TYPICAL HYDROGEOLOGICAL SCENARIOS

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Contents

Summary

This chapter aims at defining typical hydrogeological scenarios based on the geologic materials that eventually aquifers are made of. This approach is taken out of simplicity, so that the descriptions and facts offered may vary depending on the local conditions (chiefly, recharge and climate). However, as a general view it is deemed to fulfill its purpose.

The hydrogeological features of groundwater in unconsolidated deposits are first presented. Given that these deposits usually have higher porosities, permeabilities, and specific yields than other materials, a further distinction is made according to the origin of the sediments. Thus, five types emerge.

- Fluvial deposits: generated by flowing water, with good potential for groundwater development.
- Tectonic valley-filling deposits: sediments of different origin that fill up long, flat valleys bounded by faults.

- Eolian deposits: mainly refers to dune sand and loess, transported and deposited by wind.
- Coastal plain deposits: ranging from purely continental to purely marine sediments.
- Glacial deposits: glacial till is the most conspicuous, being unsorted unstratified and predominantly fine sediments that generally form confining units where it is interbedded with sand and gravel aquifers.

The second grand group involves hard rocks. Among them, two subgroups are distinguished:

- Igneous (plutonic) and metamorphic rocks: impermeable in solid form, they may be of hydrogeological interest when affected by weathering, fracturing, and mineral dissolution.
- Igneous (volcanic) rocks: lava flows (typically basalt) that, after cooling, may acquire features relevant to groundwater storage.

The third group comprises the consolidated sediments, out of which sandstones, limestones, and dolomites are the most conspicuous worldwide. From the hydrogeological standpoint, it is important to mention post-depositional changes (joints, fractures, dissolution) that may greatly enhance their water-bearing and movement characteristics.

A special mention is made of karst terrains, which strictly considered belongs to the consolidated sediments group. Post-depositional processes (notably, dissolution by circulating water, and fracturing) lead to secondary, increased porosity and hydraulic conductivity, mainly in limestones and dolomites.

Finally, the role of extreme values of rainfall and temperature is introduced, which helps defining two typical scenarios: arid regions (deserts), and perennialy frozen ground (permafrost).

1. Introduction

Coming up with a comprehensive list of typical hydrological scenarios may prove not to be an easy task because of the countless variables and facts that have to be considered which, in the end, may render a list too large, with individual elements being uncomfortably grouped into similar environments. An alternative and quite simple approach consists of taking into account the geological material in which water may be stored as well as structural, geomorphological, stratigraphical, and some other special features (mountain ranges, plains, deserts, islands, climatic features, etc.), while still keeping track of the hydrogeological meaning of such “typical” scenarios.

If the focus of the analysis is kept on the materials that make up aquifers, certain general characteristics can be described to account for their hydrogeological behavior. Thus, the subsequent headings will revolve around the unconsolidated sediments, the igneous (plutonic and volcanic) and metamorphic rocks, and the consolidated sediments (with a special reference to karst). Groundwater in extremely cold and hot climates will also be addressed. Each heading will include as much general information as possible to unravel the quantity and quality aspects attached to the hydrogeological environments being presented, along with methodological notes and preservation-oriented comments.

2. Unconsolidated sediments

Otherwise known as non-indurated sediments, these deposits may further be divided up according to their origin. Thus, the main categories would be fluvial deposits, tectonic valleys filling-up deposits, eolian deposits, coastal plains deposits, and glacial deposits. Among several advantages, these sediments are preferred in searching for groundwater because they usually have higher porosities, permeabilities, and specific yields than other materials. As examples, Table 1 presents typical values of permeability, porosity, and specific yields of several unconsolidated sediments.

Orientation of sample	Type of sediment	Dominant size	Permeability (m day^{-1})	Porosity (percent)	Specific Yield
vertical	alluvium	fine sand	26.4	51.1	45.5
horizontal	alluvium	fine sand	25.3	51.5	45.8
vertical	alluvium	fine sand	16.5	47.0	39.9
horizontal	alluvium	fine sand	13.2	45.7	39.0
vertical	loess	silt	0.33	49.3	33.1
horizontal	loess	silt	0.22	50.7	34.7
horizontal	marine	clay	0.000016	48.5	3.6
vertical	marine	medium sand	38.5	41.7	38.3
horizontal	marine	medium sand	55.0	40.2	37.6
not given	alluvium	fine sand	5.5	52.2	Not given
not given	alluvium	coarse sand	189	33.3	Not given
not given	alluvium	gravel	1130	25.1	Not given
not given	artificial	gravel (larger than 38 mm)	43,500	38.0	Not given
not given		clay (kaolinite)	0.0015	50.0	Not given
not given		clay (montmorillonite)	0.000015	66.6	Not given
not given	dune sand	medium sand	28	35.8	34.5

