TABLE 14.3
Consumptive use by various crops and native plants

		Consumptive use			
Crop	**Region**	**ft/yr**	**m/yr**	**Method**	**Authority**
Alfalfa	Bonners Ferry, Idaho	2.8	0.85	Tank	Criddle-Marr
Alfalfa	Los Angeles, Calif.	3.1	0.95	Field	Blaney
Beets	Scottsbluff, Nebr.	2.0	0.61	Field	Bowen
Citrus	Los Angels, Calif.	1.9	0.58	Field	Blaney
Cotton	Shafter, Calif.	2.5	0.76	Field	Beckett-Dunshee
Cotton	State College, N. Mex.	2.4	0.73	Tank	Israelson
Grass weeds	San Bernardino, Calif.	1.8	0.55	Tank	Blaney-Taylor
Greasewood	Escalante Valley, Utah	2.1	0.64	Tank	White
Mixed	San Luis Valley, Colo.	1.6	0.49	Field	Blaney-Rohwer
Mixed	Carsbad, N. Mex.	2.4	0.73	Field	Blaney-Morin
Mixed	Uncompahgre, Colo.	2.3	0.70	Field	Lowry-Johnson
Potatoes	San Luis Valley, Colo.	1.3	0.40	Tank	Blaney-Israelson
Rushes	Ft. Collins, Colo.	4.4	1.34	Tank	Parshall
Tamarisk	Safford, Ariz,	5.1	1.56	Tank	Turner-Halpenny
Tules	King Island, Calif.	7.5	2.29	Tank	Stout
Peaches	Ontario, Calif	2.5	0.76	Field	Blaney
Walnuts	Santa Ana, Calif.	2.1	0.64	Field	Beckett
Wheat	San Luis Valley, Colo.	1.2	0.37	Tank	Blaney-Israelson
Wheat	Bonner's Ferry, Idaho	1.5	0.46	Tank	Criddle-Marr
Wild hay	Gray's Lake, Idaho	2.6	0.79	Tank	Criddle-Marr

and other factors. Many crops are sensitive to water shortages during specific growth stages. Maximum dry-matter production occurs when water use is approximately equal to potential evaporation. The cost of water and other fixed charges on the farm, such as cost of investment, labor, fertilizer, taxes, and insurance, enter into the determination of the most economic use of water. The point of maximum yield is not necessarily the best goal, as illustrated in Figure 14.7, where the maximum net return is achieved with applied water of 1.7 ft/yr, which is considerably less than the 2.3 ft/yr of applied water required for maximum yield. The shape of curve 2 in Fig. 14.6 depends on the water-pricing schedule. The curve will be concave upward for increasing unit cost with larger water use.

14.7 Crop-Irrigation Requirement

The crop-irrigation requirement is that portion of the consumptive use that must be supplied by irrigation. It is the consumptive use less the effective precipitation, i.e., $U_c - P_{eff}$. Winter precipitation is effective only to the extent that it remains in the soil until the growing season. Average moisture retention per foot of depth for various soil types is given in Table 14.4. Effective winter precipitation is the actual precipitation or the available moisture storage, whichever is less. Only storage in the root zone, which usually extends to a depth of about 4 ft (1.2 m), should be considered.[1]

Precipitation during the growing season is effective only when it remains in the soil and is available to plants. Rainfall-runoff relations (Sec. 3.6) might be used to estimate soil moisture accretion storm by storm, but this would be a tedious job if done for a long record. More in accord with the accuracy of estimates of water requirements is the assumption of a linear variation from 100 percent effectiveness for the first inch of rain in a month to zero effectiveness for all rain over 6 in. (152 mm) in a month. Such an approach assumes a maximum effective precipitation of 3.5 in. (88 mm) in a month. This is obviously only an approximation; the value will vary depending on the soil type. The effective growing-season precipitation is the sum of the monthly values of effective precipitation. The average annual effective precipitation for the period of record is subtracted from the estimated annual consumptive use to determine the annual crop-irrigation

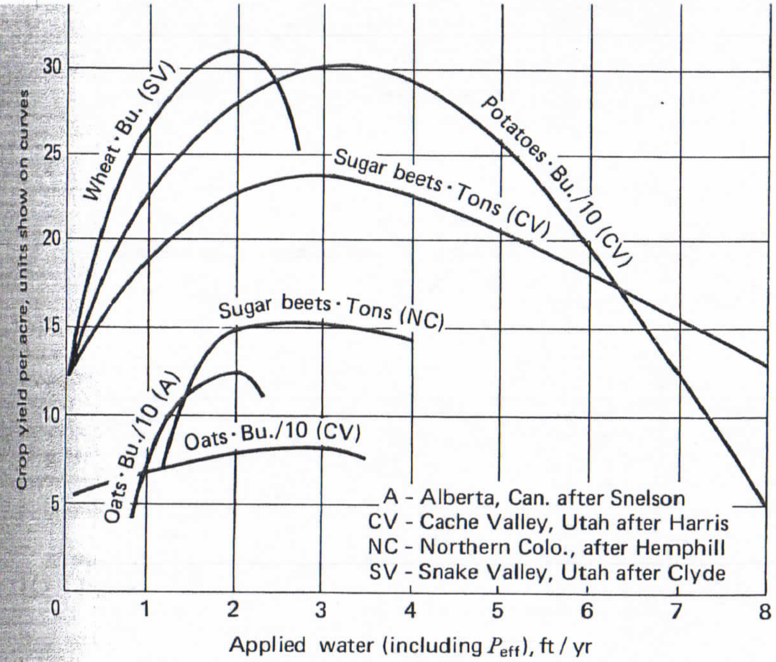

FIGURE 14.6
Some examples of the variation of crop yield with applied water.

