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**Agricultural Waste Management
Field Handbook**

Chapter 7

Geologic and Groundwater Considerations

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Chapter 7

Geologic and Groundwater Considerations

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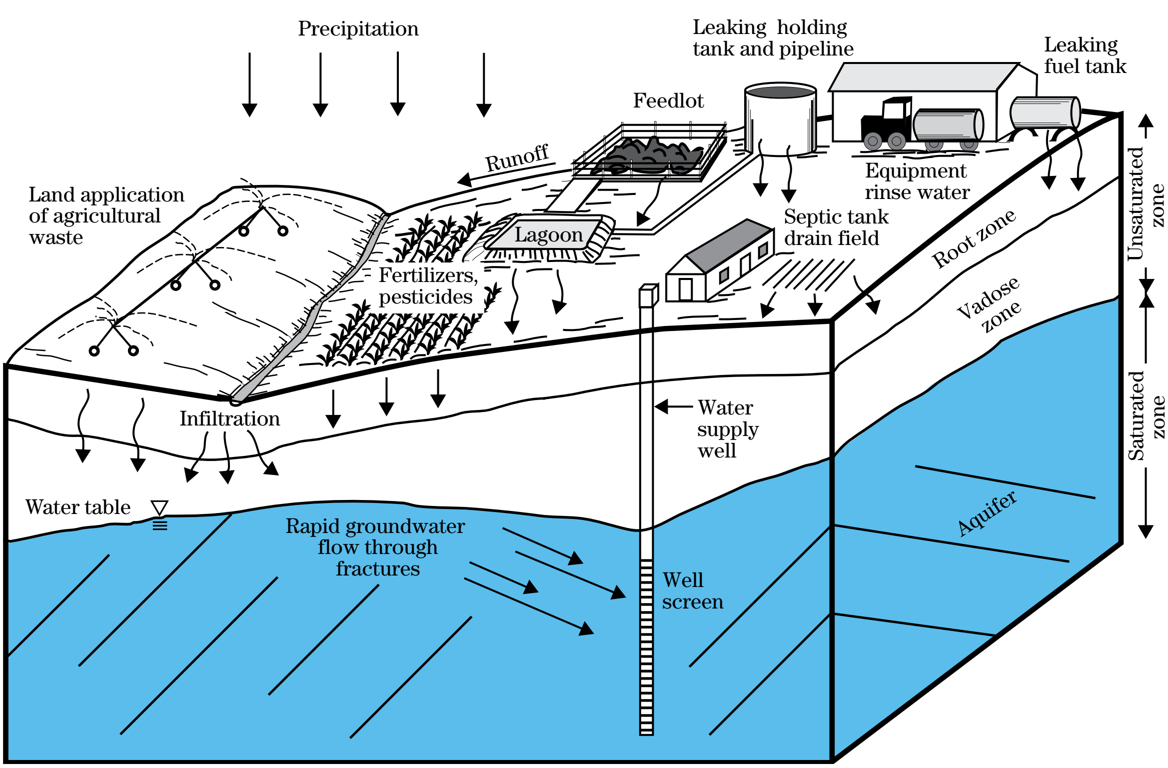
651.0700 Introduction

Chapter 7 covers geologic and groundwater considerations that may affect the planning, design, and construction of an agricultural waste management system (AWMS). Two main issues are addressed:

- engineering suitability of the soil and foundation characteristics of the site
- potential for an AWMS component to contaminate groundwater

Storing, treating, or utilizing agricultural wastes at or below the ground surface has the potential to contaminate groundwater (fig. 7–1). Many agricultural waste management components can be installed on properly selected sites without any special treatment other than good construction procedures. The key is to be able to recognize and avoid potentially problematic site conditions early in the planning process. An appropriately conducted onsite investigation is essential to identify and evaluate geologic conditions, engineering constraints, and behavior of earth materials. The requirements for preliminary (planning) and detailed (design) investigations are explained in this chapter. This chapter provides guidance in a wide variety of engineering geologic issues and water quality considerations that may be found in investigation and planning of an AWMS.

Figure 7–1 Agricultural sources of potential groundwater contamination



651.0701 Overview of geologic material and groundwater

(a) Geologic material

The term "geologic material," or earth material, covers all natural and processed soil and rock materials. Geologic material ranges on a broad continuum from loose granular soil or soft cohesive soil through extremely hard, unjointed rock.

(1) Material properties
Material properties of soil or rock are either measured in the laboratory using representative samples or assessed in the field on in-place material. Common examples of material properties include mineral composition, grain size, consistency, color, hardness (strength), weathering condition, porosity, permeability, and unit weight. Some properties may be inferred by index tests of samples; for example, permeability may be roughly inferred in soils from their gradation and plasticity values.

(2) Mass properties
Mass properties of geologic materials are large scale features that can only be observed, measured, and documented in the field. They typically cannot be sampled. These properties include regional features such as geologic structure or karst topography. Geologic structure refers to the orientation and deformation characteristics such as faults and joints. Karst topography is formed primarily in limestone terrain and characterized by joints that have been widened by dissolution. Mass properties also include discontinuities that are distinct breaks or abrupt changes in the mass. The two broad types of discontinuities are stratigraphic and structural, depending on mode of formation (see Title 210, Technical Release (TR)–78), The Characterization of Rock for Hydraulic Erodibility). The presence of discontinuities complicates the design of an AWMS.

Stratigraphic discontinuities originate when the geologic material is formed under distinct changes in deposition or erosion. They are characterized by abrupt lateral or vertical changes in composition or other material property such as texture or hardness. These features apply to all stratified soil and rocks and can occur in many shapes described with common geologic terms such as blanket, tongue, shoestring, or lens. Abrupt changes in composition or material property can result in contrasting engineering behavior of the adjacent geologic materials. A common example of a stratigraphic discontinuity is the soil/bedrock interface.

Structural discontinuities are extremely common in almost any geologic material. They include fractures of all types that develop some time after a soil or rock mass has formed. Almost all types of bedrock are fractured near the Earth's surface. Forces acting on the mass that cause deformation include physical geologic stresses within the Earth's crust; biological, such as animal burrows or tree roots; or artificial, such as blasting. Fractures in rock materials may be systematically oriented, such as joint sets, fault zones, and bedding plane partings, or may be randomly oriented. In soil materials, fractures may include soil joints, desiccation cracks, and remnant structure from the parent bedrock in residual soils.

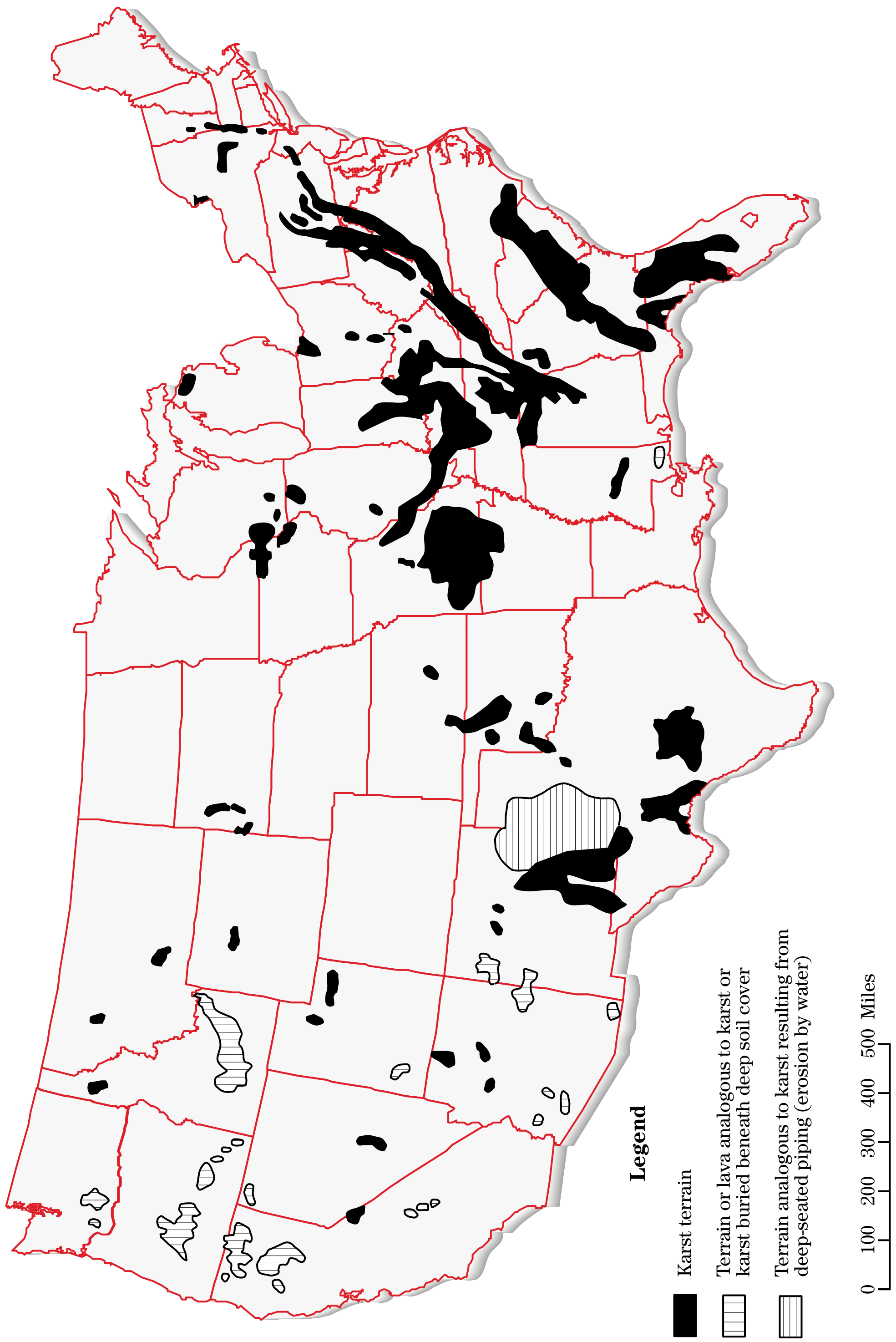
Many rural domestic wells, particularly in upland areas, derive water from fractures and joints in bedrock. These wells are at risk of contamination from waste impoundment facilities if fractured bedrock occurs within the excavation limits, within feedlots or holding areas, and in waste utilization areas. Fractures in bedrock may convey contaminants directly from the site to the well and significantly affect water quality in a local aquifer. Although karst topography (fig. 7–2) is well known as a problem because of its wide, interconnected fractures and open conduits, almost any near-surface rock type will have fractures that can be problematic unless treated in design.

(b) Groundwater

Many U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) programs deal with the development, control, and protection of groundwater resources. The planners of agricultural waste management practices should be familiar with the principles of groundwater. NRCS references that include information on groundwater are Title 210, National Engineering Handbook (NEH), Section 16, Drainage of Agricultural Lands, Part 631, Chapter 30, Groundwater Hydrology and Geology, Chapter 31, Groundwater Investigations; Chapter 32, Well Design and Spring Development, and Chapter 33, Groundwater Recharge, and Part 650, Engineering Field Handbook (EFH), Chapter 12, Springs and Wells and Chapter 14, Water Management (Drainage).

