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Field Handbook

Chapter 7 Geologic and Ground Water Considerations

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Chapter 7 Geologic and Ground Water Considerations

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Chapter 7 Geologic and Ground Water Considerations

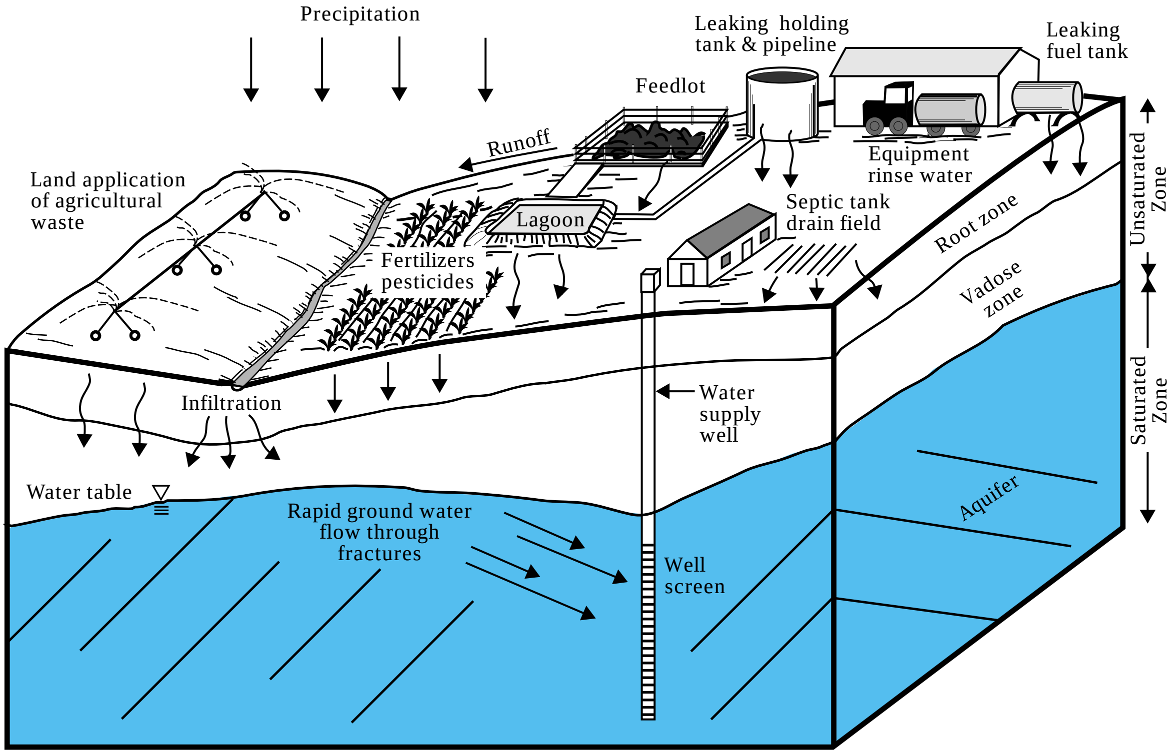
651.0700 Introduction

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

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

Storing, treating, or utilizing agricultural wastes and nutrients at or below the ground surface has the potential to contaminate ground water (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 encountered in investigation and planning.

Figure 7–1 Agricultural sources of potential ground water contamination



651.0701 Overview of geologic material and ground water

(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 inplace 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 solutionally widened joints, sinkholes, and caves. 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 NRCS 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.

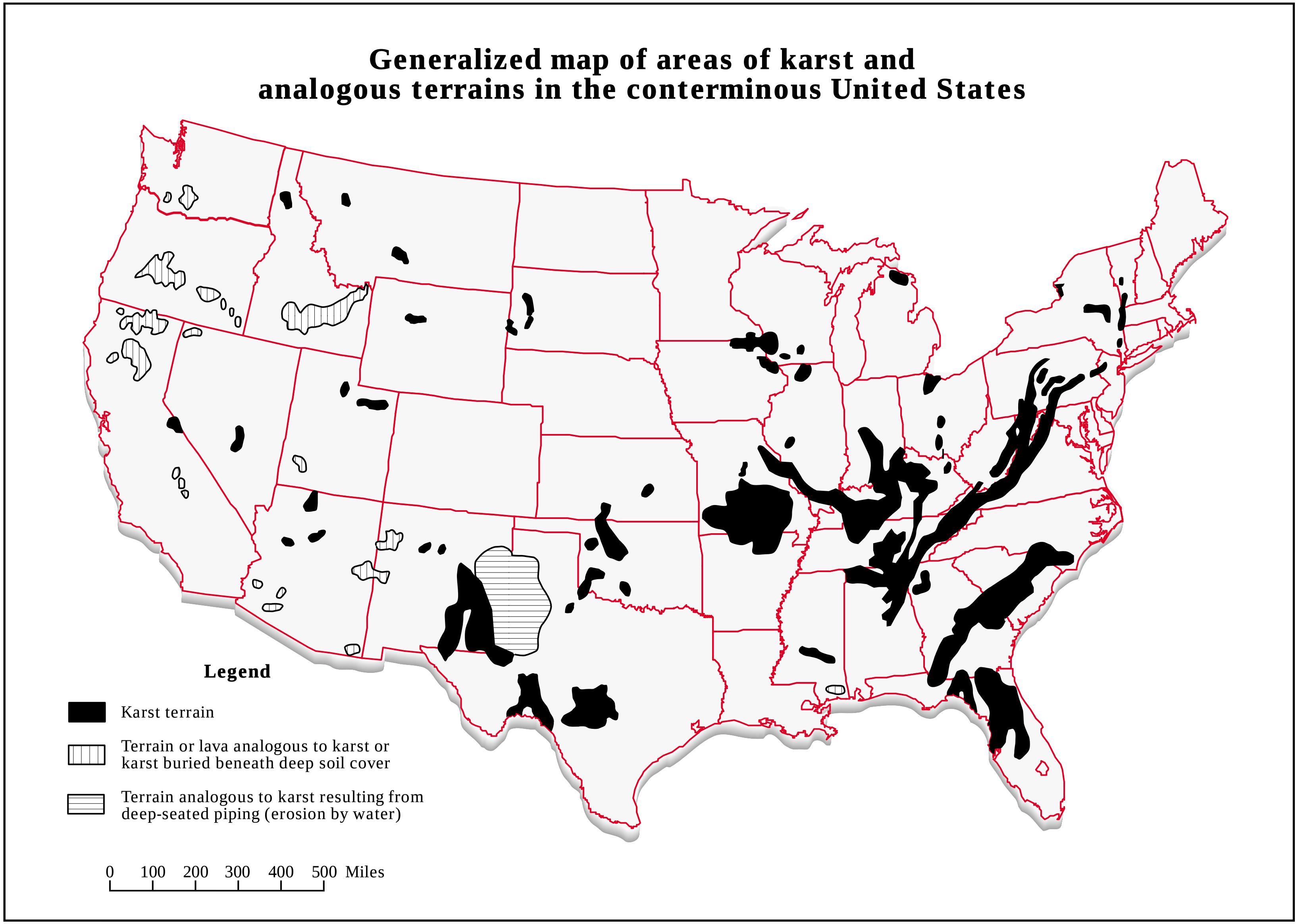
Structural discontinuities are extremely common in almost any geologic material. They include fractures of all types that develop sometime after a soil or rock mass has formed. Almost all types of bedrock are fractured near the Earth's surface. Forces acting on the mass that cause deformation include 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 rock. These wells are at risk of contamination from waste impoundment facilities if rock 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. Discontinuities can, therefore, 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) Ground water

Many Natural Resources Conservation Service (NRCS) programs deal with the development, control, and protection of ground water resources. The planners of agricultural waste management practices should be familiar with the principles of ground water. NRCS references that include information on ground water include National Engineering Handbook (NEH) Section 16, Drainage of Agricultural Lands; NEH Section 18, Ground Water; Engineering Field Handbook (EFH) Chapter 12, Springs and Wells; and EFH Chapter 14, Drainage.

