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Chapter 5
Water Sources

5-1. Introduction

a. General considerations. The selection of a water source may range from a relatively simple, straightforward choice dictated by local conditions to a complex and difficult decision involving the careful and deliberate consideration of many factors. At the very least, the following points should be considered for each available alternative source of supply:

(1) Adequacy and reliability with respect to providing water in sufficient quantity.

(2) Expected water quality.

(3) Development cost.

(4) Operation and maintenance cost.

(5) Monitoring and health requirements.

b. Alternative sources. Ordinarily, there are no more than four alternative categories of sources of supply to consider:

(1) Connection to an existing system.

(2) Water hauling.

(3) Development of groundwater resources.

(4) Development of surface water resources.

Of course there may be more than one alternative source within each category. For example, one may have the option of obtaining groundwater via wells in several locations or from springs, or of purchasing water from more than one existing system. Thus, it is theoretically possible to have several options. However, practicalities often limit the choices substantially. In any event, an important tool for the decision-making process is a sanitary survey of all alternative sources of supply. The conduct of such a survey and other important design elements are discussed in some detail in the following sections.

5-2. Sanitary Survey

a. Introduction. A sanitary survey should be performed for all alternative sources of supply. The validity of such a study is highly dependent upon the background and experience of the investigator. The services of a qualified sanitary or environmental engineer, sanitarian, or other public health professional should be obtained for this purpose.

b. Purposes. The principal purposes of a sanitary survey are to discover, investigate, and evaluate all conditions that might adversely affect the quality of a water supply or the adequacy of the supply to deliver water at a satisfactory rate. The survey also affords the opportunity to gather other basic information that may be useful in analyzing the general suitability of the source.

c. Sampling. The details of the survey will vary depending upon the source under study and prevailing local conditions. However, the collection of samples for subsequent chemical and physical analysis and microscopic and microbiological examination will always be a key element. This is no simple matter since the collection of truly representative samples is nearly always a challenge. Even when the physical constraints on sampling are minimal, it is easy to inadvertently contaminate them by faulty sampling technique and lack of attention to detail. This is especially true of samples to be subjected to microbiological examination for colifom organisms, or analysis for trace organic chemicals or trace elements. It is good practice to obtain detailed instructions and sampling procedures from laboratories that will be analyzing the samples. State and local health departments are excellent sources of information and often will supply sterile sample containers and analyze microbiological samples. Health departments usually maintain lists of approved laboratories where other analyses can be performed. All samples should be obtained, handled, processed, and analyzed in a manner conforming to American Public Health Association (1980), U.S. Environmental Protection Agency (USEPA) (1979a), or specific regulatory agency guidelines.

d. Analyses. The exact analyses to be performed are specified by either state, local, or Federal regulations generally depending on the finished system size and classification. Generally, in the absence of gross pollution, the list of analyses should include at least those itemized below:

(1) Acidity.

(2) Alkalinity.

(3) pH.

(4) Free carbon dioxide.

(5) Total residue.

(6) Total volatile residue.

(7) Total hardness.

(8) Calcium hardness.

(9) Temperature.

(10) Color.

(11) Taste.

(12) Odor.

(13) Turbidity.

(14) Nitrate nitrogen.

(15) Total chloride.

(16) Total fluoride.

(17) Total chlorine demand.

(18) Free available chlorine.

(19) Total coliforms.

(20) Fecal coliforms.

It is also good practice to have samples analyzed by some scanning-type methodology to identify the various organic compounds that may be present. This is expensive, but often worthwhile, especially if there is any reason to believe that such contaminants might be present.

e. Data interpretation. The interpretation of data generated by the water analyses must be closely coordinated with and based upon the results of other portions of the sanitary survey because the quality of water taken from different types of sources and under different conditions is naturally expected to vary. For example, water taken from an impounded river should not be judged by the same standards as water taken from a municipal distribution system. Thus, consultation with public health officials and other knowledgeable professionals is the first step in interpreting survey findings. General guidelines for evaluating the quality of water supplies were presented in Section 3-8. Other topics specifically related to various types of water sources are discussed in the following sections.