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[1] Some grasses have a root zone no greater than 1 ft (0.3 m) while the root depth of alfalfa and fruit trees often exceeds 10 ft (3 m).

The ratio of irrigation water consumed ($U_c - P_{\text{eff}}$) to q_f is called the *farm-irrigation efficiency*. Average efficiencies[1] are usually between 40 and 60 percent, although with careful choice of irrigation method, application rate, and irrigation frequency to fit the soil conditions, efficiencies above 80 percent are possible under favorable conditions.[2] As water shortages become more severe, efficient irrigation practices will become more important if agriculture is to compete with municipal and industrial uses for water.

14.9 Diversion Requirement

In addition to farm losses, some water will be lost in delivery to the farm (*conveyance loss*). This loss consists of evaporation from the canal, transpiration by vegetation along the canal bank, seepage from the canal,[3] and operational waste. Evaporation and transpiration losses from canals are ordinarily small and are usually neglected. Operational waste includes water discharged through wasteways because of refusal by users to take the total flow, leakage past gates, and losses from overflow or breakage of canal banks. The magnitude of operational waste depends on the care that is exercised in the operation of the system but should be less than 5 percent. The largest factor in conveyance loss is seepage (Sec. 10.13). The diversion requirement may be taken as the sum of the farm delivery and the estimated conveyance loss. As an alternative, conveyance losses may be estimated as a fraction of the diversion, and the diversion requirement q_d in depth per year is then

$$q_d = \frac{q_f}{1 - L_c} \tag{14.3}$$

where L_c is the conveyance loss in decimals. With open ditches, conveyance loss will usually range between 15 and 30 percent of the diversion. Conveyance losses may be virtually eliminated by using a pipe system, and economy would result if the added cost were offset by the value of the water saved.

The farm delivery and project diversion requirements expressed in terms of volume are found by multiplying q_f and q_d by the respective net areas that are to be irrigated.

Example 14.2. An irrigator plans to irrigate 200 acres of cotton whose consumptive use is estimated to be 32 in./yr. Analysis of past rainfall records indicates that the effective precipitation varies from zero in very dry years to 8 in. wet years. Water will be delivered to the irrigated acreage by canal. Assuming a delivery loss of 20 percent and a farm-irrigation efficiency of 60 percent, what would be the range of annual diversion requirements in acre feet?

Solution

Dry year: $$q_d = \frac{32 - 0}{(1 - 0.2) \times 0.6} = 66.7 \text{ in.}$$

Wet year: $$q_d = \frac{32 - 8}{(1.0 - 0.2) \times 0.6} = 50 \text{ in.}$$

Diversion requirements:

Dry year: $$200 \times \frac{66.7}{12} = 1112 \text{ acre-ft/yr}$$

Wet year: $$200 \times \frac{50}{12} = 833 \text{ acre-ft/yr}$$

14.10 Irrigation Water Quality

Not all water is suitable for irrigation use. Unsatisfactory water may contain (1) chemicals toxic to plants or to persons using the plants as food, (2) chemicals that react with the soil to produce unsatisfactory moisture characteristics, and (3) bacteria injurious to persons or animals eating plants irrigated with the water.

Actually it is the concentration of a compound in the soil solution that determines the hazard, and soil solutions are 2 to 100 times as concentrated as the irrigation water. Hence, criteria based on the salinity of the irrigation water can only be approximate. At the beginning of irrigation with undesirable water no harm may be evident, but with the passage of time the salt concentration in the soil may increase as the soil solution is concentrated by evaporation. Free drainage of soil allows the downward movement of salts and helps to prevent serious accumulations. Artificial drainage of soil (Chap. 18) may be necessary for this reason if natural drainage is inadequate.

High salt concentrations may sometimes be avoided by mixing the salty water with better-quality water from another source so that the final concentration is within safe limits. Precipitation during the nongrowing season will help to leach salts from the soil. It may, however, become necessary to apply an excess of irrigation water so that deep percolation will prevent undesirable salt accumulation in the soil. If the salinity of the irrigation water is C and the depth applied is q_a, the salinity C_s of the soil solution, after accounting for the precipitation P_{eff} and the consumptive use U_c, is $q_a C/(q_a + P_{\text{eff}} - U_c)$. Hence, from this relation, the theoretical depth of water q_a of salinity C required to maintain the soil solution at concentration C_s is

$$q_a = \frac{C_s(U_c - P_{\text{eff}})}{C_s - C} \tag{14.4}$$

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[1] M. E. Jensen, Evaluating Irrigation Efficiency, *J. Irrigat. Drainage Div., ASCE*, Vol. 93, pp. 83–98, March 1967.

[2] J. Keller, Effect of Irrigation Method on Water Conservation, *J. Irrigat. Drainage Div., ASCE*, Vol. 91, pp. 61–72, June 1965.