Figure 7–2 Karst areas in the United States

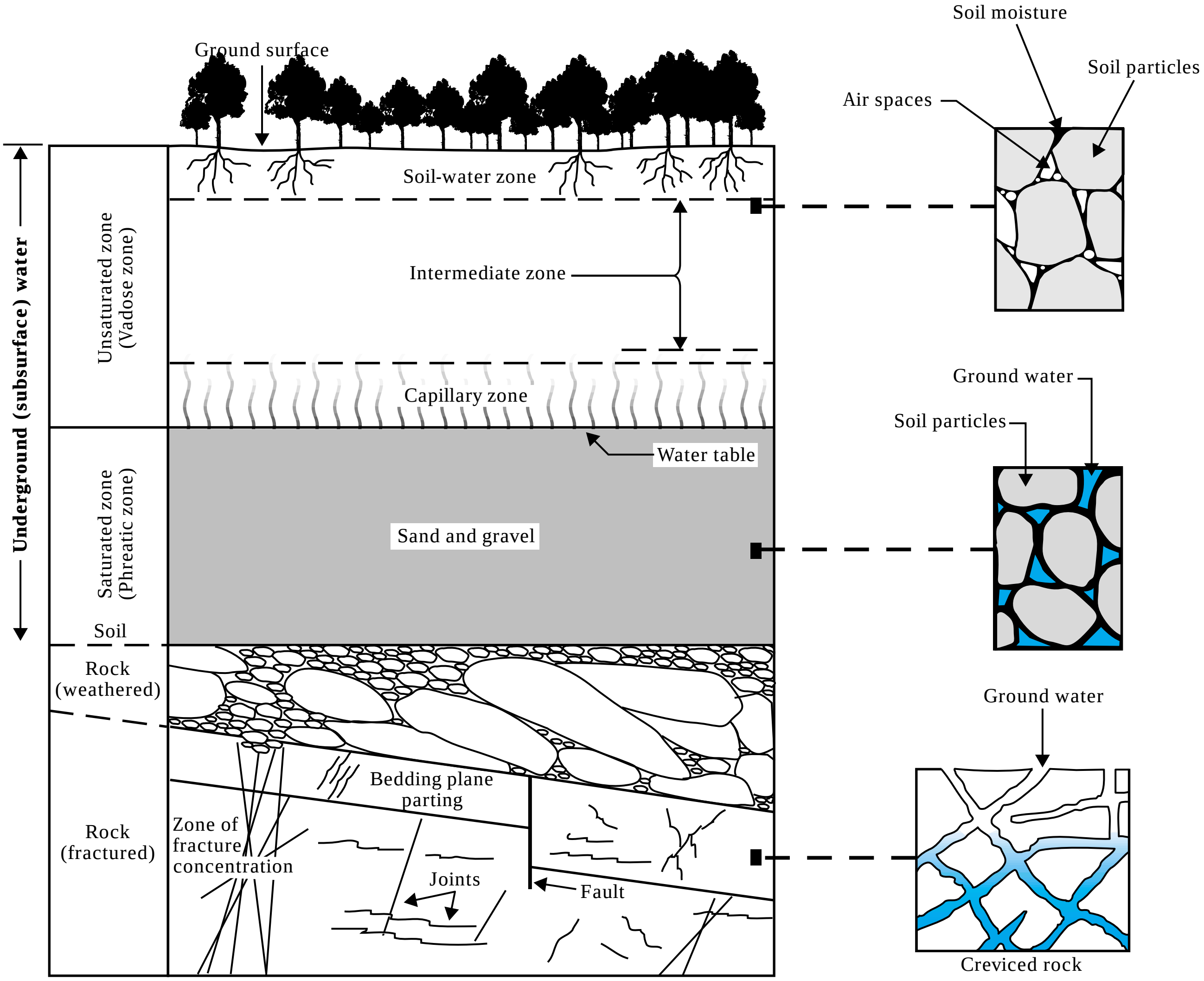


(1) Zones of underground water

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 ground water applies to the saturated zone. Ground water is the only underground water available for wells and springs.

The vadose zone includes the soil-water zone, the intermediate zone, and the capillary fringe. 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 by plants or direct evaporation. This zone is usually at less than saturation except during rainfall or irrigation. Water held by surface tension moves by capillary action. Excess water percolates through the soil-water zone by gravity. An intermediate zone may separate the soil zone from the capillary fringe. An intermediate zone does not exist where the water table (described later)

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



approaches the ground surface. Regions in the intermediate zone may be hundreds of feet thick. Water in the intermediate zone cannot move back up to the soil-water zone by capillary action. Intermediate zone water moves either downward under gravity or is held in place by surface tension.

Directly above the water table is a saturated zone, the capillary fringe. This zone occurs in fine to medium grained soils and in rocks with fractures less than 1/8 inch wide. Water in the capillary fringe is under less than atmospheric pressure. It rises a few inches to more than 10 feet above the water table, depending on the earth materials (sand, low; clay, high). Surface tension and capillary action cause water in this zone to rise. Capillary rise increases as the pore spaces decrease.

In the saturated zone, water is under hydrostatic pressure and occupies all pore spaces. The upper surface of the saturated zone is called the water table. The elevation of the water table is at atmospheric pressure. The saturated zone extends from the plane of the water table down to impermeable geologic material.

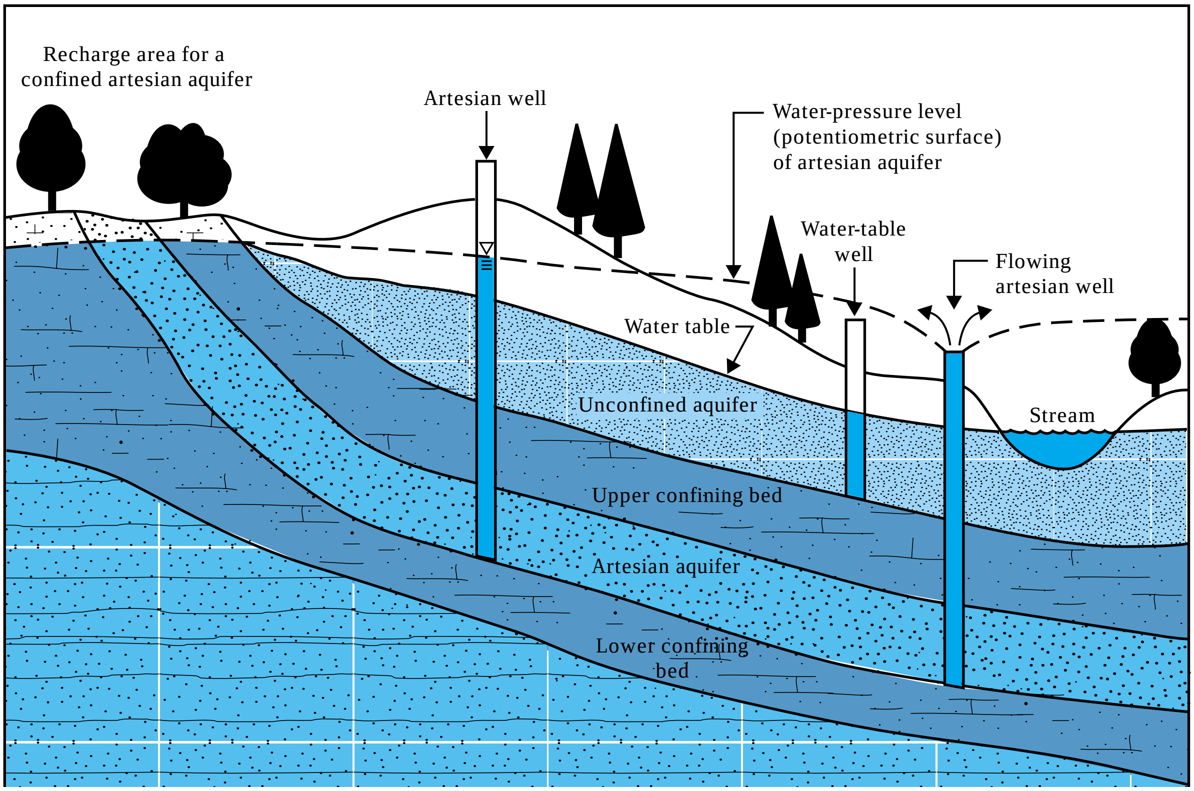
(2) Aquifers

An aquifer is a geologic unit capable of storing and conveying usable amounts of ground water to wells or springs (fig. 7–4). When siting any agricultural waste management component, it is important to know:

- What type(s) of aquifers may be present and at what depths.
- What the aquifer use classification is, if any.

Aquifers occur in many types of soil or rock material. Productive aquifers include sand and gravel alluvial deposits on flood plains of perennial streams; glacial outwash; coarse-grained, highly porous, or weakly cemented sedimentary rocks (some sandstones and conglomerates); and karst topography. An aquifer need not be highly productive to be an important resource. For example, there are millions of low-

Figure 7–4 Aquifers (from AIPG 1984)



yielding (less than 10 gpm) private domestic wells throughout the country. In upland areas, often the only aquifer available for a ground water source is fractured rock occurring near the surface (up to 300 feet deep).

An aquifer may be unconfined, confined, or perched. An unconfined aquifer, or water table aquifer, has no upper confining layer (fig. 7–5). Hence, the upper surface of the saturated zone is under only atmospheric pressure. It is, therefore, free to rise and fall with recharge or pumping. Recharge generally occurs locally. The static water level in a well in an unconfined aquifer is the elevation at which water stabilizes after pumping ceases. Unconfined aquifers are the type most commonly experienced in NRCS work.

Some unconfined aquifers result in flowing artesian wells. This occurs when the water table locally rises above the ground surface. Topography is the primary control on most flowing wells in major valley bottoms. The valleys serve as ground water discharge areas. Because hydraulic potential increases with depth in valley bottoms, deep wells frequently tap a hydraulic head contour with a head value greater than that of the land surface, and therefore, will flow (fig. 7–6).

A confined aquifer is overlain by a confining layer of lower permeability (fig. 7–7). The surface of ground water under confined conditions is often subject to higher than atmospheric pressure because it is confined by impermeable layers bounding the aquifer. A well in a confined aquifer that has higher than atmospheric pressure is called an artesian well. The potentiometric surface is the level to which ground water rises in a tightly cased well penetrating a confined aquifer. Recharge areas are typically remote from any given well location. The classic model of a flowing artesian well (see fig. 7–4) is the case where an aquifer crops out (that is, is exposed at the Earth's surface) and receives recharge in an upland area. Low permeability materials (aquicludes) lying above

Figure 7–6 Cross section through stream valley showing ground water flow lines and flowing (artesian) well from unconfined aquifer (from Fetter 1980)

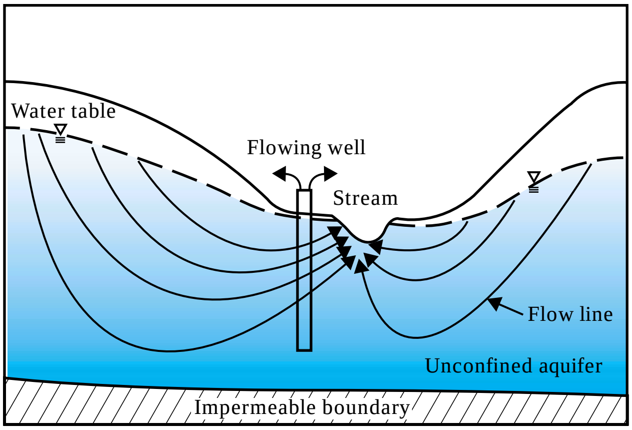
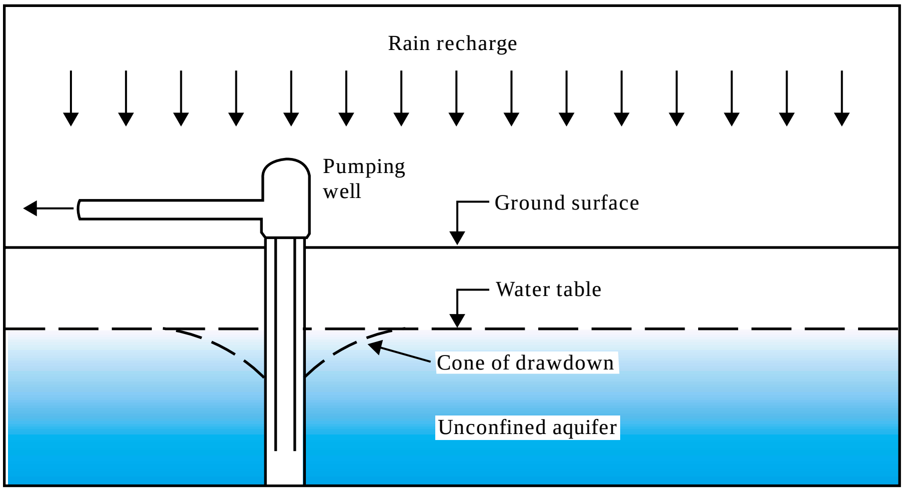


Figure 7–5 Unconfined aquifer (from AIPG 1984)



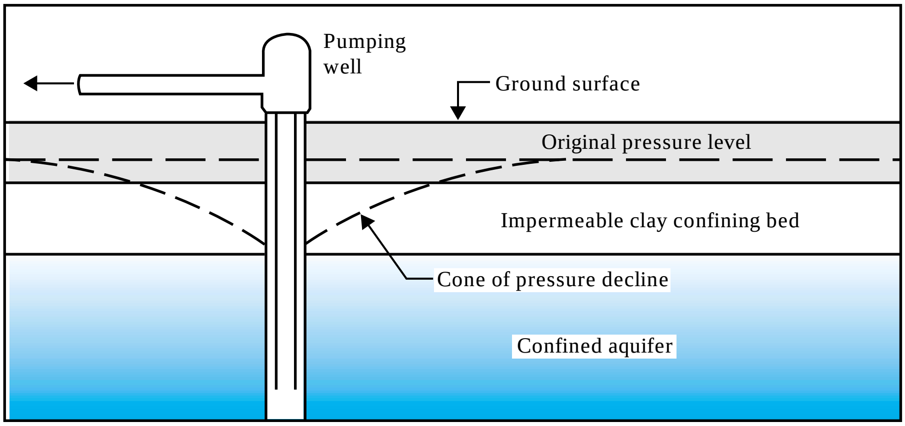
and confining the aquifer generate hydraulic heads greater than the surface elevation head. The confined aquifer, therefore, produces flowing artesian wells.

A perched aquifer is a local zone of unconfined ground water occurring at some level above the regional water table. An unsaturated zone separates the perched aquifer from the regional water table. A perched aquifer generally is of limited lateral extent. It forms in the unsaturated zone where a relatively impermeable layer, called a perching bed (for example, clay), intercepts downward-percolating water and causes it to accumulate above the bed (fig. 7–8). Perched aquifers can be permanent or temporary, depending on frequency and amount of recharge. Perched aquifers can present dewatering problems during construction if not discovered during investigation of the site.