Figure 7–2 Karst areas in the United States

Generalized map of areas of karst and analogous terrains in the conterminous United States

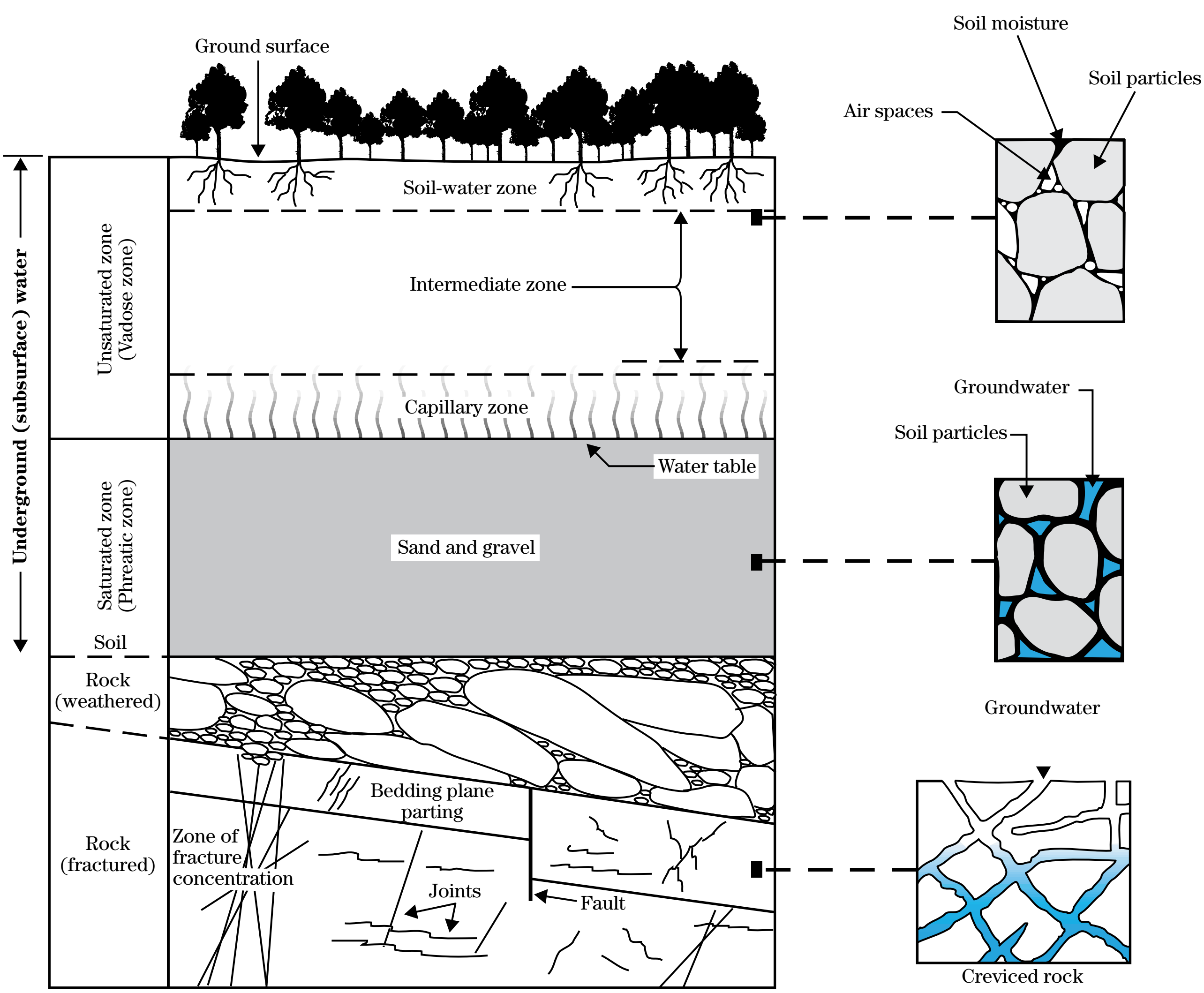


(1) Zones of underground water

All water beneath the surface of the Earth is called underground water, or subsurface water. Underground water occurs in two primary zones: an upper zone of aeration called the vadose or unsaturated zone and a lower zone of saturation called the phreatic or saturated zone. The vadose zone contains both air and water in the voids, and the saturated zone is where all interconnected voids are filled with water (fig. 7–3). The term "groundwater" applies to the saturated zone. Groundwater is the only underground water available for wells and springs.

The vadose zone has three components with differing moisture regimes: the soil-water zone, intermediate zone, and basal capillary zone (fig. 7–3). The soil-water zone extends from the ground surface to slightly below the depth of root penetration. Water in this zone is available for transpiration and direct evaporation, and the zone is unsaturated except during rainfall or irrigation events. Depending on the depth of the vadose zone, there may be an intermediate zone where water moves either downward under gravity or is held in place by surface tension. There are areas in the country where the intermediate zone is hundreds of feet thick.

Figure 7–3 Zones of underground water (AIPG 1984; Heath 1983; and Todd 1980)



Directly above the water table there can be a saturated zone called the capillary zone or fringe. Water in the capillary fringe overlies the water table, where the fluid pressure in the pores is exactly atmospheric pressure; therefore, the pore pressure above the water table is less than atmospheric. Surface tension and capillary action cause water in this zone to rise. It can rise between a few inches to more than a few feet above the water table, depending on the soil type. Capillary rise increases as the pore spaces decrease and the plasticity of the soil increases.

(2) Aquifers

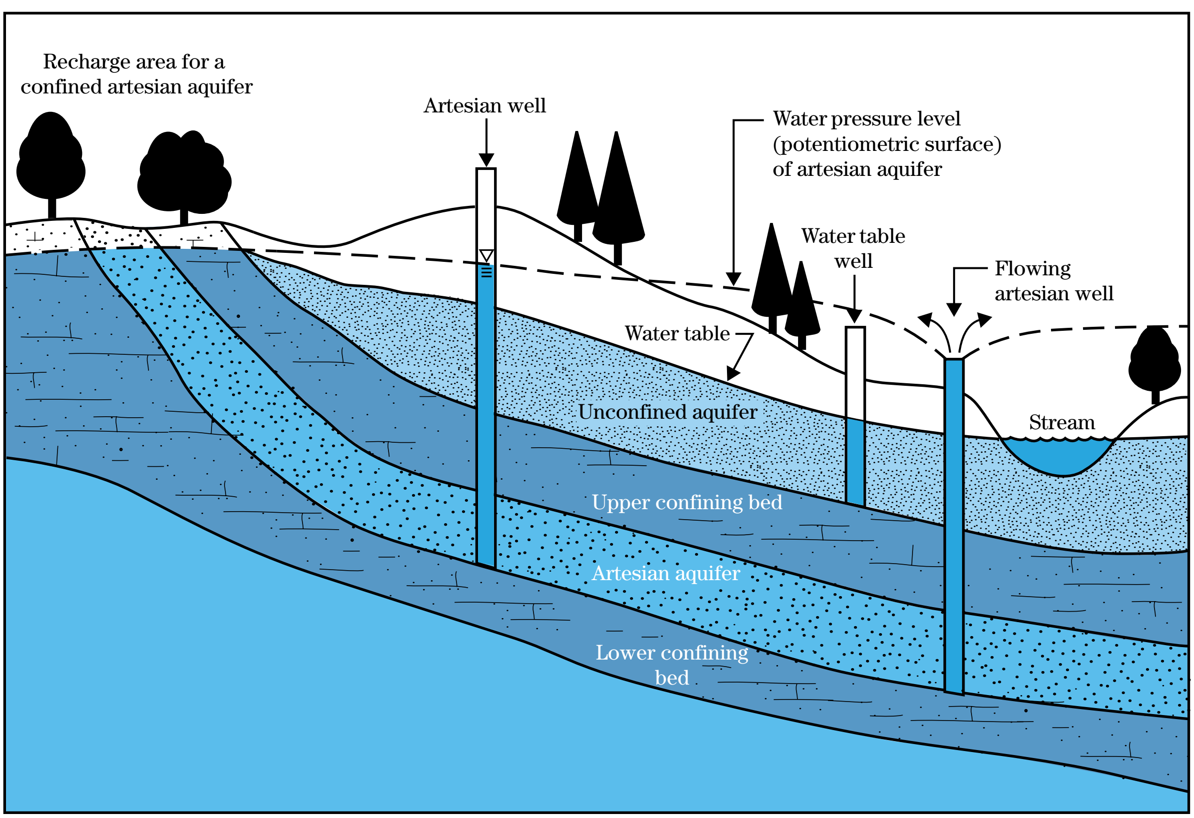
An aquifer is a saturated, permeable geologic unit capable of storing and conveying usable amounts of groundwater to wells or springs. When designing any agricultural waste management component, it is important to know:

- what type(s) of aquifers are present and at what depth
- the use classification of the aquifer, if any

Aquifers occur in many types of soil or rock materials. Productive aquifers include coarse-grained alluvial deposits; glacial outwash; coarse-grained, highly porous or weakly cemented sandstones and conglomerates; and limestones that dissolve into karst conditions. An aquifer need not be highly productive to be an important resource. For example, there are millions of private domestic wells throughout the country that yield 10 gallons per minute or less. In upland areas, often the only source of water available to wells occurs in fractured bedrock within about 300 feet of the surface. Below this depth, it is likely that the weight of the overlying rock materials will hold fractures closed and limit the volume of water they can convey.

An aquifer may be unconfined, confined, or perched (fig. 7–4). An unconfined aquifer, also known as a water table aquifer, occurs in relatively homogeneous, permeable materials that extend to a deeper, less permeable zone (fig. 7–5). It occurs near the ground surface and is affected only by atmospheric pressure and the weight of the water; it is generally recharged

Figure 7–4 Aquifers (AIPG 1984)



locally. The water table is the undulating surface that marks the top of an unconfined aquifer; it usually follows the general topography although with lesser relief. The water table, or static water level, is the elevation at which water stabilizes in a well under atmospheric pressure, although a well-developed capillary fringe will extend the saturated zone above the water table. Changing atmospheric pressures during heavy storms can cause relatively large changes in the water levels in shallow, unconfined aquifers.

A confined aquifer occurs at depth and is bounded above and below by geologic materials with lower permeabilities (fig. 7–6) known as an aquiclude. An aquiclude is a saturated geologic unit that is incapable of transmitting water, whereas an aquitard can transmit small volumes of water, but very slowly. The static water level in a confined aquifer, known as the potentiometric surface, will rise above the elevation at the top of the confining unit in a tightly cased, well penetrating the aquifer materials. It is controlled by the potentiometric pressure at the recharge area, which must be higher in elevation than that of the well. Recharge areas can be a long distance away. Slowly leaking aquitards overlying a confined aquifer can also create potentiometric pressures.

