CHAPTER 3

GEOLOGIC, SOIL, AND GROUNDWATER INVESTIGATIONS

3-1. General. Before selecting or designing a system for dewatering an excavation, it is necessary to consider or investigate subsurface soils, groundwater conditions, power availability, and other factors as listed in table 3-1. The extent and detail of these investigations will depend on the effect groundwater and hydrostatic pressure will have on the construction of the project and the complexity of the dewatering problem.

3-2. Geologic and soil conditions. An understanding of the geology of the area is necessary to plan any investigation of subsurface soil conditions. Information obtained from the geologic and soil investigations as outlined in TM 5-818-1/AFM 88-3, Chapter 7 or NAVFAC DM7.1, should he used in evaluating a dewatering or groundwater control problem. Depending on the completeness of information available, it may be possible to postulate the general

Table 3-1. *Preliminary Investigations*

Item	Investigate	Reference
Geologic and soil conditions	Type, stratification, and thickness of soil involved in excavation and dewatering	Para 3-2; TM 5-818-1/ AFM 88-3, Chapter 7 NAVFAC DM7.1
Criticality	Reliability of power system, damage to excavation or foundation in event of failure, rate of rebound, etc.	
Groundwater or piezometric pressure characteristics	Groundwater table or hydrostatic pressure in area and its source. Variation with river stage, season of year, etc. Type of seepage (artesian, gravity, combined). Chemical characteristics and temperature of groundwater.	Para 2-3 and 3-3
Permeability	Determine permeability from visual, field, or laboratory tests, preferably by field tests.	Para 3-4; Appendix C
Power	Availability, reliability, and capacity of power at site.	Para 3-5
Degree of possible flooding	Rainfall in area. Runoff characteristics. High-water levels in nearby bodies of water.	Para 3-6

characteristics and stratification of the soil and rock formations in the area. With this information and the size of and depth of the excavation to be dewatered, the remainder of the geologic and soil investigations can be planned. Seismic or resistivity surveys (as well as logged core and soil borings) may be useful in delineating the thickness and boundaries of major geologic and soil formations and will often show irregularities in the geologic profile that might otherwise go undetected (fig. 3-1).

a. ***Borings.***

(1) A thorough knowledge of the extent, thickness, stratification, and seepage characteristics of the subsurface soil or rock adjacent to and beneath an excavation is required to analyze and design a dewatering system. These factors are generally determined during the normal field exploration that is required for most structures. Samples of the soil or rock formation obtained from these borings should be suitable for classifying and testing for grain size and permeability, if the complexity of the project warrants. All of the information gathered in the investigation should be presented on soil or geologic profiles of the site. For large, complex dewatering or drainage projects, it may be desirable to construct a three-dimensional model of colored pegs or transparent plastic to depict the different geologic or soil formations at the site.

(2) The depth and spacing of borings (and samples) depend on the character of the materials and on the type and configuration of the formations or deposits as discussed in TM 5-818-1/AFM 88-3, Chapter 7. Care must be taken that the borings accomplish the following:

(*a*) Completely penetrate and sample all aquifers that may have a bearing on dewatering an excavation and controlling artesian pressures.

(*b*) Identify (and sample) all soils or rocks that would affect or be affected by seepage or hydrostatic pressure.

(c) Delineate the soil stratification.

(*d*) Reveal any significant variation in soil and rock conditions that would have a bearing on seepage flow, location and depth of wells, or depth of cutoff. Continuous wash or auger boring samples are not considered satisfactory for dewatering exploration as the fines tend to be washed out, thereby changing the character of the soil.

b. Rock coring. Rock samples, to be meaningful for groundwater studies, should be intact samples ob tained by core' drilling. Although identification of rocks can be made from drill cuttings, the determination of characteristics of rock formations, such as frequency, orientation, and width of joints or fractures, that affect groundwater flow requires core samples. The percent of core recovery and any voids or loss of drill water encountered while core drilling should be recorded. The approximate permeability of rock strata can be measured by making pressure or pumping tests of the various strata encountered. Without pressure or pumping tests, important details of a rock formation can remain undetected, even with extensive boring and sampling. For instance, open channels or joints in a rock formation can have a significant influence on the permeability of the formation, yet core samples may not clearly indicate these features where the core recovery is less than 100 percent,