Table 1. Porosity, permeability and specific yields of some unconsolidated sediments *(After Davis and De Wiest, 1966)*

2.1. Fluvial deposits

As the name implies, these deposits are generated by flowing water. They normally consist of gravel, sand, silt, and clay whose mineralogical composition is related to the parent rock that produced them. Their distribution, however, is quite erratic at the detailed level. Indeed, rivers are agents of erosion, transport and deposition of sediments. The relative predominance of any of those features will depend on the supply of sediments to the river and its carrying capacity, which in turn is a function of the water velocity (i.e. the longitudinal and transverse section of the river and its discharge). However, many authors have agreed that a general pattern can be proposed: the coarsest deposits (that is, the heaviest sediments) will settle down within the river channel. The river floodplain, occasionally occupied by water, is where finer deposits (sand, silt, clay) are found because of the lower flow velocities.

During high-water periods, channel deposits are formed on river bends; these are known as point bars. In changing its course or cutting off meanders, the river leaves behind ponds where fine sediments get accumulated (some authors call them clay plugs). Figure 1 displays the various types of river deposits.

Given enough time (measured in geological terms), the river loses its carrying capacity and the sediments that settled down in the channel are finer. Global climate changes, notably Pleistocene glaciation, that led to lower sea levels, also deepened the river valleys and produced thicker deposits at the river mouth on the coast.

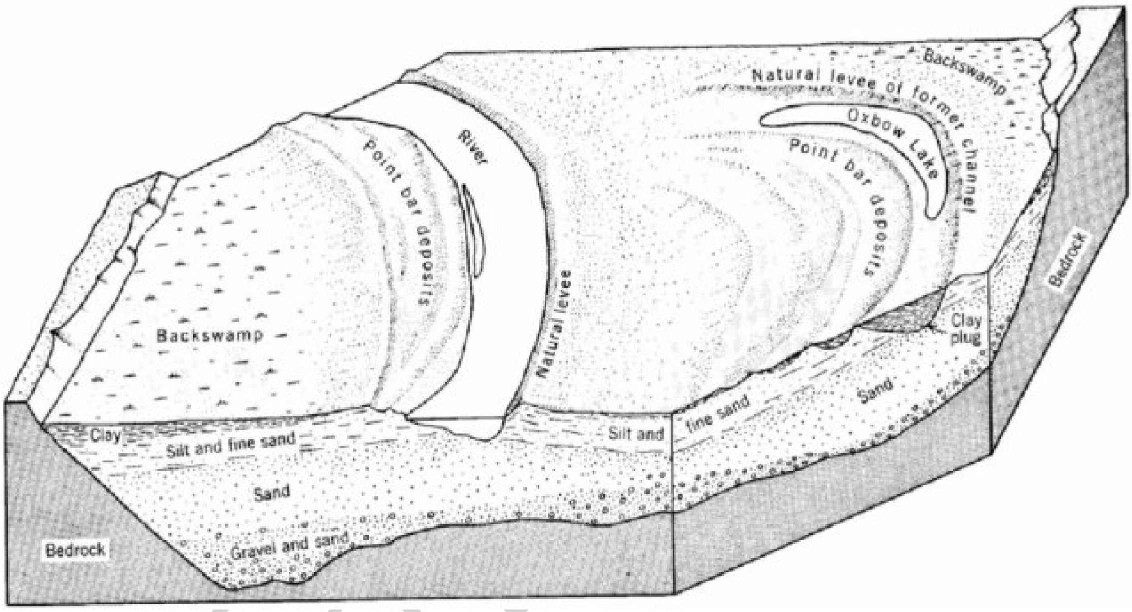

Figure 1. Three-dimensional view of deposits generated by large rivers
(After Davis and De Wiest, 1966)

Changes in the hydraulic regime (net increase of river flow) may deepen the river channel and give rise to a lower-position floodplain, so that the former floodplain will remain at a relatively high position (as a terrace).

