GROUND-WATER HYDROLOGY AND HYDRAULICS

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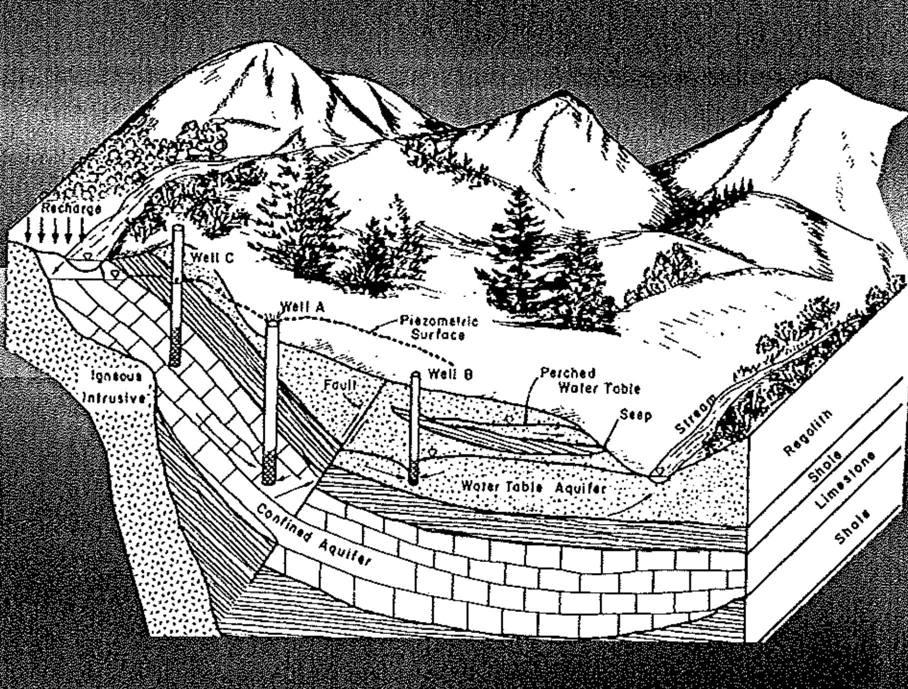

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practical concern. The utility of the concept of the representative volume element is that it provides a rational basis for the use of continuum mathematics for the description and interpretation of the storage and flow of fluids in porous media.

The porosity of aquifer materials ranges from near zero in sparsely fractured rocks and in some limestone formations to 50 percent or more in well aggregated clays. Typical values of porosity for various geologic materials are presented in Table 2-1.

Table 2-1. Porosity of Aquifer Materials
(Adapted from Morris & Johnson, 1967)

Aquifer Material	No. of Analyses	Range	Arithmetic Mean
Igneous Rocks			
Weathered granite	8	0.34-0.57	0.45
Weathered gabbro	4	0.42-0.45	0.43
Basalt	94	0.03-0.35	0.17
Sedimentary Materials			
Sandstone	65	0.14-0.49	0.34
Siltstone	7	0.21-0.41	0.35
Sand (fine)	243	0.26-0.53	0.43
Sand (coarse)	26	0.31-0.46	0.39
Gravel (fine)	38	0.25-0.38	0.34
Gravel (coarse)	15	0.24-0.36	0.28
Silt	281	0.34-0.61	0.46
Clay	74	0.34-0.57	0.42
Limestone	74	0.07-0.56	0.30
Metamorphic Rocks			
Schist	18	0.04-0.49	0.38

The porosity of clastic materials is affected by:
1) particle shape (angularity and roundness),
2) degree of compaction and cementation,
3) particle size distribution.