5-3. Existing Supplies

a. Introduction. Connection to an existing drinking water supply system is the source of choice if such can be accomplished economically. However, this decision should be based upon a careful evaluation of all available information rather than on the mere presence of an existing system.

b. Advantages.

(1) General. There are several potential advantages to tapping onto an existing water supply system. Some examples are listed below:

(a) Source development costs are avoided.

(b) Operation and maintenance are often greatly simplified.

(c) Substantial operation and maintenance costs may be avoided.

(d) Administrative responsibility may be greatly reduced.

(e) Regulatory burdens may be reduced or eliminated.

(f) Certain legal liabilities may be avoided.

(2) Operation and maintenance. While all these factors may be significant, those directly related to operation and maintenance are frequently the most important (USEPA 1979c). The most critical aspect is that small systems often cannot afford, nor do they really need, to employ highly qualified full-time water system managers and operators. The minimum level of operator qualification is specified by state, local, or Federal authorities. In evaluating the expense of any system, the cost to meet and maintain the required standard can be a heavily weighted factor. Thus, connection to an existing water system can be very attractive.

(3) Regulatory. Release from some or all of the regulatory burden of the SDWA may also be an important factor in certain situations. The NPDWR do not apply when the receiving system consists solely of storage and distribution facilities, all water is obtained from a publically owned system to which the regulations do apply, and the receiving system neither sells water nor is a carrier conveying passengers in interstate commerce. Obviously, when all these conditions are met, considerable expense and effort can be avoided. Community systems are generally precluded from taking advantage of this situation since they buy water for resale. Specialized systems, however, such as those serving rest stops and recreation areas may qualify. In theory, no major compromise with respect to water quality is involved since the water must meet or exceed the requirements of the SDWA when it enters the receiving system. The regulatory burden is merely shifted from the receiving system to the supplying system.

c. Disadvantages.

(1) General. There are also potential disadvantages to tapping onto an existing system. These may be described in broad terms as related to

(a) Management and operation.

(b) Connection costs.

(c) Water quality.

Each of these general areas is discussed below.

(2) Management and operation. One potential disadvantage is that the receiving system has virtually no control, and often little influence, over the management and operation of the supplying system. A second is that the receiving system is somewhat at the mercy of the supplying system with regard to the price paid for water. A third, and associated, potential disadvantage is that it may not be possible to negotiate a satisfactory long-term water purchase agreement. When a series of short-term agreements must be negotiated, there is always the possibility that the management of the supplying system may lose their desire to cooperate. This is especially true if the water demand in the supplying system's own service area increases to the point of taxing existing facilities. In this situation, one may expect a higher priority to be placed on meeting these local demands than selling water to other systems. Thus, it is evident that careful consideration must be given to short- and long-term effects of a water purchase agreement on both the receiving and the supplying systems.

(3) Connection costs. Major economic disadvantages may arise when the connecting pipeline must be long or pass through difficult terrain, the pressure at the connection point is low or highly variable, booster pumping is required, or substantial storage must be available to equalize the flow at the diversion point. While some of these conditions may require significant operation and maintenance expense and effort, their principal effects will be on initial capital investment. This may not always be a true disadvantage, however, since extra funds may be more readily available for initial investment than for continuing operation.

(4) Water quality.

(a) General. The existing system should be investigated in as much detail as possible during the sanitary survey phase of planning. Special emphasis should be placed on factors that might influence future water quality. It is a mistake to assume that water quality will always be acceptable simply because the supplying system must, by law, comply with state and Federal regulations.

(b) System operation and maintenance. The surveyor should look carefully at all intakes, pumping stations, treatment plants (including all operations and processes), storage facilities, distribution systems, and connections with other systems, especially industrial and fire protection systems. The system should be investigated for actual or potential sanitary defects such as direct and indirect cross connections, improper location of water mains, or broken or leaky mains. Since a complete onsite inspection of the entire distribution system is often impractical or prohibitively expensive, indirect evidence such as the existence of an aggressive cross connection control program, good maps of the system, administrative attention to detail, good record keeping, an adequate shop, and supply of spare parts and equipment may be important. Attention should be given to assessing the competence and dependability of operating and management personnel and the overall philosophy of system administrators.

d. Other considerations.