Because of the complexities of the distribution of sediments within river valleys, no general rules can be proposed to estimate the permeability of specific sectors. However, considering that sand is the most conspicuous constituent of alluviums, many studies have been carried out to establish relationships among the mean grain size and the corresponding hydraulic conductivity. One of such relationships from the Arkansas River valley, USA, is shown in Figure 2.

In terms of water yield, pumping wells in most alluvial deposits will be able to provide no less than 1 to 2 liters sec^{-1} with moderate drawdowns.Exceptionally high values of specific discharge have been measured, such as in the case of the lower basin of the Llobregat River (Barcelona, Spain) with figures in order of 10,000 to 20,000 m^2 day^{-1}.

Seeking groundwater resources in river valleys is basically a matter of locating those places where an important saturated thickness of sand and gravel may occur with proper consideration of nearby sources of recharge. It should be kept in mind that the river may have changed its course several times in the past so that buried channels most probably exist. Therefore, the first task is to find the location of palaeo-channels through drilling data as well as surface and borehole geophysical methods (most useful where there is a great contrast of electrical resistivities between the underlying bedrock and the alluvial sediments). The reconstruction of the geologic history may be of a great help, particularly if there are evidences of changes in the drainage system in the past. Figure 3 depicts the expected well yields at different points along a typical cross-section of an alluvial valley.

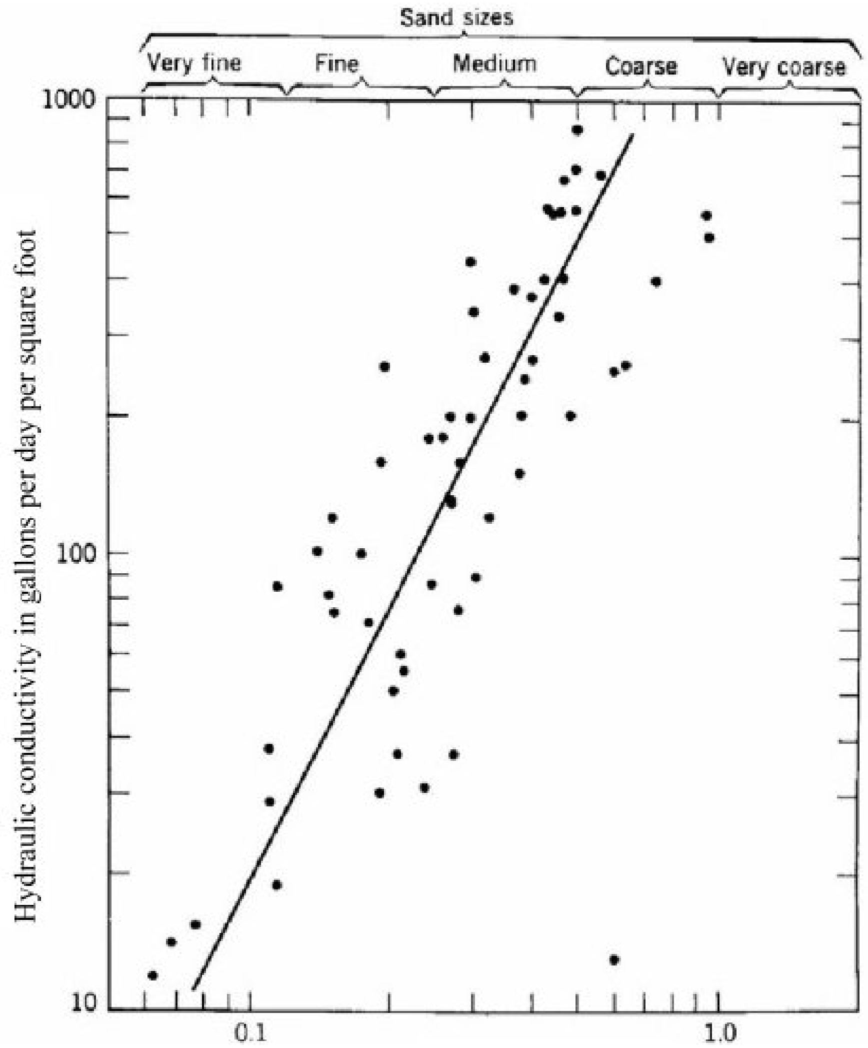

Figure 2. Functional relationship between the median grain size and the sand permeability.