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

A state may have designated use classifications just as surface water resources have. A state may have designated use classifications to protect aquifers for future use by a municipality, for example. Some aquifers may be regulated against overdraft or ground water mining.

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

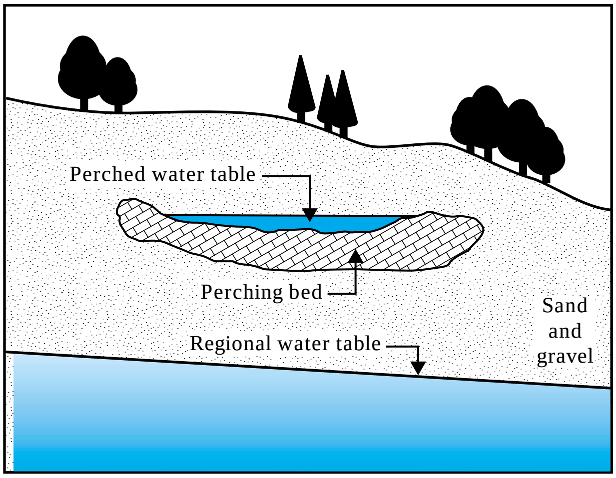


(3) Porosity

Most earth 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.

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

Figure 7–8 Perched aquifer

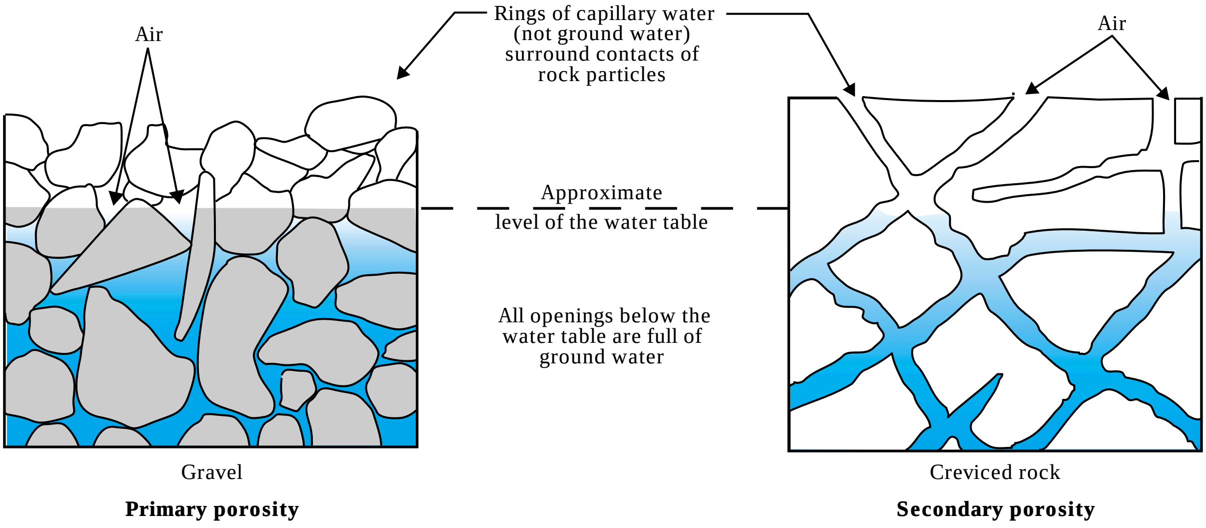


The two main types of porosity are primary and secondary (fig. 7–9).

Primary porosity refers to openings formed at the same 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. Porosity, however, is independent of particle size. Thus, a bathtub full of bowling balls has the same porosity as the same tub full of bb's. This assumes the arrangement (packing) is the same for balls and bb's. However, the tub full of a mixture of bowling balls and bb's will have a lower porosity than either the bb's or the bowling balls because bb's will occupy space between the bowling balls.

Secondary porosity refers to openings formed after initial deposition or formation of a material. Processes that create secondary porosity include physical weathering (freeze-thaw, 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.

Figure 7–9 Porosity—how ground water occurs in geologic materials



(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, 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.

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

Table 7–1 Porosity and specific yield for various geologic materials (from Driscoll 1986 and Johnson 1967)

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

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 encountered, justify requesting assistance of a geologist or other technical specialist.

(a) Corrosivity

Soil is corrosive to many materials used in AWMS components. Published soil surveys and the NRCS National Soil Characterization data base 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.

Obtain preliminary estimates of the depth to high water table from published soil surveys and the NRCS National Soil Characterization data base. Site-specific ground water 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 mottling is particularly important. Mottling indicates seasonal changes in soil moisture. Perennially saturated soil is typically gray. Perennially aerated soil is typically various shades of red, brown, or yellow.

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

Agricultural Waste Management Component	Availability and suitability of borrow material	Topography	Shrink/swell	Settlement potential	Puncturability	Permeability	Dispersion	Seismic stability	Excavatability	Stability for embankment and excavation cut banks	Depth to rock	Location of water table (uplift pressures)	Corrosivity
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
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., buried pipelines)		X											X

Engineering geology considerations

(c) Depth to rock

The selection of components that make up an agricultural waste management system 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 highly 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 rock may contaminate ground water 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. The physical hazard of ground collapse and the potential for ground water contamination through the large voids are severe limitations.

(d) Stability for embankment and excavated cut slopes

Embankments and excavated cut slopes must remain stable throughout their design life. Control of ground water 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 to prevent the increased loads caused by the static or dynamic weight of a component from causing downslope sliding or slumping, especially for a clay foundation having 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 lead to bank caving. Designers must consider this in determining the stable side slope of embankments and cutbanks, and in designing the liner thickness. Consideration should be given to addressing the maximum rate that wastewater should be withdrawn from waste impoundments to minimize this problem in operation and maintenance plans.

(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 available 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

Abrupt lateral or vertical changes in soil or rock materials may indicate faults (active or inactive) or bedrock structures, such as tight folds, shear zones, and vertical bedding. Seismic zones 3 and 4, as defined in TR-60, Earth Dams and Reservoirs, and locally delineated, typically require special considerations in design of embankments including embankment slopes, cut slopes, zoned fill, or internal drainage. A foundation consisting of loose, saturated, fine-grained, relatively clean sand is most susceptible to seismic activity. Most well compacted embankments and those foundations and embankments consisting of fine-grained soil with plasticity are inherently resistant to seismic shocks.

Determine the seismic zone of a site using the map in TR-60. Identify other geologic hazards from information as may be listed in section I of the Field Office Technical Guide (FOTG) and in geology reports, geologic maps, or other local technical resources.

(g) Dispersion

Dispersed soils are those in which the clay fraction is or may become deflocculated or disaggregated. The clay particles in these soils have minimal electrochemical attraction and are not tightly bonded when saturated resulting in reduction of effective particle size and effective pore diameters. Dispersed soils are also characterized by high soluble sodium content. Whereas calcium ions promote flocculation, sodium ions enhance dispersion in clays. Dispersion tends to decrease permeability while flocculation tends to increase it. Dispersed soils occur in all regions of the United States. If dispersion is suspected, send representative soil samples to a laboratory for testing.

Table 7–3 Excavation characteristics of geologic materials (from Kirsten 1987)

Geologic material	Excavation characteristics	Equipment size flywheel horsepower
Very soft to very stiff cohesive soil or very loose to very dense granular soil	Hand pick and spade or light equipment (common excavation)	< 100
Very soft rock to moderately soft rock	Power tools or easy ripping (common excavation)	< 150
Moderately hard to hard rock	Hard to very hard ripping (rock excavation)	< 250
Very hard to extremely hard rock	Extremely hard ripping to blasting (rock excavation)	> 350 to blasting 1/

1/ Explosives may be an alternative to equipment.