(1) Introduction. TM 5-813-1 suggests that the investigation of an existing supply include at least the following items.

(a) Source.

(b) Reliability.

(c) Quantity developed.

(d) Ultimate quantity.

(e) Excess supply available not already allocated.

(f) Type of treatment.

(g) Rates in gallons per minute at which supply is available.

(h) Cost per thousand gallons.

(i) Distance from site to existing supply.

(j) Variation in pressure at the point of diversion.

(k) Ground elevation at point of diversion and at point of use.

(l) Existence of contaminating influences.

A brief discussion of topics deserving special attention is presented below.

(2) Institutional arrangements. If the decision is made to connect to an existing system, all institutional arrangements should be made before the construction contract is let. This will aid in preventing unforeseen changes during construction that could affect the preferred water source alternative. In many projects, the Corps has paid the capital costs for construction with the larger system agreeing to accept ownership after construction and provide continued operation and maintenance of the system.

(3) The connection. The designer should be sure to specify that the actual connection between the systems be made in a readily accessible location, and that valves are placed so that the two systems can be quickly isolated from each other if necessary. The master meter should be located in a well-protected but accessible box or vault. The piping arrangement should be designed so that the meter can be bypassed easily when service is required. The possibility of backflow from the receiving system to the supplying system should be prevented in a way that will comply with the water surveyors regulations. The meter selected for use should be accurate over the expected range of flow rates. This is an important consideration since the pipeline will often be designed for a flow rate in excess of the actual flow rate, especially that for the early years of a project. Ordinarily, the actual connection and the meter installation will become the property of the supplying system. Thus, it is important that the interests of the receiving system be well protected by proper design.

e. Summary. Connecting to an existing supply system may substantially reduce routine operation and maintenance costs and effort; but water purchase costs, quality, and quantity are subject to control by the supplying system. Thus, the decision to tap onto an existing system should not be made lightly. On the whole, it appears that where economic factors are favorable, the advantages usually outweigh the disadvantages.

5-4. Groundwater

a. Introduction. When connection to an existing water supply system is not feasible or desirable, the development of groundwater resources is often the logical choice. This is especially true if the quality of the water is such that minimal treatment (and hence operator time and effort) is required. While groundwater may be obtained from springs, shallow wells, or deep wells, the emphasis in this manual is on deep wells. However, much of the basic material on deep wells is also applicable to shallow wells. Springs are usually not suitable for any but the very smallest systems, and the likelihood of finding a good spring in the right location is low. Readers interested in the development of springs are referred to American Association for Vocational Instructional Materials (1973), Cairncross and Feachem (1978), Folks (1977), Salvato (1982), USEPA (1979c), and U.S. General Accounting Office (1982).

b. Wells.

(1) Sanitary survey. When a well supply is being considered, information in addition to that described in Section 5-2 should be obtained as part of the sanitary survey. The following specific items deserve attention:

(a) Character of local geology.

(b) Slope of ground surface.

(c) Size of catchment area.

(d) Probable rate of recharge of water-bearing formations.

(e) Nature and type of soil and underlying strata.

(f) Depth to water table.

(g) Variations in depth to water table.

(h) Thickness and location of water-bearing strata.

(i) Location, log information, yield, and water quality analysis of nearby wells.

(j) Nature and location of sources of pollution.

(k) Possibility of surface water entering the supply directly.

(l) Influence of *any* surface water on the quality of the well water, indirectly.

(m) Physical, chemical, bacteriological, and radiological analyses of the raw water.

(n) Type of treatment required.

(o) Well spacing required to prevent mutual interference.

(p) Legal clearances required because of proximity to the wells of others.

(q) Drawdown data from nearby wells.

(r) Total seasonal and long-term pumpage from the area.