Figure 7–5 Unconfined aquifer (AIPG 1984)

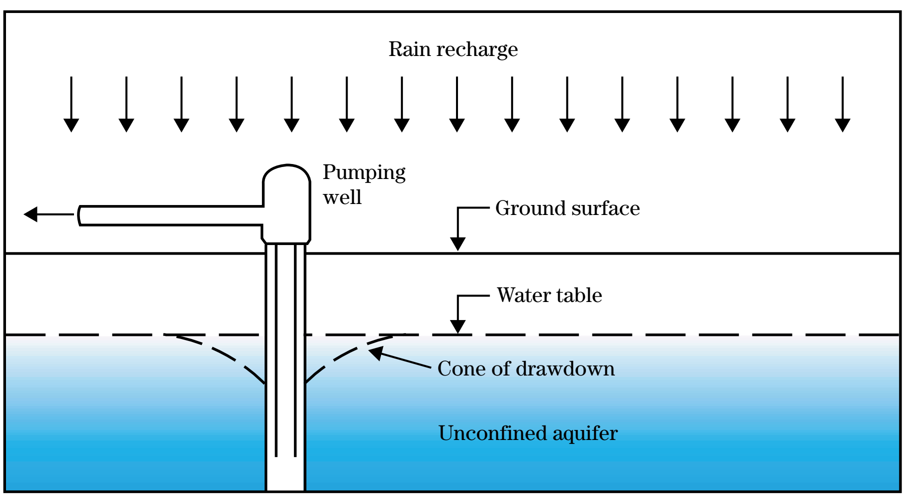
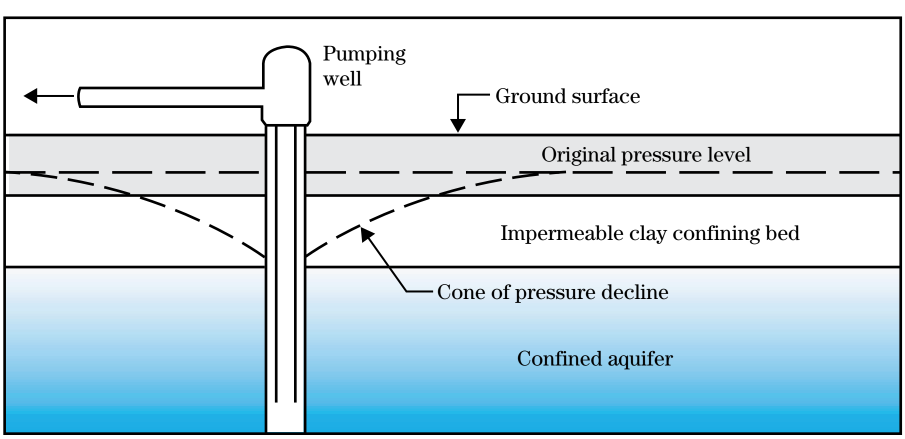


Figure 7–6 Confined (artesian) aquifer (AIPG 1984)



Confined aquifers are also known as artesian aquifers. Any well in which the static water level rises above the elevation at the top of the confining unit is called an artesian well (fig. 7–7). An artesian well that flows at the surface is called a flowing artesian well; not all artesian wells flow. To flow, the elevation of the surface of the well must lie below that of the potentiometric surface.

A perched aquifer (fig. 7–8) is a local zone of unconfined groundwater occurring at some level above the regional water table, with unsaturated conditions existing above and below it. They form where downward-percolating groundwater is blocked by a zone of lesser permeability and accumulates above it. This lower confining unit is called a perching bed, and they commonly occur where clay lenses are present, particularly in glacial outwash and till. These perched aquifers are generally of limited lateral extent and may not provide a long-lasting source of water. Perched aquifers can also cause problems in construction dewatering and need to be identified during the site investigation.

The U.S. Environmental Protection Agency (EPA), under the provisions of the Safe Drinking Water Act (1974), has the authority to designate aquifers as "sole source aquifers." A sole source aquifer is an aquifer that provides the primary, or sole, source of drinking water to an area. No Federal funds can be committed to any project that the EPA finds would contaminate a sole source aquifer and cause a significant health hazard.

An individual State may designate groundwater use classifications, in addition to their designated surface water use classifications. These designated use classifications protect aquifers for future use. There are States that regulate against groundwater overdraft, where pumping exceeds aquifer recharge.

(3) Porosity

Most materials within a few hundred feet of the Earth's surface contain solids and voids. Downward percolating water collects in voids and becomes available for wells and springs. Porosity is defined as the ratio of the volume of voids to the total volume of a soil or rock mass, expressed as a percentage.

$$\text{Porosity }(\%) = \frac{\text{Volume of voids in a given mass }(L^3)}{\text{Volume of given soil mass }(L^3)}$$

Figure 7–7 Cross section through stream valley showing groundwater flow lines and flowing (artesian) well from unconfined aquifer (Fetter 1980)

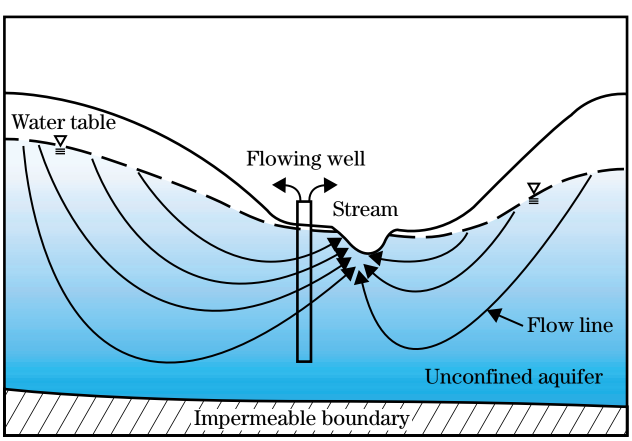
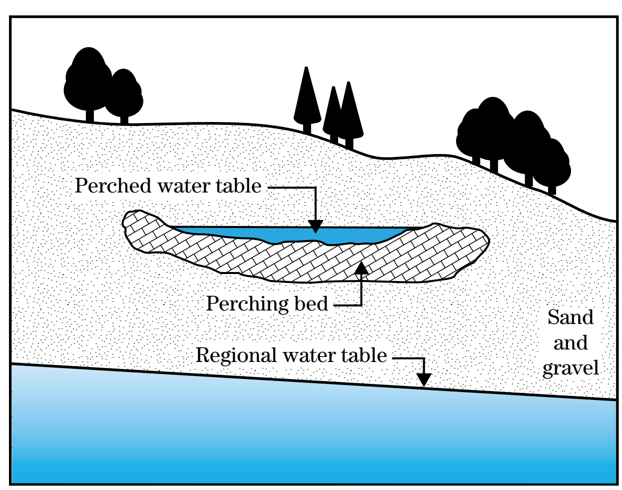


Figure 7–8 Perched aquifer



The two main types of porosity are primary and secondary (fig. 7–9).

Primary porosity refers to openings that developed at the time the material was formed or deposited. An example of primary porosity is the voids between particles in a sand and gravel deposit. Primary porosity of soil depends on the range in grain size (sorting) and the shape of the grains and is independent of particle size. Thus, a bathtub full of bowling balls has the same porosity as the same tub full of BBs. This assumes the arrangement (packing) is the same for balls and BBs. However, the tub full of a mixture of bowling balls and BBs will have a lower porosity than either the BBs or the bowling balls because BBs will occupy space between the bowling balls. Secondary porosity refers to openings formed after initial formation or deposition of a material. Processes that create secondary porosity include physical weathering (freezing-thawing, wetting and drying, heating and cooling), chemical or biological action, and other stresses that produce fractures and joints. Secondary porosity is extremely common in most geologic materials near the Earth's surface. This type of porosity enables contaminants to move with little attenuation (reduction) or filtration.

(4) Specific yield

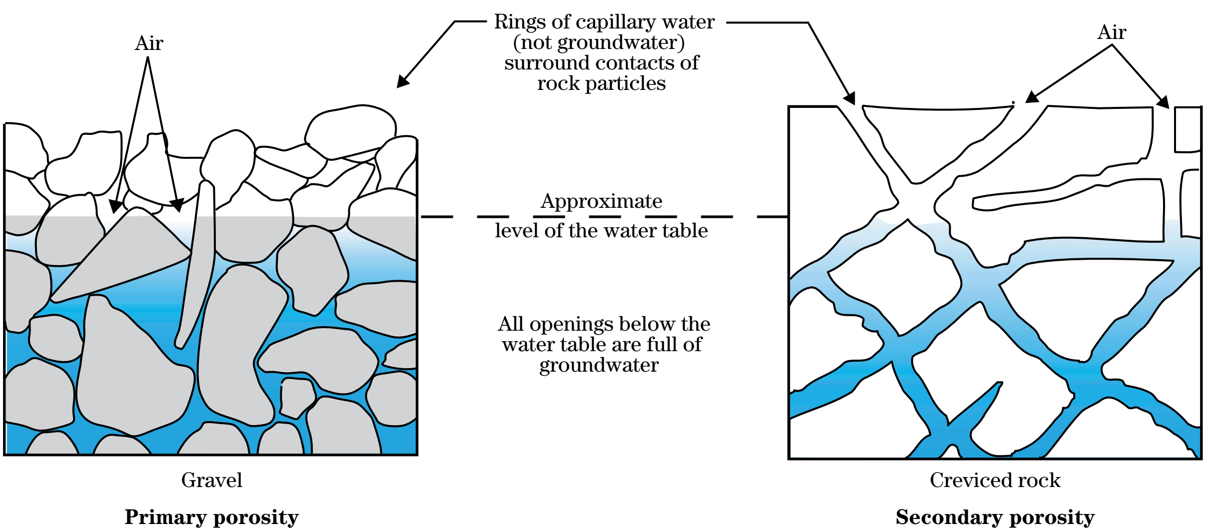
Specific yield is the ratio of the volume of water that an unconfined aquifer (soil or rock) releases by gravity drainage to the volume of the soil or rock mass. A material that has high porosity, such as clay, does not necessarily yield a high volume of water if the material also has low permeability (see section 651.0702 (h), Permeability of aquifer material). Such a material has low specific yield. See table 7–1 for comparison of porosity and specific yield of some geologic materials.

$$\text{Specific yield } (\%) = \frac{\text{Volume of water drained } (L^3)}{\text{Volume of given geologic material } (L^3)}$$

Table 7–1 Porosity and specific yield for various geologic materials (from Sterrett 2007)

Geologic material	Porosity (%)	Specific yield (%)
Soil:		
Gravel (mix)	25–40	15–30
Sand (mix)	25–40	10–30
Silt	35–50	5–10
Clay	45–55	1–10
Sand, silt, clay mixes	25–55	5–15
Sand and gravel mixes	10–35	10–25
Rock:		
Fractured or porous basalt	5–50	5–50
Fractured crystalline rock	0–10	0–10
Solid (unfractured) rock	0–1	0
Karst topography	5–50	5–50
Sandstone	5–30	5–15
Limestone, dolomite	1–20	0.5–5
Shale	0–10	0.5–5

Figure 7–9 Porosity—how groundwater occurs in geologic materials



651.0702 Engineering geology considerations in planning

This section provides guidance in determining what engineering geology considerations may need to be investigated for various waste management components (table 7–2). The significance of each consideration is briefly described with some guidance given on how to recognize it in the field. Most issues serve as signals or red flags that, if found, justify requesting assistance of a geologist or other technical specialist.

(a) Corrosivity

Soil is corrosive to many materials used in AWMS components. Soil survey data available through Soil Data Mart (SDM) (for GIS users) and Web Soil Survey (WSS) give corrosion potentials for steel and concrete for soil map units. Note that data for map units normally apply only to the top 60 inches of soil.

