Introduction
to
WATER RESOURCES
AND
DOMESTIC WATER SUPPLY
IN OKLAHOMA

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INTRODUCTION

Purpose of Manual

The purpose of this manual is to provide information on the occurrence, characteristics, and utilization of the various water resources available in Oklahoma. It is designed especially for those individuals who live in suburban and rural areas who do not have access to municipal water-supply systems. The information is general, but it should provide enough data for the reader to obtain sufficient knowledge of water quality, treatment, and construction of a supply source to at least discuss problem situations with individuals who might actually install a system.

Hydrologic Cycle

Water on the earth's surface can occur as a liquid, a solid, or as vapor. It is convenient to think of the occurrence and movement of water in terms of a "Hydrologic Cycle", which is a continuous process without beginning or end (Fetter, 1980). Water from the oceans and land masses evaporates to form clouds, which leads to precipitation. On the land the precipitation either flows into streams and lakes, infiltrates into the ground, or evaporates. Water in streams eventually flows into lakes or the oceans to be evaporated again. Some of the water that infiltrates into the ground adds to the soil moisture content and permits plants to grow. Plants transpire and return some of this water to the atmosphere. Water that percolates deeper into the earth becomes ground water. Ground water provides part of the flow of streams and all of the water that discharges from springs. Ultimately this water also returns to the oceans (fig. 1).

Though two-thirds of the earth's surface are covered with water, fresh water accounts for less than 3 percent of the total volume. Because 75 percent of the total freshwater is locked in glacial ice, only a small percentage of the world's total water supply is available for use. Ninety-eight percent of this total occurs as ground water.

Water Use in Oklahoma

According to the Oklahoma Water Resources Board, the average quantity of water withdrawn each day in 1980 in Oklahoma by public water suppliers was 515 million gallons. Surface

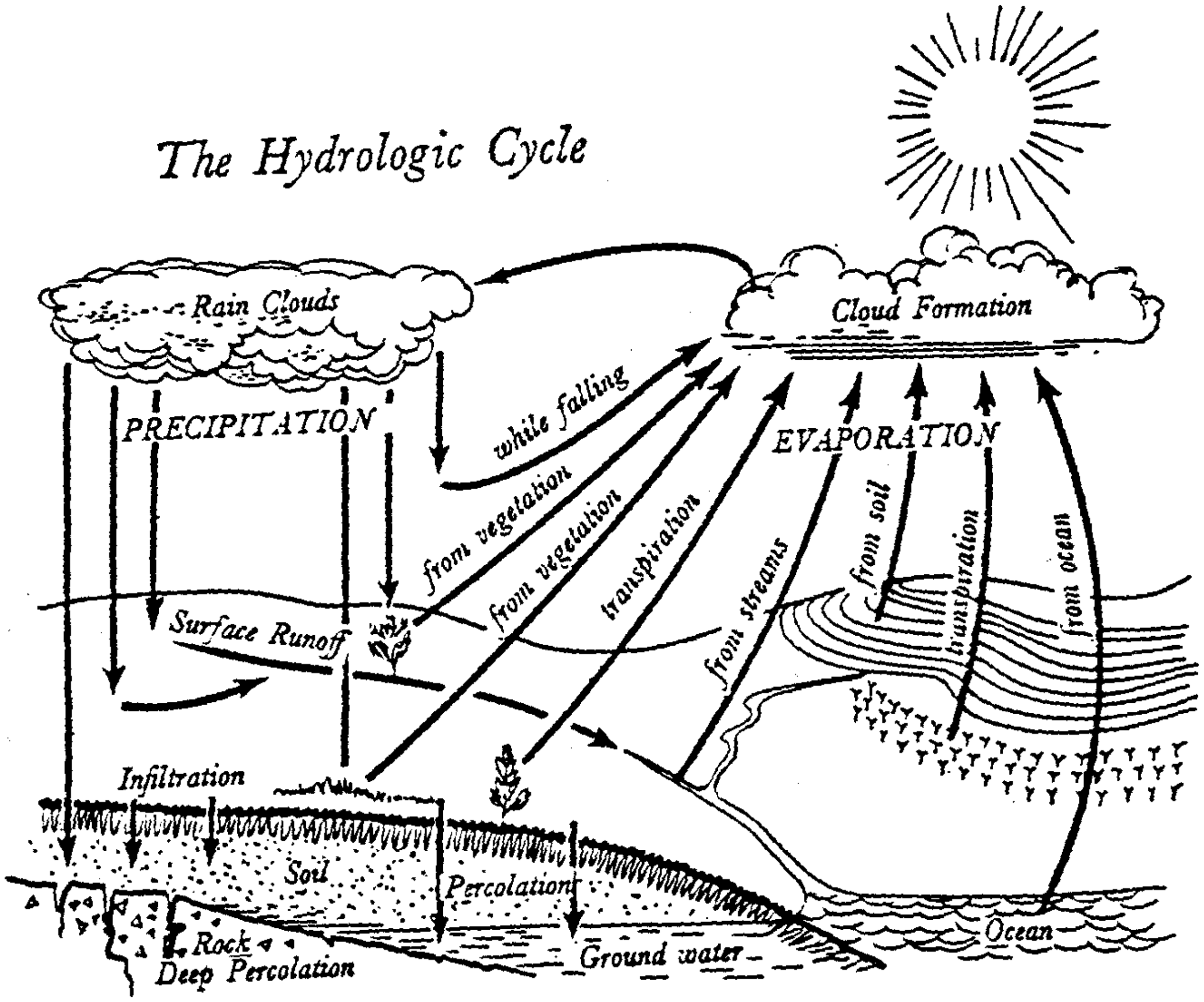

Figure 1. The hydrologic cycle, which is powered by the sun, keeps water in continuous motion.

water provided 78 percent of this total and ground water supplied the remaining 22 percent (O.W.R.B., 1980). These figures do not include the tremendous volume of ground water pumped for irrigation. If irrigation with both surface water (84 million gallons) and ground water (608 million gallons) is considered, then ground water accounts for 60 percent of the total water used in the State.

Rural Water Use

In 1963 the Oklahoma legislature passed a law allowing for the organization, formation and operation of public nonprofit rural water districts. The purpose of the "Rural Water Districts Act" was to develop and provide adequate rural water supply facilities to serve the needs of rural residents. The original act has been modified several times and is currently called the "Rural Water, Sewer, Gas and Solid Waste Management District Act". By 1979 there were almost 400 rural water systems in operation that served slightly more than a half million people (O.W.R.B., 1980). Most of these rural water systems are in eastern Oklahoma where there is abundant surface water. Despite this fact, approximately half the districts utilize ground water.

Water Supply Planning Considerations

Development of a domestic water supply system depends on the availability of a source of water. Where water is plentiful and easily accessible, planning considerations are minimal. In areas where water is either scarce or typically of poor quality, careful planning is essential to the successful development of a water supply (Gibb, 1973).

The first step in planning a water supply system is to determine water requirements. An adequate system should provide both enough water to meet daily needs throughout the year and at rates sufficient to satisfy peak daily demands.

Average rural water use in the United States is 66 gallons per day (gpd) per person. Additional water needs, as for livestock, must also be considered. The water requirement is the sum of the amounts of water required for all purposes. Peak water demand periods seldom occur at the same time and it is rarely necessary to equip a domestic well with a pump capable of producing more than 10 gallons per minute.

Once the water requirements have been determined, data on the available ground-water resources should be gathered. The Oklahoma Water Resources Board is the most logical and practical agency to first contact. They maintain copies of drillers logs of water wells completed and information on yield and water quality. These data from wells in the vicinity of a proposed site may provide a reasonable idea of the nature of a new water supply. In some instances, U.S. Geological Survey reports may provide additional information. Local well drillers, familiar with the ground-water conditions in the area, may be consulted to obtain information and estimates of the cost of completing a production well. Information from neighbors concerning their wells can also be beneficial.

CONSTITUENTS AND PROPERTIES OF WATER

Natural waters, including rainfall, always contain a certain amount of impurities. The impurities may be either chemical, biological, or physical.

Chemical Constituents

Chemical constituents can be divided into two broad groups;(1) inorganic and (2) organic. In general, organic constituents are differentiated from inorganic constituents by the presence of carbon. Based on their relative abundance in water, dissolved inorganic constituents may be classed as major, secondary, minor, or trace (Table 1).

Inorganic Chemical Constituents

The concentration of all of the dissolved mineral constituents in water is referred to as "dissolved solids" or "total dissolved solids" and is commonly expressed in terms of milligrams per liter (mg/L) or parts per million (ppm). Gases, colloids, and sediments are not included as dissolved solids. The concentration of dissolved solids in natural waters ranges from less than 10 mg/L in precipitation to more than several hundred thousand mg/L in brines (Lehr et al, 1980). The U.S. Geological Survey ranks saline waters on the basis of their relative concentration of dissolved solids (Table 2). The recommended limit for dissolved solids in drinking water, 500 mg/L, is based on taste criteria and not physiological effects. Some municipalities provide water with a dissolved solids concentration that exceeds 5000 mg/L where less mineralized waters are not available . It should be noted that a high concentration of certain individual ions may render a water supply unusable even though the dissolved solids concentration is low.

Major Ions

There are seven major dissolved ionic substances in water. The "Cations" or positively charged ions include calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K). The "Anions", negatively charged ions, consist of bicarbonate (HCO_3), chloride (Cl), and sulfate (SO_4). Generally, these seven constituents account for 95 percent or more of the dissolved solids in water.

<u>Hardness</u> Hardness is related to the precipitation of

TABLE 1

CLASSIFICATION OF DISSOLVED CHEMICAL CONSTITUENTS

Major (1-1000 mg/L)	Secondary (0.01-10 mg/L)	Minor (0.0001-0.1 mg/L)	Trace (< 0.001 mg/L)
Sodium	Iron	Antimony	Beryllium
Calcium	Strontium	Aluminum	Bismuth
Magnesium	Potassium	Arsenic	Cerium
Bicarbonate	Carbonate	Barium	Cesium
Sulfate	Nitrate	Bromide	Gallium
Chloride	Fluoride	Cadmium	Gold
	Boron	Chromium	Indium
		Cobalt	Lanthanum
		Copper	Niobium
		Germanium	Platinum
		Iodide	Radium
		Lead	Ruthenium
		Lithium	Scandium
		Manganese	Silver
		Molybdenum	Thallium
		Nickel	Thorium
		Phosphate	Tin
		Rubidium	Tungsten
		Selenium	Ytterbium
		Titanium	Yttrium
		Uranium	Zirconium
		Vanadium	
		Zinc	

Source: Todd (1980).

"lime scale" in pipes and boilers and the reaction with soap to form an insoluble "scum". Hardness is due primarily to the presence of calcium and magnesium in water. It is described in

the inexact terms of "hard" and "soft". The classification of water hardness is shown in Table 3. Hardness does not present a health hazard.

TABLE 2
CLASSIFICATION OF SALINE WATER

Classification	Dissolved Solids, in mg/L
Slightly saline	1000 - 3000
Moderately saline	3000 - 10,000
Very saline	10,000 - 35,000
Briny	More than 35,000

TABLE 3
CLASSIFICATION OF WATER HARDNESS

Concentration, mg/L	Description
0 - 60	soft
61 - 120	moderately hard
121 - 180	hard
more than 180	very hard

Source: Hem (1970).

<u>Sodium and Potassium</u> Water analyses commonly combine sodium and potassium because of their similar chemical properties and the fact that potassium is less abundant than sodium (Hem, 1970). Sodium and its salts are very soluble and tend to remain in solution. Probably all natural waters contain some sodium. As sodium has no apparent adverse effect on healthy people, a recommended limit in drinking waters has not been established, but individuals with an abnormal sodium metabolism should consult a physician to plan a low-sodium diet if the water supply has a high sodium content . Concentrations of sodium in excess of 500 mg/L, when combined with chloride, produce a salty taste.

Like sodium, potassium salts are very soluble and tend to remain in solution. Potassium is an essential nutrient though very high concentrations have a laxative effect. There is no recommended limit for potassium in drinking water.

Bicarbonate Carbon dioxide (CO_2) occurs in water and appears in chemical analyses as bicarbonate (HCO_3). Bicarbonate concentration is commonly expressed as "alkalinity", which is the capacity to neutralize acid. The concentration of bicarbonate is governed by carbonate equilibria (Hem, 1970). Surface waters may contain up to 200 mg/L of bicarbonate. Streams that contain little or no bicarbonate are easily contaminated by acid mine drainage. Alkalinity itself is not detrimental to human health and there is no current limit for bicarbonate in drinking-water supplies.

Chloride Chloride salts are typically highly soluble and the chloride ion tends to remain in solution. It is generally not reactive to earth materials and is valuable as a ground-water tracer. Concentrations of chloride in excess of 250 mg/L may impart a salty taste to water, hence, this is the recommended limit for drinking-water supplies. In excess of 1000 mg/L, chloride may have a detrimental effect on health.

Sulfate Many compounds that contain sulfate, especially gypsum, are readily soluble in water. Sulfates are difficult to remove from solution and have a detectable taste at concentrations in excess of 300 mg/L. Individuals unaccustomed to high sulfate waters are subject to a laxative effect. For this reason a recommended maximum limit of 250 mg/L of sulfate has been established for drinking water.