[3] A. Bandini, Economical Problems of Irrigation Canals: Seepage Losses, *J. Irrigat. Drainage Div., ASCE*, Vol. 92, pp. 35-57, December 1966.

Because of variations in soil characteristics and salt concentrations, actual applications for leaching are usually higher than indicated by Eq. (14.4).

A large number of elements may be toxic to plants or animals. Traces of boron are essential to plant growth, but concentrations[1] above 0.5 mg/L are considered deleterious to citrus, nuts, and deciduous fruits. Some truck crops, cereals, and cotton are moderately tolerant to boron, while alfalfa, beets, asparagus, and dates are quite tolerant. Even for the most tolerant crops a concentration of boron exceeding 4 mg/L is considered unsafe. Boron is present in many soaps and thus may become a critical factor in the use of wastewater for irrigation. Selenium, even in low concentration, is toxic to livestock and must be avoided.

Salts of calcium, magnesium, sodium, and potassium may also prove injurious in irrigation water. In excessive quantities these salts reduce the osmotic activity of plants, preventing the absorption of nutrients from the soil. In addition they may have indirect chemical effects on the metabolism of the plant and may reduce soil permeability, preventing adequate drainage or aeration. The effect of salts on the osmotic activity of plants depends largely on the total salts in the soil solution. The critical concentration in the irrigation water depends upon many factors; amounts in excess of 700 mg/L are harmful to some plants, and more than 2000 mg/L of dissolved salts is injurious to almost all crops.

Most normal soils of arid regions have calcium and magnesium as the principal cations, with sodium representing generally less than 5 percent of the exchangeable cations. If the sodium percentage in the soil is increased to 10 percent or more, the aggregation of soil grains breaks down and the soil becomes less permeable, crusts when dry, and its pH increases toward that of alkaline soils. Since calcium and magnesium will replace sodium more readily than vice versa, irrigation water with a low *sodium-adsorption ratio* (SAR) is desirable. The SAR is defined as

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})/2}} \qquad (14.5)$$

where the concentration of the ions is expressed in *equivalents per million* (epm).[2] The SAR indicates the relative activity of the sodium ions in exchange reactions with the soil. An irrigation water with a high SAR will cause the soil to tighten up.

The U.S. Department of Agriculture[3] has classified irrigation waters into four groups (Fig. 14.8) with respect to sodium hazard depending on the SAR value and the specific conductance (Sec. 15.7). By adding gypsum, $CaSO_4$, to the water or directly to the soil, the SAR value can be reduced. Observations of water quality in streams or groundwater may not be sufficient to judge their suitability for irrigation. Evaporation from reservoirs increases salt concentration in surface water and leached salts from irrigation may progressively raise the concentration of salts in groundwater. These changes must be considered in the planning phase.

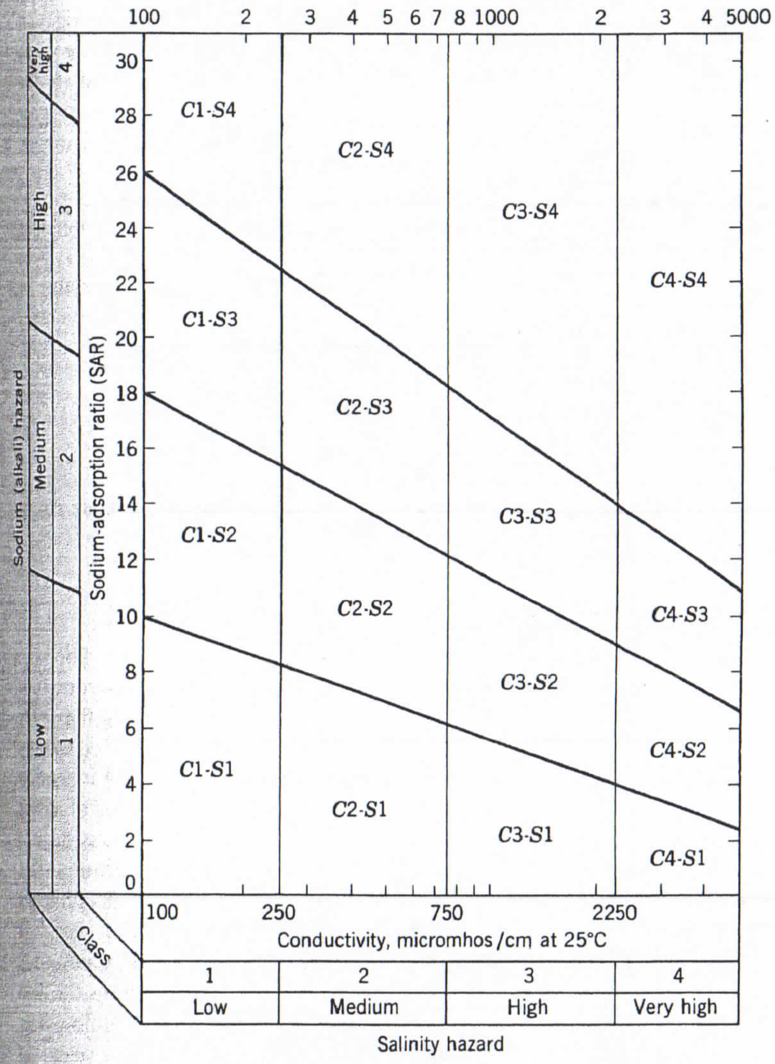

FIGURE 14.8
Diagram for classification of irrigation waters.