(s) Permeability of the aquifer.

(t) Velocity of groundwater flow.

(u) Rainfall amount, distribution, and intensity.

Much of this information may be available from state and local health departments, state geological agencies, the U.S. Geological Survey, local water utilities, well drillers, and private citizens. However, there is no real substitute for test well data. The ease of obtaining such data varies widely depending upon a number of factors including the relative abundance of groundwater resources in the local area, the attitudes and practices of local well drillers, the nature of the subsurface materials, and the depth to water-bearing strata. Where subsurface conditions are favorable, experienced local well drillers may be willing to guarantee to locate sufficient quantities of high-quality water. In this situation, test wells involve little risk. When conditions are unfavorable, the risk factor increases dramatically, but the need for test wells increases also. Although they can be expensive, pump tests are usually a good investment. In fact, it is not possible to complete the design of a well system until the wells are actually opened and tested. In some cases exploration costs can be mitigated by converting test wells to production wells.

(2) Water quality. A word of caution concerning the quality of groundwaters is in order. It has long been widely believed that groundwater, especially that taken from deep wells, is relatively free of contamination of anthropological origin when compared to surface water. However, such an assumption can no longer be safely made. A study of groundwater in New Jersey (Page 1982) revealed that groundwaters (from more than 1,000 wells) exhibited the same pattern of contamination as did surface waters (from over 600 sites), and that groundwater was at least as contaminated as surface water. The toxic contaminants investigated included 27 light hydrocarbons, 20 heavy chlorinated hydrocarbons, and 9 metals. The concentrations of the majority of the substances were either not significantly different or were greater in the groundwater samples when compared to the surface water samples. Much of this type of contamination was generated by landfill disposal practices. In 1977, the USEPA (1977b) estimated that as much as 220 million metric tons of industrial wastes end up in land disposal areas each year. While the health significance of long-term exposure to low levels of many contaminants has yet to be determined, it is obvious that groundwater is not necessarily “purer” than surface water. The problem of groundwater contamination is complicated by the possibility of long lag periods (even many years) between application of contaminants to the soil and their appearance in aquifers used for water supply. On the whole, it is prudent to expend resources as necessary to determine if a potential groundwater source is, or is likely to be, so contaminated that it is rendered unacceptable. This is one justification for test wells and detailed sanitary surveys.

(3) Construction. Excellent guidance relative to well construction is available in USEPA (1975). In addition, state and local health departments usually provide detailed information concerning well construction within their jurisdictions. Where applicable, wells should be constructed in accordance with Standard A100-66 of AWWA (1966). Several key elements to be considered in well design are presented below.

(a) Types. Wells may be dug, bored, driven, jetted, or drilled. While no single construction method is universally superior, deep wells (more than 30 m (100 ft) deep) are usually constructed by percussion or rotary drilling. Drilling may also be used for shallow wells, but is often not the most economical technique for that purpose. Properly constructed drilled wells are usually more dependable and less likely to be contaminated than other types (Salvato 1982). There are, however, exceptions. Well construction is highly specialized and local conditions are quite variable. Therefore, it is advantageous to obtain the services of someone who is knowledgeable, experienced, and fully familiar with well construction in the project area before writing specifications and contract documents for constructing wells.

(b) Location. As a rule, wells should be located on fairly high ground to ensure against contamination by surface water. The site chosen should be as far away as is practicable from known sources of pollution such as septic tanks, cesspools, privies, sewer lines, sanitary landfills, hazardous waste disposal sites, feedlots, or barnyards. It is not possible to say exactly what a safe distance is without detailed information on the site. A good rule of thumb is to maintain a minimum distance of 30 m (100 ft) between shallow wells (less than 15 m (50 ft) deep) and possible sources of contamination with an even greater distance in karst topography. In addition, such wells should always be located hydraulically upgradient of the source of contamination. Groundwater flow in shallow aquifers often parallels that of surface flow, but this should be verified before final site selection is made. Consult the appropriate regulations prior to selecting the final well location.