Secondary Ions

Nitrate Nitrate in water can originate from several sources, including decaying plant debris, animal wastes, sewage, nitrogenous fertilizers, and some industrial wastes. Nitrogen compounds tend to be readily soluble and are leached from the soil into the ground water. Nitrate concentrations in water are reported as either nitrate (NO_3) or nitrogen (N). The limit of nitrate as "N" is 10 mg/L, and for nitrate as NO_3 the limit is 45 mg/L. In concentrations greater than these limits, nitrate can cause infant methemoglobinemia or "blue-babies".

Shallow dug or bored wells, and improperly completed wells, are especially susceptible to contamination by nitrates. Barnyard wastes, cesspools, and septic tanks can easily contaminate wells that are not protected from surface runoff by a proper surface seal. If a water supply has a high nitrate concentration and a high chloride concentration, then the well could be contaminated by sewage and should be improved or abandoned.

Fluoride Fluoride occurs in just a few types of rock and is only slightly soluble in water. Fluoride is important in water because it strengthens teeth and aids in the prevention of dental caries. In high concentrations it is toxic and may causes chronic fluorosis. This condition is first noticeable through a mottling of the teeth. Limits on fluoride concentration vary depending on the annual average of the maximum daily air temperature (Table 4). This is due to the assumption that more water will be drunk when the climate is warmer.

Iron Iron in water supplies may be due to the presence of nonpathogenic bacteria or other corrosive phenomena. The limit on iron concentration (0.3 mg/L) is due to aesthetic and taste considerations and not on physiological effects. Concentrations in excess of 0.3 mg/L result in staining of laundry and utensils. If iron concentrations exceed 0.5 mg/L, wells and well screens may become encrusted, and if it exceeds 1.0 mg/L the water may be unpalatable.

TABLE 4
MAXIMUM CONCENTRATIONS OF FLUORIDE PERMITTED IN DRINKING WATER

Temperature		Concentration
Degrees F	Degrees C	(mg/L)
53.7 and below	12.0 and below	2.4
53.8 to 58.3	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

Minor and Trace Ions

These elements normally occur in concentrations less than 1 mg/L in water. Many trace elements are essential nutrients, but in some cases there is only a small safety margin between healthy and toxic concentrations.

Heavy Metals Heavy metals in water are commonly the result of man's activities. Inadequate disposal of certain industrial and mining wastes, the careless use of pesticides, and several common household items can pollute water with dangerous concentrations of toxic substances. Among the more common toxic heavy metals are arsenic, barium, beryllium, cadmium, chromium (hexavalent), copper, lead, manganese, mercury, nickel, silver, and zinc.

Radioactive Elements The presence of radioactive elements, except tritium, in water is primarily the result of drainage from uranium mining and milling operations. The primary elements of concern in water are uranium, radium, radon, and thorium (Fetter, 1980). These elements occur in low concentrations and are measured in units of disintegrations per second called "curies". One curie is defined as 3.7×10^{10} disintegrations per second. This is actually a very large number and water analyses commonly express the concentration of these elements in "pico-curies", which is curies x 10^{-12} (Hem, 1970).

Organic Chemical Constituents

There are more than two million known organic chemicals including 1500 that are suspected carcinogens. Many organic compounds are so highly toxic that even trace concentrations can render a water supply unusable. New organic chemicals are being synthesized every year and many will undoubtedly end up in water supplies through manufacturing processes, use, and disposal. The chemistry of these compounds is highly complex and more than a brief description is beyond the scope of this manual. Some of the drinking water standards for organic contaminants are listed in Table 5.

TABLE 5
DRINKING WATER STANDARDS FOR SOME ORGANIC CHEMICALS

Compound	Limit (mg/l)
Benzidine	0.001
Detergents (total)	0.2
Methylene Blue Active Substances (MBAS)	0.5
Phthalate Esters	0.003
2,4-D	0.1
2,4,5-TP Silvex	0.01
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005

Source: O.W.R.B. (1982).

There are two primary classes of organic compounds that are commonly encountered in water supplies; (1) hydrocarbons, which include pesticides, fuels, oils, and grease, and (2) soaps and detergents.

Hydrocarbons

One class of organic compounds, the chlorinated hydrocarbons, are widely used in industry and agriculture. These compounds are resistant to degradation and can persist in the environment for a long time. Many are also fat-soluble and accumulate in the food chain. Because many organic chemicals exist as polymers it is often impossible to identify the exact compound that is contaminating a water supply.

Contamination of water supplies by petrochemicals is usually caused by spills, leakage of fuel storage tanks, or transportation accidents. The most common types of these contaminants are gasoline, oil, and diesel fuel. Most of these compounds are lighter than water and float on the water table. Large-scale clean-up of this type of contamination is often costly and may require years.

Soaps and Detergents

The presence of soaps and detergents in a water supply usually indicate contamination by sewage. The cleaning agents contained in soaps and detergents include several synthetic organic compounds. Prior to 1965, the most widely used cleaning agent used in soaps and detergents was alkyl benzene sulfonate or ABS(Hem, 1970). This compound is resistant to biodegradation and at concentrations of only 1 mg/L produces a noticeable froth. Since 1965, other cleaning agents have been added to soaps and detergents and these are more readily biodegradable. All of the compounds are referred to as methylene-blue active substances (MBAS). The presence of MBAS in water indicates recent contamination of the water-supply by sewage.

Biological Constituents

Water can be a transmitting medium for many types of organisms and parasites. These biological contaminants (organisms) can be divided into two general classes; (1) the pathogens or those which cause disease, and (2) non-pathogens.

Pathogens

Pathogenic organisms typically originate in the intestines of man and other animals. These organisms range in size from the ultrasmall virus to relatively large cysts and encompass three classes; (1) protozoans, (2) bacteria, and (3) viruses.

Protozoans Protozoans are responsible for the common diseases of amoebic dysentery, and giardiasis. Amoebic dysentery is caused by the ameba *Entamoeba histolytica*, which lives in man's intestines. Water polluted by sewage can spread the disease. Giardiasis, a sickness that can last 2 to 3 months, is caused by the protozoan *Giardia lamblia*. Because of their relatively large size, both of these organisms can be removed from water by filtration.

Bacteria The most common waterborne diseases caused by bacteria include typhoid, paratyphoid, Asiatic cholera, and bacillary dysentery. Tularemia, brucellosis, shigella, and jaundice may also be transmitted by water. These organisms can be removed by proper treatment.

Viruses There are more than 76 pathogenic viruses and many of these can be transported in polluted water. "Contrary to popular belief, viruses can migrate considerable distances in water and even in the ground, particularly in limestone regions where sinkholes and underground caverns occur" (Lehr et al, 1980, p.141). Diseases caused by viruses include polio and infectious hepatitis.

Non-pathogens

These organisms include algae, fungi, and bacteria, all of which can render a water supply unusable, although they do not cause disease themselves.

Algae Algae, which are plant cells and colonies of cells, require sunlight for photosynthesis. Though quite common in surface water, algae are rarely present below ground except in relatively shallow, large diameter wells. Algae can cause problems related to the taste and/or odor of the water and, in extreme cases, can clog water filters.

Fungi Fungi include yeasts and molds that are rarely encountered below ground. Yeasts have been artificially introduced into the ground water in some areas as tracers. These organisms are frequently filamentous and can clog filters. They can also cause taste and odor problems.

Bacteria Non-pathogenic bacteria include fecal coliform bacteria, sulfate-reducing bacteria, and iron-reducing bacteria, amoung others. The presence of fecal coliform bacteria indicates recent and possibly dangerous pollution of the water supply by sewage. Sulfate-reducing bacteria metabolize sulfate (SO_4) to form sulfide (S) which, when combined with hydrogen (H), forms hydrogen sulfide gas (H_2S). Hydrogen sulfide is extremely flammable and can potentially accumulate in pump houses with explosive results (Lehr et al, 1980). The presence of hydrogen sulfide is indicated by a "rotten egg" odor. Iron-reducing bacteria metabolize dissolved iron and form a gelatinous scum that can clog well screens and reduce well efficiency. Chlorination of the well is usually sufficient to eliminate iron-reducing bacteria.

Physical Constituents

Water supplies may contain physical constituents or properties that render the water supply unusable, either for health or aesthetic reasons, or indicate that the supply is contaminated.

Turbidity

Turbidity is caused by the presence of suspended sediment, which imparts a "murky" or "dirty" appearance to the water. Turbidity is almost exclusively limited to surface water because soil and rock filter the water moving through the ground.

Color

Pure water is colorless, or faintly blue. Water that is discolored contains foreign substances that are either chemical or organic. Decaying organic matter may color water brown to almost black. Metallic ions, such as iron and manganese, also discolor water. Colored water is objectionable because it can stain household fixtures and clothing, and have an unpleasant taste.

Taste

Pure water is tasteless, but a variety of inorganic and organic chemicals, as well as organisms, can impart a distinctive or even objectionable taste. In some instances a bad taste may indicate that the water supply is contaminated and not fit for consumption.

Odor

"Most odors are detectable at concentrations too low to permit their detection or definition by chemical or mechanical analysis" (Lehr et al, 1980). The human nose is remarkably well adapted to detection of certain contaminants in water. Algae, bacteria, and hydrocarbons all may impart odors to water. Table 6 lists some inorganic chemicals and their odor and taste characteristics in water. Table 7 lists the detection concentration of some organic chemicals that may cause water to have an odor and taste.

TABLE 6
ODOR AND TASTE CHARACTERISTICS OF COMMON INORGANIC CHEMICAL CONSTITUENTS FOUND IN WATER

Chemical	Taste or Odor Characteristic
Iron	Bitter taste
Manganese	Bitter taste
Sulfate	Bitter taste
Hydrogen Sulfide	"Rotten-egg" odor
Sodium Chloride	Salty taste
Bicarbonates	Flat, soda taste
High Dissolved Solids	Salty taste

Source: Lehr et al (1980).

TABLE 7
CONCENTRATION OF SOME ORGANIC COMPOUNDS CAUSING TASTE AND ODOR

Compound	Detectable Concentration (parts per billion)
Formaldehyde	50,000
Picolines	500 - 1,000
Phenolics	250 - 4,000
Xylenes	300 - 1,000
Refinery hydrocarbons	25 - 50
Petrochemical wastes	13
Chlorinated phenolics	1 - 100

Source: Lehr et al (1980).

WATER TREATMENT

Almost all water from public water supplies that is consumed in the United States undergoes one method of treatment or another. Some of the treatment methods remove harmful constituents and others remove merely annoying constituents. These techniques range from the relatively simple and inexpensive chlorination process to sophisticated and expensive reverse osmosis.

Chlorination

Chlorine is an effective and popular disinfecting agent used extensively to disinfect both municipal and individual water supplies. Chlorine will kill biological contaminants but will not aid in the removal of most chemical constituents. Chlorine is available in three forms: solid, liquid and gas.

In its dry form, chlorine is available as calcium hypochlorite. It is commonly used for chlorination of swimming pools and can be obtained commercially as either a soluble powder or tablets. These compounds are relatively strong because they contain 65-75% available chlorine by weight. These compounds are stable and will not deteriorate if properly stored and handled.

Liquid sodium hypochlorite, which is sold in grocery stores as household bleach, is commonly used in domestic chlorination systems. These products consist of a 5.25% solution of sodium hypochlorite, which yields about 5% available chlorine by weight. Other sodium hypochlorite solutions vary in strength from 3 to 15% available chlorine by weight. These solutions are diluted with potable water to achieve the desired solution strength. Chlorine solutions are photo-sensitive and should be stored in a dark, cool place to prevent them from losing their potency.

Chlorine gas is frequently used for purification by municipalities and community water systems. Chlorine in its gaseous state, however, is not safe to handle and the equipment required is too expensive to use for treatment of individual water supply systems.

Filtration

Filtration of water removes suspended and colloidal materials, most if not all living organisms, and many organic chemicals. Filtration techniques fall into two categories; (1) physical(sieving or straining) and (2) chemical(adsorption). With physical filtration, the degree of removal depends on the character and size of the filter media and the size and quantity of the suspended solids. Turbidity and organisms are removed by physical filtration. Chemical filtration is based on the attraction and bonding of certain substances to a reactive filter media. Chemically reactive media are commonly used to remove taste- and odor-causing organic substances, chlorine, pesticides and other toxic organics, and even viruses. Common filter systems include cartridge-type, conventional sand, multi-media, precoat, and activated carbon filters.

Cartridge-type filters These filters, which are produced by a variety of manufacturers, have grown in popularity and are readily available through water system contractors, water-conditioning specialists, and department stores. The popularity of a cartridge filter is due to its simplicity of installation and maintenance, and its relatively low cost. These filters are small and generally used to filter only water used for cooking and drinking. The entire unit consists of a pressure container and a cartridge element that fits on water outlet pipes just before a discharge tap--i.e. kitchen faucet.

These filters are primarily for removing turbidity. Some provide excellent fine filtration, while others provide only marginal coarse filtration. Cartridges that contain activated carbon may also remove tastes and odors and some by-products of chlorination. As the cartridge is used the filter gradually becomes clogged. The quality of the water remains high but the rate of flow is reduced. Generally, they simply require a periodic replacement of either the cartridge element or the entire unit.

Proper filters should be selected on the basis of the pre-filtered water quality, required quality of the filtered water, required flow rate, and filter replacement costs. It is especially important to read filter labels carefully to evaluate the capability of the cartridge filter being considered for purchase.

Conventional sand filters Sand filters physically remove particles as "dirty" water passes through a single layer of sand that is usually about 24 inches thick. They are designed primarily to remove suspended particles, though several types of granular filter material can be selected to remove other undesirable constituents. Particles of "dirt" are trapped near the top of the unit and, after a period, the filter becomes clogged. The filter must then be backwashed to restore permeability and regain the desired flow rate.