(b) Location of water table

The elevation and shape of the water table may vary throughout the year. High water tables and perched water tables in borrow areas can create access problems for heavy machinery. Rising water tables can also crack, split, and lift concrete slabs and rupture impoundment liners. The occurrence of a high water table may restrict the depth of excavation and require installation of relief or interceptor drainage systems to protect the practice from excessive uplift pressures. A preliminary field investigation will identify estimates of the depth to high water table using soil survey data available through SDM (for GIS users) and WSS. Site-specific groundwater depths may vary from values given in these sources. Stabilized water levels observed in soil borings or test pits provide the most accurate determination in the field. Seasonal variations in the water table also may be inferred from the logs of borings or pits. Recording soil color and redoximorphic features is particularly important. Redoximorphic features indicate seasonal changes in soil moisture. Perennially saturated soil is typically gray. Perennially aerated soil is typically various shades of red, brown, or yellow.

(c) Depth to rock

The selection of components that make up an AWMS may be restricted by shallow depth to bedrock because of physical limitations or State and local regulations.

The occurrence of hard, dense, massive, or crystalline rock at a shallow depth may require blasting or heavy excavators to achieve the designed grade. If the rock surface is irregular, differential settlement can be a hazard for steel tanks and monolithic structures, such as reinforced concrete tanks. Vegetative practices, such as filter strips, may be difficult to establish on shallow soil or exposed bedrock. Waste applied in areas of shallow or outcropping bedrock may contaminate groundwater because fractures and joints in the rock provide avenues for contaminants.

For waste impoundments, shallow bedrock generally is a serious condition requiring special design considerations. Bedrock of all types is nearly always jointed or fractured when considered as a unit greater than 0.5 to 10 acres in area. Fractures in any type of rock can convey contaminants from an unlined waste storage pond or treatment lagoon to an underlying aquifer. Fractures have relatively little surface area for attenuation of contaminants. In fact, many fractures are wide enough to allow rapid flow. Pathogens may survive the passage from the site to the well and thereby cause a health problem. Consider any rock type within 2 feet of the design grade to be a potential problem. The types of defensive design measures required to address shallow rock conditions depend on site conditions and economic factors. Design options include linings, waste storage tanks, or relocating to a site with favorable foundation conditions.

Sinkholes or caves in karst topography or underground mines may disqualify a site for a waste storage pond or treatment lagoon. Sinkholes can also be caused by dissolving salt domes in coastal areas. The physical hazard of ground collapse and the potential for groundwater contamination through the large voids are severe limitations.

Table 7–2 Engineering geology consideration for selected waste management components

Agricultural Waste Management Component	Engineering geology considerations: Corrosivity	Location of water table (uplift pressures)	Depth to rock	Stability for embankment and excavation cut banks	Excavatability	Seismic stability	Dispersion	Permeability	Puncturability	Settlement potential	Shrink/swell	Topography	Availability and suitability of borrow material
1. Waste empoundments												X	
A. Earthfill embankment		X	X	X		X	X	X	X	X	X		X
B. Excavated cutbank		X	X	X	X		X	X	X		X		
C. Clay liners		X									X		
2. Waste storage structure (tanks and stacking facilities)	X	X	X		X	X			X	X	X	X	X
3. Vegetative filter strips							X	X				X	
4. Waste utilization area (land application)	X	X					X	X				X	
5. Constructed wetland		X					X	X	X		X	X	X
6. Composting facility										X		X	
7. Waste transfer - (e.g., concrete lined waterways, buried piplines)	X											X	
8. Heavy use area protection	X	X	X		X	X			X	X	X	X	X
9. Waste separation facility/components	X	X	X		X	X			X	X	X	X	X

(d) Stability for embankment and excavated cut slopes

Embankments and excavated cut slopes must remain stable throughout their design life. Control of groundwater prevents stability problems related to excessive pore pressure. Subsurface interceptor drains, relief drains, or open ditches may be needed to control excessive water pressure around structures. The foundation must be free-draining. This will prevent increased loads caused by the static or dynamic weight of a component from causing downslope sliding or slumping, especially for a clay foundation with low shear strength.

Embankments and excavated cutbanks may be vulnerable to failure when wastewater is emptied or pumped out of a waste impoundment. Rapid drawdown of wastewater may leave the soil in the bank above the liquid level saturated, which may then lead to bank caving. Designers must consider this in determining the stable side slope of embankments and cut banks and in designing the liner thickness. Consideration should be given in operation and maintenance plans to addressing the maximum rate that wastewater should be withdrawn from waste impoundments to minimize this problem.

(e) Excavatability

Excavation characteristics of the geologic materials at the site determine the type and size of equipment needed and the class of excavation, either common or rock, for pay purposes (table 7–3). Commonly avail-

Table 7–3 Excavation characteristics

Classification elements	Class I	Class II	Class III
	Very hard ripping to blasting	**Hard ripping**	**Easy ripping**
	Rock material requires drilling and explosives or impact procedures for excavation may classify [1/] as rock excavation (NRCS Construction Spec. 21). Must fulfill **all** conditions below:	Rock material requires ripping techniques for excavation may classify [1/] as rock excavation (NRCS Construction Spec, 21). Must fulfill **all** conditions below:	Rock material can be excavated as common material by earthmoving or ripping equipment may classify [1/] as common excavation (NRCS Construction Spec. 21). Must fulfill **all** conditions below:
Headcut erodibility index, k_h (210–NEH, Part 628, Chapter 52)	$k_h \geq 100$	$10 < k_h < 100$	$k_h \leq 10$
Seismic velocity, approximate (ASTM D 5777 and Caterpillar Handbook of Ripping, 1997)	≥ 2,450 m/s (≥ 8,000 ft/s)	2,150–2,450 m/s (7,000–8,000 ft/s)	≤ 2,150 m/s (≤ 7,000 ft/s)
Minimum equipment size(flywheel power) required for to excavate rock. All machines assumed to be for heavy-duty, track-type blasting, for backhoes or tractors equipped with a single tine, rear-mounted ripper.	260 kW (350 hp), for $k_h < 1,000$ 375 kW (500 hp), for $k_h \leq 10,000$ Blasting for $k_h > 10,000$	185 kW (250 hp)	110 kW (150 hp)

1/ The classification implies no actual contract payment method to be used nor supersedes NRCS contract documents. The classification is for engineering design purposes only.

able equipment may not be suitable in some situations. Blasting or specialized high horsepower ripping equipment may be required. Cemented pans, dense glacial till, boulders, an irregular bedrock surface, or a high water table can all increase the difficulty and cost of excavation.

(f) Seismic stability

Projects located in seismic zones 3 and 4, as defined in 210–TR–60, Earth Dams and Reservoirs, require special geologic investigations. These include investigations to determine the liquefaction potential of noncohesive strata, including very thin beds and the presence of any faults that have been active in the Holocene Epoch, which began 11,500 years ago.

These considerations are used in the design of embankment slopes, cut slopes, zoned fill, or internal drainage. A foundation consisting of loose, saturated, fine-grained, relatively clean sand is most susceptible to liquefaction during seismic events. Most well compacted embankments consisting of fine-grained plastic soils are inherently resistant to seismic shock. Determine the seismic zone of a site using the map in 210–TR–60 Earth Dams and Reservoirs. Other geologic hazards may be identified in Section I of the Field Office Technical Guide (FOTG) and local geologic reports and maps and other local technical references.

(g) Dispersion

Dispersive clay soils are unusually erodible and have been responsible for a significant amount of damage to NRCS channels and structures. Dispersive clay soils are distinguished from typical clay soils by differing electrochemical properties. Normal clays are composed primarily of calcium, magnesium, and potassium cations and have two positive charges. Dispersive clays are characterized by higher sodium contents, and have only one positive charge. With only one positive charge, the electrochemical forces are imbalanced. The imbalance causes the individual particles in a dispersive clay soil to be repulsed rather than attracted to one another. Because these particles are very small, they are easily detached and transported by even slow moving water. Small flows can erode significant volumes of material.

Typical characteristics of dispersive soils:

- They often occur in layers or lenses within a soil profile rather than as a mappable unit with consistent mineral, structural, and hydraulic characteristics. Color is not a reliable indicator of dispersive characteristics.
- They have high erodibility. Clay and colloidal fractions go readily into suspension and remain there. In small ponds and puddles, the colloidal clay particles stay suspended for long periods of time, and the water will remain turbid. The water may rarely clear up, if ever.
- Surface exposures, including streambanks and cut slopes, have the appearance of melted sugar. Gullying and rilling are extensive, forming a "badland" topography of jagged ridges and deep, rapidly-forming channels and tunnels. Lush vegetation does not prevent erosion on earthfill embankments.
- They have high shrink-swell potential and are thus subject to severe cracking when dried. "Jugging" can occur when rainfall and runoff concentrate in a crack. The crack is eroded from the bottom up, eroding a larger volume of the underlying soil than at the surface opening. The result is a jug-shaped feature; erosion to a depth of 4 to 8 feet is common.

(h) Permeability

Permeability or hydraulic conductivity refers to rate at which water flows through a material. The permeability of the underlying material is an important geologic consideration in the planning process. For example, permeability of the soil material at the excavation limits of a waste impoundment is an important factor in determining the need for a liner. Permeability can also affect the attenuation of contaminants that are land applied in waste utilization. Soils with lower permeability may allow the time needed for transformation and plant uptake of nutrients while soils with high permeability may leach contaminants. Permeability can be measured in the laboratory or estimated based on the characteristics of the material. Further description of permeability is given in 210–NEH, Part 651, Agricultural Waste Management Field Handbook (AWMFH), Chapter 10, Appendix D, Design and Construction Guidelines for Waste Impoundments Lined with Clay or Amendment-treated Soil.

(i) Puncturability

Puncturability is the ability of foundation materials to puncture a flexible membrane liner or steel tank. Angular rock particles greater than 3 inches in diameter may cause denting or puncturing in contact with a tank. Angular particles greater than 0.5 inch can puncture plastic and synthetic rubber membranes. Sharp irregularities in the bedrock surface itself also can cause punctures. Large angular particles can occur naturally or be created by excavation and construction activity.

(j) Settlement potential

Monolithic structures are designed to behave as a structural unit, and they are particularly vulnerable to settlement. Examples include tanks made out of steel and poured-in-place reinforced concrete. Differential settlement occurs when settlement is uneven across the entire foundation.

The potential for differential settlement can be an important design consideration in certain earthfill and concrete waste impoundment structures. Although the potential for differential settlement may be less significant, some segmentally designed structures may be susceptible to settlement as well.

Segmentally designed structures are built of structurally independent units such as precast, reinforced concrete retaining wall units. The designer should be familiar with the 210–NEH, Part 650, EFH, Chapter 4, Elementary Soil Engineering.