After Davis and De Wiest (1966)

Note: On the vertical axis, to convert from gallons day^{-1} ft^{-2} to m day^{-1}, multiply by 0.0407.

The chemical characteristics of groundwater stored in unconsolidated sediments depend primarily on the composition of the parent rock where they were derived. Down a given river valley, however, groundwater may change its chemical composition according to the material it is flowing through, the recharge coming from nearby sources (lateral streams, for example), and the existence of human settlements.

Naturally, most river valleys exhibit good water quality as it originates from local recharge. Inasmuch as the riverbed is usually in intimate contact with the aquifer sediments, some changes in water quality can be expected depending on the hydraulic head in the river with respect to that in the aquifer.

That is a central point in terms of groundwater quality. In those occasions in which the river recharges the aquifer, the groundwater will be affected by the chemistry and temperature of the recharged water.

For instance, river recharge introduces temperature fluctuations in the aquifer water, so that groundwater loses its characteristic of having almost constant temperature throughout the year (about the mean annual air temperature). Such an effect is shown in Figure 4.

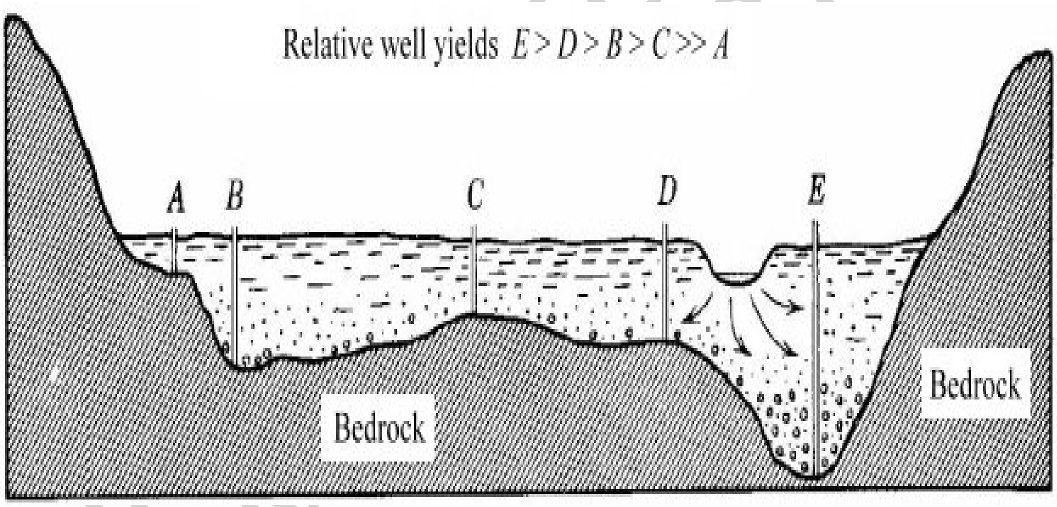

Figure 3. Sketchy cross-section of an alluvial valley showing the effects of aquifer thickness and hydrogeological boundaries on well yields *(After Davis and De Wiest, 1966).*

Frequently, groundwater stored in alluvium bears relatively high concentrations of iron (Fe^{++}) and/or manganese (Mn^{++}). Those ions may be mobilized by low pH and Eh near subsurface accumulations of organic debris. That would explain the rather erratic distribution of such constituents.

Alluvial deposits contain abundant layers of silt and clay, which in most cases will filter pathogenic organisms. The same may apply to many chemical contaminants, at least retarding their movement to underlying more permeable horizons. However, if such contaminants find their way to permeable gravels, the pollution effect is bound to expand greatly because of their rapid movement through those materials.