Multi-media filters Multi-media filters consist of 3 or 4 layers of various materials; coarser at the top and progressively finer downward. Like conventional filters, multi-media filters are predominantly for removal of turbidity from the water. Depending on the specific materials that make up the various layers, these filters can also remove many undesirable chemical constituents. Because the size of the filter granules is different and undesirable constituents are trapped over the entire thickness of the filter, the multi-media filter can be operated for a longer period than conventional sand filters, but they are more costly. Sometimes the cost difference can be offset by selecting a smaller diameter tank, which will perform as well as a larger diameter sand filter.

Precoat filters Precoat filters are entirely different from conventional type filters in both theory and operation. They consist of a pressure canister, which contains both a porous filter material and filter media compound. As water enters the filter, the powdered media mixes with the water and forms an even "coat" or deposit on the filter media, thereby forming the "pre-coat filter cake". As the water flows through this cake, its impurities are trapped in the cake's small pores. If the filter material is activated carbon then the filter is capable of absorbing taste and odor causing impurities.

Activated carbon filters Activated carbon filters employ chemical rather than physical filtration. They are effective in removing a variety of organic compounds that cause taste and odor problems as well as some potentially toxic chemicals.

There are two basic types of activated-carbon filter systems; (1) the cartridge-type filter described earlier, and (2) the activated-carbon bed filter. The bed-type activated carbon filter is usually large enough to treat most of the water being used in a home. Typically, the filter bed is situated after the chlorinator and/or water softener. The effectiveness of the bed is gradually reduced as the pores in the carbon are saturated. When odors and tastes are no longer being adequately removed the bed must be replaced. For an average household, the activated carbon will last from one to three years depending on the intensity of the taste and odor being removed, as well as the quantity of water being treated.

Softening

Water hardness is caused by the presence of calcium and magnesium. Hardness is very common and occurs in over 90% of the available water supplies in the United States. The most obvious consequences of hard water is the reaction with soaps and detergents, which form an insoluble residue. Hardness can also cause a "scale" to form in water heaters, humidifiers, boilers and pipes, discolor of laundry, and form an unsightly ring around the bath tub. An indication of the hardness of ground water in Oklahoma is shown in Figure 2.

Calcium and magnesium are removed by passing the water through an ion-exchange unit. An ion-exchange unit is a tank that contains specially treated resin beads. The resin beads have a strong affinity for calcium and magnesium ions. As hard water passes over the beads, the calcium and magnesium ions become attached to them and in the process sodium ions are released into the water. When all the sodium ions have been displaced from the resin beads, softening no longer occurs and the resin beads must be regenerated. Regeneration is accomplished by passing a concentrated solution of sodium chloride through the resin beads, which replaces the calcium and magnesium ions. Sodium ions are left on the resin and the calcium and magnesium ions are discharged along with the spent brine. The spent brine consists largely of calcium, magnesium, sodium, and chloride The regenerate cycle does not damage the resin beads and the process can be repeated almost indefinitely.

The size of water softener required for a particular application is dependent upon three things; (1) initial hardness of the raw water, (2) amount of water to be treated daily, and (3) flow rate of the system.

A water softener is only one way to overcome hardness problems. In situations where a water softener is impractical, certain polyphosphate compounds can be used that help alleviate some hard water problems. These compounds chelate or "lock-up" calcium and magnesium ions, which reduces the potential for the formation of boiler scale.

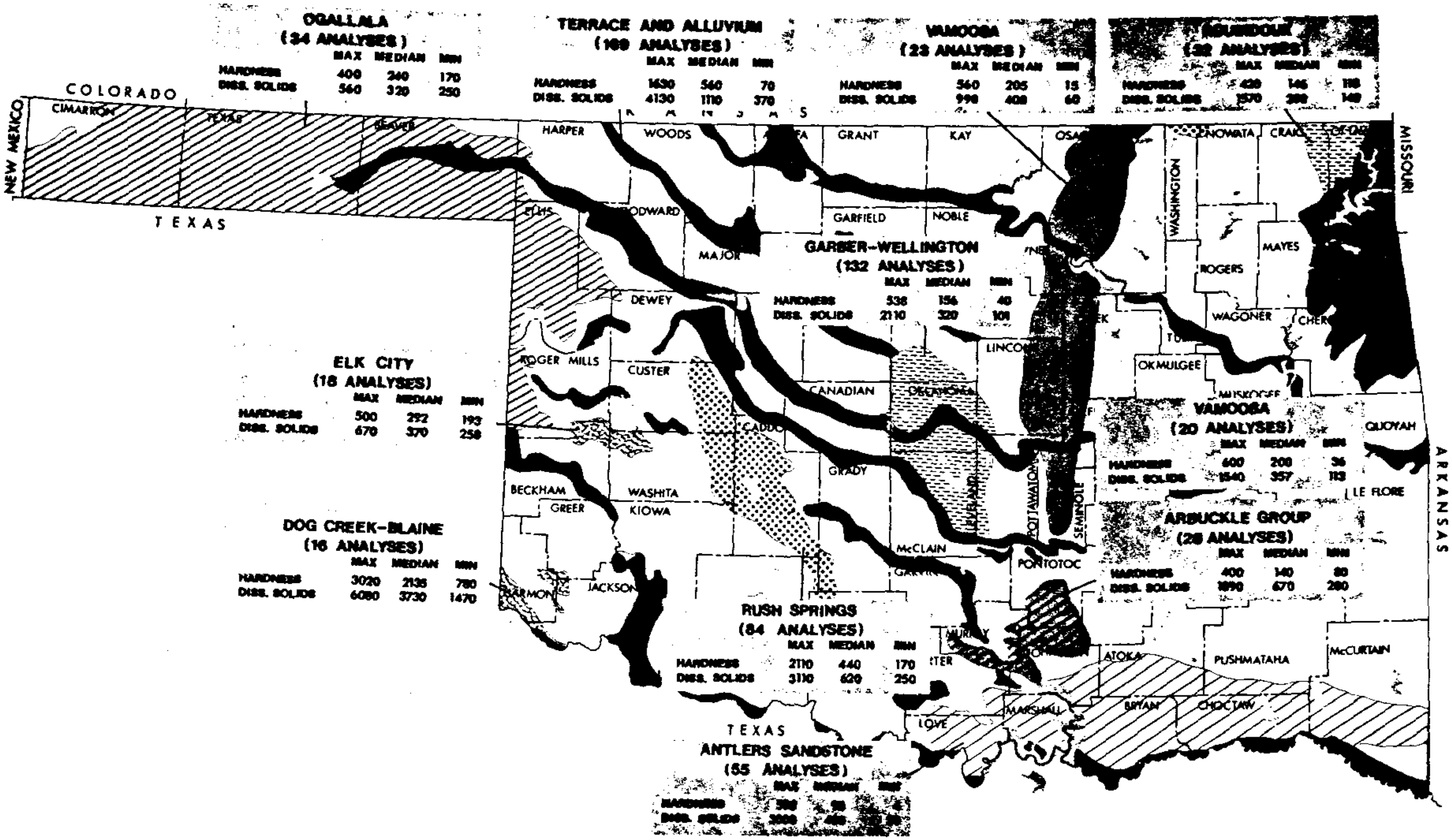

Figure 2. Hardness and dissolved solids concentrations in major aquifers.

SOURCES OF WATER FOR DOMESTIC SUPPLY

Surface Water

Surface water supplies are in contact with the atmosphere and thus are easily contaminated. Examples include air-borne constituents, spills on the land surface, surface runoff, barnyard wastes, overflow from holding ponds, lagoons, cesspools, and septic tanks, and from organisms, such as bacteria, viruses, protozoans, algae, and fungi. Surface water supplies may be derived from streams, impoundments, cisterns, and rain barrels. The availability of surface water is closely related to rain fall. The map in Figure 3 indicates the variability of Oklahoma's precipitation.

Streams

Stream flow is composed of two components; (1) surface runoff, which flows over the land surface until it reaches a stream and (2) baseflow, which is the ground-water contribution. Surface runoff, derived from excess precipitation and snowmelt, is generally very low in dissolved solids. Baseflow, on the other hand, is typically more highly mineralized because of longer contact with rock materials. The average summer temperature of streams in Oklahoma range from about 76 degrees F. in the northeast, 82 degrees F in the Panhandle, and 84 degrees F. in the southeastern corner of the state.

Streams are commonly used for disposal of municipal sewage as well as agricultural and industrial wastes and as such, their suitability for a water supply is dependent upon proper treatment. Water supplies that are developed from streams are generally easily accessible. Records of the quantity of flow are kept for many streams as are water-quality data. Annually the U.S. Geological Survey publishes a report, " Water Resources Data for Oklahoma", that contains an abundance of information on stream flow and water quality. The average annual runoff of streams throughout Oklahoma is shown in Figure 4.

Impoundments

Construction of surface water storage impoundments must include careful consideration of drainage basin conditions and precipitation. There are 3 primary considerations; (1) water quality, (2) proximity to possible sources of contamination, and (3) quantity of water lost through evaporation, transpiration,

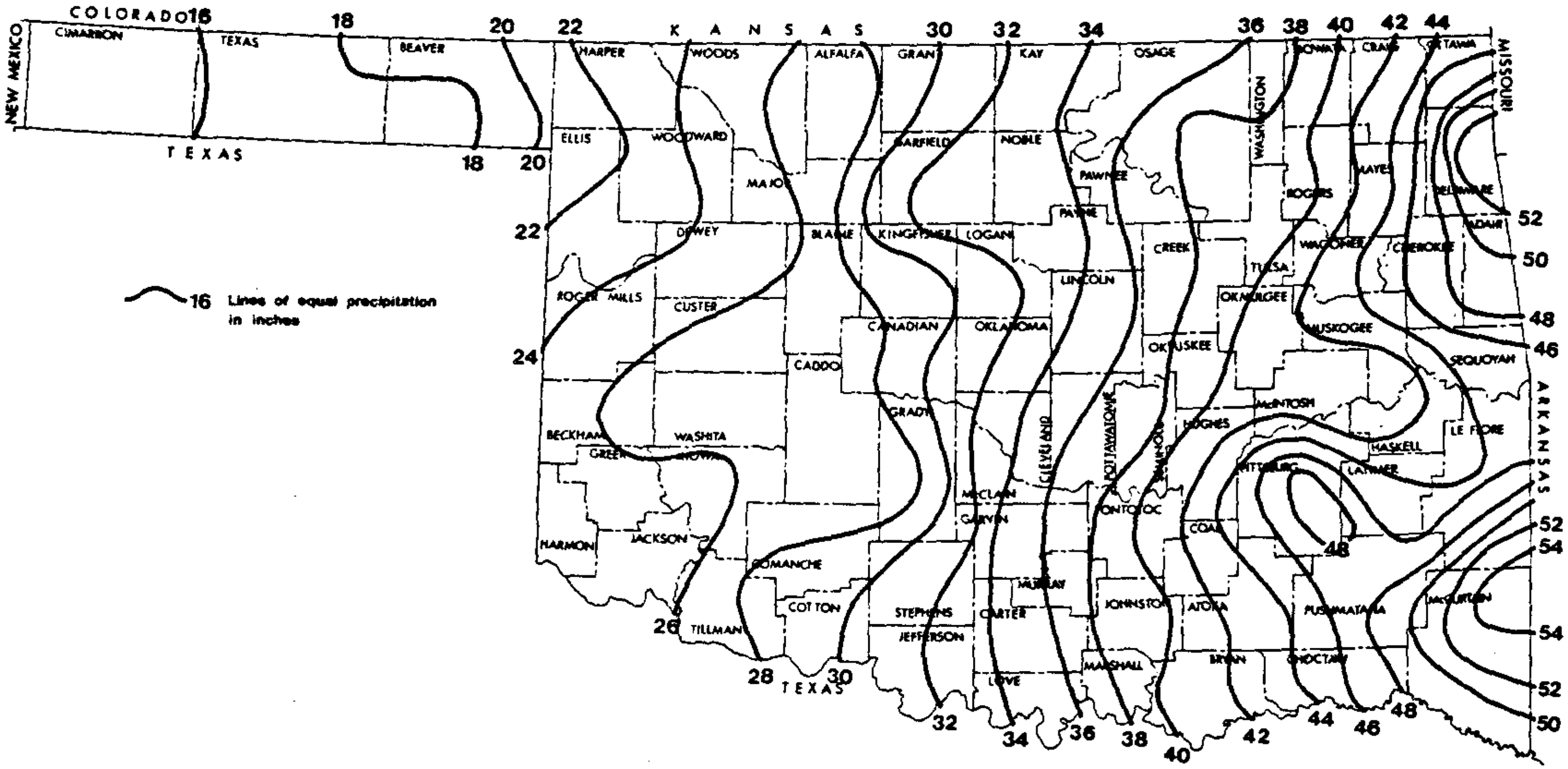

Figure 3. Average annual precipitation (in inches)
(Period 1970-79)