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[1] Concentrations are commonly expressed in milligrams of salt per liter of water. This is numerically equal to the old term, parts per million by weight.

[2] Equivalents per million are determined by dividing the concentration of the salt in milligrams per liter (ppm) by the combining weight. See Appendix A-11.

[3] L. V. Wilcox, Classification and Use of Irrigation Waters, *U.S. Dept. Agr. Circ.* 969, 1955.

Bacterial contamination of water is normally not serious from the irrigation viewpoint unless severely contaminated water is used on crops which are eaten uncooked. Raw wastewater is used for irrigation in many countries, but in the United States its use is frowned upon except for nursery stock, cotton, and other crops processed after harvesting. Most states have regulations governing the use of wastewater for irrigation.

Example 14.3. Find the sodium-adsorption ratio of a water with the following characteristics: sodium 250 mg/L, calcium 110 mg/L, and magnesium 48 mg/L. If the conductivity of this water is 80 micromhos/cm at 25°C, is this water suitable for agriculture?

Solution

$$\text{SAR} = \frac{250/23}{\left(\dfrac{110/20 + 48/12}{2}\right)^{0.5}} = 4.99$$

Reference to Fig. 14.8 shows that the salinity hazard is a bit high, but there should be no problem with sodium.

14.11 Irrigation Methods

There are five basic methods of applying irrigation water to fields—flooding, furrow irrigation, sprinkling, subirrigation, and trickle irrigation. Numerous subclasses exist within these basic methods. *Wild flooding* consists in turning the water onto natural slopes without much control or prior preparation. It is usually wasteful of water, and unless the land is naturally smooth, the resulting irrigation will be quite uneven. Wild flooding is used mainly for pastures and fields of native hay on steep slopes where abundant water is available and crop values do not warrant more expensive preparations. *Controlled flooding* may be accomplished from *field ditches* or by use of *borders*, *checks*, or *basins*. Flooding from field ditches is often adaptable to lands with topography too irregular for other flooding methods. It is relatively inexpensive because it requires a minimum of preparation. Water is brought to the field in permanent ditches and distributed across the field in smaller ditches spaced to conform to the topography, soil, and rate of flow (Fig. 14.9). Under ideal conditions, the ditch spacing and flow rate should be such that the water will just infiltrate in the time it is flowing across the field. If the flow is too rapid, some of the water will not have time to infiltrate and surface waste will occur at the lower edge of the field. If flow is too slow, excessive percolation will occur near the ditch, and too little water will reach the lower end of the field.

The border method of flooding requires that the land be divided into strips 30 to 60 ft (10 to 20 m) wide and 300 to 1200 ft (100 to 400 m) long. The strips are separated by low levees, or *borders*. Water is turned into each strip through a head gate along one of the narrow sides and flows downhill the length of the strip. Preparation of land for border-strip irrigation is more expensive than for ordinary flooding, but this may be offset by a decrease in water waste because of the improved control. *Check flooding* is accomplished by turning water into relatively level plots, or checks, surrounded by levees. If the land is initially level, the plots may be rectangular but with some initial slope the checks will usually follow the contours. Check flooding is useful in very permeable soils where excessive percolation might occur near a supply ditch. It is also advantageous in heavy soils where infiltration would be inadequate in the time required for the flow to cross the field. In check flooding the check is filled with water at a fairly high rate and allowed to stand until the water infiltrates. The *basin-flooding* method is check flooding adapted to orchards. Basins are constructed around one or more trees depending on topography, and the flow is turned into the basin to stand until it infiltrates. Portable pipes or large hoses are often used in place of ditches for conveying water to the basins.

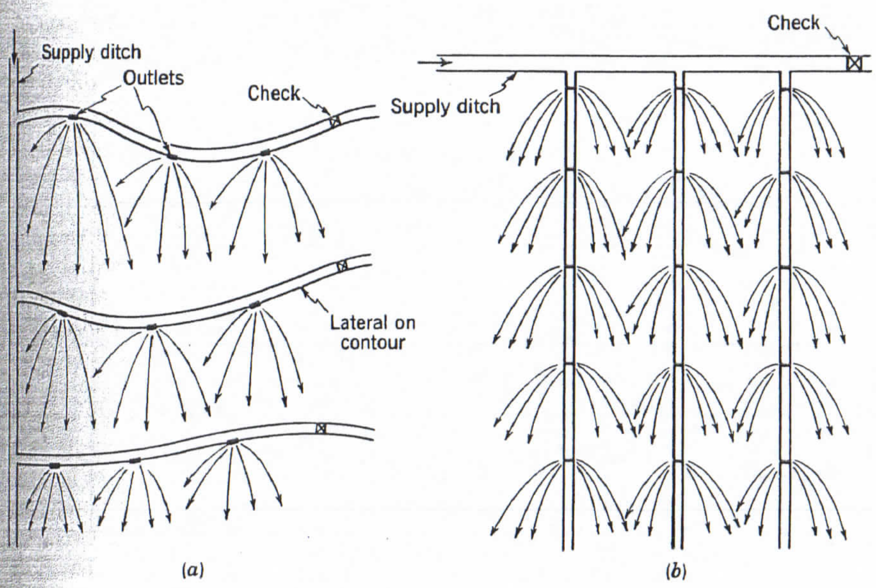

FIGURE 14.9
Methods of flooding from ditches: (*a*) from contour laterals; (*b*) from downslope ditches.