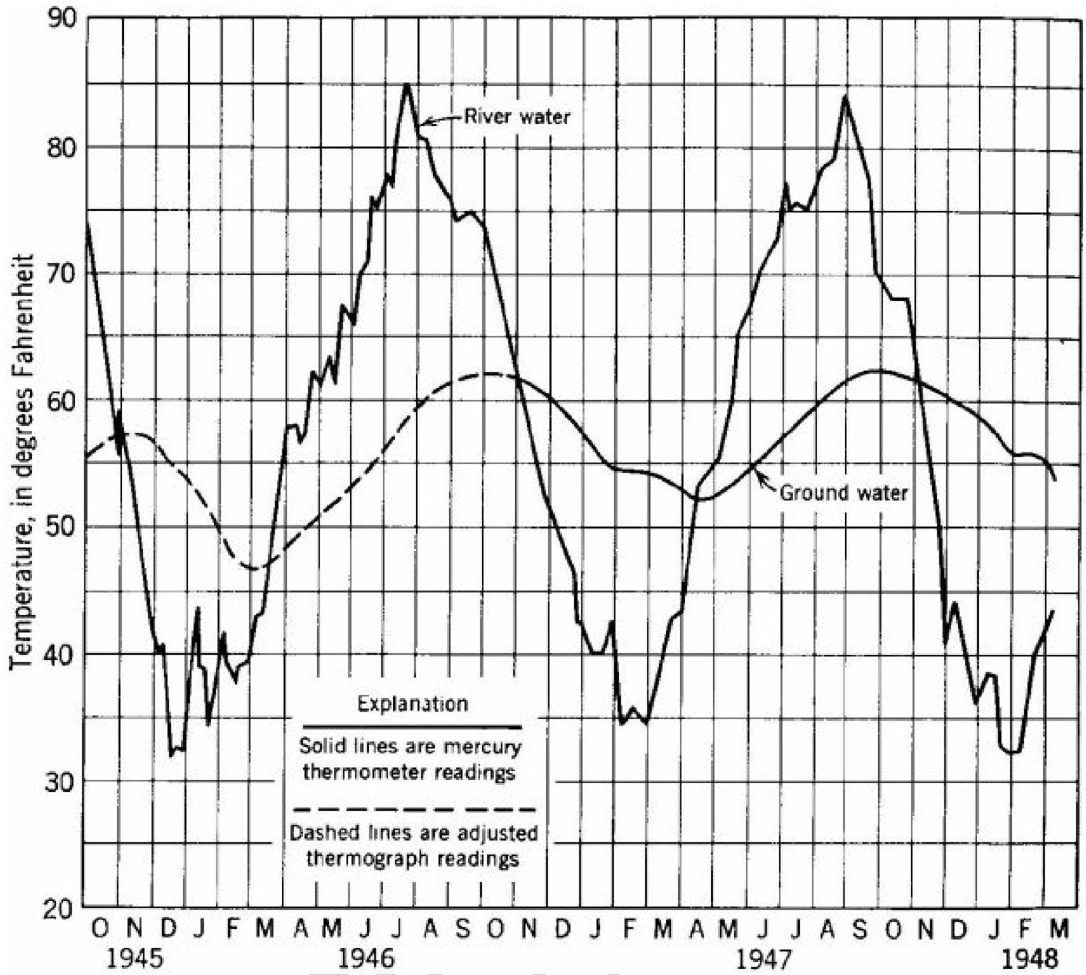

Figure 4. Temperature fluctuations in groundwater partly attributed to recharge from the Ohio River *(After Davis and De Wiest, 1966)*

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Biographical Sketch

Eduardo Jorge Usunoff was born in Bahía Blanca, Buenos Aires Province, Argentina in September 1953. He graduated in Geosciences (Universidad Nacional del Sur, Bahía Blanca, Argentina) in March 1979, and was hired by that University to teach and do research on hydrogeology. He soon showed his interest in groundwater hydrology, and in 1980 took a six-month leave for deepening his knowledge in Spain (Curso Internacional de Hidrología Subterránea, Barcelona). In 1982 went to the Hydrology and Water Resources Department of the University of Arizona, Tucson, USA, where he received an M.Sc. in Hydrology (May 1984) and a Ph.D. in Hydrology with minor in Geosciences (August 1988).

Back in Argentina, he was hired by the Universidad Nacional del Centro de la Provincia de Buenos Aires and the Comisión de Investigaciones Científicas de la Provincia de Buenos Aires to head a research institute dealing with hydrological topics—the Instituto de Hidrología de Llanuras (IHLLA). His main profesional interests are: hydrochemistry, hydrogeology of large plains, and integrated water resources management. In his spare time he likes to play basketball and volleyball, as well as listening to music (jazz, pop, blues, and rock).