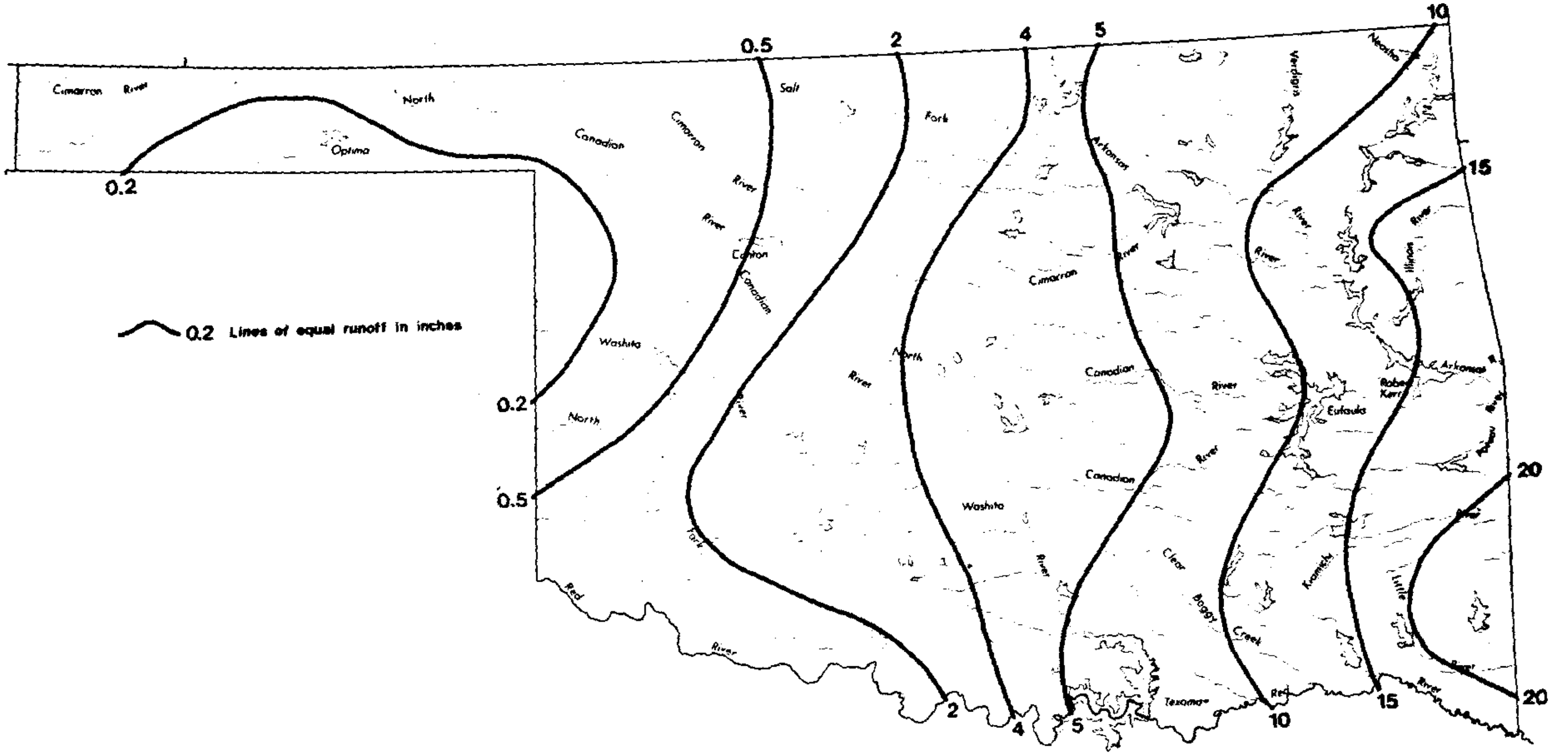

Figure 4. Average annual runoff (in inches)
(Period 1970-79)

and seepage. Because of safety considerations for individuals that live in adjacent lower areas, catchment basins that exceed 2 to 3 acres should have the impoundment designed by competent engineers. Water in impoundments can be polluted by various sources and should not be considered safe without treatment.

Ponds are designed to store water for use during periods of low rainfall and, therefore, they should contain a minimum of one year's estimated water supply, including allowances for seepage and evaporation. Evaporation from ponds and lakes in Oklahoma range from about 60 to 70 inches per year. The pond should be sufficiently deep to prevent bottom-growing plants from eventually domineering the pond. A maximum depth of at least 8 feet and an average water depth of at least 3 feet is considered optimal (Lehr et al, 1980). The pond should be fenced in order to protect it from wandering livestock and to reduce weed and debris accumulation.

Care must be taken to protect the pond's watershed. It should be located in a grassy area as far away from barns and septic tanks as possible. Pesticides and/or fertilizers should not be used on a pond's watershed.

Water loss by transpiration can be reduced by removing plants that consume large amounts of water in the vicinity of the pond. Plants that use large quantities of water include willow, saltcedar, cottonwood, alder, mesquite, and boxelder.

Many of the methods that minimize evaporation from ponds employ a cover over the water surface. Among the more practical covers are blocks, rafts, or beads that float on the pond's surface. Sand and rock dams, which store large amounts of water out of direct contact with the atmosphere, also reduce evaporative losses.

Drinking water obtained from ponds usually requires more extensive treatment than any other source. Because of its susceptibility to contamination, pond water may require turbidity, odor, and taste control in addition to chlorination and softening.

Cisterns

A cistern (fig. 5) is a reservoir, generally underground, that collects rain water from a roof, or ground water from seeps, small springs, or low-yield wells. Based upon the average yearly rainfall and the roof area available to catch precipitation, the expected water yield to a cistern can be determined with the aid of Figure 6.

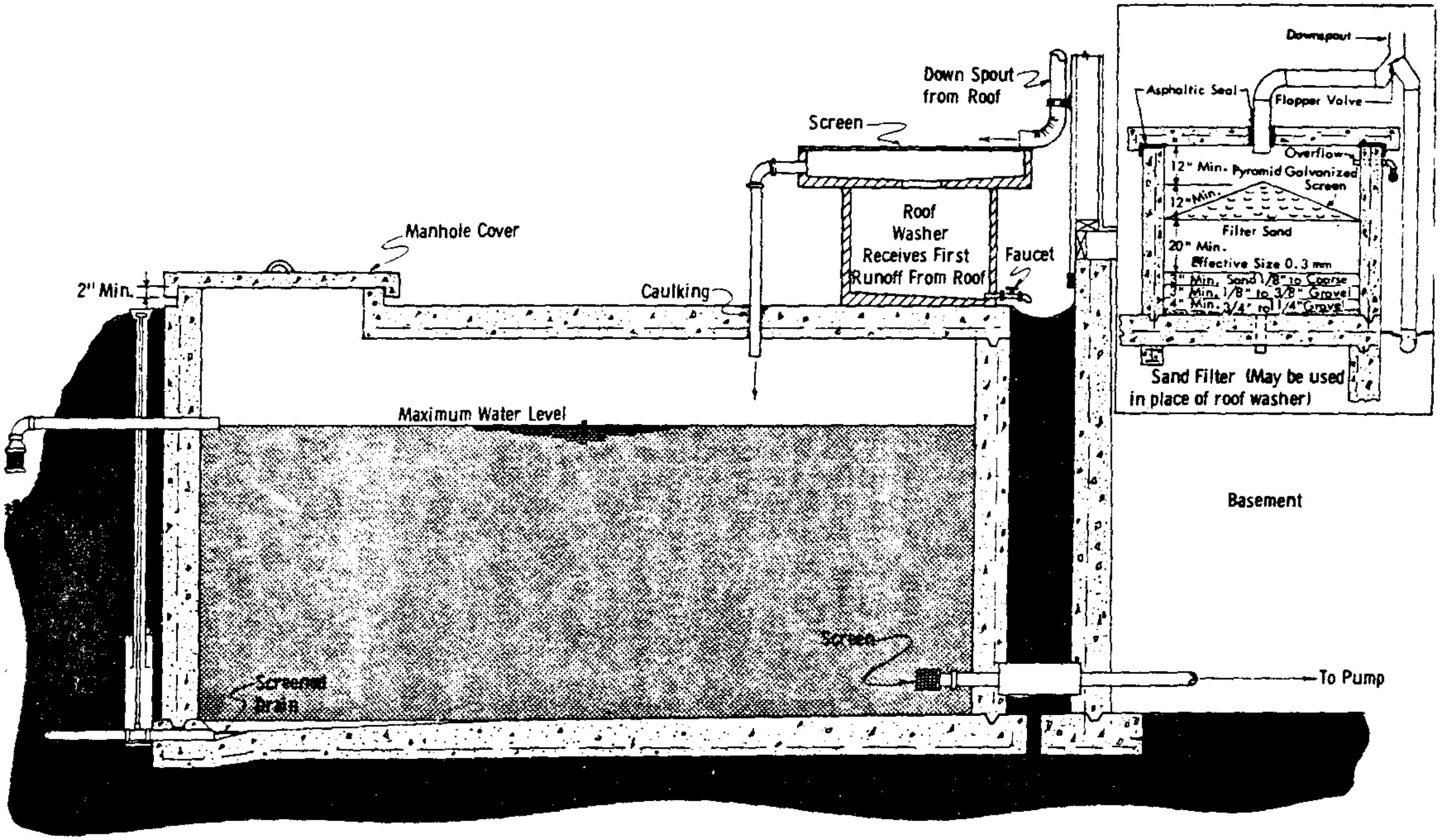

Figure 5. Generalized diagram of a cistern

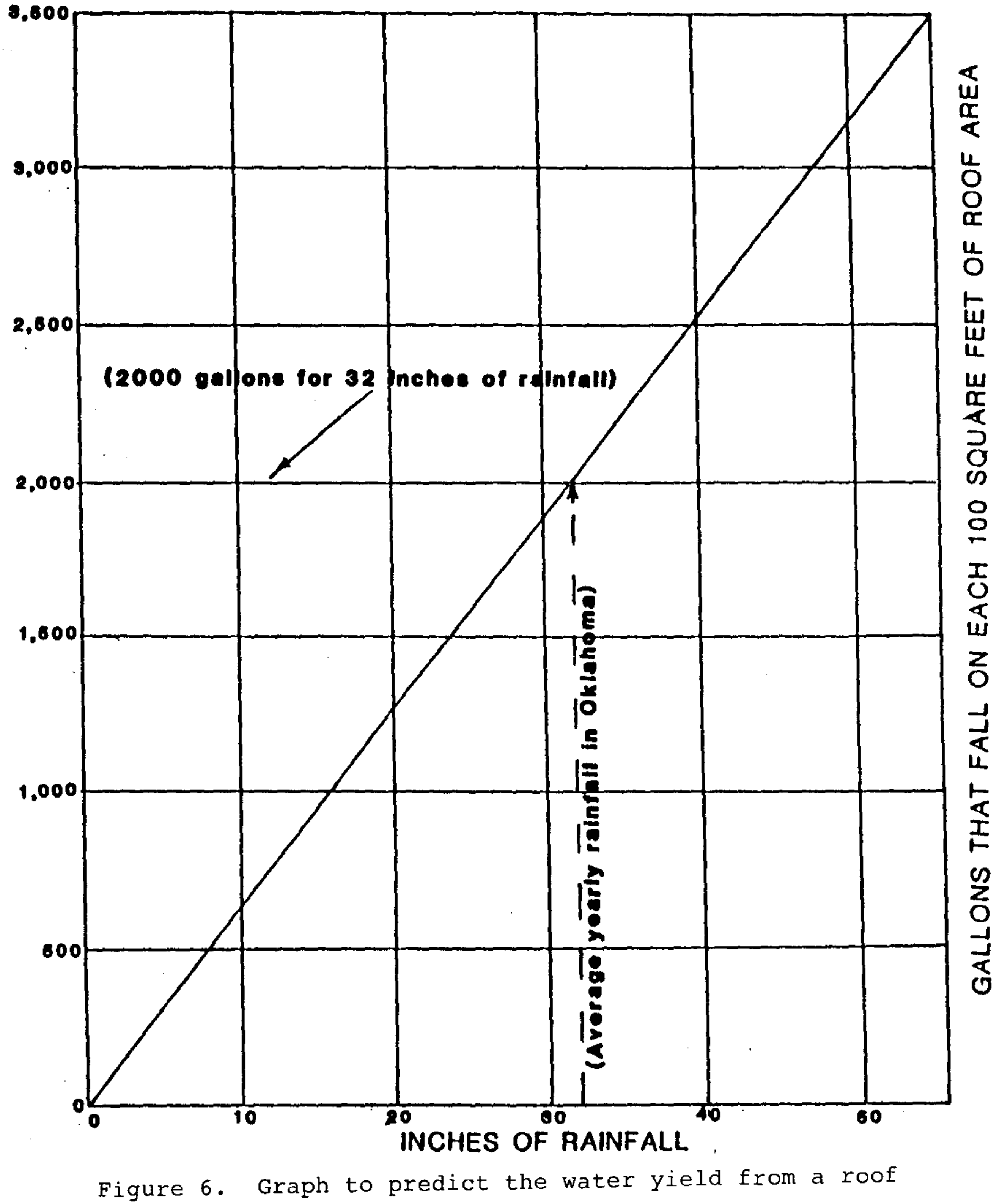

Figure 6. Graph to predict the water yield from a roof to a cistern.

Underground cisterns are preferable to those above ground because they offer protection from freezing. In areas where temperature variations are not extreme, the cistern may be maintained above ground if satisfactory water temperature can be maintained. Above ground cisterns are especially desirable in other situations as, for example, where excavation is difficult, or where flooding is probable.

Cisterns should not be located near surface drainages and they should be at least 50 feet from sewers, septic tanks, cesspools, vault privies, stables, manure piles, or other potential sources of contamination. Cisterns should be properly constructed with (1) a firm foundation to prevent settling and cracking, (2) water-tight sealing around vent pipes and water inlet and outlet pipes, and (3) a durable top with an inspection manhole and securely fastened cover.