Particle shape influences porosity because particle shape affects the manner in which particles arrange themselves (Fig. 2-2). Highly angular and irregularly shaped, noncemented particles tend to result in a larger porosity than smooth, regularly shaped particles, although the difference is not always a substantial one. The degree of compaction or cementation changes the porosity significantly, however. Cement, formed by iron and calcium compounds (among others), at interparticle contacts, occupies a portion of the interstitial volume that would otherwise be void. Comparison of the porosities in Table 2-1 for sandstone and siltstone with their uncemented equivalents, sand and silt, illustrates the effect of cementation.

of aquifer material immediately above the water table that remains practically at $\theta=\theta_m$. The top of the capillary fringe corresponds to the capillary pressure at which the largest of the pores can no longer maintain interfaces with radii sufficient to prevent desaturation. The height of the capillary fringe may be in the range of 1-5 cm in a coarse sand and in excess of 1 m in clay or clay loam soils.

The reader should take special note that while $p_c(\theta)$ relationships are usually regarded as being valid for both static and dynamic situations, Eq. 2-5 is valid for equilibrium conditions only. Capillary-pressure head bears no simple relation to elevation z under conditions of evaporation, recharge, or rapidly falling water tables, and therefore, the distribution of θ is correspondingly more complex.

Specific Yield and Apparent Specific Yield

The concept of specific yield was introduced in groundwater hydrology as a practical means of characterizing the storage capacity of water-table aquifers. Notwithstanding its practical utility, specific yield is a somewhat ambiguous concept (Duke, 1972; Youngs, 1969). To some degree, the ambiguity results from the use of the term -- specific yield -- as both an objective property of porous solids and as a characterization of the storage behavior of aquifer systems as a whole. In the latter case, many factors, other than properties of the aquifer material itself, may dominate the changes in storage associated with water-table fluctuations.

Specific yield, S_y, as used herein, is defined as the difference between porosity and specific retention and is

$$S_y = \phi - S_r \quad . \qquad (2\text{-}6)$$

Insofar as porosity and specific retention are relatively objective properties of porous solids, the specific yield is a characteristic property. Specific retention is dependent upon the fluids used during its laboratory determination, however, so neither specific retention nor specific yield is entirely characteristic of the porous solids for which they are measured. Specific yield is a dimensionless parameter, often interpreted as being the ratio of the drainable volume to the bulk volume of the medium. Specific yield is also known as *effective porosity*.

Apparent specific yield, S_{ya}, is defined as the ratio of the volume of water added or removed directly from the saturated aquifer to the resulting change in the volume of aquifer below

Table 2-2. Specific Yield of Aquifer Materials
(Adapted from Morris & Johnson, 1967)

Aquifer Material	No. of Analyses	Range	Arithmetic Mean
Sedimentary Materials			
Sandstone (fine)	47	0.02-0.40	0.21
Sandstone (medium)	10	0.12-0.41	0.27
Siltstone	13	0.01-0.33	0.12
Sand (fine)	287	0.01-0.46	0.33
Sand (medium)	297	0.16-0.46	0.32
Sand (coarse)	143	0.18-0.43	0.30
Gravel (fine)	33	0.13-0.40	0.28
Gravel (medium)	13	0.17-0.44	0.24
Gravel (coarse)	9	0.13-0.25	0.21
Silt	299	0.01-0.39	0.20
Clay	27	0.01-0.18	0.06
Limestone	32	~0 -0.36	0.14
Wind-Laid Materials			
Loess	5	0.14-0.22	0.18
Eolian Sand	14	0.32-0.47	0.38
Tuff	90	0.02-0.47	0.21
Metamorphic Rock			
Schist	11	0.22-0.33	0.26

EXAMPLE 2-5

The initial water levels (with respect to an arbitrary datum) and the levels after 8 hrs and 22 min of pumping are tabulated below for six observation wells in the vicinity of the pumped well. The average pumping rate for the test period is 0.0312 m^3/s . The aquifer is a mixture of clayey sand and gravel. The effective radius of the pumped well is 0.3 m . Calculate the apparent specific yield using the data provided.

Observation Well Number	HF1	HF2	HF3	HF4	HF5	HF6
Distance from Pumped Well - m	4.6	10.4	19.8	34.5	65.8	91.8
Initial Water Level - m	96.49	96.52	96.53	96.55	96.56	96.57
Water Level After 8 hr-22 min	95.14	95.58	95.88	96.14	96.36	96.43