The six common geologic conditions that cause settlement to occur are:

- Abrupt, contrasting soil boundaries—A foundation is susceptible to differential settlement if underlain by zones, lenses, or beds of widely different soil types with boundaries that change abruptly either laterally or vertically.
- Compressible soil—Some layers or zones of materials over 1 foot thick may settle excessively when loaded by an embankment or concrete structure. These include soft clays and silts, peat and organic-rich soil (OL and OH in the Unified Soil Classification System (USCS)), and loose sands.
- Areas that have been active or abandoned underground mines and areas with high rates of groundwater withdrawal
- Steep abutments—Differential settlement of embankments may occur on abutment slopes that are steeper than 1 horizontal to 1 vertical. Compaction must be done by hand to achieve the density necessary to limit settlement and provide the necessary bond to retard leakage along the interface. Settlement cracks may occur in the fill in the area where the base of a steep abutment joins the flood plain.
- Uneven rock surfaces—A foundation may settle if it is constructed on soil materials overlying a highly irregular, shallow bedrock surface or other uneven, unyielding material. As a rule, consider a foundation problematic if the difference between the maximum and minimum thickness of compressible soil above an uneven rock surface divided by the maximum observed thickness is greater than 25 percent. This thickness ratio is expressed as:

$$100\left(\text{max. thickness} - \frac{\text{min. thickness}}{\text{max. thickness}}\right)$$
$$= \text{thickness ratio (percent)}$$

- Collapsible soil—This soil condition is common, particularly in the arid areas of the Western United States. These soils collapse or consolidate rapidly in the presence of water. They are characterized by low densities and low water contents and are generally fine-grained (CL, ML, CL-ML and MH, with an occasional SM). There are several types of soils which are water-sensitive and several causes of their unstable structure. They are:
  - — Fine-grained alluvial deposits with a random and unstable configuration that have not been saturated since their deposition—Most were deposited as debris flows from unvegetated watersheds in events with heavy rain. When they are eventually saturated, they collapse under their own weight.
  - — Wind-blown silt deposits known as loess that are very loose and contain appreciable voids—They characteristically have clay ma-

terial acting as a binding agent, which rapidly looses strength when wetted loaded.

— Gypsiferous soils in which the gypsum has been dissolved and then recrystallized—They form a porous mass which collapses easily.

(k) Shrink/swell

Soil containing montmorillonite clay may undergo substantial changes in volume when wetted and dried. Some minerals found as components in rock, such as gypsum or anhydrite, also may change volume dramatically when wetted and dried. Soil that has a high shrink/swell hazard is identified in Soil survey data available through SDM (for GIS users) and WSS. Field investigations and previous experience in the area may often be the only ways to foresee this problem.

(l) Topography

Recognition of land forms and their associated problems is a valuable asset when planning a component for an AWMS. For example, flood plain sites generally have a higher water table compared to that of adjacent uplands, are subject to surface flooding, and can indicate presence of permeable soils, as the alluvium may be more permeable.

Topography can indicate the direction of regional groundwater flow. Uplands may serve as aquifer recharge areas; valley bottoms, marshes, and lowlands serve as groundwater discharge areas.

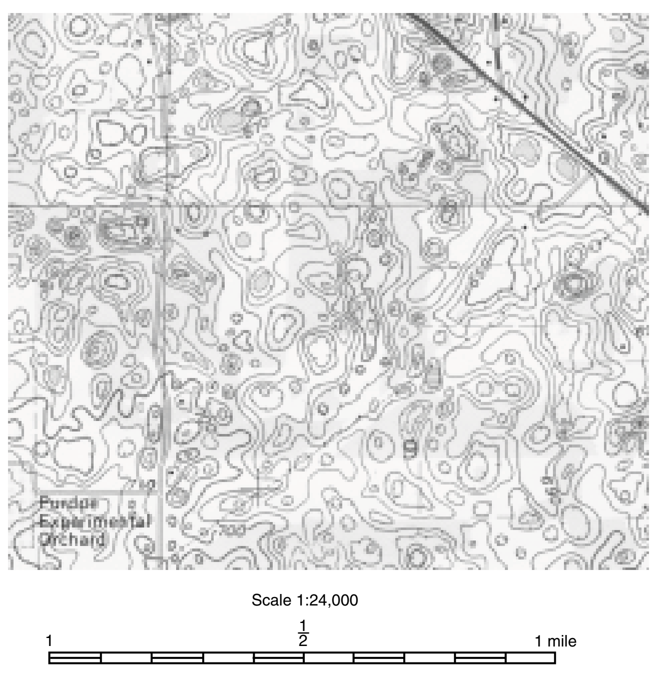
Steep slopes restrict use for some structural and vegetative measures. Potential hazards include landslides and erosion.

Karst topography is formed on limestone, gypsum, or similar rocks by dissolution and is characterized by sinkholes, caves, and underground drainage. Common problems associated with karst terrain include highly permeable foundations and the associated potential for groundwater contamination, and sinkholes can open up with collapsing ground. As such, its recognition is important in determining potential siting problems. Figure 7–10 illustrates karst topography near Mitchell, Indiana. Note the lack of stream development and the formation or presence of numerous sinkholes and depressions.

(m) Availability and suitability of borrow material

Borrow must meet gradation, plasticity, and permeability requirements for its intended use and be in sufficient quantity to build the component. Losses routinely occur during handling, transport, placement, and consolidation of fill materials. To compensate, as much as 150 percent of the design fill requirements should be identified within an economical hauling distance. Conditions of the borrow area itself may limit its use as borrow materials. Limitations may include such things as moisture content, thickness, location, access, land use, vegetation, and/or cultural resources.

Figure 7–10 Karst topography



(n) Presence of abandoned wells and other relics of past use

The site and its history should be surveyed for evidence of past use that may require special design considerations of the site relocation. If there is an abandoned well on the site, special efforts are required to determine if the well was sealed according to local requirements. An improperly sealed well can be a direct pathway for contaminants to pollute an aquifer.

Other remnants of human activity, such as old foundations, trash pits, or filled-in areas, require special AWMS design or site relocation. See section 651.0704 for guidance in planning investigations.

651.0703 Factors affecting groundwater quality considered in planning

(a) Attenuation potential of soil

Many biological, physical, and chemical processes break down, lessen the potency, or otherwise reduce the volume of contaminants moving through the soils in the root zone. These processes, collectively called attenuation, retard the movement of contaminants into deeper subsurface zones. See 210–NEH, Part 651, AWMFH, Chapter 3, Section 651.0303, Factors affecting the pollution process, for more details. The degree of attenuation depends on the time a contaminant is in contact with the material through which it travels. It also depends on the distance through which it passes and the total amount of surface area of particles of the material. Attenuation potential increases as clay content increases, soil depth increases, and distance increases between the contaminant source and the well or spring. Organic materials in the soil also increase the attenuation potential.

(1) Clay content
Increased clay content increases the opportunity for attenuation of contaminants because of its cation exchange capacity and its effect of reducing permeability. Clay particles hold a negative charge that gives them the capacity to interchange cations in solution and have a very low permeability (see fig. 7–11). As such, clay can absorb contaminant ions and thus attenuate the movement of contaminants.

(2) Depth of soil
Deeper soil increases the contact time a contaminant will have with mineral and organic matter of the soil. The longer the contact time, the greater the opportunity for attenuation. Very shallow (thin to absent) soil overlying permeable materials provides little to no protection against groundwater contamination.

(3) Distance between contaminant source and groundwater supply
Both the depth and the horizontal distance to a groundwater supply affect the attenuation of contaminants. The greater the horizontal distance between the source of the contamination and a well, spring, or the

groundwater supply, the greater the time of travel will be with increased potential for attenuation of contaminants.

(b) Groundwater flow direction

A desirable site for a waste storage pond or treatment lagoon is in an area where groundwater is not flowing away from the site toward a well, spring, or important underground water supply.

The direction of flow in a water table aquifer generally follows the topography, with lesser relief. In most cases, the slope of the land indicates the groundwater flow direction. In humid regions, the shape of the water table is a subdued reflection of surface topography. Unconfined groundwater moves primarily from topographically higher recharge areas down gradient to discharge areas. Lower areas serve as discharge points where groundwater rises and merges with perennial streams and ponds, drainage ditches, or flows as springs. Radial flow paths and unusual subsurface geology can too often invalidate this assumption. Consider the case where secondary porosity governs the flow. A common example is bedrock in upland areas where the direction of groundwater flow is strongly controlled by the trend of prominent joint sets or fractures. Fracture patterns in the rock may not be parallel to the slope of the ground surface. Thus, assuming that groundwater flow is parallel to the topography can be misleading in terrain where flow is controlled by bedrock fractures.

Appendix 7A demonstrates a method of calculating groundwater flow direction in a water table aquifer.

(c) Permeability of aquifer material

Permeability is a material property that is determined by laboratory analysis, but is also commonly determined as a mass property through field testing. The mass property is more accurately known as the aquifer's hydraulic conductivity, which integrates all of the aquifer's characteristics to conduct water.

The time available for attenuation in aquifer materials decreases as the permeability of the materials increases. Permeability may vary significantly between different types of materials or at different places within the same material. Permeability is often many times greater laterally than vertically. Ignored or undetected, a thin (0.5 inch or less) clay or shale seam in an otherwise uniform soil or rock aquifer can profoundly alter the outcome of mathematical analyses and design assumptions. Figure 7–11 shows the permeability of various geologic materials.

(d) Hydraulic conductivity

The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient.

Hydraulic conductivity is one of the hydraulic properties of the soil; the other involves the soil's fluid retention characteristics. These properties determine the behavior of the soil fluid within the soil system under specified conditions. More specifically, the hydraulic conductivity determines the ability of the soil fluid to flow through the soil matrix system under a specified hydraulic gradient; the soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition.

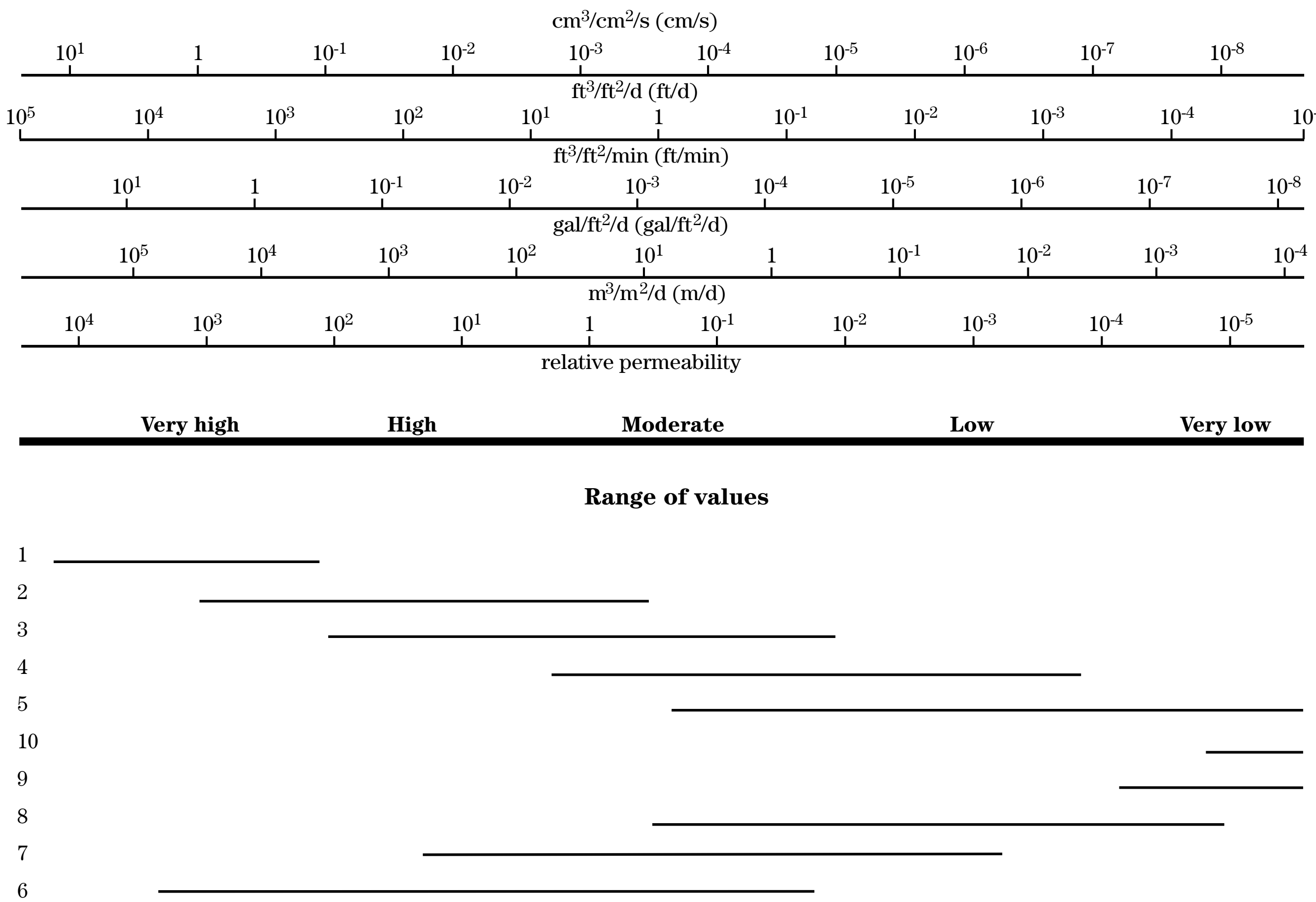
The hydraulic conductivity depends on the soil grain size, structure of the soil matrix, type of soil fluid, and relative amount of soil fluid (saturation) present in the soil matrix. The important properties relevant to the solid matrix of the soil include pore size distribution, pore shape, tortuosity, specific surface, and porosity.

