family could dip its water directly from a nearby stream or spring. Today neither surface nor ground water can be so readily or safely secured. Not everyone lives near surface water, and ground water does not usually rise to the surface naturally. An ample and convenient supply for all is not available without human intervention.

Even if available in quantity, the quality of nearly all surface and ground water is highly suspect following years of dumping raw or poorly treated sewage as well as countless other contaminants into streams and underground. Purification of nearly all surface water and to some extent ground water is necessary. Adequate water facilities have become a prerequisite for an adequate water supply.

Water facilities in use in the United States may be classified in a number of ways:

1. ***By number of households served.*** Water supplies may be individual (serving one household) or community (serving several households at least and usually a substantial number). The terms public and sometimes municipal are also often used as nearly synonymous with community. Roughly 75 per cent of the American people are served by community water facilities. Nearly all the individual water plants and many of the community facilities are found in rural areas.

*Rainwater can be trapped directly and used as a water source, of course, but this is only done to a minor degree in the United States. Also, "saline water," surface or ground water mixed with salt, is a possible future water source, but technology has not yet been able to convert it for use.

Well Construction

Well-Site Selection

The proper selection of the well site is based on the ground water aquifer to be developed, depth to the water-bearing formation, and the lithologic character of the formations to be penerated in order to reach the water-bearing formation. Other factors which must be considered include: freedom from flooding; the relation to existing or potential sources of contamination; and, in many cases where aquifers are extensive, convenience. The best supply of water available in the area which will meet the quantitative and qualitative needs of the system should be developed. However, under some circumstances, a supply of lower, though acceptable quality may be utilized because it is less expensive to treat.

County and state health departments should be contacted for local regulations concerning well location and minimum state and local water quality standards should be met. Minimum horizontal protection distances between the well and common sources of pollution should not be less than those specified by the respective state health department or equivalent. Table 6 is an example of typical minimum distances. These protective mini-

Table 6. Minimum Distances Between Well and Sources of Pollution.* (feet)

Source of Pollution	Driven Well	Drilled Well
Property Line	50	20
Improperly Abandoned Well or Sink Hole	—	200
Seepage Pit	400	200
Disposal Field or Bed	400	200
Industrial Lagoon	—	†
Water-tight Sewer Lines	50	10
Other Sewer Lines	100	50

Courtesy CRW

*Distances specified should be increased, if necessary, to meet the minimum requirements of the state and county health authorities.

†Minimum safe distance from a waste pond should be specified according to nature of the waste, geological surface and subsurface conditions, and the recommendations of the state and local health authorities.

Well Pump Systems

There are many types, kinds, and sizes of pumps available for water systems today. Some pumps are designed only to remove water from a source. Some are designed to remove the water and force it through the rest of the water system. Others are designed to do only special jobs such as boosting pressure or supplying a special outlet.

The variety of pumps available is a great benefit to those planning a water system. However, pumps must be selected carefully so that the correct pump is chosen for the specific water-system application. [For additional general information on pumps, their operation, and maintenance, see 66.]

Kinds of Pumps

A shallow-well pump is one that can draw water from a maximum depth of about twenty-two feet. It depends on atmospheric pressure to force water into the vacuum that the pump develops within the suction pipe. Shallow-well pumps are also used to pump water from tanks and other storages. (See Figure 25.)

A deep-well pump is used to obtain water from any depth, depending on pump design. These pumps lift or push the water up by using pistons, impellers, or jets. (See also Figure 25.)

A positive-displacement pump is one that delivers water at a pulsating rate regardless of the pressure or distance it must overcome. It may be either of shallow-well or deep-well design.

Pump Selection and Sizing

The selection of a pump should be based on the following general factors: [61]

(1) Quality of the water—Iron and iron bacteria cause more problems and expense with submersible pumps than other types. Sand and sediment are abrasive and will damage pumps; select a relatively resistant pump. Methane gas causes vapor lock and requires special pump features.

Water-Treatment Facilities

The objective of any water-treatment facility is to provide water of bacteriological, chemical, and physical quality which is both palatable and acceptable to the consumer and to state and local health authorities. All water from natural sources contains impurities. Some of these impurities adversely affect the usefulness and suitability of water, while others may improve its palatability.

Because pure water is such a good solvent, it picks up impurities easily. Most impurities are picked up naturally, but some are added either accidentally or intentionally by man. Water may be cleansed or polluted as it flows over, or filters through, soil or other subsurface material; it may pick up or lose bacteria; it may dissolve or lose chemicals, minerals, and sediment.

The belief that flowing or soil-filtered water has purified itself is false, and leads to unjustified conclusions about water safety. Clear water is not necessarily safe water.

To determine whether or not a specific water system is acceptable for its intended uses:

(1) Determine the quality needed for each use;

(2) Test the water for bacteriological quality;

(3) Analyze for chemical quality; and

(4) Treat the water if needed. If periodic contamination is suspected, a schedule of sampling should be maintained.

Some of the procedures, processes, and equipment that may be used to do these tasks are described herein. [For further information on water treatment, see 55, 61, and 67 to 70.]