Because most cisterns derive their water from roof runoff, the water is subject to contamination from several sources. Roofs tend to collect dirt, debris, and bird droppings and some roofs have soluble coatings that wash into the cistern. Therefore, routine cleaning and maintenance of gutters and downspouts is essential to minimize the risk of contamination. Screen or mesh coverings for gutters is good preventive maintenance. It is also good practice for the first flush of each rain to be diverted from entering the cistern. This can be achieved through installation of an automatic flap valve on the inlet pipe.

Once the cistern has been installed and filled, the water should be disinfected. Automatic chlorination is essential for a safe water supply.

Rain Barrels

Rain barrels can be thought of as small-scale, above ground cisterns. They are subject to the same sources of contamination as cisterns and the same precautions should be observed to minimize the risk of contamination.

Ground Water

Ground water occurs in saturated geological formations that are called aquifers(fig. 7). "These rock formations may be unconsolidated (sand or gravel), consolidated (sandstone, conglomerate, shale) or crystalline (granite, limestone, marble)" (Lehr et al, 1980, p.63). Contrary to popular belief, ground water does not occur in underground "rivers". Except in

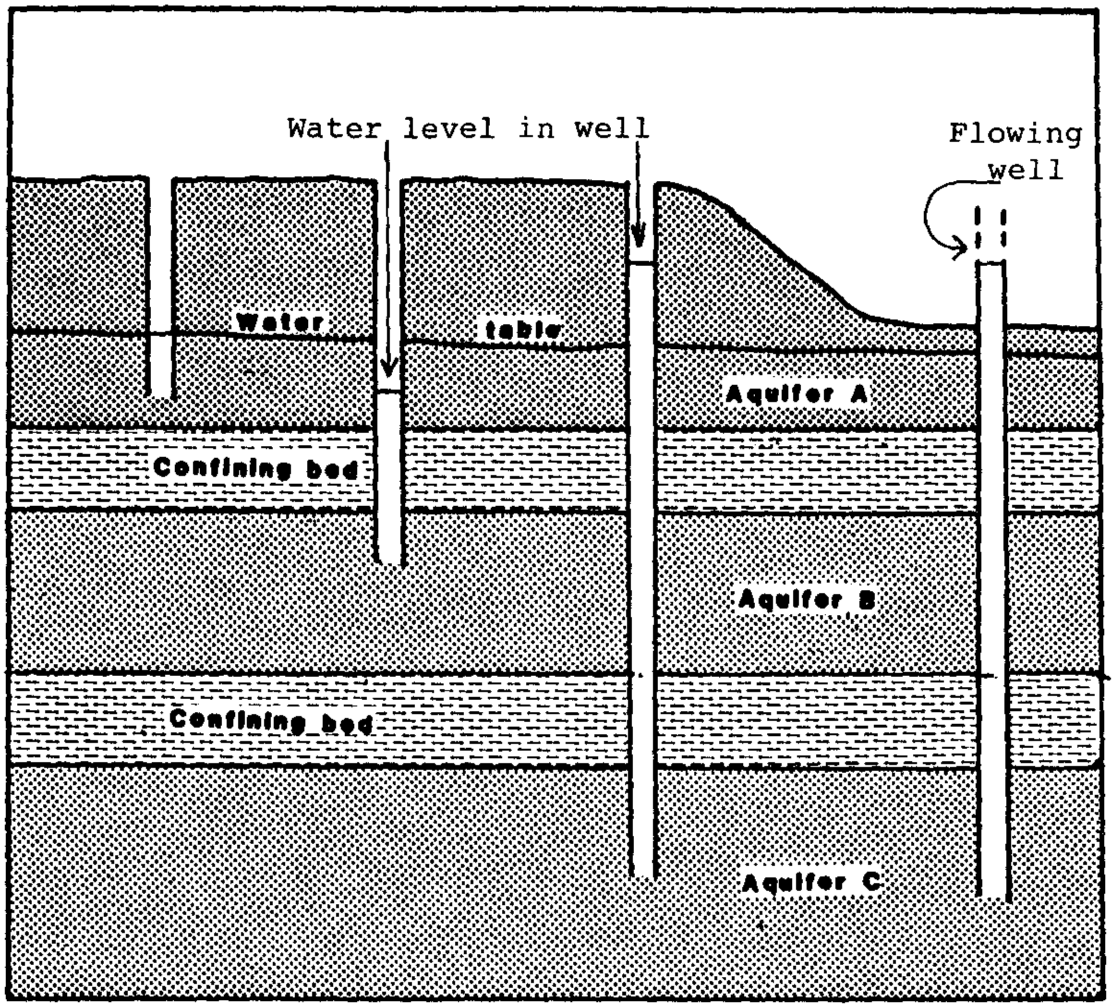

Figure 7. A water-table aquifer is recharged by direct infiltration of rain and is easily contaminated. A confined or artesian aquifer is overlain and underlain by rocks of low permeability. Water in an artesian aquifer is under sufficient pressure to rise in a well above the base of the overlying confining bed. A few artesian wells flow.

limestone areas, where solution of the rock has created large openings and caverns, ground water exists within fractures or in pore spaces between the individual mineral grains that compose most rocks. Therefore, ground water is present nearly everywhere.

The water table, which represents the upper surface of the shallowest aquifer, lies anywhere from a few to several hundred feet below land surface. Where no layers of impermeable rock or clay lie between land surface and the water table the aquifer is said to be "unconfined". When the aquifer is between two impermeable layers and the water is under pressure such that the water level is above the base of the overlying confining bed, the aquifer is said to be "confined" or "artesian". If the water is under enough pressure to flow out of a well at land surface, the well is a "flowing artesian" well. The water table is not a static phenomenon and the water level in all aquifers rises and falls at least a few feet annually. The water table is generally highest in the spring and lowest in the fall. The difference between the highest and the lowest levels is generally less than 10 feet. During extended dry periods, however, the water level may decline to such an extent that a well will no longer provide its designed yield or it might provide no water at all. Commonly, however, the water level will recover to its usual position after the drought is over. The variation in water level is largely due to the difference between ground-water recharge and ground-water discharge. It rises when recharge exceeds discharge and declines when discharge exceeds recharge.

Ground water provides water to supply systems through springs and seeps, wells, and artificial aquifers.

Springs and Seeps

A spring represents a point where the water-table is slightly above or at the same elevation as the land surface. A seep is an area of ground-water discharge rather than a single point as is the case with a spring. Discharge from springs and seeps generally varies considerably throughout the year, but a few remain nearly constant over many years depending on the nature of the spring. Springs may result from many natural geologic situations such as faults, depressions, changes in lithology, and jointing and fracturing. Man's influence can also cause a spring to form as in an excavation, or where a tunnel, highway foundation, or other construction has cut through saturated formations. Similar activities can also cause a spring or seep to cease flowing.

If properly protected and of sufficient flow and quality, a spring or seep can provide a reliable water supply. In some instances a spring that does not have sufficient discharge to meet daily water requirements may be used in conjunction with a supply provided by a well or other source.

Two methods to protect springs and seeps from contamination are shown in Figure 8. Reservoirs for spring water are similar to cisterns and the same precautions should be observed. As with ponds, it is good practice to protect the "water-shed" of the spring with fences and to use considerable care when applying agricultural chemicals in the recharge area of the spring.

Springs are especially common in limestone (karst) areas. Because of the relatively large solution openings characteristic of karstic regions, ground water can be easily and quickly contaminated. In these areas it is especially important to have samples of the water analyzed on a regular basis as a safe guard against contamination and the potential for water-borne disease.

Wells--Construction and Design

The classification of water wells is as varied as the methods of construction. Dug, driven, jetted and bored wells seldom exceed 50 feet in depth. They are usually more susceptible to contamination and may not always provide a safe, reliable water supply. Drilled wells, on the other hand, not uncommonly exceed 1,000 feet in depth and, when properly constructed, they usually produce an adequate yield and and are well protected against contamination from the surface.

Dug wells Dug wells probably represent the oldest type of construction and are generally excavated by hand. To prevent caving during excavation, a "crib", culvert, or surface casing is used. When the well is completed, the walls are lined with brick, stone, or culvert, and a few inches of gravel are spread over the bottom(fig. 9). Dug wells are especially difficult to protect from contamination. They are commonly inadequately sealed and may become contaminated by surface water that flows into the well or along the well lining, or by seepage of contaminated ground water. Because dug wells are generally shallow, extending only a few inches or feet below the water table, they are also likely to fail during droughts, or when large quantities of water are withdrawn.

Driven wells These are probably the least expensive and simplest to construct. A special well point, constructed of

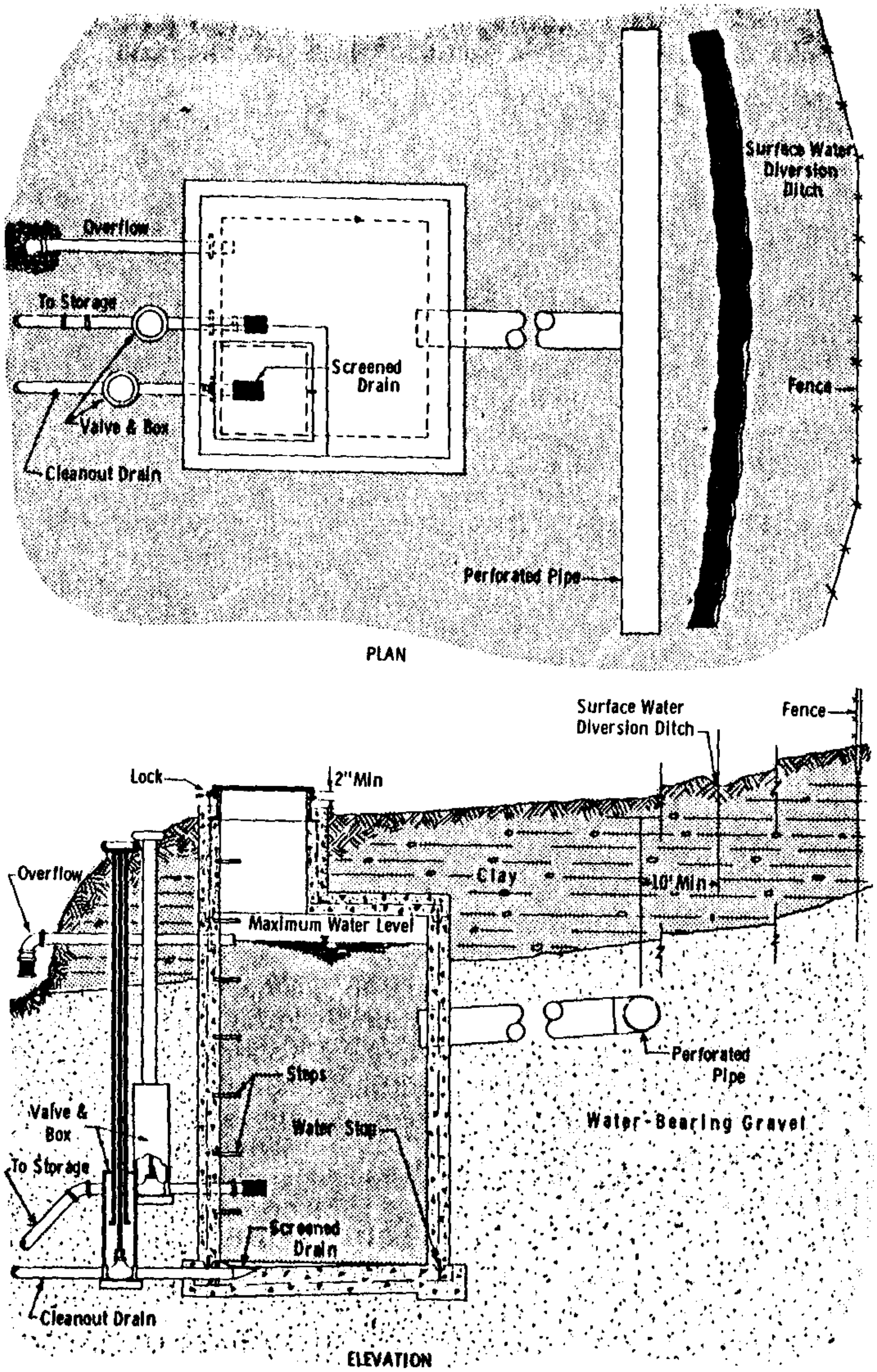

Figure 8. Methods to provide protection of a spring.