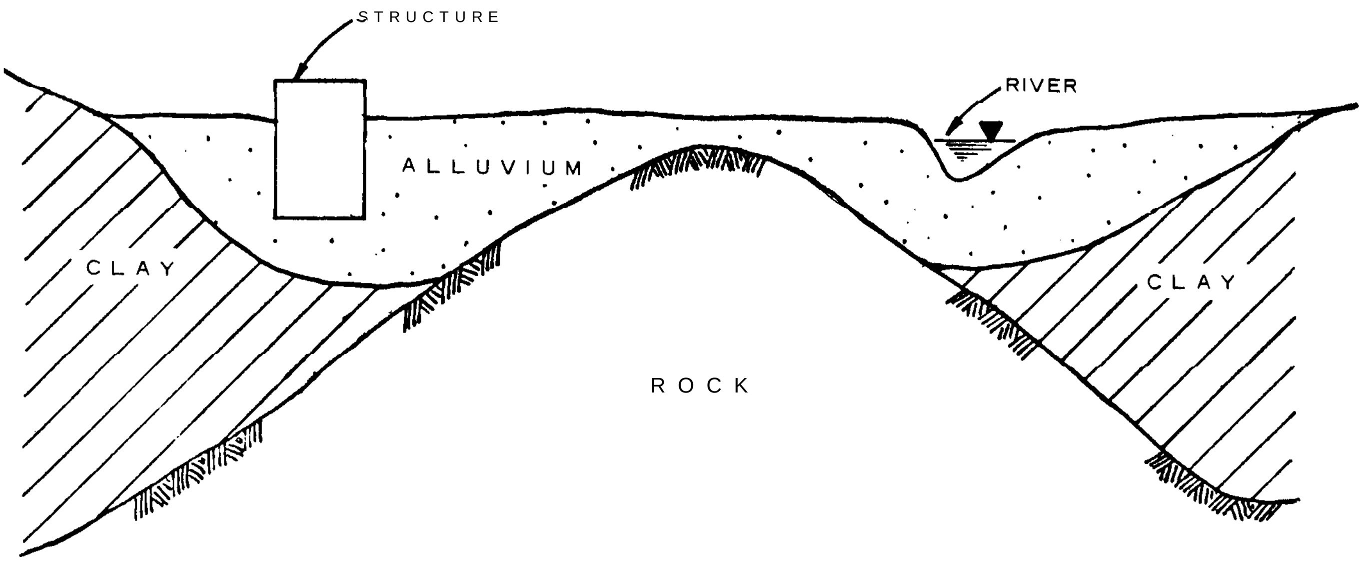

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Figure 3-1. Geologic profile developed from geophysical explorations, *c. Soil testing,*

(1) All soil and rock samples should be carefully classified, noting particularly those characteristics that have a bearing on the perviousness and stratification of the formation. Soil samples should be classified in accordance with the Unified Soil Classification System described in MIL-STD-619B. Particular attention should be given to the existence and amount of fines (material passing the No. 200 sieve) in sand samples, as such have a pronounced effect on the permeability of the sand. Sieve analyses should be made on representative samples of the aquifer sands to determine their gradation and effective grain size D_{10}. The D_{10} size may be used to estimate the coefficient of permeabililty k . The gradation is required to design filters for wells, wellpoints, or permanent drainage systems to be installed in the formation. Correlations between k and D_{10} are presented in paragraph 3-4.

(2) Laboratory tests depicted in figure 3-2 can be used to determine the approximate coefficient of permeability of a soil or rock sample; however, permeabilities obtained from such tests may have little relation to field permeability even though conducted under controlled conditions. When samples of sand are distributed and repacked, the porosity and orientation of the grains are significantly changed, with resulting modification of the permeability. Also, any air en trapped in the sand sample during testing will significantly reduce its permeability. Laboratory tests on samples of sand that have been segregated or contaminated with drilling mud during sampling operations do not give reliable results. In addition, the permeability of remolded samples of sand is usually considerably less than the horizontal permeability k_h of a formation, which is generally the more significant k factor pertaining to seepage flow to a drainage system.