Furrow irrigation is widely used for row crops, and small furrows called *corrugations* have been used for forage crops such as alfalfa. The furrow is a narrow ditch between rows of plants. An important advantage of the furrow method is that only 0.2 to 0.5 as much surface area is wetted during irrigation as compared with flooding, and evaporation losses are correspondingly reduced. Furrow irrigation is adapted to lands of irregular topography. Customarily the furrows are run normal to the contours, although this should be avoided on steep slopes where soil erosion may be severe. Spacing of furrows is determined by the proper spacing of the plants. Furrows vary from 3 to 12 in. (10 to 30 cm) deep and may be as much as 1500 ft (500 m) long. Excessively long furrows may result in too much percolation near the upper end and too little water at the downslope end. Water may be diverted by an opening in the bank of the supply ditch, but many farmers now use small siphons made out of 4-ft lengths of plastic or aluminum tubing about 2 in. in diameter. These siphons are easily primed by immersion in the ditch and provide a uniform flow to the furrow without the necessity of damaging the ditch bank.

In contrast to flooding and furrow irrigation, which depend on gravity flow, *sprinkler irrigation* requires a pressurized system. Pressure may be provided by gravity flow from a high-elevation reservoir or elevated tank or directly from a pump. The pressurized system is an added expense when compared to a gravity system. The development of lightweight pipe with quick couplers resulted in a rapid increase in sprinkler irrigation after World War II. Sprinkler irrigation offers a means of irrigating areas whose topography is so irregular that they prevent the use of any surface-irrigation methods. Sprinkler irrigation is now widely used on level land as well as on land with rough topography. High labor costs have increased the attractiveness of sprinkler irrigation. Sprinkling may be accomplished using a hand-move system in which nozzles are moved by hand from time to time; this is a low capital-cost system that requires substantial labor. A solid-set system is one in which the nozzles are set in a quasipermanent position. They may be moved occasionally, though sometimes are left in a permanent location. A *side-roll system*[1] (Fig. 14.10) is often used on level fields. The side-roll system consists of a series of aluminum wheels that serve to suspend the sprinkler pipeline above the ground. The entire line is moved by a motor installed near the center or end of the line and water is supplied by a flexible hose. The sprinkler heads are self-leveled with a weighted block. The amount of water applied to the field can be regulated by adjusting the speed of the motor. Other systems include the fixed center-pivot system, which may or may not provide overlap of the areas to which water is applied (Fig. 14.11). Some areas may receive water from two, three, or more sprinklers depending on their spacing. Sprinkler systems must be carefully designed so that water is distributed as evenly as possible over the irrigated fields. Sprinkler systems are usually designed so that pressures at the sprinkler nozzle are in the range of 30 to 60 psi though some systems may have pressures as high as 150 psi.

In a few areas soil conditions are favorable to *subirrigation*. The required conditions are a permeable soil in the root zone, underlain by an impermeable horizon or a high water table. Water is delivered to the field in ditches spaced 50 to 100 ft (15 to 30 m) apart and is allowed to seep into the ground to maintain the water table at a height such that water from the capillary fringe is available to the crops. Low flow rates are necessary in the supply ditches; and free drainage of water must be permitted, either naturally or with drainage works, to prevent waterlogging of the fields. The irrigation water should be of good quality to avoid excessive soil salinity. Subirrigation results in a minimum of evaporation loss and surface waste and requires little field preparation and labor. Subirrigation has been employed in the Egin Bench project, Idaho; in Cache Valley, Utah; in San Luis Valley, Colorado; and in the delta of the Sacramento and San Joaquin Rivers in California.

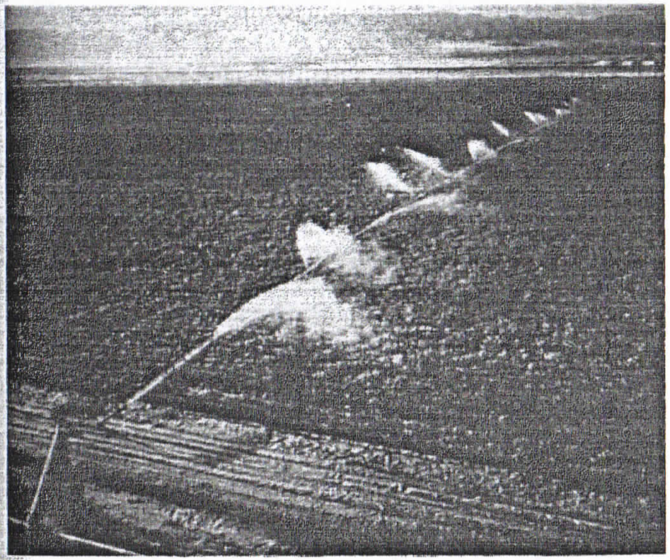

FIGURE 14.10
Side-roll sprinkling system. The pipe is supported by twenty-four 5-ft-diameter wheels that are not visible in the photograph. (*Thunderbird Irrigation, Inc.*)