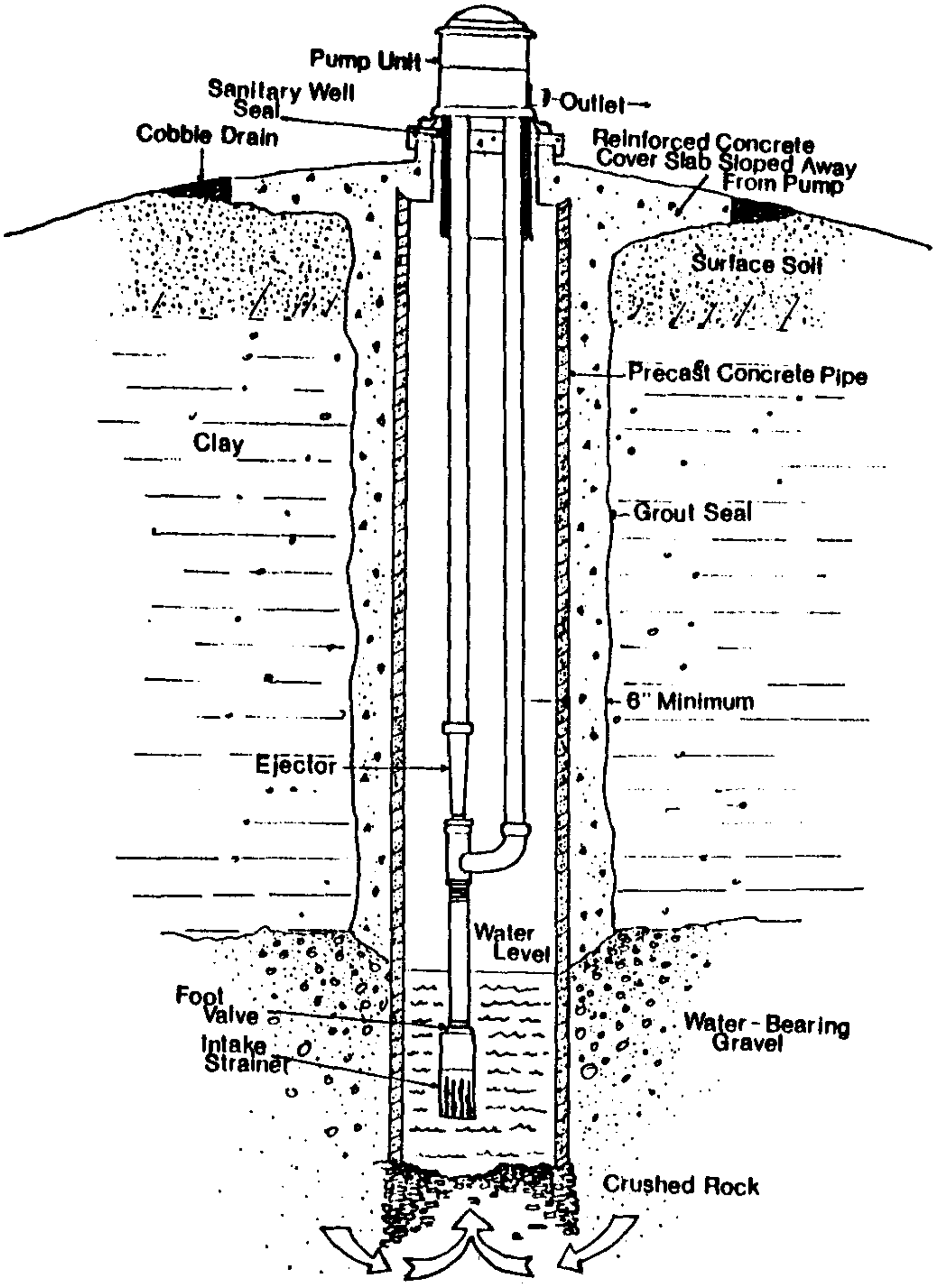

Figure 9. Dug well with a two-pipe jet pump.

forged or cast steel and attached to a steel pipe, is simply driven into the ground with a special weight or maul. The well point and "casing" are usually less than 6 inches in diameter. Consequently, the yield of driven wells is generally less than 7 gpm.

Bored wells Similar in design to dug wells, bored wells typically are deeper. Various augering devices are used to drill the wells, which are then cased with tile, concrete pipe, or wrought iron or steel casing. Proper protection of bored wells includes sealing the space between the well bore and the casing with cement grout to prevent surface water from contaminating the well(fig. 10).

Jetted wells Jetting provides a quick and effective way to sink well points in soft, loose material. The jetting process involves pumping water down a pipe at high pressure, which then issues from a special washing point. A hole is created as the water loosens the earth materials and then the materials are washed to the surface. A protective casing may be installed around the jetting pipe to protect the well from surface or shallow sources of contamination.

Drilled wells Constructed with machine-operated drilling equipment called "rigs", drilled wells are generally preferred since they usually provide the safest and most reliable water supply. Drilling techniques fall into two general categories; (1) percussion, and (2) rotary. Developed centuries ago in China, the percussion or cable-tool method is the oldest method of mechanical well construction. This method employs a heavy drill bit and stem that is alternately raised and dropped to pulverize the formation. Small pieces of rock, dislodged by the bit, mix with water to form a slurry that is bailed to the surface. As drilling proceeds, casing slightly larger than the drill bit is driven into the ground to prevent caving.

Hydraulic or mud-rotary drilling, which has gained in popularity in recent years, has all but replaced cable-tool drilling in most parts of the country. Rotary drilling rigs are typically composed of a truck-mounted derrick and hoist, a revolving table to turn the bit, a cutting bit, a series of drill pipe sections, a pump to circulate drilling fluid, and a power source to rotate the table. The rig drills by rotating and advancing the bit to break up rock material. Drilling fluid (water or special drilling "mud") is pumped down the hollow drill pipe, into the borehole through openings in the bit, and then returns to the surface as it flows between the drill rod and the wall of the hole. The fluid serves to cool and lubricate the bit as well as remove rock cuttings from the borehole. The

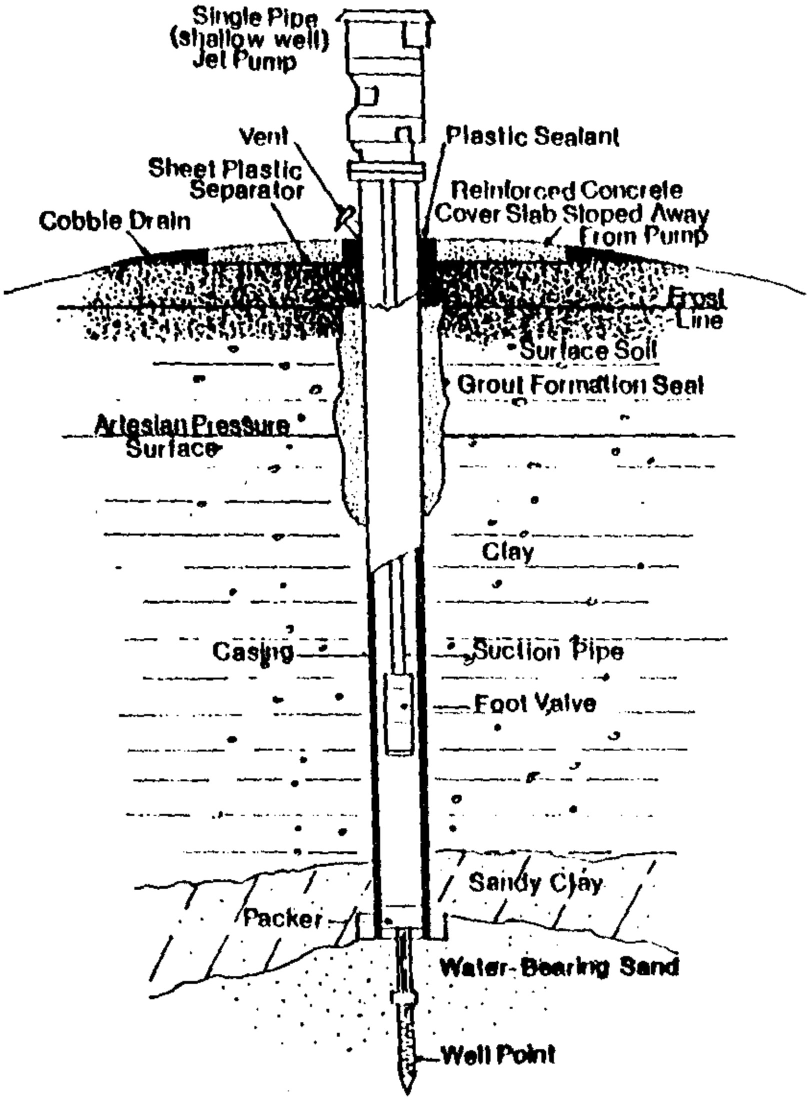

Figure 10. Bored well with driven well point and shallow well jet pump.

cuttings and return fluid are discharged into a settling pit, commonly called the mud pit. When the desired borehole depth has been reached, the drill stem is withdrawn and casing and screen are set. The hole is typically back-filled with gravel around the screened sections in order to keep fine material from entering the well and to increase well yield. The space between the annulus and the casing is sealed with grout to prevent leakage of surface or shallow water along the casing, which might contaminate the aquifer.

Other rotary drilling methods include reverse-circulation rotary, air rotary, and pneumatic hammer. The reverse-circulation rotary method is basically the same as mud rotary except that the drilling fluid is pumped down the annulus and rises to the surface carrying cuttings within the hollow drill pipe. Air-rotary simply substitutes air for the drilling fluid of the mud-rotary technique. This technique allows rapid penetration in hard, consolidated formations, but is poorly suited to drilling in unconsolidated materials, such as sand and gravel. The pneumatic hammer method combines percussion and rotary techniques and is particularly well suited to drilling in very hard formations.

<u>Well Location</u> Construction of a domestic well requires compliance with state and local codes that serve to protect both the potential ground-water user and the ground-water resource itself. In some areas water in certain aquifers may be contaminated and unfit for human consumption, while in other cases new development may be restricted as a conservation measure. Additional well-site selection considerations include aquifer type, depth to water-bearing zone, topography, land use, and convenience.

It is important that steps be taken to minimize the risk of contamination by flooding or contamination. The well should be located at the highest elevation that is practical in order to reduce the potential of surface water entering the well and to allow contaminants to migrate away from the well bore. The area should also be well drained. To facilitate well maintenance, the top of the well should not be buried or located beneath a building.

<u>Casing</u> The top of the well should extend above the surface of the ground and be surrounded by mounded dirt or, preferably, a poured concrete apron to prevent surface water from flowing into the well. The casing should be new and strong enough to withstand installation. Most well casing is steel pipe, although thermo-plastic and fiber-glass casings have also proven to be satisfactory for some applications. In order to

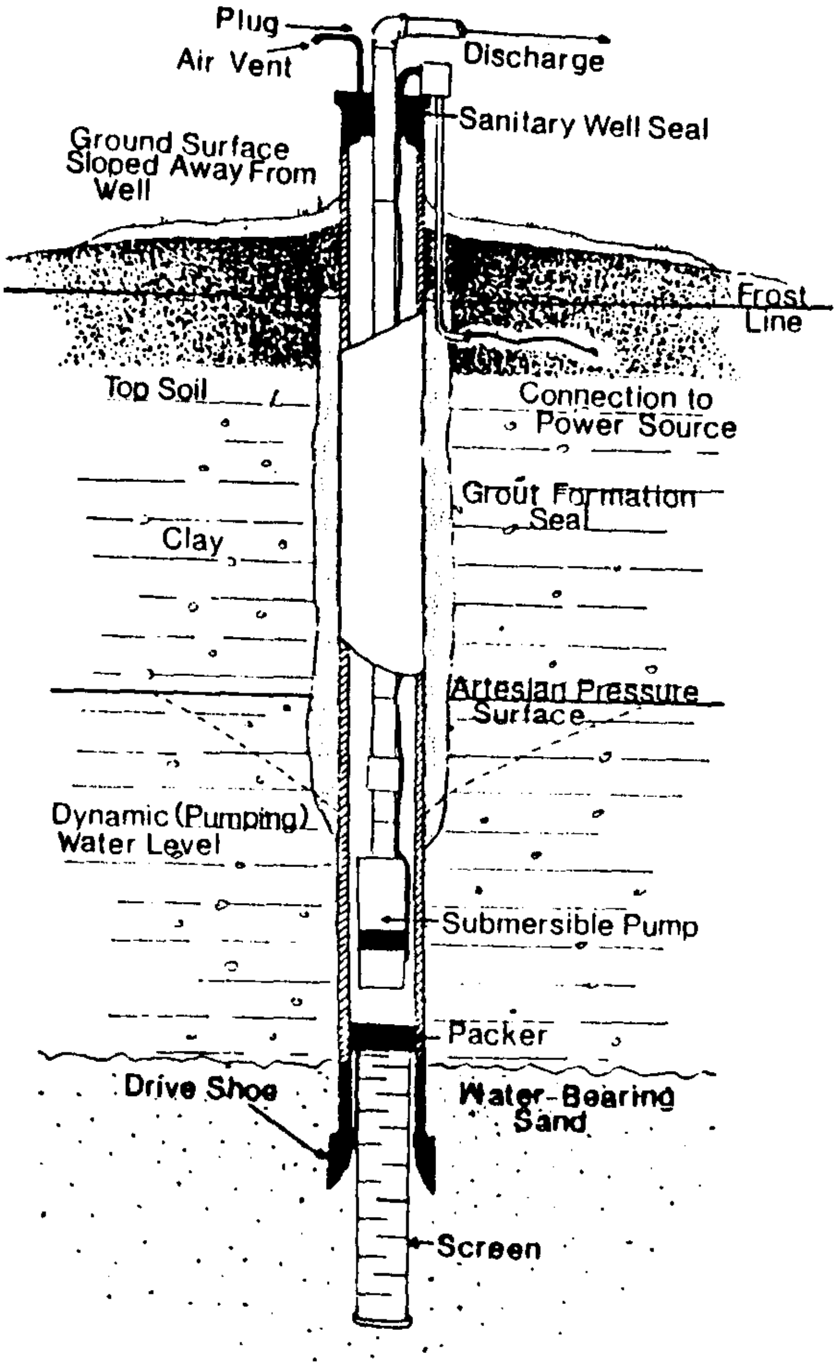

Figure 11. Construction details of a drilled well.

reduce the risk of seepage from undesirable zones and possible contamination from other aquifers, casing joints should be watertight--either welded, cemented, or threaded. When completed the well should be covered with a sanitary well seal, cap, or pump mounting. It is also desirable that the well be vented with the vent pipe pointing downward and covered with a fine mesh screen(fig. 11).