(3) Where a nonequilibrium type of pumping test (described in app C) is to be conducted, it is necessary to estimate the *specific yield* S_y of the formation, which is the volume of water that is free to drain out of a material under natural conditions, in percentage of total volume. It can be determined in the laboratory by:

(*a*) Saturating the sample and allowing it to drain. Care must be taken to assure that capillary stresses on the surface of the sample do not cause an incorrect conclusion regarding the drainage.

(*b*) Estimating S_y from the soil type and D_{10} size of the soil and empirical correlations based on field and laboratory tests. The specific yield can be computed from a drainage test as follows:

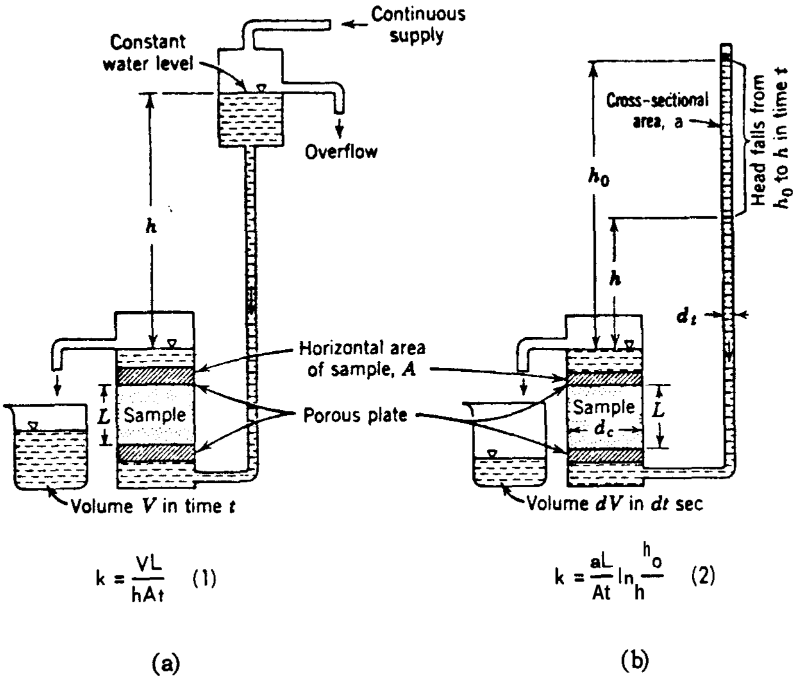
$$S_y = \frac{100V_y}{V} \qquad (3\text{-}1)$$

where

V_y = volume of water drained from sample

V = gross volume of sample

The specific yield can be estimated from the soil type



(From "Ground Water Hydrology" by D. K. Todd, 1959, Wiley & Sons, Inc. Used with permission of Wiley & Sons, Inc.)

Figure 3-2. Permeameters: (a) constant head and (b) falling head.

(or D_{10}) and the relation given in figure 3-3 or table 3-2.

3-3. Groundwater characteristics.

a. An investigation of groundwater at a site should include a study of the source of groundwater that would flow to the dewatering or drainage system (para 2-2) and determination of the elevation of the water table and its variation with changes in river or tide stages, seasonal effects, and pumping from nearby water wells. Groundwater and artesian pressure levels at a construction site are best determined from piezometers installed in the stratum that may require dewatering. Piezometers in pervious soils may be commercial wellpoints, installed with or without a filter (para 4-6*c*) as the gradation of foundation material requires. Piezometers in fine-grained soils with a low permeability, such as silt, generally consist of porous plastic or ceramic tips installed within a filter and attached to a relatively small diameter riser pipe.

b. The groundwater regime should be observed for an extended period of time to establish variations in level likely to occur during the construction or operation of a project, General information regarding the groundwater table and river or tide stages in the area is often available from public agencies and may serve as a basis of establishing general water levels. Specific conditions at a site can then be predicted by correlating the long-term recorded observations in the area with more detailed short-term observations at the site.

c. The chemical composition of the groundwater is of concern, because some groundwaters are highly corrosive to metal screens, pipes, and pumps, or may contain dissolved metals or carbonates that will form incrustations in the wells or filters and, with time, cause clogging and reduced efficiency of the dewatering or drainage system. Indicators of corrosive and incrusting waters are given in table 3-3. (Standard methods for determining the chemical compositions of groundwater are available from the American Public Health Association, Washington, DC

d. Changes in the temperature of the groundwater will result in minor variations of the quantity of water flowing to a dewatering system. The change in viscosity associated with temperature changes will result in a change in flow of about 1.5 percent for each 1° Fahrenheit of temperature change in the water. Only large variations in temperature need be considered in design because the accuracy of determining other parameters does not warrant excessive refinement.