In *trickle* (or *drip*) *irrigation* a perforated plastic pipe is laid along the ground at the base of a row of plants. The perforations are designed to emit a trickle (5 L/h or less) and spaced to produce a wetted strip along the crop row or a wetted bulb at each plant. The main advantage of trickle irrigation is the excellent control, since water can be applied at a rate close to the rate of consumption by the plant. Evaporation from the soil surface is minimal and deep percolation almost entirely avoided. Nutrients can be applied directly to the plant roots by adding liquid fertilizer to the water. Salinity problems are minimal for the salts move to the outer edge of the wetted zone away from the roots. Investment costs are high, but

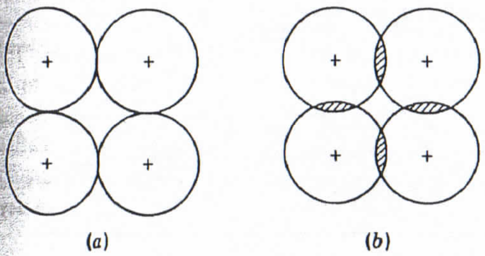

FIGURE 14.11
Irrigation water coverage with a center-pivot system: (*a*) with no overlap; (*b*) with overlap (hatched areas get water from two sprinklers).

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[1] The side-roll system is also referred to as the *wheel-follower sprinkling system*.

labor costs are low once the system is set up. The technique of trickle irrigation was developed in Israel.

14.12 Supplemental Irrigation

Even in humid regions where rainfall is usually adequate for crop growth, drought periods of several days and longer do occur. Such droughts may have a serious effect on crop production if they occur when seeds require moisture for germination or during other critical periods in plant growth. Many farmers in humid regions of the country have installed equipment for supplying irrigation water during droughts. Sprinkler irrigation is most common because it can be introduced without prior preparation of the land. Row crops can often be irrigated by the furrow method with perforated pipe in lieu of supply ditches. In some instances the return in increased crops in a single year has repaid the investment. In general, however, supplemental irrigation must be viewed as a long-term investment in insurance against serious drought. Sprinkler equipment has in some instances been used as a means of frost protection. If a crop is wet when freezing temperatures occur, the water must be frozen before the plant temperature will drop below the freezing point. Because of the high heat of fusion of water, this offers considerable protection against air temperatures as low as 25°F (−4°C).

14.13 Drainage of Irrigated Lands

It is important that irrigated lands be properly drained to prevent the land from becoming waterlogged. In many situations the formations underlying the top soil are of such a nature that proper drainage occurs naturally. In areas where the water table is near the ground surface or where there may be an underlying layer of hardpan or other relatively impermeable material, it is essential that the land be provided with a drain system. This is most commonly achieved through use of open ditches set at a low-enough elevation to provide drainage. Details of land drainage are presented in Sec. 18.10 through 18.16.

14.14 Irrigation Systems and Structures

A typical irrigation system may include structures and devices such as dams, spillways, diversion works, canals, ditches, wells, pumps, and pipelines. These have been discussed in Chaps. 8 through 12. Delivery from the point of diversion to the irrigated farm may be by canal or pipeline. The latter is more costly, but the former results in large water loss due to seepage from the canals. Lining canals (Sec. 10.13) to reduce water loss and thus conserve water is commonplace. The capacity required of the delivery system depends on the size of the area to be irrigated, the type of crop, the effective precipitation and the irrigation scheduling program—not all fields are irrigated at the same time. For example, if irrigation takes place once every 5 days, one-fifth of the total use rate is the required capacity of the delivery works. This assumes irrigation occurs uniformly for 24 hr each day. Assuming an 8-hr irrigation period each day, the required capacity of the delivery channel would be three-fifths of the total use rate. The same concepts should be applied when designing distribution canals and ditches. If delivery and distribution is by pipeline to sprinklers, the pipe system must be designed to provide adequate pressure (Sec. 14.11) so that the sprinkler nozzles operate properly.

Farm ditches must be at a sufficient elevation to permit gravity flow to the field. Hence, they are rarely fully excavated but are made in broad, shallow dikes (Fig. 14.12). Gates for regulating flows in the ditch system may be of wood, steel, or concrete. Steel or wooden gates are used for temporary installations where the gate is replaced each time the ditch is rebuilt. Permanent gates (Fig. 14.13) are often of concrete with wooden or metal flashboards. In order to raise the level of the water in a ditch to make diversion into a field possible, a check may be required. These may be wooden or steel dams, but often a timber laid across the channel and supporting a piece of heavy canvas with its lower end weighted down with earth is sufficient.

Division boxes (Fig. 14.14) may be used to distribute flow to several channels. If an accurate division of flow is required, a symmetric Y divider or a division weir (Fig. 14.15) may be used. For accurate flow division, the divider must be installed in a long, straight channel in order that the velocity distribution across the channel may be reasonably uniform. A proportional division of flow from an underground pipe may be accomplished by bringing the water into a stilling basin with overflow weirs discharging into separate channels (Fig. 14.16).