Hydraulic conductivity is an important soil property when determining the potential for widespread groundwater contamination by a contaminating source. Soils with high hydraulic conductivities and large pore spaces are likely candidates for far reaching contamination.

(e) Hydraulic head

Hydraulic head is the energy of a water mass produced mainly by differences in elevation, velocity, and pressure, expressed in units of length or pressure. Groundwater moves in the direction of decreasing hydraulic head. Hydraulic head in an aquifer is measured using piezometers. For more information, see 210–NEH, Part 631, Chapter 32, Well Design and Spring Development.

Figure 7–11 Permeability of various geologic materials (from Freeze and Cherry 1979)



Representative materials

Numbers

Soil types

1. Clean gravel (GP)
2. Clean sand, clean sand and gravel mixes (GW, GP, SW, SP, SM)
3. Fine sand, silty sand and gravel mixes (SP, SM, GM, GW–GM, GP–GM, SW–SM, SP–SM)
4. Silt, clay, and sand-silt-clay mixes, organic silts, organic clays (GM, GC, SM, SC, MH, ML, ML–CL, OL, OH, GW–GC, GC–GM, SW–SC, SP–SC, SC–SM)
5. Massive clay, no soil joints or other macropores (CL, CH)

Rock types

6. Cavernous and karst limestones and dolomites, permeable basalts
7. Fractured igneous and metamorphic rocks
8. Limestones, dolomites, clean sandstones
9. Interbedded sandstones, siltstones, and shales
10. Most massive rocks, unfractured and unweathered

(f) Hydraulic gradient

The hydraulic gradient is the change in hydraulic head per unit distance of flow in a given direction; it is expressed in units of height (elevation) per length (distance). Groundwater velocity is a function of the hydraulic gradient. Most water in an unconfined aquifer moves slowly unless it has been developed during the well construction process. Well development is a procedure that alters the physical characteristics of the aquifer near the borehole so that water will flow more freely to the well.

Pumping water from a well can steepen local hydraulic gradients drawdown. This results in acceleration of flow toward the well, carrying any contaminants with it. Appendix 7A provides a method to calculate the hydraulic gradient in water table aquifers.

(g) Hydrogeologic setting

Hydrogeology is the study of the occurrence, movement, and quality of underground water. The hydrogeologic setting of an AWMS component includes all the various geologic factors that influence the quality and quantity of underground water. Information on the hydrogeologic setting of a site is in the following sources:

- State water quality management and assessment reports of surface and groundwater use designations and impairments
- geologic maps showing rock types and structures
- regional water table maps and, if available, tables of static water levels in wells
- groundwater vulnerability maps

(h) Land topography

Topographic features that impound contaminated runoff water increase the potential for groundwater contamination by infiltration. Examples include seasonal wetlands and level terraces. The hazard of contaminating surface water flowing across the ground increases as the slope and slope length increase.

(i) Proximity to designated use aquifers, recharge areas, and well head protection areas

State water management and assessment reports and the following maps should be reviewed to ascertain the proximity of sensitive groundwater areas:

- sole source or other types of aquifers whose uses have been designated by the State
- important recharge areas
- wellhead protection areas

(j) Type of aquifer

See section 651.0701, Overview of geologic material and groundwater, for details on unconfined, confined, and perched aquifers.

(k) Vadose zone material

The types of material in the vadose (unsaturated) zone affect the flow path and rate of flow of water and the contaminants percolating through it. Flow rate is a function of the permeability of the material (fig. 7–11). Flow rate in the mass is greatly increased by macropores such as soil joints. The time available for attenuation in this zone decreases as the permeability of the materials increases. Permeability rates may be inferred from the types of materials.

651.0704 Site investigations for planning and design

(a) Preliminary investigation

The purpose of a preliminary site investigation is to establish feasibility for planning purposes. A preliminary site investigation also helps determine what is needed in a detailed investigation. A site investigation should be done only after local regulations and permit requirements are known. The intensity of a field investigation is based on several factors including:

- quality of information that can be collected and studied beforehand
- previous experience with conditions at similar sites
- complexity of the AWMS or site

Clearly defined objectives for investigation are essential in this phase. Table 7–2 may be useful in defining objectives. For example, the objectives for investigating a site for a steel storage tank are significantly different from those for an earthen structures. The tanks involve consideration of differential settlement of the foundation, while the objectives of the subsurface investigation of earthen structures involves consideration of excavatability and permeability of foundation materials.

For many sites the preliminary investigation and experience in the area are adequate to determine the geologic conditions, engineering constraints, and behavior of the geologic materials. Hand-auger borings and site examination often provide adequate subsurface information so that a detailed subsurface investigation is not required. A detailed investigation must be scheduled if reliable information for design cannot be obtained with the tools available during the preliminary investigation phase.

An initial field evaluation should be performed on the potential layout(s) of the component, access to the site, and location of active or abandoned wells, springs, and other such features.

All wells and well records near the site should be examined for proper construction. The condition of the concrete pad and, if possible, the annular seal or grout around the well casing also need to be examined. See the Field Office Technical Guide (FOTG) for the National Conservation Practice Standard (CPS), Code 642, Water Well. Some State water agencies may have more restrictive minimum requirements.

Valuable background information about a proposed site is obtained from the following sources:

- soil survey reports—Provide soil map units, aerial photos, information on seasonal flooding and the water table, and engineering interpretations and classification of soils
- topographic maps—USGS topographic quadrangles or existing survey data from the site provide information about slopes, location of forested areas, topographic relief, and distances to identified resource features such as wells, watercourses, houses, roads, and other cultural features
- aerial photos—Provide information on vegetation, surface runoff patterns, erosion conditions, proximity to cultural features, and other details.
- local geologic maps and reports—Provide information on depth to and types of bedrock, bedrock structure, location of fault zones, characteristics of unconsolidated deposits, depth to water table, aquifer characteristics, and other geologic and groundwater information
- conservation plans and associated logs

(b) Detailed investigation

The purpose of a detailed geologic investigation is to determine geologic conditions at a site that will affect or be affected by design, construction, and operation of an AWMS component. Determining the intensity of detailed investigation is the joint responsibility of the designer and the person who has engineering job approval authority. Complex geology may require a geologist. Detailed investigations require application of individual judgment, use of pertinent technical references and state-of-the-art procedures, and timely consultation with other appropriate technical disciplines. Geologic characteristics are determined through digging or boring, logging the types and characteristics of the materials, and securing and testing representative samples. An onsite investigation should always be conducted at a proposed waste impoundment location. State and local laws should be followed in all cases.

(1) Investigation tools

Soil probes, hand augers, shovels, backhoes, bulldozers, power augers, and drill rigs all are used to allow direct observations for logging geologic materials, collecting samples, and access for field permeability testing. Soils that have been drilled with an auger are considered to be disturbed, and soil zones can be mixed, obscuring thin layers of potential permeability. Test pits expose a detailed view of the subsurface conditions; however, they cannot be safely excavated below the water table.

Geophysical methods are indirect techniques that are used in conjunction with direct methods of investigation such as test pits and soil borings. They require trained and experienced specialists to operate the equipment and interpret the results. The data must be ground truthed at a particular site, and the geology must be well understood to interpret the additional information accurately. These methods include electromagnetic induction, resistivity, refraction seismographs, ground penetrating radar, and cone penetrometer testing (see Soil Mechanics Note 11: The Static Cone Penetrometer: the Equipment and Using the Data).

(2) Logging geologic materials

During a geologic investigation, all soil and rock materials at the site or in borrow areas are identified and mapped. From an engineering standpoint, a mappable soil or rock unit is defined as a zone that is consistent in its mineral, structural, and hydraulic characteristics and sufficiently homogeneous for descriptive and mapping purposes. A unit is referred to by formal name such as Alford silt loam or Steele shale, or is set in alphanumeric form such as Sand Unit A–3.

The NRCS classifies rock material using common rock type names as given in 210–NEH, Part 631, Chapter 12, Rock Material Field Classification System and Part 628, Chapter 52, Field Procedures Guide for the Headcut Erodibility Index; and 210–TR–78, The Characterization of Rock for Hydraulic Erodibility. Soils are classified for engineering purposes according to the USCS, ASTM D 2488, Standard Practice for Description and Identification of Soils, Visual Manual Procedure. Appendix 7B provides criteria for identifying soils by the USCS. Any geologic material, regardless of origin, that meets the criteria in this standard practice is considered soil for classification purposes.

When greater precision is needed, representative samples are analyzed in a soil mechanics laboratory. The laboratory uses ASTM D 2487, Standard Test Method for Classification of Soils for Engineering Purposes. Laboratory determinations of particle characteristics and Atterberg limits (liquid limit and plasticity index) are used to classify soils.

Use standard NRCS log sheets, such as NRCS–533, or the soil log sheet and checklists in appendix 7B. Logs also may be recorded in a field notebook. Be methodical when logging soils.

Identify and evaluate all applicable parameters according to criteria given in ASTM D 2488. Thorough logging requires only a few minutes on each boring or test pit and saves a trip back to the field to gather additional or overlooked information. Also, be prepared to preserve a test hole or pit to record the stabilized water table elevation after 24 hours.

Each log sheet must contain the name of the project, location, date, investigator's name and title, and type of equipment used (backhoe) including make and model, and test pit or boring identification number, or each soil type found in a test pit or drill hole, record the following information, as appropriate.