3-4. Permeability of pervious strata.

The rate at which water can be pumped from a dewatering system is directly proportional to the coefficient of permeability of the formation being dewatered; thus, this parameter should be determined reasonably accurately prior to the design of any drainage system. Methods that can be used to estimate or determine the permeability of a pervious aquifer are presented in the following paragraphs.

a. *Visual classification.* The simplest approximate method forestimating the permeability of sand is by visual examination and classification, and comparison with sands of known permeability. An approximation of the permeability of clean sands can be obtained from table 3-4.

b. Empirical relation between D_{10} and k. The permeability of a clean sand can be estimated from em-

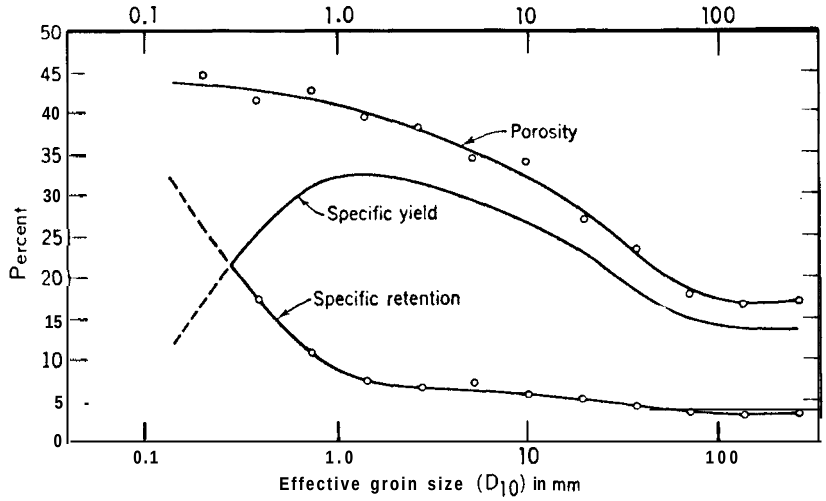


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Figure 3-3. Specific yield of water-bearing sands versus D_{10}, South Coastal Basin, California.

Table 3-2. Specific Yield of Water-Bearing Deposits in Sacramento Valley, California

Material	Specific Yield percent
Gravel	25
Sand, including sand and gravel, and gravel and sand	20
Fine sand, hard sand, tight sand, sandstone, and related deposits	10
Clay and gravel, gravel and clay, cemented gravel, and related deposits	5
Clay, silt, sandy clay, lava rock, and related fine-grained deposits	3

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Table 3-3. Indicators of Corrosive and Incrusting Waters

Indicators of Corrosive Water	Indicators of Incrusting Water
1. A pH less than 7	1. A pH greater than 7
2. Dissolved oxygen in excess of 2 ppm	2. Total iron (Fe) in excess of 2 ppm
3. Hydrogen sulfide (H_2S) in excess of 1 ppm, detected by a rotten egg odor	3. Total manganese (Mn) in excess of 1 ppm in conjunction with a high pH and the presence of oxygen
4 Total dissolved solids in excess of 1,000 ppm indicates an ability to conduct electric current great enough to cause serious electrolytic corrosion	4. Total carbonate hardness in excess of 300 ppm
5 Carbon dioxide (CO_2) in excess of 50 ppm	
6. Chlorides (Cl) in excess of 500 ppm	

(Courtesy of UOP Johnson Division)

Table 3-4. Approximate Coefficient of Permeability for Various Sands

Type of Sand (Unified Soil Classification System)	Coefficient of Permeability k $\times 10^{-4}$ cm/sec	$\times 10^{-4}$ ft/min
Sandy silt	5-20	10-40
Silty sand	20-50	40-100
Very fine sand	50-200	100-400
Fine sand	200-500	400-1,000
Fine to medium sand	500-1,000	1,000-2,000
Medium sand	1,000-1,500	2,000-3,000
Medium to coarse sand	1,500-2,000	3,000-4,000
Coarse sand and gravel	2,000-5,000	4,000-10,000