To avoid loss of water and the annual cost of ditch construction, many farmers are turning to the use of pipe distribution systems. Concrete pipe is widely used for permanent underground installation with riser pipes at intervals to bring the water to the surface. The risers may discharge through top boxes, designed to control erosion at the outlet, into small field ditches which convey the water to the furrows or basins. Special valves called *alfalfa*, or *orchard*, *valves* can be attached to the top of the riser pipes to control the flow. Portable hydrants (Fig. 14.17) can be installed on the top of the alfalfa valves to direct flow in a definite

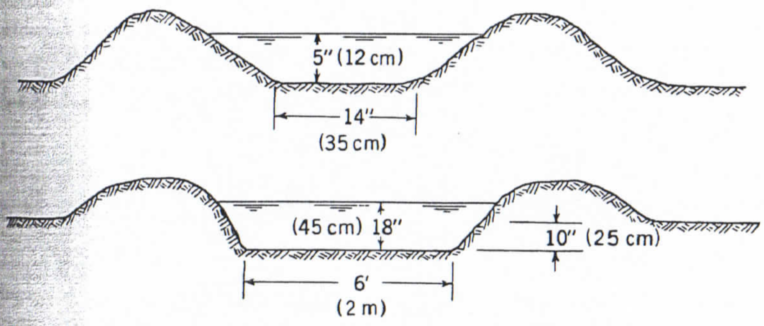

FIGURE 14.12
Typical cross sections for farm ditches.

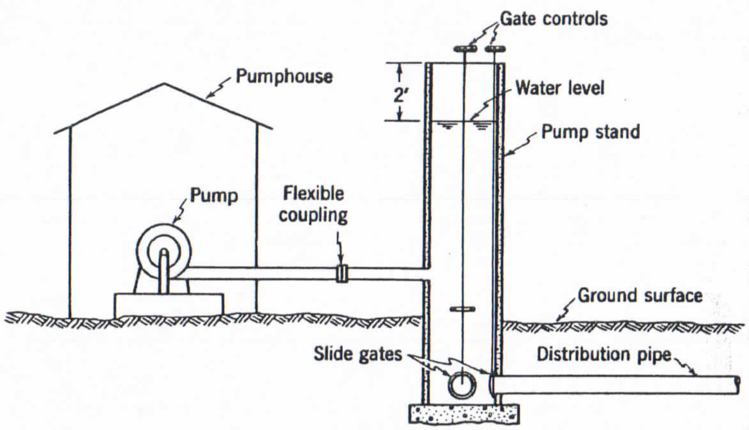

FIGURE 14.18
Typical irrigation pump house and pump stand.

off orifices not in use. Portable pipe is often used to carry water from a well to a field. In addition to conservation of water, use of pipes increases the area available for cultivation and permits a flexibility of operation which is difficult to obtain with ditch irrigation.

Considerable labor is involved in operating an irrigation system, and some of the inefficiencies of irrigation result from inadequate attention to such operation. Consequently much attention is now being given to automation of irrigation using float-activated systems which can operate unattended.[1]

14.15 Legal Aspects of Irrigation

A single farm may sometimes be irrigated by diversion of flow from a small stream at a cost which an individual farmer can bear. Projects requiring expensive storage or conveyance works are usually beyond the capability of an individual to develop and require some sort of group effort. The first large irrigation projects in the United States were privately developed under two different types of organizations. The earliest projects were *irrigation cooperatives*, or *mutual irrigation companies*, in which farmers banded together to construct and maintain the necessary works. These companies were often unincorporated, and division of water was on the basis of labor contributed to the construction. Later, incorporated mutual companies were organized in which the participating farmers were shareholders and water was sold at cost in quantities based on established water rights.

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[1] H. R. Haise, E. G. Kruse, and L. Erie, Automating Surface Irrigation, *Agr. Eng.*, Vol. 50, pp. 212–216, April 1969.

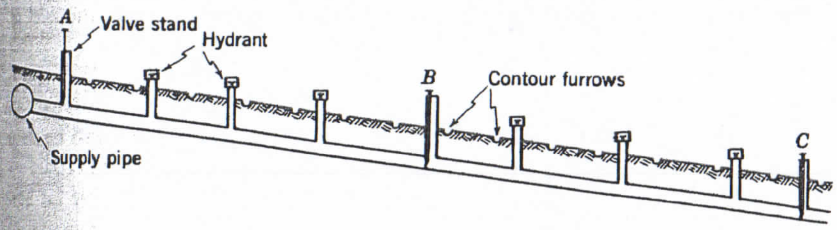

FIGURE 14.19
Pipe distribution system for irrigating hillsides.

During the irrigation boom of the late nineteenth century, many *commercial irrigation companies* were organized. These companies, financed by stock sale to nonresident as well as resident investors, constructed irrigation projects and obtained water rights so that they might sell water. These speculative operations ran into many difficulties. Farmers sometimes let their land lie idle until the water company went bankrupt for lack of water sales. They then purchased the bankrupt company at a fraction of its value and organized a new company, either commercial or mutual. Other speculators sometimes purchased land and held it idle to force a water company out of business. The most effective commercial operation was the development company, which owned both water and land and developed the project for the potential profit from the increased land values. Many commercial irrigation enterprises are still in operation, but many more have been converted to mutual companies.