Typical characteristics of dispersed soils are:

- Relatively high content of soluble sodium and varying amounts of exchangeable sodium.
- Highly erodible. Clay and colloidal fractions go readily into suspension and remain there. Surface exposures have appearance of melted sugar. Gullying or rilling is extensive.
- Shear strengths are lower than normal in CL, CH, and ML soils. Clay fraction goes into suspension within the pore fluid and reduces electrochemical attraction between particles.
- Generally have high shrink-swell potential and are thus subject to severe cracking when dried.
- Often occur in layers or lenses in a soil profile rather than as extensive masses of a mappable soil series.

Further information on dispersion is in Soil Mechanics Note 13, Dispersive Clays.

(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 planning consideration. 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 utilization of wastes. 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 discussion of permeability is given in 651.1080 Appendix 10D, Geotechnical, Design, and Construction Guideliens

(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 in contact with a tank may cause denting or puncturing. Angular particles greater than 0.5 inch can be a puncture hazard to 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. Examples include poured-in-place reinforced concrete tanks and steel tanks. These structures are particularly vulnerable to settlement. Differential settlement occurs when the settlement is not even over the entire foundation. The potential for differential settlement can be an important design consideration in certain earthfill and concrete waste impoundment structures. Segmentally designed structures are built of structurally independent units, such as, precast reinforced concrete retaining wall units. Although the potential of differential settlement may be less significant, some segmentally designed structures may be susceptible to settlement. The designer should be familiar with Engineering Field Handbook, Chapter 4, Elementary Soil Mechanics.

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—Layers or zones greater than 1 foot thick consisting of soft clays and silts, peat and organic-rich soil (OL and OH in the Unified System), and loose sands may settle excessively when loaded by an embankment or concrete structure.
- Weak foundations—Structures located in areas of active or abandoned underground mining or areas that have a high rate of ground water withdrawal can have problems resulting from settlement of the material.
- Steep abutments—Differential settlement of embankments may occur on abutment slopes steeper than 1 horizontal to 1 vertical. Adequate compaction is difficult to achieve on steep slopes. Settlement cracks may occur in the fill in the area where the base of a steep abutment joins the flood plain.
- Uneven rock surface—A foundation may settle if underlain by normally consolidated soil materials over a highly irregular, shallow bedrock surface or other uneven, unyielding material. As a rule, consider a foundation problematic if, in the foundation area, the difference between maximum and minimum thicknesses of the overlying compressible soil above an uneven rock surface divided by the maximum observed soil thickness is greater than 25 percent. This is expressed as "Problem foundation" when
  [100 (max. depth – min. depth/max.depth)]>25%
- Collapsible soil—This soil is common especially in the western continental States. It has low density and low water content and formed in windblown silts and fine sands and rapidly deposited alluvial fans. This soil may undergo large, sudden settlement when it becomes saturated after loading by a structure built on it.

(k) Shrink/swell

Soil containing montmorillonite clay may undergo substantial changes in volume when saturated or dried. Some types of 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 published soil surveys or the NRCS National Soil Characterization data base. Field investigations and previous experience in the area may often be the only ways to foresee this problem.

(l) Topography

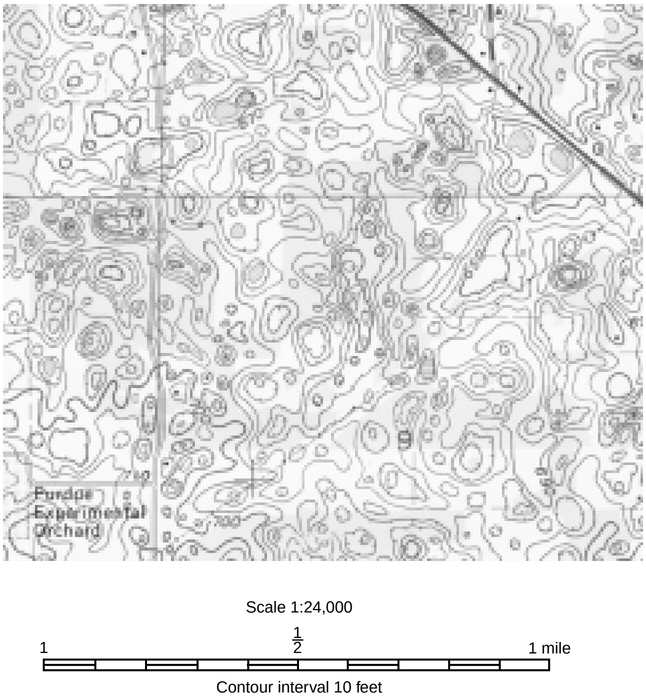
Recognition of land forms and their associated problems is a valuable asset when planning a component for an AWMS. For example, flood plain sites generally have a higher water table compared to that of adjacent uplands, are subject to surface flooding, and can indicate presence of permeable soils.

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

Steep slopes restrict use for some structural and vegetative measures. Hazards include instability (landslide potential) 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 ground water contamination, and collapsible ground. As such, its recognition is important in determining potential siting problems. Figure 7-10 is a topographic map that illustrates karst topography near Mitchell, Indiana. Note the lack of surface streams and numerous sinkholes and depressions.

Figure 7–10 Karst topography



(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 located within an economical hauling distance. Conditions of the borrow area itself may limit the usefulness of borrow materials. Limitations may include such things as moisture, thickness, location, access, land use, vegetation, or cultural resources.

(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 or AWMS component site relocation. If an abandoned well exists 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 651.0704 for guidance in planning investigations.

651.0703 Factors affecting ground water 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 root zone of surface soils. These processes, collectively called attenuation, retard the movement of contaminants into deeper subsurface zones. See section 651.0303 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 making up the material. Thus, attenuation potential increases as clay content increases, the soil deepens, and distance increases between the contaminant source and the well or spring.

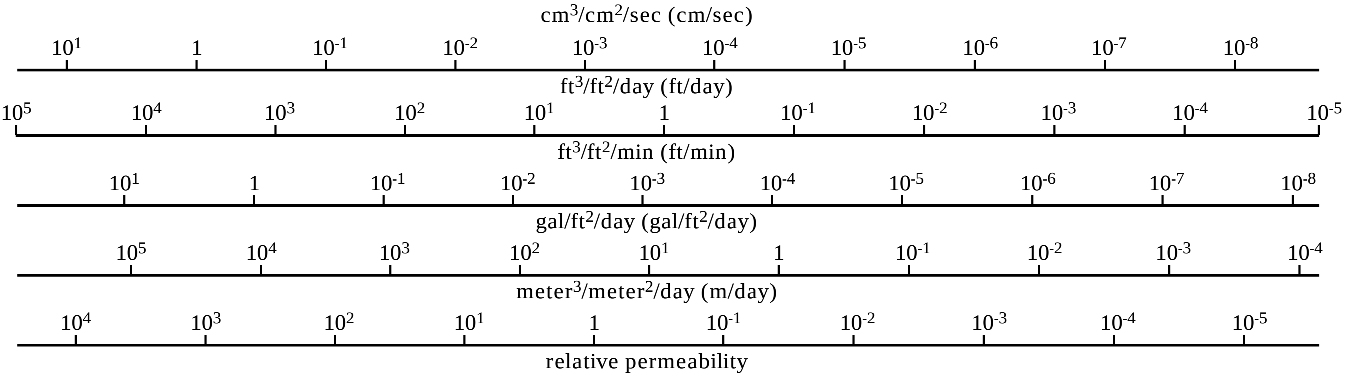
(1) Clay content

Increased clay content increases the opportunity for attenuation of contaminants because of its cation exchange capacity and its affect of reducing permeability. Clay particles hold a negative charge that gives them the capacity to interchange cations in solution. As such, clay can absorb contaminant ions and thus attenuate the movement of contaminants. Clay has a very low permeability (see fig. 7-11). Therefore, the greater the amount of clay, the slower contaminants move and the greater the contact time that allows more opportunity for attenuation.