(c) Casings. Well casings serve to provide a stable, uniform opening from the surface to the aquifer by preventing collapse of the well wall. They also serve to prevent the entry of possibly contaminated water from other waterbearing strata or the surface. Sometimes the casing is placed as the well is being drilled depending on the method of well construction. Sometimes lightweight temporary casings are used and then replaced if the well proves satisfactory. In order to seal the well against possible contamination, it is common practice to grout the region between the outside of the casing and the well hole. The casing should be large enough to accommodate equipment that must be lowered into the well (e.g., submersible pump) and strong enough to resist the forces and stresses to which it is exposed during placement and operation. Leakproof joints between casing segments are important; thus, welded or threaded connections are usually used. All things considered, the requirements favor black steel casings. However, various plastics can be used for this purpose and may be of use, especially when severe corrosion of iron or steel would occur. Local well construction regulations may not permit plastic well casing. Ordinarily, casing sizes vary from a minimum of about 100 millimeters (mm) (4 in.) in diameter for wells with yields of less than 200 liters (50 gallons) per minute to 600 mm (24 in.) or more for wells with yields of around 8000 to 11 000 liters (2000 to 3000 gallons) per minute. TM 5-813-1 specifies that, except when water requirements are small, the minimum diameter of deep wells should be 200 mm (8 in.).

(d) Screens. When water is to be removed from unconsolidated geologic formations, it will be necessary to install a well screen. The ideal screen would be designed to allow water to pass without significant resistance, while at the same time prohibiting the entry of solid particles into the well and preventing collapse of the walls. A variety of designs are available from equipment manufacturers and suppliers. The size of the screen required for a given installation depends upon the type of screen selected, its hydraulic capacity, and the expected pumping rate as well as other factors. Screen selection should be influenced heavily by possible effects of corrosion and encrustation and the difficulty of cleaning and replacement. Screen selection should be performed by someone experienced in well design.

(e) Alignment. A drilled well should be reasonably straight and plumb. Of the two, straightness is usually the more important since it determines if a vertical turbine or submersible pump of a given size can be installed in the well. However, deviations from plumb may cause excessive wear or reduction in performance of some pumps. Most well codes specify allowable tolerances. Typical specifications suggest that a well should not vary from the vertical by more than one well diameter per 30 m (100 ft) of length and that a well should be straight enough to allow a 9-m- (30-ft-) long dummy having an outside diameter 13 mm (0.5 in.) less than the casing to move freely to the lowest anticipated pump location (Steel and McGhee 1979).

(f) Development. Development is a technical term for the process of removing “fines” (silt, fine-grained sand, etc.) from the vicinity of the well screen. The term is also applied to well construction in general. Development is almost always practiced when the aquifer being tapped is in an unconsolidated formation and is usually needed in other situations, such as a rock-wall well. The basic technique is to alternate the direction of flow across the screen and thus flush the fines away. Hydrojetting, bailing, overpumping, intermittent pumping, surging with a surge block or compressed air, and backwashing are all used for this purpose. Surging with a surge block or compressed air or hydrojetting is usually the preferred method in screened wells. The result is that the well screen is surrounded by a highly permeable layer of “clean,” well-graded material that allows free flow into the well; thus, the yield is increased. Such wells are sometimes referred to as “naturally gravel packed.” When suitable natural material is not present, it may be necessary to enlarge the diameter of the bottom of the well and introduce well-graded gravel. Wells constructed in this manner are called “gravel packed.” The development method should be chosen with care since it is possible to inadvertently clog the well. One practice that encourages good development procedures is to build into the contract a bonus for capacity in excess of some stated amount and a penalty for lesser capacity.