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pirical relations between D_{10} and k (fig. 3-4), which were developed from laboratory and field pumping tests for sands in the Mississippi and Arkansas River valleys. An investigation of the permeability of filter sands revealed that the permeability of clean, relatively uniform, remolded sand could be estimated from the empirical relation:

$$k = C\,(D_{10})^2 \qquad (3\text{-}2)$$

where

k = coefficient of permeability, centimetres per second

C ≅ 100 (may vary from 40 to 150)

D_{10} = effective grain size, centimetres

Empirical relations between D_{10} and k are *only approximate* and should be *used with reservation* until a correlation based on local experience is available.

c. *Field pumping tests.* Field pumping tests are the most reliable procedure for determining the in situ permeability of a water-bearing formation. For large dewatering jobs, a pumping test on a well that fully penetrates the sand stratum to be dewatered is warranted; such tests should be made during the design phase so that results can be used for design purposes and will be available for bidders. However, for small dewatering jobs, it may be more economical to select a more conservative value of k based on empirical relations than to make a field pumping test. Pumping tests are discussed in detail in appendix C.

d. *Simple field tests in wells or piezometers.* The permeability of a water-bearing formation can be estimated from constant or falling head tests made in wells or piezometers in a manner similar to laboratory permeameter tests. Figure 3-5 presents formulas for determining the permeability using various types and installations of well screens. As these tests are sensitive to details of the installation and execution of the test, exact dimensions of the well screen, casing, and filter surrounding the well screen, and the rate of inflow or fall in water level must be accurately measured. Disturbance of the soil adjacent to a borehole or filter, leakage up the borehole around the casing, clogging or removal of the fine-grained particles of the aquifer, or the accumulation of gas bubbles in or around the well screen can make the test completely unreliable. Data from such tests must be evaluated

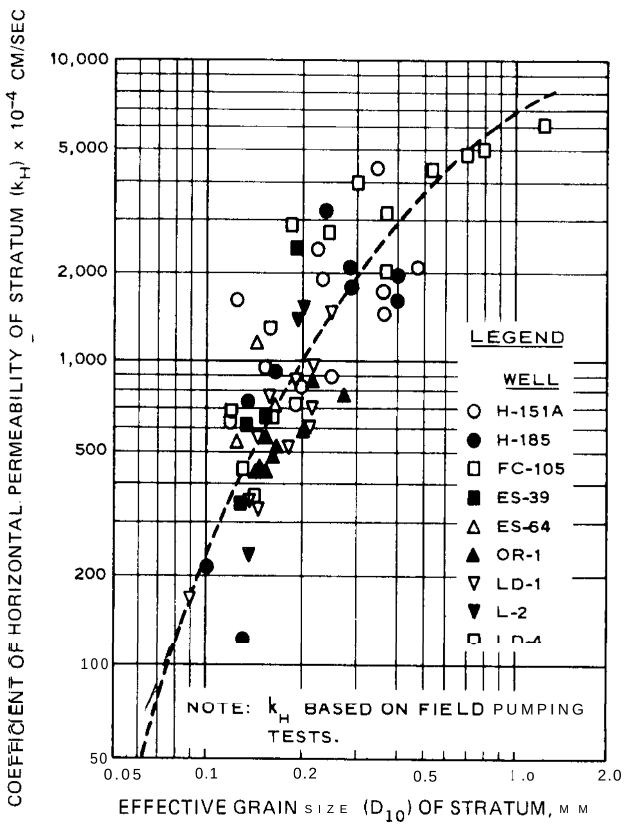
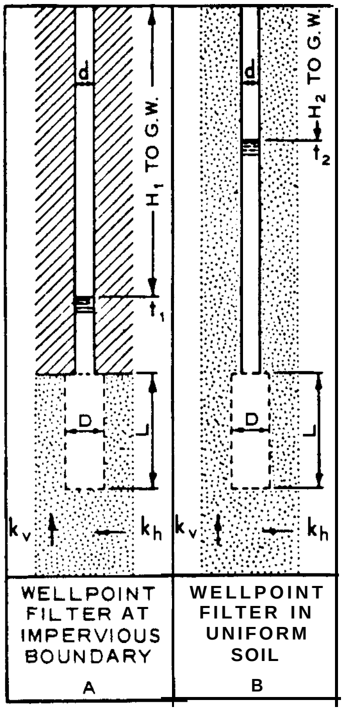