- station and elevation of test hole or pit
- interval (depth range through which soil is consistent in observed parameters)
- particle size distribution by weight, for fraction less than 3 inches
- percent cobbles and boulders by volume, for fraction greater than 3 inches
- angularity of coarse material
- color of moist material including presence of redoximorphic feature which occur in the zone of water table fluctuation
- relative moisture content
- structure

- consistency in saturated fine-grained materials or relative density in coarse-grained materials
- plasticity of fines
- group name and USCS symbol according to ASTM D 2488 flow charts
- geologic origin and formal name, if known
- sample (size, identification number, label, depth interval, date, location, name of investigator)
- other remarks or notes (mineralogy of coarse material, presence of mica flakes, roots, odor, pH)
- depth (or elevation) of water table after stabilizing; give date measured and number of hours open
- depth to rock, “refusal” (where the equipment meets resistance and cannot penetrate any further) or total depth of hole

For more details, see 210–NEH, Part 650, EFH, Chapter 4, Elementary Soil Engineering.

(3) Samples

Samples of soil and rock materials collected for soil mechanics laboratory testing must meet minimum size requirements given in Geology Note 5, Soil Sample Requirements for Soil Mechanics Laboratory Testing. Sample size varies according to testing needs. Samples must be representative of the soil or rock unit from which they are taken. A geologist or engineer should help determine the tests to be conducted and may assist in preparing and handling samples for delivery to the lab. Test results are used in design to confirm field identification of materials and to develop interpretations of engineering behavior.

(4) Guide to detailed geologic investigation

For foundations of earthfill structures, use at least four test borings or pits on the proposed embankment centerline, or one every 100 feet, whichever is greater. If correlation of materials between these points is uncertain, use additional test borings or pits until correlation is reasonable. The depth to which subsurface information is obtained should be no less than equivalent maximum height of fill, or to hard, unaltered rock or other significant limiting layer. For other types of waste storage structures, the depth should be to bedrock, dense sands or gravels, or hard fine-grained soils. Report unusual conditions to the responsible engineer or State specialist for evaluation. These conditions are listed in table 7–2.

For structures with a pool area, use at least five test holes or pits or one per 10,000 square feet of pool area, whichever is greater. These holes or pits should be as evenly distributed as possible across the pool area. Use additional borings or pits, if needed, for complex sites where correlation is uncertain. The borings or pits should be dug no less than 2 feet below proposed grade in the pool area or to refusal (limiting layer). Log the parameters listed in this section. Report unusual conditions to the responsible engineer or other specialist for further evaluation. Pay special attention to perched or high water tables and highly permeable materials in the pool area.

Borrow areas for embankment type structures and clay liners should be located, described, and mapped. Locate at least 150 percent suitable borrow of the required fill volume. Soil samples for natural water content determinations should be obtained from proposed borrow and clay liner sources. Samples should be collected and maintained in moisture proof containers. The parameters listed in this section should be logged.

Consult soil survey reports and local surficial geologic maps to help identify potential borrow areas for investigation. Some designs may require bentonite or chemically treated soil to reduce permeability (see 210–NEH, Part 651, AWMFH, Chapter 10, Appendix 10D). A qualified soil mechanics engineer should be consulted for guidance.

Depth to the water table in borrow areas is an important consideration. Dewatering a borrow area is usually impractical for small components such as waste structures. Installing drainage or excavating and spreading the materials for drying before placement generally is not cost-effective. It may be necessary to do so, however, when suitable borrow is limited. Adhere to any State or local requirements for back filling test pits or plugging borings.

651.0705 References

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Appendix 7A Determining Groundwater Flow Direction and Hydraulic Gradient

If a published water table map is not available for the area, but several wells and springs are nearby, a contour map of the water table should be developed. Plot on a topographic map (at an appropriate scale) a sufficient number of points of static levels of water wells, observation wells, and test pits. Include spot elevations of perennial streams, ponds, and lakes. Using an appropriate contour interval, contour the data points to produce a useful water table map. Record dates of observations to allow comparison over time, from season to season, or in areas of suspected water table fluctuations.

If information on water table depths is not available and the aquifer is controlled by primary porosity, such as alluvium and glacial outwash, sketch several lines perpendicular to the elevation contours in the area of interest. The pattern that develops will indicate general groundwater flow directions. Groundwater discharge areas occur where the lines converge, such as most valleys, perennial streams, and ponds. Recharge areas, such as hilltops and upland areas converge, occur where the lines diverge.

For planning purposes, the general groundwater flow direction and hydraulic gradient of the water table should be calculated using data from three wells located in any triangular arrangement in the same unconfined aquifer (Heath 1983). They may be observation wells, test holes, test pits, or water wells. Also, the elevation of a perennial pond or stream can serve as an observation point. There is an 8-step procedure for this planning method, and figure 7A–1 gives an example.

Step 1—Obtain a detailed topographic map of the site, such as a USGS quadrangle or a field survey map. Be sure the map has a north arrow.

Step 2—Plot the position of the proposed AWMS component and all springs, wells within at least a half-mile radius. If the existence of wells is unknown, assume every rural house or farm/ranch headquarters represents the location of a well. Black squares on USGS quadrangles symbolize houses.

Step 3—Select three wells not in a line, and measure the static (nonpumping) levels using a commercial water depth meter or a lead weight on a measuring tape. Record on the map the head (elevation of the water table) for each well. Use consistent units (meters or feet above mean sea level or an arbitrary datum plane) throughout this exercise.

Step 4—Measure the distance between the wells with the highest and lowest water level elevations, and record on the map.

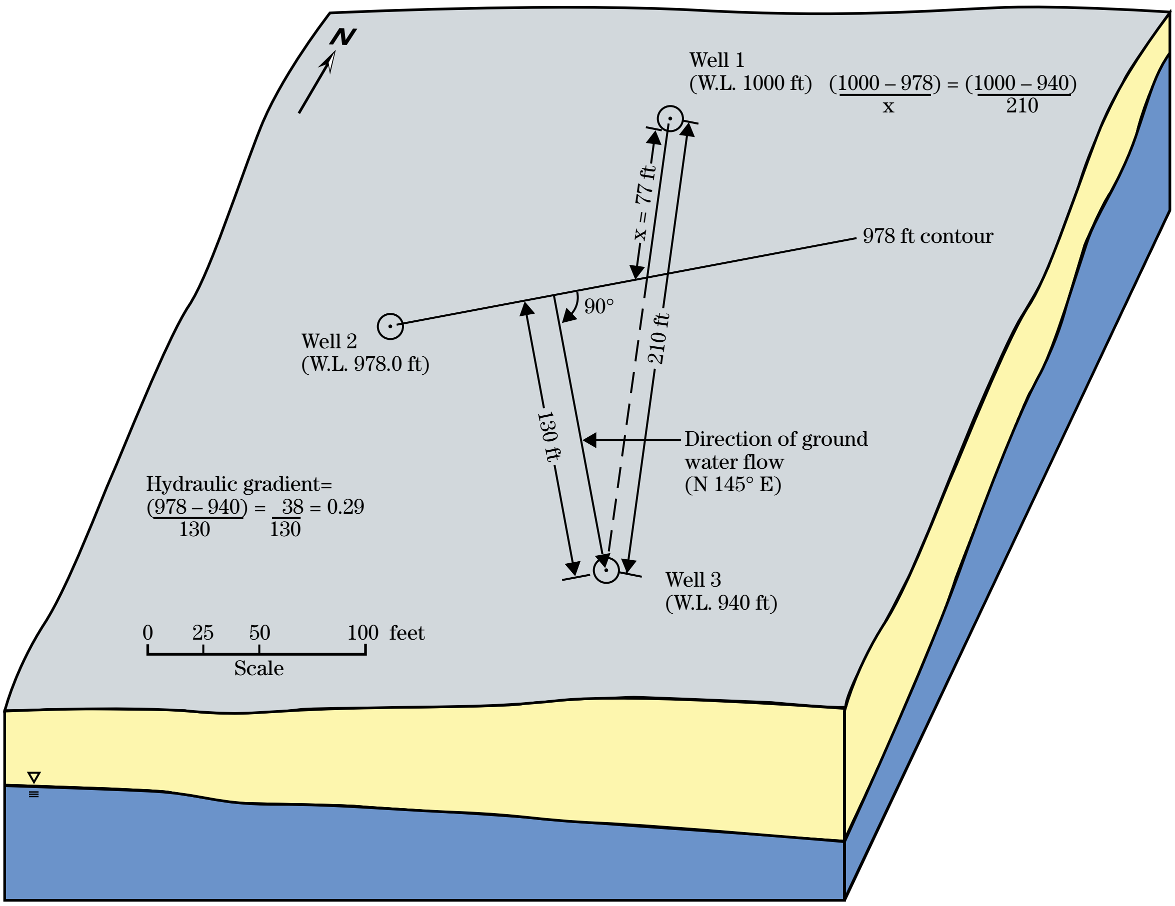
Step 5—Using the map, identify the well with the intermediate water table elevation (that is, neither the highest nor the lowest). Interpolate the position between the well with the highest head and the well with the lowest head where the head is equal to that in the intermediate well. Mark this point on the map. Measure the distance between this point and the well with the lowest water level.

Step 6—Draw a straight line between the intermediate well and the point identified in step 5. This line represents a segment of a water table contour along which the head is the equal to that in the intermediate well.

Step 7—Draw a line perpendicular from this contour to the lowest head well, and measure the distance. This line is parallel to the groundwater flow direction. Using the north arrow as a guide, orient a protractor to measure the compass direction of the line. Express the orientation of the groundwater flow direction in degrees azimuth (clockwise east from north).

Step 8—Subtract the head of the lowest well from that of the intermediate well. Divide the difference by the distance measured in step 7. The result is the hydraulic gradient.

Figure 7A–1 Determining direction of groundwater flow and hydraulic gradient (from Heath 1983)



Appendix 7B Identifying Soils for Engineering Purposes

Soil Log Sheet

Project________ Location________ Date________

Investigator________ Title________ Equipment________

Interval (feet)	Particle size distribution by weight			Particle size distribution by volume		Angularity (coarse fraction)	Color (when moist)	Relative moisture content	Saturated consistency of fines	Density (coarse fraction)	Group name	Unified symbol	Geologic origin	Sample no.
	Percent fines	Percent sand	Percent gravel	Percent cobbles	Percent boulders									

Notes:

Test hole no.______ Station______ Elevation______ Water table elevation______ after______ hours Sheet____ of____

The following tables are derived from ASTM D 2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). Tables 7B–1 through 7B–11, except 7B–7, copyright ASTM Int'l. Reprinted with permission.