(g) Testing. Following development, a pumping test should be performed. The major purpose of this test is to determine the yield and drawdown characteristics of the well. If the data are taken carefully, it is also possible to learn a great deal about the hydraulic characteristics of the aquifer. This is especially true if observations at a nearby well in the same aquifer can be made simultaneously. However, a well pumping test serves primarily to test the completed well as a hydraulic structure and not the aquifer itself. Detailed procedures for conducting well pumping tests are readily available elsewhere (American Association for Vocational Instructional Materials 1973; AWWA 1966; Campbell and Lehr 1973; Folks 1977); and guidance is also available from the U.S. Geological Survey, state and local health departments, state geological survey agencies, well equipment manufacturers, etc., and is not presented herein. However, a few especially important points deserve mention. One is that the quality of information gleaned from a pumping test is closely linked with the accuracy to which determinations of flow rate and pumping depth are made. A second factor is that the temporary pump selected for the test should have a capacity at least 50 percent in excess of that of the pump planned for permanent installation. An even better approach is to select a pump having a capacity equal to or greater than the expected yield of the well. Thirdly, the discharge of the test pump should be easily controlled so that tests can be performed at several flow rates. The minimum flow rate needed is usually about 50 percent of the maximum. Deep well turbines are suitable for this purpose, as is any type of pump powered by a gasoline motor (can be throttled to vary flow rate). Finally, the pumping test should be continued long enough to provide a high degree of confidence in the results. There is no way to say in advance how long will be necessary, but 24 to 48 hours is a good estimate. When the well yield is not guaranteed by the driller, it is good practice to write the contract for this portion of the work on a per hour basis. This way it is not to the driller's advantage to end the test prematurely. When yield is guaranteed, the contract documents should clearly state the basis on which yield will be determined.

(h) Preventing contamination. Regardless of the construction method used, the well must be sealed effectively to prevent the entry of any water except from the aquifer being tapped. There are several techniques that may be used to accomplish this. One is to fill the region between the outside of the casing and the well wall with neat grout. The best method is to pump the grout in from the bottom up. Another technique is to extend the top of the casing at least 0.3 m (1 ft) above the pump house floor when applicable. The use of a pitless adapter (i.e., no well pit) and an effective sanitary seal is also important. Where practical, the area around the top of the well should be covered with concrete sloped to divert runoff away from the well. Other means of diversion may also be employed. It is usually better to drill a new well rather than try to extend a large-diameter well (e.g., a dug well) by drilling in the bottom. The old well will almost always serve as a source of contamination for the new well. Care should also be taken to avoid contamination, accidental or otherwise, during construction. Failure to exclude undesirable water is a frequent cause of well contamination. Wells generally should be vented unless the pump utilized demands an airtight installation (this is true for certain types of jet pumps). The vent should be considered as a possible source of contamination and located accordingly. It is good practice to extend the vent at least 600 mm (2 ft) above the highest known flood level, turn the opening downward, and cover it with a screen.

(i) Disinfection. Once construction is completed, the well should be cleaned of all ropes, oil, grease, timbers, pipe dope, tools, cement, etc., and disinfected. The standard procedure (AWWA 1966) calls for chlorine to be added to the well in a sufficient amount to produce an initial theoretical concentration of at least 50 mg/L and then remain in the well for at least 2 hours. A longer period, e.g., 24 hours, is better. Virtually any form of free available chlorine and any technique for application may be used. (To be effective, the chlorine must be in a valence state greater than -1. Therefore, chlorides are not useful.) Calcium hypochlorite is a popular dry form and sodium hypochlorite, a liquid, is readily available in several strengths as well as household bleach (about 50 000 mg/L free available chlorine). All equipment in contact with the water should also be disinfected (e.g., the pump). Following disinfection, the chlorine solution should be pumped out and the well should be sampled and tested for total coliform organisms. The absence of any coliforms is taken as evidence of disinfection. Samples should then be taken and subjected to chemical and physical analysis to ensure that the water is suitable for human consumption. The disinfection process should be repeated whenever the well is opened for maintenance (e.g., pump replacement), or if excessive coliform organisms are detected by routine testing.

(j) Number of wells. The number of wells required is a function of the total need for water, the yields of individual wells, the desired operating schedule, the water storage facilities available, regulatory requirements, and the desired excess capacity. It is advantageous to have at least two wells if economically feasible, and it is good practice to construct enough wells to meet average daily needs in substantially less than a full day of operation. TM 5-813-1 specifies an operating day of 16 hours (or less), and a minimum of two wells except for very small camps, or when flowing artesian wells or springs serve as the source. It should be noted that all wells should be provided with some way to measure water levels.