A quasi-public *irrigation district* is now the most common type of organization in the United States. An irrigation district is an organization formed in accordance with state laws[1] on the basis of a majority vote of the voters of the district. Funds to finance district operations are raised by water tolls, bond issues, assessments on the irrigable land within the district, and assessments on lands benefiting indirectly from the district operations as, for example, the business centers of the area. Districts are usually governed by directors elected by the district voters, and their management of district affairs is subject to regulations prescribed by state law.

Early federal laws made it possible to settle on public lands, but since title to the land remained with the government until the land was reclaimed, it was impossible to use the land as security for loans to finance the irrigation works needed. The Carey Act (1894) attempted to correct this by allotting each Western state 1 million acres (400,000 hectares) of public land for development. State laws varied but, in general, provided that individuals or corporations might, by contract with the state, construct irrigation works and sell water rights to the settlers on

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[1] The first such law was passed in California in 1887.

the land. On the whole, the Carey Act was a disappointment because the cost of reclamation was too great for most potential developers.

The Reclamation Act (1902) provided a revolving fund for federal development of irrigation in the 16 Western states.[1] The fund was initially to consist of all money received from the sale of public land in these states, and was to be used for projects at the discretion of the Secretary of Interior, the cost to be repaid by the settlers over a period of 10 yr, thus making the money again available for new construction. Subsequent acts have increased the statutory repayment period to 40 yr with a 10-yr development period before repayment must begin. Longer repayment periods are possible with special congressional approval. Project costs chargeable to navigation or flood mitigation need not be repaid by water users, and revenue from power sales is credited against the irrigation costs. Since 1915 congressional approval for expenditures from the fund has been necessary. The act of 1920 provided that 52.5 percent of royalties from public-land oil leases be included in the Reclamation Fund. The 1926 act limited the land for which a single owner could obtain water from federal projects to 160 acres, to encourage development of small farmsteads instead of large, corporation-owned ranches. Acreage limitation was fought long and hard by irrigation districts and farmers. In 1982 the Reclamation Reform Act raised the amount of land for which a family can receive subsidized federal project water from 160 to 960 acres. Special acts govern major projects such as the Boulder Canyon and Columbia Basin projects.

Throughout the world in recent decades there have been a number of national programs of agrarian reform aimed toward improving the living conditions in rural areas by developing irrigation projects to provide water for irrigation. Various procedures for acquiring land ownership are included in these programs. Unfortunately many of these programs have been unsuccessful because the people were not properly trained to farm the land efficiently.

14.16 Some Economic Aspects of Irrigation

The water supply for an irrigation project need not meet the demand for optimum plant growth in all years. Though water deficiency will result in reduced crop yields, it will be economic to have a water deficiency in drier years if the savings in cost of a smaller system exceed the value of the reduced crop yield over the project planning period.

The large water requirement inherent in irrigating large areas is augmented by wasteful irrigation practices, conveyance losses, and leaching requirements. That part of the applied water which eventually returns to the stream after irrigation is called *return flow*. Because of evaporative loss and additional salts leached from the soil, salt concentrations in streams of irrigated regions tend to increase downstream. The actual consumptive use of irrigation water is that part returned to the atmosphere by evaporation and transpiration, i.e., diverted water less return flow and accretion to deep groundwater. However, the water which is not consumptively used has been degraded by increased salt content and has lost economic value.

Many federal reclamation projects sell water to the irrigator at prices well below cost. This subsidy encourages irrigated agriculture and may help the economic development of the region. Such subsidies also lead to irrigation of marginal crops on marginal land and encourage wasteful use of water. Subsidized irrigation may limit the supply of water for industry, which yields much higher returns per unit of water than agriculture. The relation of the expected crops from irrigated agriculture to the existing surpluses must also be considered in evaluating a proposed irrigation project.

14.17 Planning the Irrigation Project

No two irrigation projects are identical, and no absolute outline of procedure for project design is feasible. The list that follows summarizes in general terms the steps required for most projects:

1. Land classification (Sec. 14.1).
2. Estimate of irrigation water requirement (Secs. 14.2 to 14.6).
3. Determination of sources of available water (Chaps. 2 to 4).
4. Establishment of legal title to water (Chap. 6).
5. Analysis of chemical quality of available water (Sec. 14.10).
6. Design of storage reservoir to assure necessary water (Chap. 7).
7. Design of dam and spillway for storage reservoir or diversion works (Chaps. 8 and 9).
8. Design of distribution works (Chaps. 10 and 11).
9. Economic analysis of the project to determine whether the estimated cost is returnable from the potential benefits (Chap. 13), and financial analysis to establish a repayment plan (Sec. 21.9).
10. Analysis of the environmental and social impacts of the various project alternatives (Sec. 21.10).
11. Project evaluation based on economic, financial, environmental, and social considerations (Sec. 21.8).
12. Establishment of the organization that will operate the project (Sec. 14.13). In some cases this is a necessary first step, since the operating organization may also design the project.

PROBLEMS

14.1. Shown in the following are the particle-size distributions for several soils. Classify these soils texturally on the basis of the classification triangle of Fig. 14.1.

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[1] Texas was included as the seventeenth state at a later date.