Table 7B–1 Criteria for describing angularity of coarse-grained particles

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

Table 7B–2 Criteria for describing particle shape

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

Table 7B–3 Criteria for describing moisture condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible moisture
Wet	Visible free water, usually soil is below water table

Table 7B–4 Criteria for describing the reaction with HCL

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

Table 7B–5 Criteria for describing cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

Table 7B–6 Criteria for describing structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

Table 7B–7 Criteria for describing consistency

Description	Criteria for Fine-grained Saturated Soils	Penetrometer tons/ft^2 or kg/cm^2	Std. Penetration Test (ASTM D 1586) blows/ft
Very soft	Thumb will penetrate soil more than 1 in	< 0.1	< 2
Soft	Thumb will penetrate soil about 1 in	0.10–0.25	2–4
Firm	Thumb will indent soil about 1/4 in	0.25–1.00	4–15
Hard	Thumb will not indent soil, but readily indented with thumbnail	1.00–2.00	15–30
Very hard	Thumbnail will not indent soil	> 2.00	> 30

Table 7B–8 Criteria for describing dry strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen crumbles into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

Table 7B–9 Criteria for describing dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

Table 7B–10 Criteria for describing toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

Table 7B–11 Criteria for describing plasticity

Description	Criteria
Nonplastic	A 1/8-in (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

Checklist—Description of coarse-grained soils (ASTM D 2488)

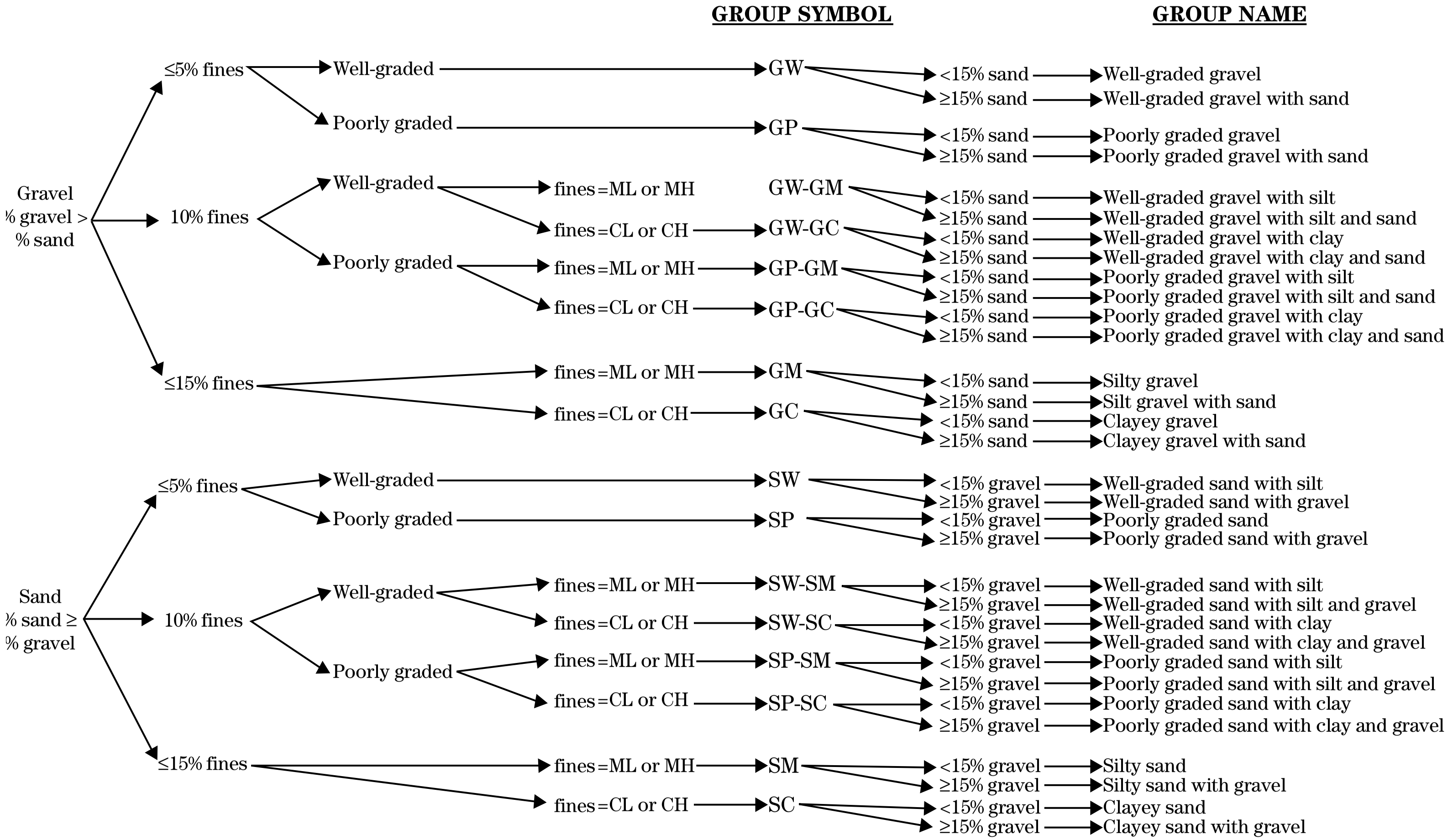
1. **Typical Name:** Boulders Cobbles Gravel Sand
   Add descriptive adjectives for minor constituents.
2. **Gradation:** Well-graded Poorly graded (uniformly graded or gap-graded)
3. **Size Distribution:** Percent gravel, sand, and fines in fraction finer than 3 inches (76 mm) to nearest 5 percent. If desired, the percentages may be stated in terms indicating a range of values, as follows:
   Trace: < 5%
   Few: 5–10%
   Little: 15–25% Or, with gravel
   Some: 30–45% Or, gravelly
   Mostly: 50–100%
4. **Percent Cobbles and Boulders:** By volume
5. **Particle Size Range:** Gravel—fine, coarse
   Sand—fine, medium, coarse
6. **Angularity of Coarse Material:** Angular Subangular Subrounded Rounded
7. **Particle Shape (if appropriate):** Flat Elongated Flat and elongated
8. **Plasticity of Fines:** Nonplastic Low Medium High
9. **Mineralogy:** Rocky type for gravel, predominant minerals in sand. Note presence of mica flakes, shaly particles, and organic materials.
10. **Color:** Use common terms or Munsell notation (in moist or wet condition).
11. **Odor (for dark-colored or unusual soils only):** None Earthy Organic
12. **Moisture Content:** Dry Moist Wet

—For intact samples—

13. **Natural Density:** Loose Dense
14. **Structure:** Stratified Lensed Nonstratified
15. **Cementation:** Weak Moderate Strong
16. **Reaction (dilute with HCL):** None Weak Strong (or pH)
17. **Geologic Origin:** Examples—Alluvium, Residuum, Colluvium, Glacial Till, Outwash, Dune Sand, Alluvial Fan, Talus
18. **Unified Soil Classification Symbol:** Estimate (see table 7B–12, Field identification of coarse-grained soils)

Note: See tables 7B–1 through 7B–11 for criteria for describing many of these factors.

Figure 7B–1 Flow chart for identifying coarse-grained soils (less than 50% fines) (Source: ASTM D 2488 (fig. 2). Copyright ASTM Int'l. Reprinted with permission.)



Note 1—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

Table 7B–12 Field identification—coarse-grained soils

Coarse Particle Grade Sizes

Grade name	Grade size	Sieve no	Comparative size
Boulders	12" +	–	Basketball or larger
Large cobbles	6" - 12"	–	Cantaloupe to basketball
Small cobbles	3" - 6"	–	Orange to cantaloupe
Coarse gravel	3/4" - 3"	-	Cherry to orange
Fine gravel	1/4" - 3/4"	4 - 3/4"	Pea to cherry
Coarse sand	2.0 - 4.76 mm	10 - 4	Wheat grain to pea
Medium sand	0.42 - 2.0 mm	40 - 10	Sugar to wheat grain
Fine sand	0.074 - 0.42 mm	200 - 40	Flour to sugar

<table>
<tr><td rowspan="8">Coarse-grained soils[1]</td><td rowspan="4">Gravel and gravelly soils[2]</td><td rowspan="4">More than half of coarse fraction (by weight) is larger than 1/4-inch.</td><td rowspan="2">Clean gravels
Will not leave a dirt stain on a wet palm.</td><td>Wide range in grain sizes and substantial amounts of all intermediate sizes.</td></tr>
<tr><td>Mostly one size or a range of sizes with some intermediate sizes missing.</td></tr>
<tr><td rowspan="2">Dirty gravels
Will leave a dirt stain on a wet palm.</td><td>Low to nonplastic fines (for identifying fines see Field Identification of Fine-grained Soils for ML soils).</td></tr>
<tr><td>Plastic fines (for identifying fines see Field Identification of Fine-grained Soils for CL soils).</td></tr>
<tr><td rowspan="4">Sand and Sandy soils[2]</td><td rowspan="4">More than half of coarse fraction (by weight) is smaller than 1/4-inch.</td><td rowspan="2">Clean sands
Will not leave a dirt stain on a wet palm.</td><td>Wide range in grain sizes and substantial amounts of all intermediate particle sizes.</td></tr>
<tr><td>Mostly one size or a range of sizes with some intermediate sizes missing.</td></tr>
<tr><td rowspan="2">Dirty sands
Will leave a dirt stain on a wet palm.</td><td>Low to nonplastic fines (for identifying fines see Field Identification of Fine-grained Soils for ML soils).</td></tr>
<tr><td>Plastic fines (for identifying fines see Field Identification of Fine-grained Soils for CL soils).</td></tr>
</table>

1/ To classify as coarse-grained, more than half of the material (by weight) must consist of individual grains visible to the naked eye. Individual grains finer than no. 200 sieve cannot be seen with the naked eye nor felt by the fingers.
2/ For visual classification, 1/4-inch size may be used as equivalent to no. 4 sieve.

Checklist—Description of fine-grained soils (ASTM D 2488)

1. **Typical Name:** Silt Elastic silt Lean clay Fat clay
   Silty clay Organic silt or clay Peat
2. **Dry Strength:** None Low Medium High Very high
3. **Size Distribution:** Percent gravel, sand, and fines in fraction finer than 3 inches (76 mm) to nearest 5 percent. If desired, the percentages may be stated in terms indicating a range of values, as follows:
   Trace: < 5%
   Few: 5–10%
   Little: 15–25% Or, with sand
   Some: 30–45% Or, sandy
   Mostly: 50–100%
4. **Percent Cobbles and Boulders:** By volume
5. **Dilatancy:** None Slow Rapid
6. **Toughness of Plastic Thread:** Low Medium High
7. **Plasticity of Fines:** Nonplastic Low Medium High
8. **Color:** Use common terms or Munsell notation (in moist or wet condition).
9. **Odor (for dark-colored or unusual soils only):** None Earthy Organic
10. **Moisture content:** Dry Moist Wet

—For intact samples—

11. **Consistency:** Very soft Soft Firm Hard Very hard
12. **Structure:** Stratified Laminated (varved) Fissured Slickensided Blocky Lensed Homogeneous
13. **Cementation:** Weak Moderate Strong
14. **Reaction (dilute with HCL):** None Weak Strong (or pH)
15. **Geologic Origin:** Examples—Alluvium, Residuum, Colluvium, Loess, Glacial till, Lacustrine
16. **Unified Soil Classification Symbol:** Estimate (see table 7B–13, Field identification of fine-grained soils)

Note: See tables 7B–1 through 7B–11 for criteria for describing many of these factors.

Table 7B–13 Field identification—fine-grained soils

Dry Strength	Dilatancy	Toughness	Plasticity	Symbol
None to low	Slow to rapid	Low or no thread	Nonplastic to low	ML
Medium to high	Slow	Medium	Low to medium	CL
Low to medium	None to slow	Low (spongy)	None to low	OL
Medium	None to slow	Low to medium	Low to medium	MH
Very high	None	High	Medium to high	CH
Medium to high	None	Low to medium (spongy)	Medium to high	OH
Highly organic soils	Primarily organic matter, dark in color, spongy feel, organic odor, and often fibrous texture			PT

Note—To classify as fine-grained, more than half the material (by weight) must consist of fines (material finer than the no. 200 sieve).

Figure 7B–2 Flow chart for identifying fine-grained soils (50% or more fines) (Source: ASTM D 2488 (figs. 1 a and 1 b). Copyright ASTM Int'l. Reprinted with permission.)