(k) Abandoned wells. On occasion, it is necessary that a well be closed, for example, a test well or an existing well that will no longer be used. Failure to properly seal such wells can lead to the contamination of entire aquifers. This has already occurred in some locations. AWWA (1966) presents a procedure to be used. Local regulatory agencies may have their own specifications.

5-5. Surface Water

a. General. Surface water is usually the source of last resort for small water systems because surface water almost invariably requires substantial treatment prior to use. Treatment, of course, requires a treatment plant, which, in turn, requires considerable capital investment and operation and maintenance effort. The picture is made even less favorable by the fact that surface water quality usually varies to such an extent that even the most automated treatment plants require considerable operator attention. Thus, the economics are often unfavorable. However, many times conditions are such that surface water is a viable alternative or the only feasible choice. The diversity of surface waters is so great that extended discussion herein would serve no useful purpose. However, some key design elements are considered briefly in the following sections.

b. Sanitary survey. The purposes and some major elements of the sanitary survey were presented in Section 5-2. Other specific points of interest for surface water supplies are listed below. The particular source being investigated will dictate the principal thrust of the study.

(1) Topography.

(2) Geology.

(3) Land use.

(4) Vegetative cover.

(5) Rainfall (amount and distribution).

(6) Streamflow and surface runoff patterns.

(7) Adequacy of the supply including seasonal effects.

(8) Wastewater discharges (type, location, strength, quantity, type of treatment provided).

(9) Necessity for an impoundment.

(10) Potential reservoir sites.

(11) Development costs.

(12) Legal constraints (use doctrine, prior rights).

(13) Historical water quality.

(14) Potential for protection of water quality.

(15) Future plans of other users.

c. Types. Surface water supplies are generally of one of three basic types: unregulated streams, impoundments, or natural lakes. Lengthy discussion of these categories is unwarranted since local conditions vary so widely. However, some general points of interest are presented in the following sections.

(1) Unregulated streams. Wide variations in both streamflow and water quality make unregulated streams a poor choice in most cases. If such a stream is chosen, the dry-weather flow should be estimated carefully since it determines the safe yield. If the maximum demand is greater than the safe yield, alternative sources, such as wells, must be developed or water shortages will occur. Even if the flow is sufficient, water quality may still be a serious problem, especially for small water systems, since close attention to treatment plant operation will be required. Off-stream raw water storage can help alleviate both problems, but can be rather expensive.

(2) Large lakes and impoundments. Large lakes or impoundments are often good sources of supply if they are located so that transmission costs are not excessive. The quality of such waters changes seasonally, but in a somewhat predictable fashion and, on a day-to-day basis, is less variable than for unregulated streams. The effects of varying water quality can be offset to some degree by the flexibility to take water from different depths. This is especially effective for deeper bodies of water that undergo a seasonal thermal stratification/destratification cycle. Lakes or impoundments receiving significant wastewater discharges should be viewed with caution since the buildup of nutrients such as phosphorous and nitrogen may lead to excessive algal productivity. Algae can cause operational difficulties for treatment processes, e.g., filtration, and can produce a wide variety of taste and odor problems. In addition, algae are producers of trihalomethane precursors; thus their presence can complicate disinfection or require additional treatment.

(3) Small lakes and impoundments. Small impoundments and natural lakes may be good sources of supply. This is especially true when the water system can own or control the entire watershed. This arrangement allows the water resource to be managed in such a way to protect and enhance water quality and ensure that competing uses do not adversely affect water supply. Economical yields of 75 to 90 percent of the annual streamflow can be realized in favorable situations. Methods for determining the storage volume needed to meet specific water demands were introduced in Section 4-3 and are given excellent coverage in many water supply oriented textbooks (Clark, Viessman, and Hammer 1977; Fair, Geyer, and Okun 1966a; Salvato 1982; Steel and McGhee 1979; and Viessman et al. 1977). The Federal Highway Administration (Folks 1977) has identified the following characteristics of the ideal small rural water supply watershed:

(a) Clean.