(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

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



	Very high	**High**	**Moderate**	**Low**	**Very low**
			Representative materials		
Soil types	Clean gravel (GP)	Clean sand, clean sand and gravel mixes (GW, GP, SW, SP, SM)	Fine sand, silty sand and gravel mixes (SP, SM, GM, GW-GM, GP-GM, SW-SM, SP-SM)	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)	Massive clay, no soil joints or other macropores (CL, CH)
			Any soil mass with joints, cracks or other macroporosity		
Rock types		Cavernous and karst limestones and dolomites, permeable basalts	Limestones, dolomites, clean sandstones	Interbedded sandstones, siltstones, and shales	Most massive rocks, unfractured and unweathered
		Fractured igneous and metamorphic rocks			

for attenuation. Very shallow (thin to absent) soil provides little to no protection against ground water contamination.

(3) Distance between contaminant source and ground water supply

Both the depth and the horizontal distance to a ground water supply affect the attenuation of contaminants. Depth refers to the vertical distance through which a contaminant must pass to reach the top of an aquifer. Assuming all other factors remain constant, the greater this depth, the greater the time of travel, and the greater the travel time, the more opportunity for a contaminant to be in contact with the surrounding material for attenuation processes. Horizontal distance also affects attenuation of contaminants. The greater the horizontal distance between the source of the contamination and a well, spring, or other ground water supply, the greater the time of travel will be. The greater the travel time, the greater opportunity for attenuation of contaminants.

(b) Ground water flow direction

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

The direction of flow in a water table aquifer generally can be ascertained from the topography. In most cases the slope of the land indicates the ground water flow direction. In most humid regions the shape of the water table is a subdued reflection of surface topography. Unconfined ground water moves primarily from topographically higher recharge areas down gradient to withdrawal areas at lower elevations. Lower areas serve as discharge points where ground water rises and merges with perennial streams and ponds, or flows as springs. However, 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 rock in upland areas where the direction of ground water 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 ground water flow is parallel to the ground slope can be significantly misleading in terrain where flow is controlled by bedrock fractures. Appendix 7A gives a method of calculating ground water 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. See "Hydraulic conductivity".

The time available for attenuation in aquifer materials decreases as the permeability of the materials increases. Permeability may vary significantly among 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

Hydraulic conductivity is a mass property of an aquifer that is determined through field testing, such as pump tests or slug tests. It is commonly known as permeability and is the rate of flow (L/t) of water through an aquifer. Hydraulic conductivity reflects all of the aquifer's characteristics to transmit water. Note that in most aquifers the difference between vertical and horizontal conductivity rates is significant.

(e) Hydraulic head

Hydraulic head is the energy of a water mass produced mainly by difference in elevation, velocity, and pressure, expressed in units of length or pressure. Ground water moves in the direction of decreasing hydraulic head. Hydraulic head in an aquifer is measured using piezometers. See EFH Chapter 12, Springs and Wells, and Chapter 14, Drainage, for more information.

(f) Hydraulic gradient

Hydraulic gradient is the change in hydraulic head per unit distance of flow in a given direction and is expressed in units of length (elevation) per length (distance). Ground water velocity is a function of the hydraulic gradient. Most water in an unconfined aquifer moves slowly in undeveloped aquifers. However, an action such as pumping water from a well can steepen local hydraulic gradients. This results in acceleration of flow in toward the well, carrying any dissolved contaminants with it into the well. Appendix 7A gives a method calculating the hydraulic gradient in a water table aquifer.

(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 ground water use designations and impairments
- Geologic maps showing rock types, faults, and similar information
- Regional water table maps and, if available, tables of static water levels in wells
- Ground water vulnerability maps

(h) Land topography

Topographic features that pond contaminanted runoff water increase the potential for ground water contamination by infiltration. Example features include seasonal wetlands and level terraces. The hazard of surface water contamination from sediment 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 ground water areas:

- Sole source or other types of aquifers whose uses have been designated by the State
- Important recharge areas
- Well-head protection areas

(j) Type of aquifer

Refer to section 651.0701 for details on perched, confined, and unconfined 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 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:

- The 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 waste impoundment. The tank involves consideration of differential settlement of the foundation, while the earthen waste impoundment 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.

Make an initial evaluation of potential layout(s) of the component, access to the site, and location of active or abandoned wells, springs, and other such features. Farm*A*Syst worksheets and the Farm Bureau self-help water quality checklists are valuable tools in making initial site evaluations. These tools are not, however, suitable for making final design decisions.

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 need to be examined. Refer to the Field Office Technical Guide (FOTG) for the National Conservation Practice Standard, 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—These reports provide soil map units, photos of features near a site, information on seasonal flooding and the water table, and engineering interpretation 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, distances to identified resource features, such as wells, watercourses, houses, roads, and other cultural features.
- Aerial photos—These photos provide information on vegetation, surface runoff patterns, erosion conditions, proximity to cultural features, and other details.
- Local geologic maps and reports—These sources 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 ground water 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. The intensity of a detailed investigation is the joint responsibility of the designer and the person who has engineering job approval authority. 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 conditions of materials encountered, 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, and power augers are used to allow direct observations for logging geologic materials, collection of samples, and access for field permeability testing. When logging soils with an auger, always consider that the augering process can obscure thin zones or mix soil layers. Test pits expose more of the foundation for detecting thin, but significant lenses of permeable soil.

Geophysical methods are indirect techniques that employ geophysical equipment, such as electromagnetic induction meters, resistivity meters, refraction seismographs, and ground penetrating radar units, to evaluate the suitability of sites and the performance of the component. These techniques require trained, experienced specialists to operate the equipment and interpret results. Geophysical methods require corrolation with test pits or borings for best results.

(2) Logging geologic materials

During an 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 TR-71, Rock Material Field Classification Procedure; TR-78, The Characterization of Rock for Hydraulic Erodibility; and NEH part 628, Dams, Chapter 52, Field Procedure Guide for the Headcut Erodibility Index. Soils are classified for engineering purposes according to the Unified Soil Classification System, ASTM D 2488, Standard Practice for the Description and Identification of Soils, Visual-Manual Procedure. This system is described in EFH Chapter 4, Elementary Soil Engineering; and NEH Section 8, Engineering Geology. Appendix 7B provides tables of criteria for identifying soils by the Unified System. 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 at the end of this chapter (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 (back hoe) including make and model. For each soil type encountered in a test pit or drill hole, record the following information, as appropriate. See EFH Chapter 4, Elementary Soil Engineering, for more details.

- Interval (depth range through which soil is consistent in observed parameters)
- Estimate particle size distribution (by weight, for fraction < 3 inches)
- Percent cobbles and boulders (by volume, for fraction > 3 inches)
- Angularity of coarse material
- Color of moist material, including presence of mottling. Mottling may be an indicator of the zone of water table fluctuation
- Relative moisture content
- Structure
- Consistency (saturated fine-grained materials) or relative density (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)
- Test hole or pit identification number
- Station and elevation of test hole or pit
- Depth (or elevation) of water table after stabilizing; give date measured and number of hours open
- Depth to rock, refusal (limiting layer), or total depth drilled or dug

(3) Samples

Samples of soil and rock materials collected for soil mechanics laboratory testing must meet minimum size requirements given in Geology Note 5. Sample size varies according to test 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 investigation

For foundations of earthfill structures, use at least four test borings or pits on the proposed enbankment 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. 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 (b)(2) of 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 for clay liners should be located, described, and mapped. Locate suitable borrow to at least 150 percent of the required fill volume. Soil samples for natural water content determinations should be obtained from proposed borrow and clay liner sources. Samples taken for testing should be maintained in moisture proof containers. The parameters listed in (b)(2) of this section should be logged.