Pumping, Storage and Distribution Systems

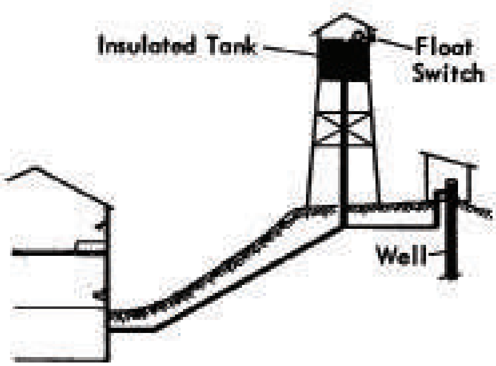
The overall objective of pumping and storage facilities is to provide a sufficient and continuous supply of water at adequate pressure that will satisfy all domestic and related needs under all conditions of demand. To meet this objective, the design of the pumping and storage facilities must be properly integrated to obtain effective service with the most economical design from the standpoint of initial and future investment and operating costs. Pumping can be provided in various ways, such as lowlift and highlift pumping stations, booster stations, or combinations thereof. Storage can be provided by elevated tanks, ground-storage tanks, pressure tanks, or combinations thereof. [55]

Pump-House Facilities

Location of Stations and Tanks

Pumping stations and tanks should be located on level sites except where hillside installations can be proven to be advantageous. If the location is on filled ground or a hillside, special precautions should be taken to assure adequate structural stability. A report, to the extent applicable, should be submitted providing assurance that suitable, well-compacted fill material is provided and that the underlying original soil is adequate to support the weight of the fill, plus the weight of the structure without damaging settlement. For hillside construction, the footings should be supported on original soil and a berm of at least ten feet should be provided from the bottom of the footing to the edge of the slope.

Elevated storage tank.



The site should be free from flooding or excessive surface-wash conditions. Establishment of elevations of structures with respect to flood levels is specified under the applicable headings herein. Adequate grading around the structures should be provided to divert and otherwise control surface water. Ditches of adequate capacity to divert and carry off storm-water runoff should be provided for facilities on a hillside.

Design of Pump House and Arrangement of Equipment

Design of the pump house should be that which will assure maintenance of the sanitary quality of the water passing through the station, and which will facilitate a sanitary and

Cost Analyses and Cost Comparisons

Surface Water Reservoir and Transmission Line Cost Analysis

A cost analysis follows as a guide for comparing the initial cost of a surface water supply with the cost of well installations. All cost data should be adjusted for additional inflationary increases since the study was completed. The data should also be modified according to variations in local costs.

Cost of Reservoirs

Use of this material will give an estimate of total project cost for a reservoir project in the range of storage capacity from 100 to 100,000 acre-feet. This is intended only as an instrument for establishing orders of magnitude as a basis for comparisons, and will not take the place of the detailed estimates prepared by engineers for a specific site. [6]

The study was based on cost data collected from consulting engineers, private and municipal water utilities, and state and federal agencies for reservoirs constructed in Illinois since 1946. All cost figures were brought to the 1964 cost level by means of the Handy-Whitman index. [14]

Project cost, as used here, is the sum of construction cost, engineering and legal services, contingencies, and land cost. The term construction cost includes land clearing, dam and spillway construction, and relocations. Engineering and legal services have been added as a fixed percentage, 15 per cent of construction cost. Contingencies were added as 10 per cent of the construction cost. The amount of land required for a project was determined to be 50 per cent greater than the actual normal pool surface area derived from a relationship of lake surface area versus storage capacity. The reservoir project cost is estimated by the following equation: [6]

$$P_c = C_1 C + C_2 L_a k$$

Where: P_c = Total project cost in dollars

$C_1 = 1.25$, a combined constant accounting for engineering and legal services (15 per cent of C) plus contingencies (10 per cent of C)

Water System Maintenance

Well and Pump Maintenance

Well and pump maintenance is of vital importance to the longevity of the water system. The following is a brief survey of the salient factors of well and water system maintenance.*

Pumping Records

After a well has been drilled and permanent pumping equipment installed, it becomes an integral part of a planned water system. The operator or maintenance personnel of the water supply system utilizing wells and pumps should fully acquaint themselves with the structural details of the well or wells, casing sizes, types of screen, screen elevations and other pertinent data, and particularly with the record of the pumping test prior to the acceptance of the installation from the well contractor. [24]

This record should include static water level, gallons per minute pumped and pumping levels. A complete pump record indicating the type of pump installed, sizes and dimensions of component parts, amount or lengths of pump column, air line lengths, and a performance curve of the pump bowl unit should be made available to the operator or maintenance personnel. After such data are obtained from the well contractor or the pump installer, the completed well and pump installation can be put into service.

These data are highly important, as they provide a basis for comparison with the daily pumping records. A marked discrepancy between the original test data and current pumping records would indicate problems. This discrepancy may become progressively worse if a diagnosis of the condition is not made and corrective measures taken immediately. Water company personnel should have a comprehensive knowledge of the basic operation of the water system. An awareness of the early signs of malfunction will allow water company personnel to record data of interest to the well contractor or consulting engineer responsible for the maintenance of the water system.

*Comprehensive coverage of this topic is planned by the CRW for future publication.

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(Numbers in Italics refer to pages on which Figure or Table appears.)