(b) Grassed.

(c) Free of contamination sources (barns, feedlots, privies, septic tanks, and disposal fields, etc.).

(d) Protected from erosion.

(e) Protected from drainage from livestock areas.

(f) Fenced to exclude livestock.

In addition, they suggest the following criteria for the impoundment or lake:

(a) At least 2-1/2 m (8 ft) deep at the deepest point.

(b) Maximum possible water storage in areas more than 1 m (3 ft) deep.

(c) Able to store at least a one-year water supply.

(d) Fenced.

(e) Free of weeds, algae, or floating debris.

d. Water quality and treatment. Water treatment facilities represent a significant portion of the total cost of a typical surface water system. The specific operations and processes required are determined by a combination of raw water quality, desired finished water quality, and regulatory requirements. Conventional surface water treatment involves removal of turbidity followed by disinfection. Processes used for these purposes are virtually required by regulation regardless of the quality of the raw water. Additional processes and operations for iron and manganese removal, softening, taste and odor control, etc., can be easily integrated into the treatment scheme, but contribute significantly to both first and continuing costs. Therefore, surface waters requiring specialized treatment should be avoided when possible. Sources exhibiting wide or rapid changes in water quality should also be avoided since such variations increase operating difficulty considerably. For more information that may be useful in choosing among alternative sources on the basis of the treatment required, the reader is referred to standard works on water treatment (AWWA 1971, 1990; Clark, Viessman, and Hammer 1977; Fair, Geyer, and Okun 1966a, 1966b; Salvato 1982; Sanks 1978; Steel and McGhee 1979).

e. Intakes. Intake systems are required to remove the water from the source and deliver it to transmission facilities. Design of intakes is highly site-specific; however, most can be categorized as submerged or exposed tower types. Regardless of the system chosen, intakes should be located well away from wastewater or stormwater discharges or other potential sources of contamination. Other factors that may impact on the design of intakes are type of source; water depth; bottom conditions; navigation requirements; effects of floods, currents, and storm or bottom conditions, and exposed structures and pipelines; prevalence of floating materials; and freezing.

(1) Submerged intakes. Submerged intakes may be applicable to lakes, streams, and impoundments, and are frequently utilized by small water systems. A common design consists of a wooden crib held in place by riprap or concrete. The inlet ports lead directly to submerged pipelines, and are covered by wooden slats that act as a screen. Inlet velocities are kept quite low so that clogging does not occur. This type of intake is located where bottom materials are stable and there is no interference with navigation. The pipelines carry the water to a pumping station located on shore. Such installations usually require very little maintenance. Another approach is to simply extend submerged pipes, with special fittings (e.g., flared end with strainer or a section of well screen) attached, into the water. The pipelines can be supported at the desired depth or held in place by a system of floats and anchors if flexible piping is used. Movable intakes have been used when the water depth varies over a large range, but they tend to be troublesome and require considerable attention.

(2) Tower intakes. More elaborate intakes consisting of exposed towers with multiple inlets are frequently used for larger flows. These systems can be very complex and may include automatically cleaned screens, pumping stations, and even living quarters.

(3) Infiltration galleries. When bottom conditions are unstable or water surface elevations fluctuate widely, infiltration galleries should be considered. These types of installation may be considered as surface or groundwater intakes since they perform essentially as horizontal wells, but are located at shallow depths and very near surface water sources. Typical designs call for well screens or perforated pipes to be laid near the edge of the water source, at an elevation below the lowest water level. Occasionally the infiltration gallery may be constructed directly under the water source rather than alongside it. Water flows through the soil from the surface source to the intakes, and is pumped out to a treatment facility. Water quality is similar to that typically expected from shallow wells. Frequently the only treatment required is disinfection. The use of this type of intake may result in substantially reduced treatment plant construction costs, as well as lower operation and maintenance requirements.