In most wells the upper 20 to 30 feet of the borehole is drilled over-sized to allow space for the permanent well casing to be grouted in place. The annular space between the hole and casing should be grouted with watertight cement or clay filled to whatever depth necessary to insure that surface runoff does not infiltrate into the aquifer along the outside of the casing. A grout should also be used to seal off contaminated or highly mineralized water in aquifers above the water-supply aquifer.

Well Development Well construction should not be considered complete until the well has been properly "developed". Well development is important for three reasons; (1) well yield and efficiency are increased, (2) pump life is extended, and (3) the water is free of turbidity. Development consists of surging the well by one means or another. This may be accomplished by use of a surge-block, hydraulic or air jet, a pump, a special set of pipes, or by the drillstem itself. The simplest method is to turn the pump on and off at closely spaced intervals. This forces water to flow into and out of the screen. Surging causes a natural gravel-pack to form around the well screen. Finer material adjacent to the screen enters the well leaving the coarser material behind. The fine material can then be removed from the well by bailing or pumping. Consequently, the gravel-pack has a higher permeability than the surrounding aquifer materials and more water can flow into the well with less friction loss. This ultimately results in increased well yield and decreased drawdown. When the natural gravel-pack stabilizes, that is, no additional fine materials enter the well, the pump may be installed. Because the fine material is removed before installation of the pump, the pump does not produce sandy or dirty water and there is less wear on its moving parts.

Disinfection The final step in well completion is disinfection to kill any organisms introduced into the well during construction. Chlorination is a common method of disinfection. A concentrated chlorine solution is poured into the well and mixed with well water. After being allowed to stand overnight, the well is pumped to to waste to flush out excess chlorine. The water should then be tested for the presence of bacteria before drinking.

It is important to note that state and county health departments have specific rules concerning well construction. Representatives from these agencies should be contacted prior to construction in order to determine their requirements.

Maintenance Routine inspection of the well should be conducted as part of a proper preventive maintenance program. These examinations can save money through early detection of problems before they become serious. The well should be inspected for physical as well as sanitary adequacy. Periodic measurements of the water level in the well should be recorded in order to determine the long term decline, if any. At the very least, the depth to water in the well should be recorded when it is drilled and any time it is serviced. These measurements allow determination of well efficiency and can indicate early problems with the well screen.

Continued sanitary protection is also essential. Maintenance of the well seal and connections, and protection from surface drainage are extremely important to aid in the prevention of contamination.

Cluster Wells

In some areas the yield from a single well may be insufficient to meet water requirements. A cluster well arrangement employs several low-yield wells (1-5 gpm each) in close proximity that may be pumped continuously or as needed. The water is discharged to a central reservoir where it is stored and treated. Although the quantity of water in storage is reduced during periods of peak demand, it recovers at other times. Five wells that continuously produce only 1 gallon per minute each will provide 7200 gallons per day. Assuming a water use of 66 gallons per day per person, this volume of water could supply a community in excess of 100 persons. Because the wells do not pump at high rates, several cluster well systems per community could be used in relatively close proximity without significant interference between them.

Subsurface Dams

Well yields are dependent upon, among other things, the saturated thickness of the aquifer--the thicker the aquifer, the higher the potential well yield. In areas where aquifer deposits are only partially saturated or drain rapidly, subsurface dams can be constructed to impound ground water and increase the saturated thickness. A subsurface dam is typically constructed of compacted clay although concrete or bentonite could be used. Figure 12 illustrates the basic elements of a subsurface dam.

Induced Infiltration

Induced infiltration presents a means to increase well yield and to augment the amount of water in underground storage. Induced infiltration requires a surface-water supply of acceptable quality and one or more wells located adjacent to the surface water source. When pumped, the wells establish a hydraulic gradient that reaches outward to the stream, lake or pond. This causes infiltration of water from the surface-water source, which supplements the ground-water supply(fig. 13).

Depending on the quality of the surface and ground water, the mixing of the two could result in larger quantities of better quality water than one of the individual sources.

Artificial Recharge

Artificial recharge refers to techniques that serve to increase both the rate at which water infiltrates into the ground, and the total volume of water added to storage in an aquifer. As with induced infiltration, artificial recharge is not in itself a direct source of water supply. Artificial recharge stores underground excess surface water that would ordinarily flow to waste(fig. 14). It then becomes available for use at a later time.

The feasibility of artificial recharge is dependent upon a variety of factors that include; a source of recharge water, acceptable quality of the recharge source, and geologic conditions favorable to infiltration. Artificial recharge techniques have been practiced throughout the world for more than 200 years and the technology is broad enough to allow implementation over a wide range of geologic conditions (Pettyjohn, 1981). The feasibility of artificial recharge must be determined on a site to site basis.

Artificial Aquifers

Water supply problems in arid or semi-arid areas present a compound problem because of minimal rainfall and high evaporation rates (Pettyjohn, 1981). In some situations, water supplies may be derived from artificial aquifers. An artificial aquifer is constructed by placing coarse material, such as sand or gravel, into an excavation. Slotted plastic pipes may be

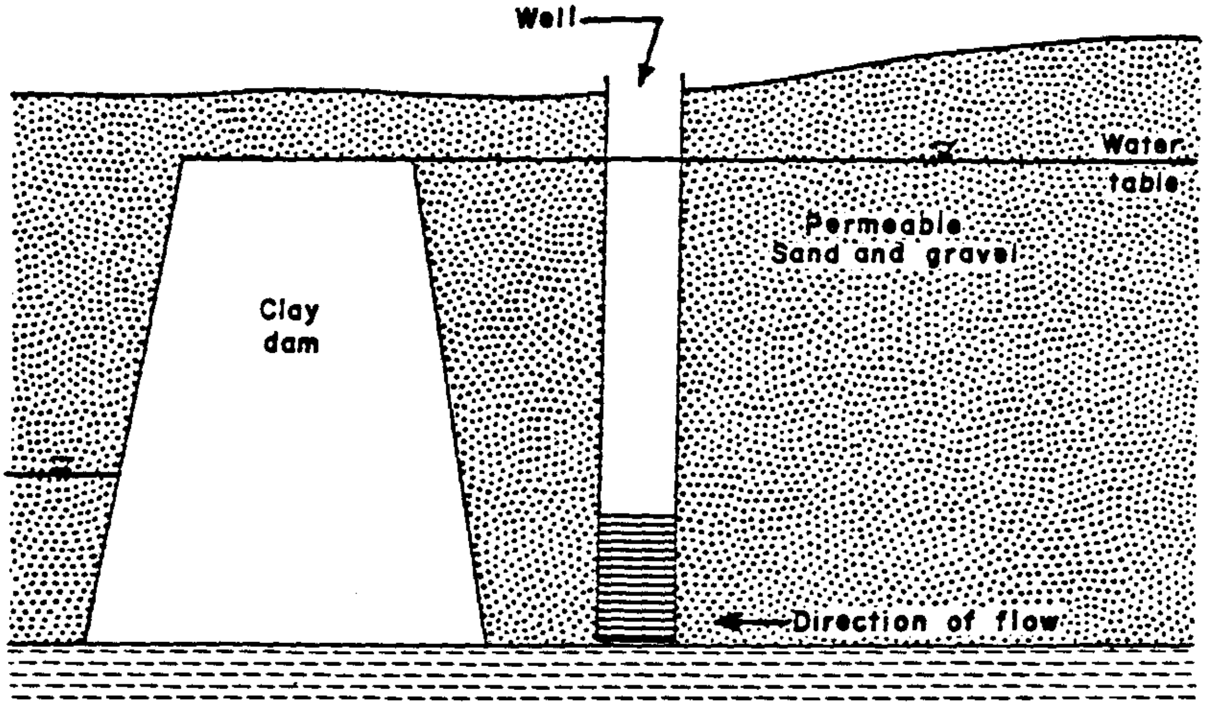

Figure 12. Generalized cross-section of a subsurface dam.

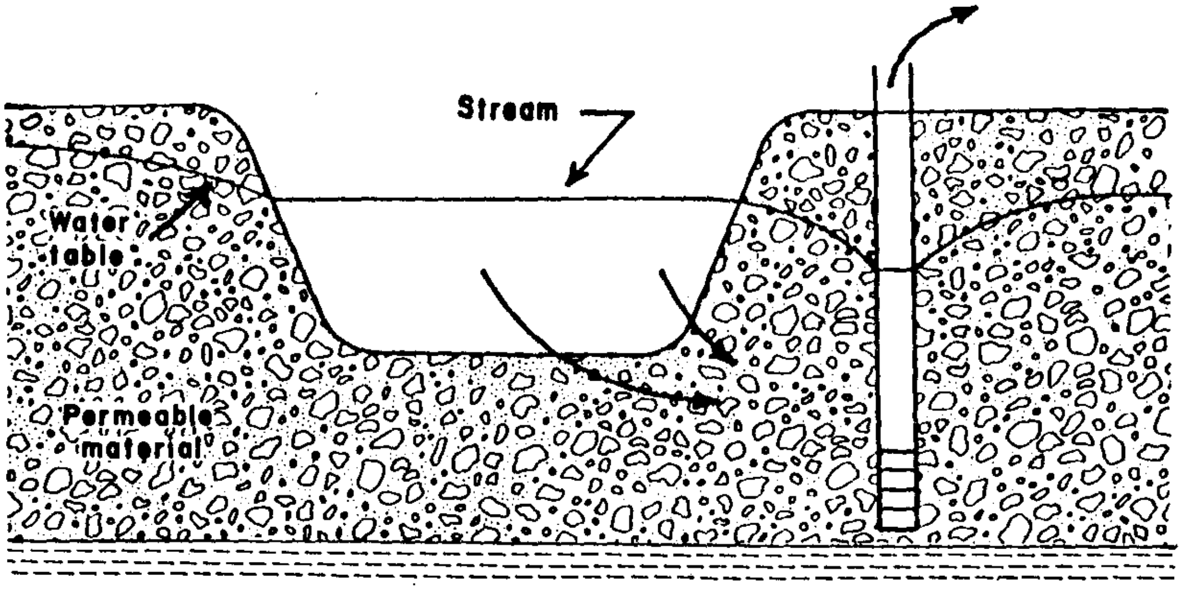

Figure 13. Example of indirect infiltration.

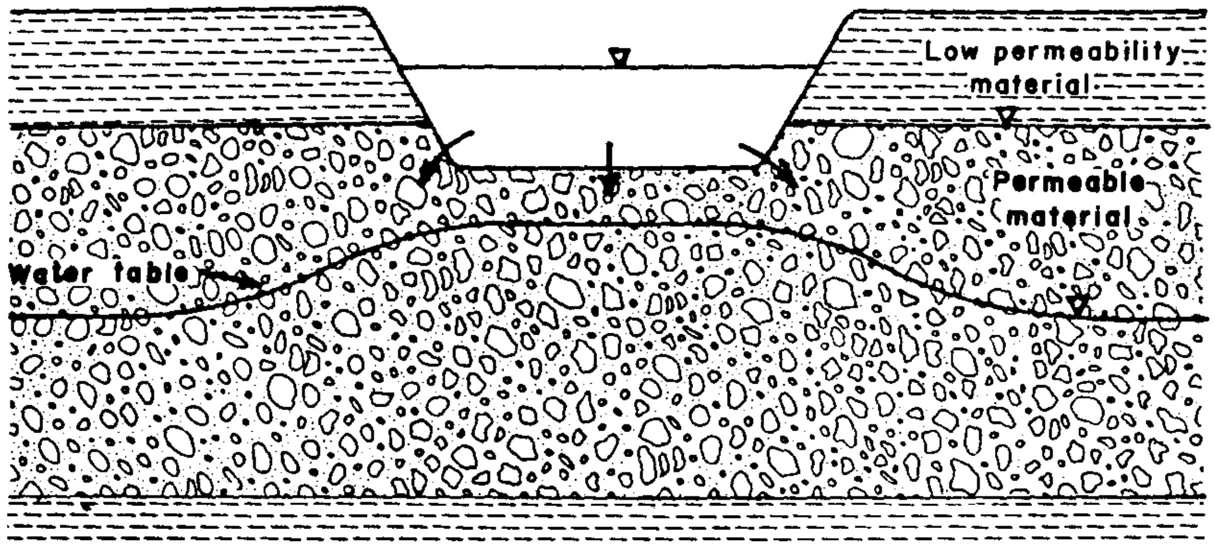

Figure 14. Generalized example of an artificial ground-water recharge facility.

installed along the bottom of the "aquifer" excavation before backfilling. Precipitation and surface runoff that infiltrates will seep into the slotted pipes and can then be diverted to a storage tank, cistern, well, or discharge pipe.

The artificial aquifer collects rainfall during the wet season for use in the dry season. It is similar to a roof and cistern system, and much the same as a pond, except losses by evaporation and transpiration are far less.

Artificial aquifers require substantial labor to construct, but they do not require expensive equipment for operation or maintenance. An artificial aquifer is illustrated in Figure 15.