If a system requires a soil liner, consult soil survey reports and local surficial geologic maps to help identify potential borrow areas for investigation. Nearby clay-rich deposits for potential borrow sources should be located, mapped, and logged. Some designs may require bentonite or a chemically treated soil to reduce permeability (see AWMFH Ch. 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 such small components 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 investigation pits or plugging test holes.

651.0705 References

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Appendix 7A

Determining ground water 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 may be drawn. 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 ground water flow directions. Ground water 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 ground water flow direction and hydraulic gradient of the water table is 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. The 8-step procedure for this planning method follows, 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, whether developed or undeveloped, and 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 having the highest and lowest water level elevations, and record on the map.

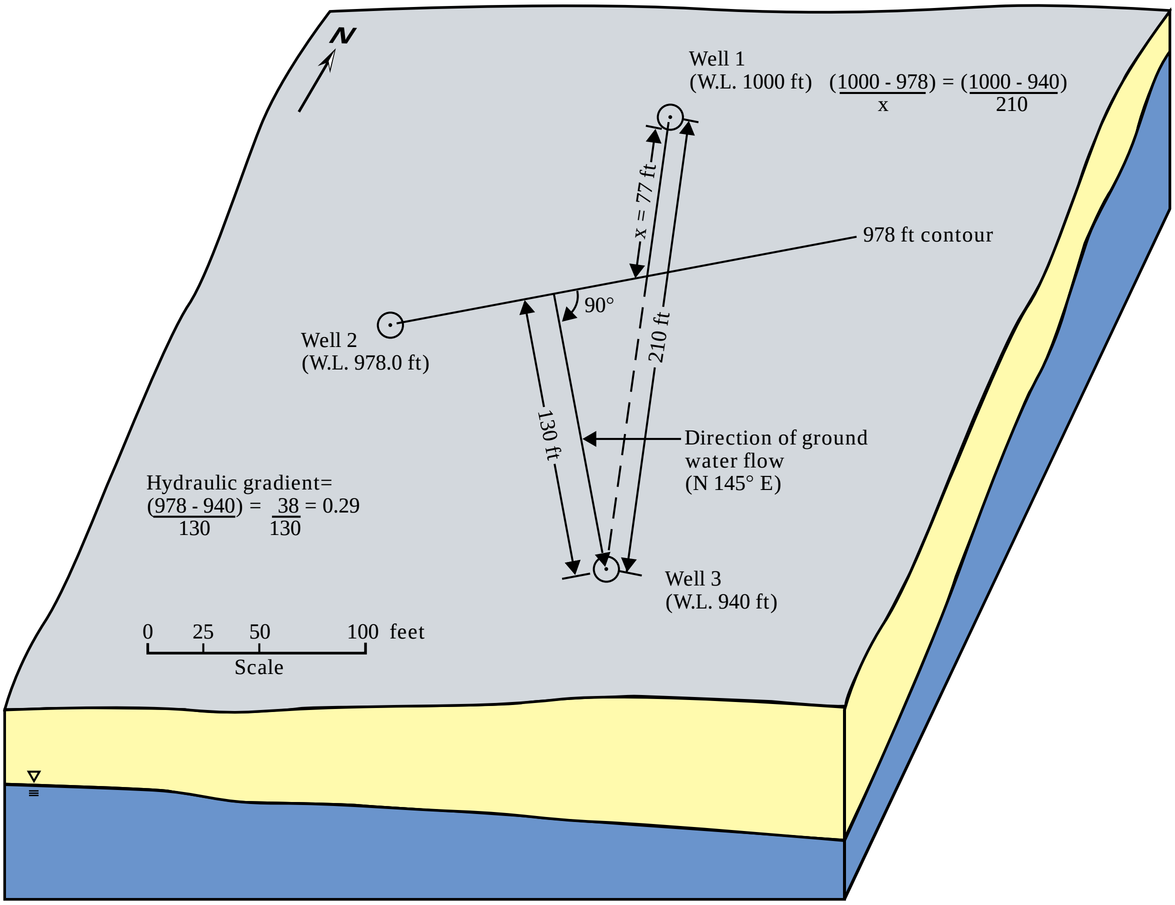
Step 5—Using the map, identify the well with the intermediate water table elevation (that is, neither the highest nor the lowest). Interpolate the position between the well with the highest head and the well with the lowest head where the head is equal to that in the intermediate well. Mark this point 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 (90°) from this contour to the lowest head well, and measure the distance. This line is parallel to the ground water 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 ground water 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 ground water 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			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_____

Table 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 2 Criteria for describing particle shape (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 & elongated	Particles meet criteria for both flat and elongated

Table 3 Criteria for describing moisture condition

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

Table 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 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 6 Criteria for describing structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 1/4 in (6 mm) thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 1/4 in (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

Table7 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 inch	< 0.1	< 2
Soft	Thumb will penetrate soil about 1 inch	0.10 – 0.25	2 – 4
Firm	Thumb will indent soil about 1/4 inch	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 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 powder with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and hard surface
Very high	The dry specimen cannot be broken between thumb and hard surface

Table 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 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 near the plastic limit.
High	The thread and the lump have medium stiffness. Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

Table 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; thread cannot be rerolled after reaching the plastic limit; lump crumbles when drier than the plastic limit
High	Considerable time rolling and kneading to reach the plastic limit; thread can be rerolled several times after reaching the plastic limit; 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 Field Identification of Coarse-grained Soils below.)

Note: Refer to tables 1 through 11 for criteria for describing many of these factors.