Figure 3-4. D_{10} versus in situ coefficient of horizontal permeability—Mississippi River valley and Arkansas River valley,



NOTATION

- D = DIAM, INTAKE, SAMPLE, CM
- d = DIAM, STANDPIPE, CM
- L = LENGTH, INTAKE, SAMPLE, CM
- H_c = CONSTANT PIEZ HEAD, CM
- H_1 = PIEZ HEAD FOR $t = t_1$, CM
- H_2 = PIEZ HEAD FOR $t = t_2$, CM
- q = FLOW OF WATER, CM^3/SEC
- t = TIME, SEC
- k'_v = VERT PERM CASING, CM/SEC
- k_v = VERT PERM GROUND, CM/SEC
- k_h = HORIZ PERM GROUND, CM/SEC
- k_m = MEAN COEFF PERM, CM/SEC
- m = TRANSFORMATION RATIO

$$k_m = \sqrt{k_h k_v} \qquad m = \sqrt{k_h/k_v}$$

$$\ln = \log_e = 2.3 \log_{10}$$

CASE	CONSTANT HEAD	VARIABLE HEAD
A	$k_h = \dfrac{q \ln\left[\dfrac{2mL}{D} + \sqrt{1 + \left(\dfrac{2mL}{D}\right)^2}\right]}{2\pi L H_c}$	$k_h = \dfrac{d^2 \ln\left[\dfrac{2mL}{D} + \sqrt{1 + \left(\dfrac{2mL}{D}\right)^2}\right]}{8L(t_2 - t_1)} \ln\dfrac{H_1}{H_2}$ $k_h = \dfrac{d^2 \ln\left(\dfrac{4mL}{D}\right)}{8L(t_2 - t_1)} \ln\dfrac{H_1}{H_2}$ FOR $\dfrac{2mL}{D} > 4$
B	$k_h = \dfrac{q \ln\left[\dfrac{mL}{D} + \sqrt{1 + \left(\dfrac{mL}{D}\right)^2}\right]}{2\pi L H_c}$	$k_h = \dfrac{d^2 \ln\left[\dfrac{mL}{D} + \sqrt{1 + \left(\dfrac{mL}{D}\right)^2}\right]}{8L(t_2 - t_1)} \ln\dfrac{H_1}{H_2}$ $k_h = \dfrac{d^2 \ln\left(\dfrac{2mL}{D}\right)}{8L(t_2 - t_1)} \ln\dfrac{H_1}{H_2}$ FOR $\dfrac{mL}{D} > 4$

ASSUMPTIONS

SOIL AT INTAKE, INFINITE DEPTH AND DIRECTIONAL ISOTROPY (k_v AND k_h CONSTANT) - NO DISTURBANCE, SEGREGATION, SWELLING, OR CONSOLIDATION OF SOIL - NO SEDIMENTATION OR LEAKAGE - NO AIR OR GAS IN SOIL, WELLPOINT, OR PIPE - HYDRAULIC LOSSES IN PIPES, WELLPOINT, OR FILTER NEGLIGIBLE.

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Figure 3-5. Formulas for determining permeability from field falling head tests.

carefully before being used in the design of a major dewatering or drainage system.