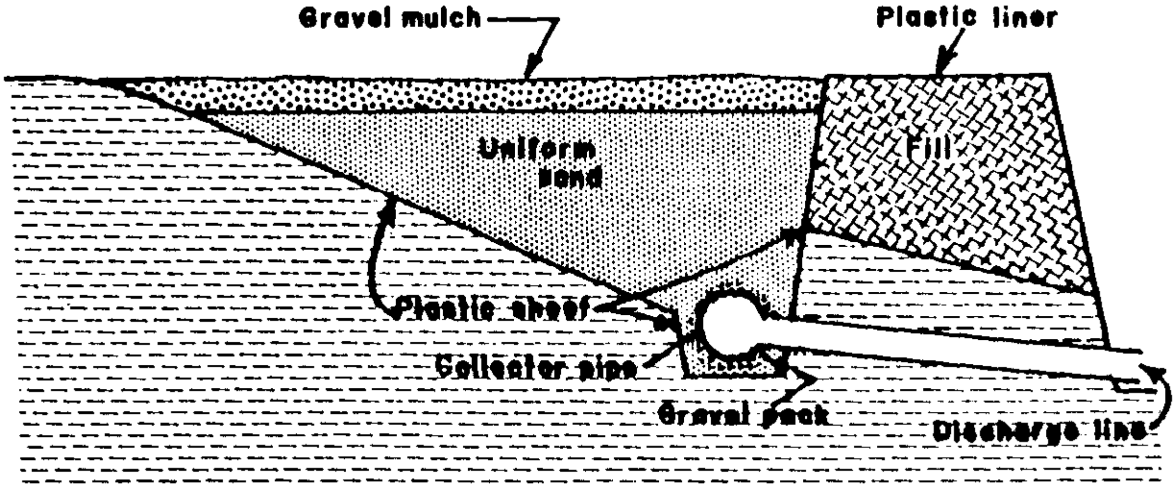

Figure 15. Generalized cross-section of an artificial aquifer.

WATER PROBLEM AREAS AND SITUATIONS IN OKLAHOMA

Oklahomans locally suffer from water problems brought about by either an inadequate supply or contamination, either natural or man induced. In a number of cases these problems can be solved rather inexpensively, in others they can not.

Shown in Figure 16 are the States' major aquifers, as defined by the Oklahoma Water Resources Board. The depth of potential wells, chemical quality, and water level in the defined areas can be predicted rather accurately. On the other hand, yields can range widely and there is a large total area within the State in which there are no major aquifers. In areas lacking well defined ground-water systems, one can only estimate or provide an experienced guess as to potential well depth, yield, and chemical quality. The shallowest, and commonly the best, small aquifers consist of sand or sand and gravel deposits in the vicinity of streams and rivers. Where these deposits are lacking, bedrock units provide the only potential source of supply.

Experience has shown that wells drilled into the bedrock commonly produce higher yields if they intersect a fracture. Fracture traces are not easily detectable, in most cases, at ground surface but many tend to appear clearly on air photographs. In areas of typically low well yields, an examination of air photographs might provide a means of increasing the supply. It should be noted, however, that even though yields might be increased by drilling into fractures, the fractures are zones of high permeability that could easily permit the migration of contaminants from the surface to the water-bearing zone.

Elsewhere in Oklahoma where yields from individual wells are small, one could consider using cluster wells, cisterns, or even artificial aquifers as described previously.

Generally speaking, there are four chemical constituents that can create, in particular, ground-water quality problems in Oklahoma. These include fluoride, nitrate, chloride, and sulfate. Both north and south of the Wichita Mountains and especially in Comanche County, excessive concentrations (as much as 28 mg/L) of fluoride occur in water from wells that produce from the Post Oak Formation. Apparently the fluoride was derived by erosion of the igneous rocks forming the core of the Wichita complex and deposited in the Post Oak Formation. Since the source of the fluoride is natural, nothing can be done to reduce its concentration in the ground water other than by some means of dilution.

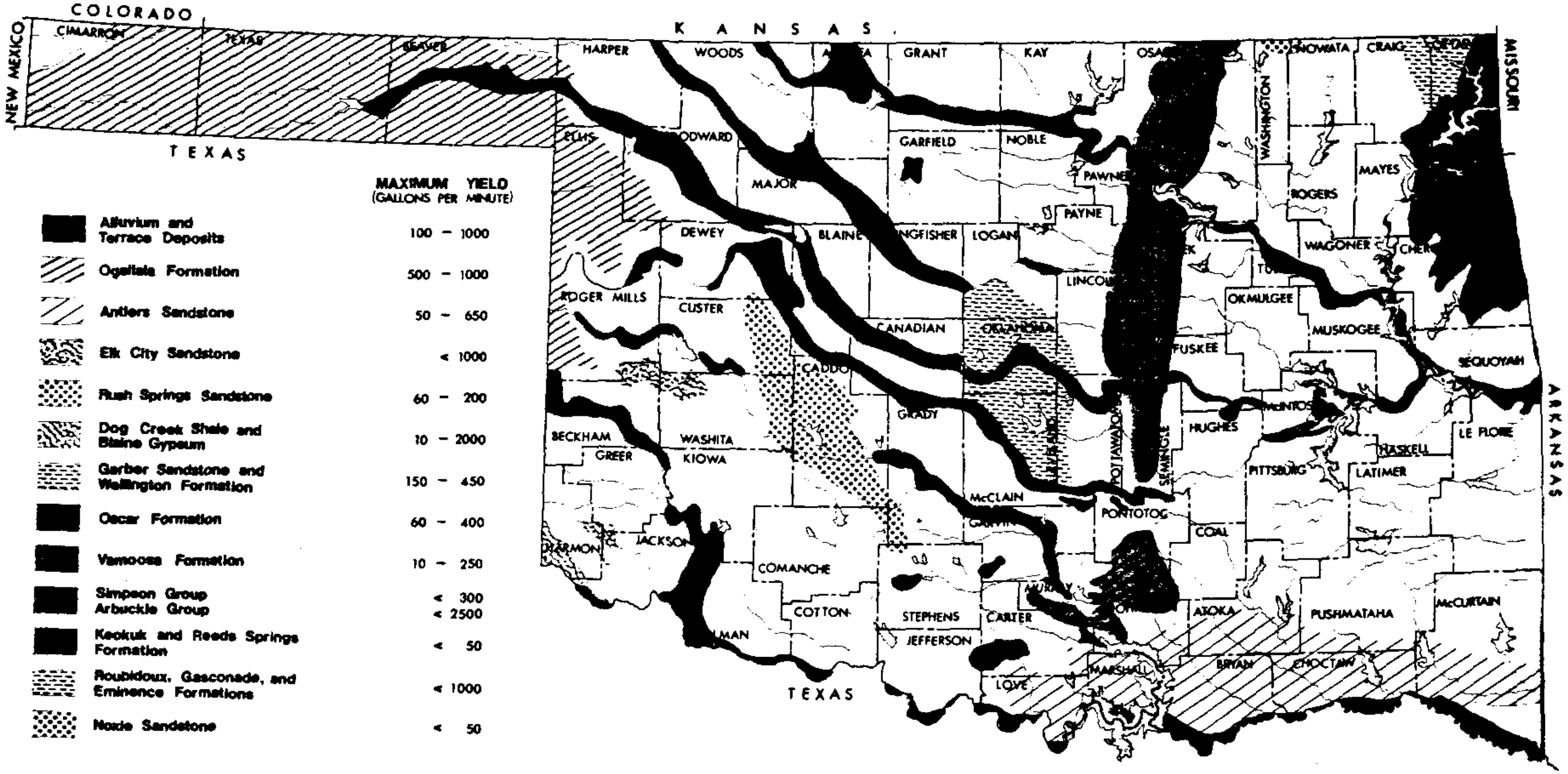

Figure 16. Major ground-water basins in Oklahoma.

At first glance, one possibility for improving the quality of water in the Post Oak is by artificial ground-water recharge. An examination of subsurface geological data strongly indicate that this technique would not be a viable solution in those areas where fluoride concentrations are high. First, artificial recharge would need to depend on injection through deep wells, which would be both expensive to construct and maintain, and the recharge water would require extensive chlorination and filtration in order to retard clogging of the well by sediment and bacterial slime. Secondly, if a source of recharge water were readily available, it would be more economical to use it as the source of supply. Finally, even if successful would serve to dilute only a very small part of the aquifer.

As described earlier, consumption of fluoride enriched water over a long period may lead to mottled teeth or even more serious effects, although lower concentrations are beneficial. Despite the locally high concentrations, the writers are not aware of any incidents of fluorosis in Comanche County. To overcome the potential adverse effects of high concentrations of fluoride in ground water from the Post Oak Formation, several options are available. These include blending the water with other sources to provide dilution, use other sources for drinking and cooking (bottled water or that obtained from other sources), and deepen existing Post Oak wells to tap the underlying Arbuckle limestone. In the latter case, it would be necessary to grout the casing at least through the lower part of the Post Oak so that high fluoride water would not leak downward into the limestone.

Another chemical that can cause a health problem is nitrate, which was also discussed previously. Nitrate, particularly in ground-water supplies, can occur naturally or through the activity of man. Wells contaminated with large concentrations of nitrate in Oklahoma, which occur sporatically throughout the State, generally have either one of two major causes--poor well construction and agricultural activities. The first case generally appears in shallow, dug wells that are either poorly grouted or not grouted at all. This allows contaminated surface water to flow directly into the well or down the side of the casing or cribbing. Barnyard wells or those constructed in the vicinity of septic tanks or cesspools are particularly susceptible. The user of well water that contains large concentrations of nitrate derived from barnyard runoff, septic tank effluent, or cesspool wastes should be concerned not only with the nitrate but also with other constituents that potentially might occur, such as pathogenic organisms. In cases such as these, the aquifer, for all practical purposes, is not likely to be contaminated but rather only the water in the well or in its near vicinity. This is generally not the case where agricultural sources of nitrate are concerned.

Where an aquifer, which is generally shallow or surficial, is contaminated as a result of agricultural activities, the nitrate is usually more wide spread. It is probably caused by the application of excessive amounts of fertilizer on coarse textured soils and the use of too much irrigation water. The presence of agriculturally derived nitrate should cause the well owner to show some concern about the potential presence of other agricultural chemicals, such as pesticides, which might also migrate through the unsaturated zone to the aquifer along with the fertilizer.

Infant methemoglobinemia, a disease characterized by blood changes and cyanosis, may be caused by preparing feeding formulae from water that contains high nitrate concentrations. On the other hand, clinical evidence is not entirely clear on the concentration levels that actually cause the disease and many other factors may be involved. Most reported cases have been associated with use of water that contains more than 50 mg/L of NO_3-N(McKee and Wolf, 1963). To the writers knowledge, there have been no reported cases of methemoglobinemia in the Central Plains regions for the past 30 years. Nonetheless, care should be exercised in the use of high nitrate water by pregnant women and children less than 6 months of age.

Since the population of individuals that could be affected by nitrate poisoning is very small at any one time, alternate sources of water could be used, particularly bottled water. There seems to be little value to the development of another source or the installation of expensive treatment equipment to remove nitrate when the problem for any one family would exist for only a few months and could be solved by the purchase of bottled water for drinking and formula preparation.

Contamination of ground-water supplies by chloride is a problem that appears to be common in all oil-producing states. Brine is a product of no value that is commonly produced with oil and disposing of it, commonly through pits, has led to a variety of problems. Other sources of chloride include leakage of brine from old abandoned wells and from disposal wells. Regulatory controls presently provide a substantial safeguard against contamination, but old sites, particularly old evaporation or disposal ponds, will probably continue to contaminate ground water, as well as streams, for years if not decades.

The limit of chloride in drinking water, 250 mg/L, was established only because of taste considerations rather than health. Taste thresholds between individuals range widely, but most individuals can not detect a salty taste unless the concentration of chloride exceeds 200 mg/L or more. Many plants, however, are quite sensitive to chloride, particularly alfalfa, fruit trees, and potatoes (McKee and Wolf, 1963). In some cases adverse effects appear when the concentration is less than 200 mg/L. Chlorides also increase the rate of corrosion of steel and aluminum.

Little can be done once a well is contaminated by objectionable concentrations of brine, other than to abandon the source. It may require years before the chloride is naturally flushed from the aquifer. It would be of no value to drill a new well of similar depth in the vicinity of the abandoned well because if the new one is not contaminated when it is constructed, it no doubt will become so some time after pumping starts. It might be possible to deepen the existing well or drill a new one deeper, so long as the contaminated zone is effectively sealed by grout. This is a questionable practice, but it may provide the only reasonable solution. Other alternatives include rather expensive treatment, use of cisterns, or the development of a surface supply.

Sulfate concentrations, particularly in ground water, can range widely from one place to another and with depth. They can be derived from natural sources, such as leaching of gypsum and through bacterial action, and from the degradation of organic compounds including sewage. The limit of 250 mg/L was established because of the laxative effect encountered by individuals unaccustomed to the water and in some place concentrations in excess of 600 mg/L have been or are used.

In Oklahoma sulfate and chloride is discharged from springs and seeps along the Cimarron River in Harper, Woods, and Woodward counties and in the southwestern part of Oklahoma (Greer, Kiowa, Harmon, Jackson, and Tillman counties) where the Blaine Gypsum and Dog Creek Shale crop out. Home owners in these areas who find sulfate concentrations objectionable might consider bottled water for selected domestic use, construction of a cistern, or a surface source whose drainage basin does not contain gypsum-rich strata at or near the surface.

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