Field Identification—Coarse Grained Soils

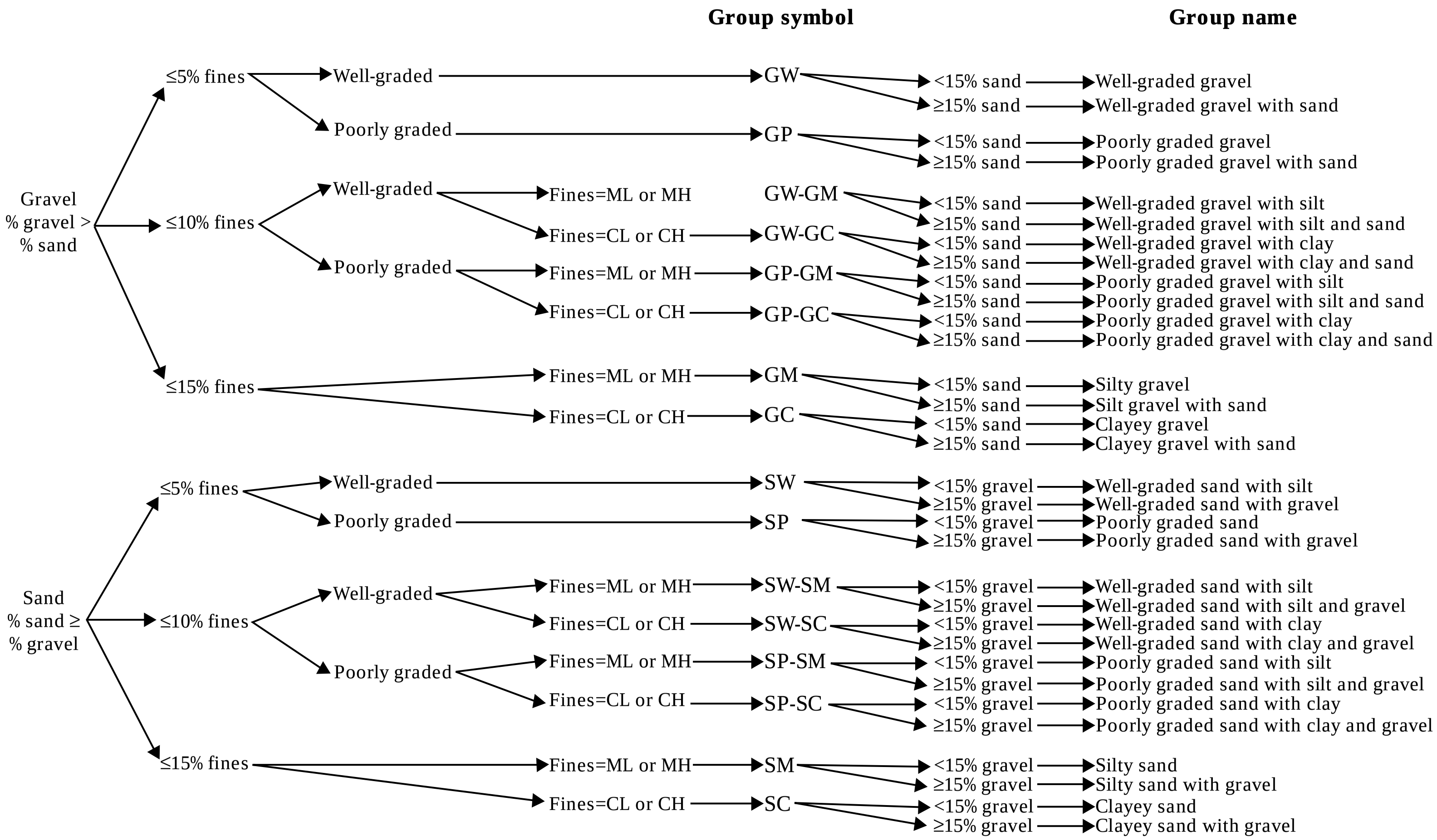
Coarse Particle Grade Sizes

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

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

[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.

Identifying Coarse Grained Soils (less than 50% fines)



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

Source: ASTM D 2488 (fig. 2). Copyright ASTM. Reprinted with permission.

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 Field Identification of Fine-grained Soils below.)

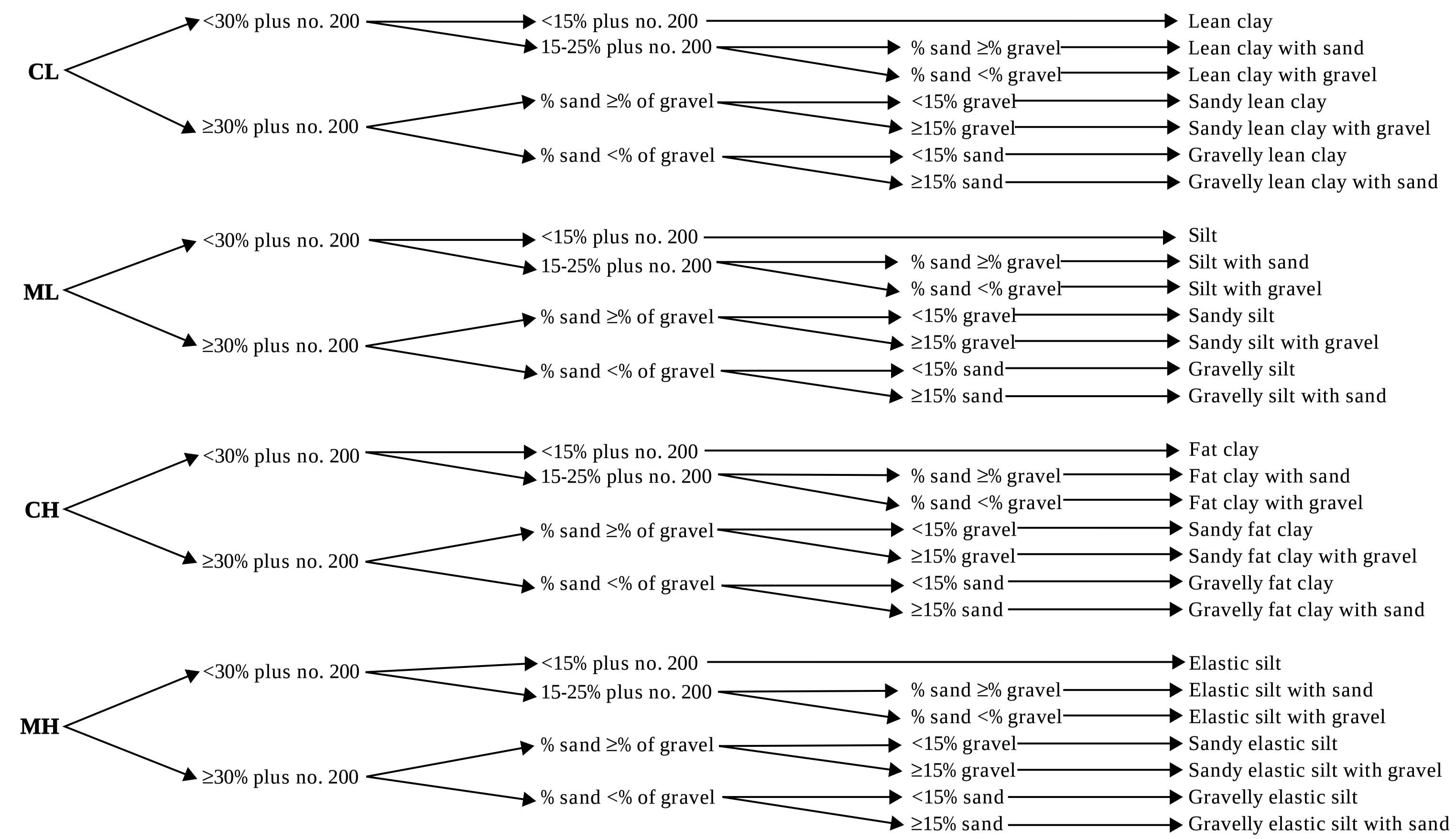
Note: Refer to tables 1 through 11 for criteria for describing many of these factors.

Field Identification—Fine Grained Soils [1/]

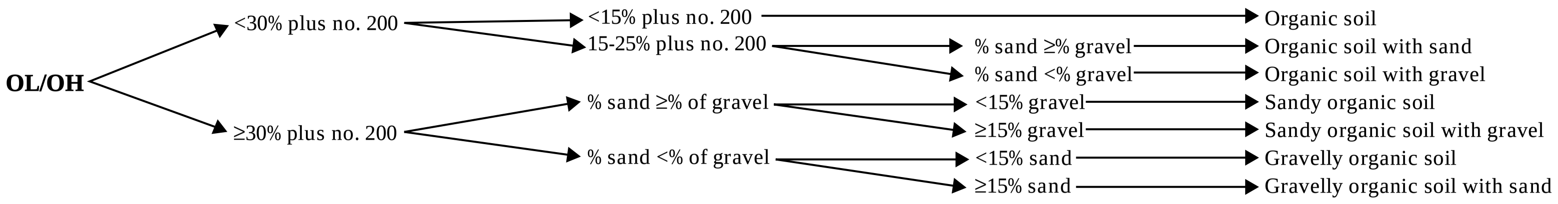
Dry Strength	Dilatancy	Toughness	Plasticity	Symbol
None to low	Slow to rapid	Low or no thread	Nonplastic to low	ML
Medium to high	Slow	Medium	Low to medium	CL
Low to medium	None to slow	Low (spongy)	None to low	OL
Medium	None to slow	Low to medium	Low to medium	MH
Very high	None	High	Medium to high	CH
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

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

Identifying Fine Grained Soils



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



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

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