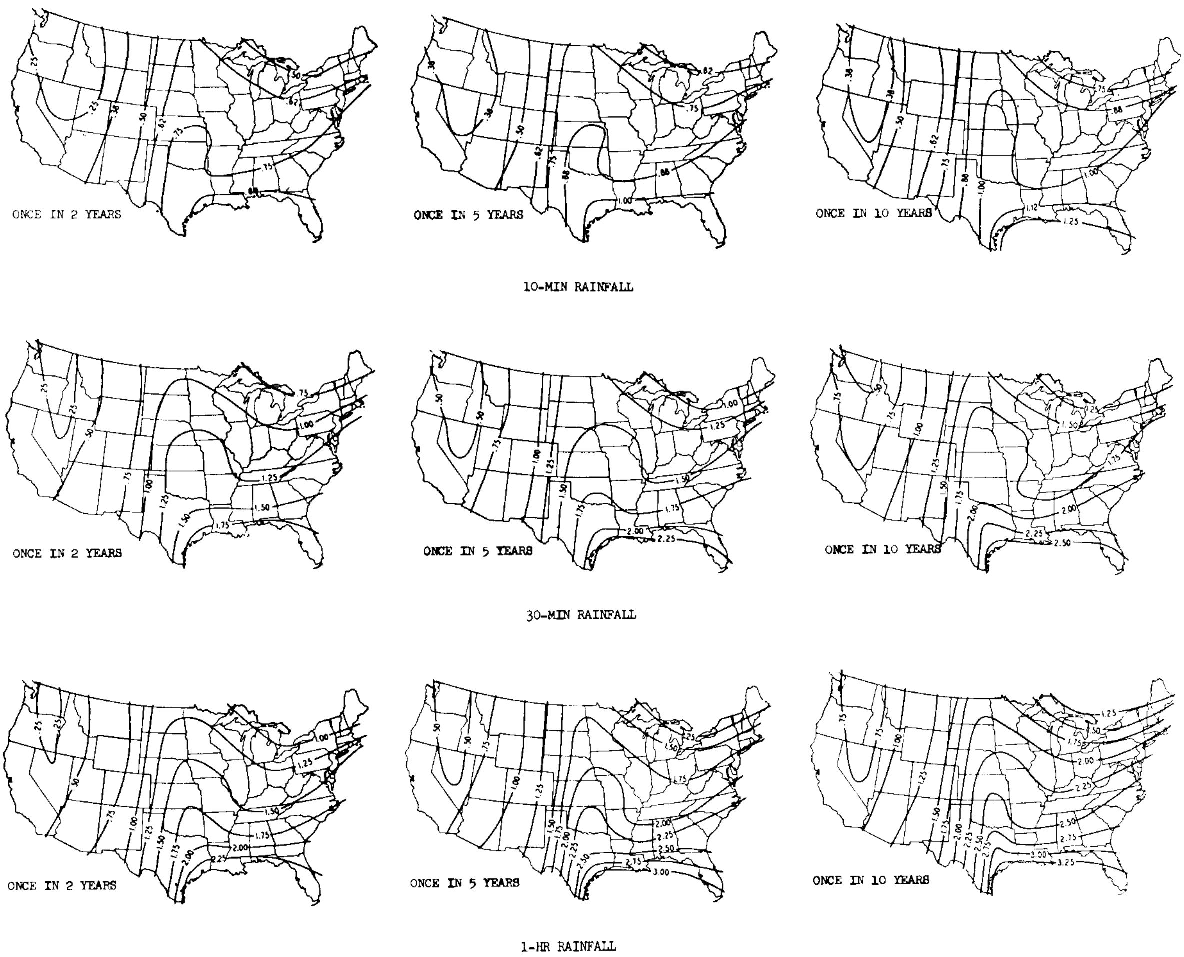
3-5. Power. The availability, reliability, and capacity of power at a site should be investigated prior to selecting or designing the pumping units for a dewatering system. Types of power used for dewatering systems include electric, natural gas, butane, diesel, and gasoline engines. Electric motors and diesel engines are most commonly used to power dewatering equipment.

3-6. Surface water. Investigations for the control of surface water at a site should include a study of precipitation data for the locality of the project and determination of runoff conditions that will exist within the excavation. Precipitation data for various localities and the frequency of occurrence are available in publications of the U.S. Weather Bureau or other reference data. Maps showing amounts of rainfall that can be expected once every 2, 5, and 10 years in 10-, 30-, and 60-minute duration of rainfall are shown in figure 3-6. The coefficient of runoff c within the excavation will depend on the character of soils present or the treatment, if any, of the slopes. Except for excavations in clean sands, the coefficient of runoff c is generally from 0.8 to 1.0. The rate of runoff can be determined as follows:

$$Q = ciA \qquad (3\text{-}3)$$

where

- Q = rate of runoff, cubic feet per second
- c = coefficient of runoff
- i = intensity of rainfall, inches per hour
- A = drainage area, acres



(U. S. Department of Agriculture Miscellaneous Publication No. 204)

Figure 3-6. Inches of rainfall during 10- and 30-minute and 1-hour periods.