Zeitschrift: Bulletin der Vereinigung Schweiz. Petroleum-Geologen und -Ingenieure

Herausgeber: Vereinigung Schweizerischer Petroleum-Geologen und -Ingenieure

Band: 38 (1971)

Heft: 93

Artikel: Hydraulic conductivity tendencies in fractured and jointed rock

Autor: Haefeli, Charles

DOI: https://doi.org/10.5169/seals-197908

Bull. Ver. Schweiz. Petrol.-Geol. u. -Ing., Vol. 38, Nr. 93, Oktober 1971, S. 41–46

Hydraulic conductivity tendencies in fractured and jointed rock

with 4 textfigures

by CHARLES HAEFELI *

To determine the amount of groundwater flowing into Lake Ontario, an objective for the International Hydrological Decade (IHD), the hydraulic characteristics of the surrounding rock was analyzed. For this purpose a large number of water well records were scanned and evaluated. Since the pumping test data were frequently incomplete, mean values for well and aquifer properties had to be computed for an overall evaluation. The present report is mainly concerned about the hydraulic conductivity of the sedimentary rock, limestone and shale of paleozoic age.

The effective porosity of dense bedrock is generally so small, that the groundwater movement through the intergranular spaces is almost negliagble. Under this conditions groundwater flow takes mainly place through fracture and joint systems. Concequently, the permeability of the dense bedrock bordering Lake Ontario is essentially a function of the opening and spacing of rock fractures rather than intergranular porosity.

It has been observed in crystalline rocks and to a minor degree in sedimentary rocks that the fracture porosity decreases with depth (DAVIS and TURK, 1964; SNOW, 1968, and others). To obtain any tendency by which the permeability changes, a total of 1123 bedrock wells within the 2.5 mile (approx. 4 km) wide shorebelt of Lake Ontario and its vicinity, were analyzed. The wells were grouped according their depth of penetration into bedrock. Depending on the available number of wells the following depth zones in feet (1 foot = 0.30 m) were chosen: 0–10 ft., 11–20 ft., 21–30 ft., 31–50 ft., 51–75 ft., 76–100 ft., >100 feet below bedrock surface. Each zone contained 12–50 wells. Although the analyzed limestone and shale formations are not uniform, the lithological change should not affect the fracture porosity within the formation significantly. In fact it became evident that the trend was very similar between different lithostratigraphic units.

The specific capacity, Q/s, of wells, as the only available permeability parameter, was used in this study for estimating the transmissibility of the strada penetrated by them:

$$T = \frac{114.6\ Q}{s}\left[-0.577 - \log_e\left(\frac{2242\ r_w^2\ S}{Tt}\right)\right]$$

where: Q = discharge of pumped well, in imperial gallons per minute. (1 Imp.g/min = $7.58 \cdot 10^{-5}$ m³/sec)

s = drawdown, in feet.

T = coefficient of transmissibility, in imperial gallons per day per foot. (1 Imp.gpd/ft. = $1.73 \cdot 10^{-7}$ m²/sec)

S = coefficient of storage.

r_w = nominal radius of well, in feet.

t = time after pumping started, in minutes.

W(u) = Well function for nonleaky artesian aquifer (WENZEL, 1942).

(The above THEIS equation may also be written in the metric system [HAEFELI, 1970]).

* Dept. of EMR, Inland Waters, Hydrologic Science Div., Ottawa/Canada, now with Electro-Watt Engineering Services Ltd., Zürich.

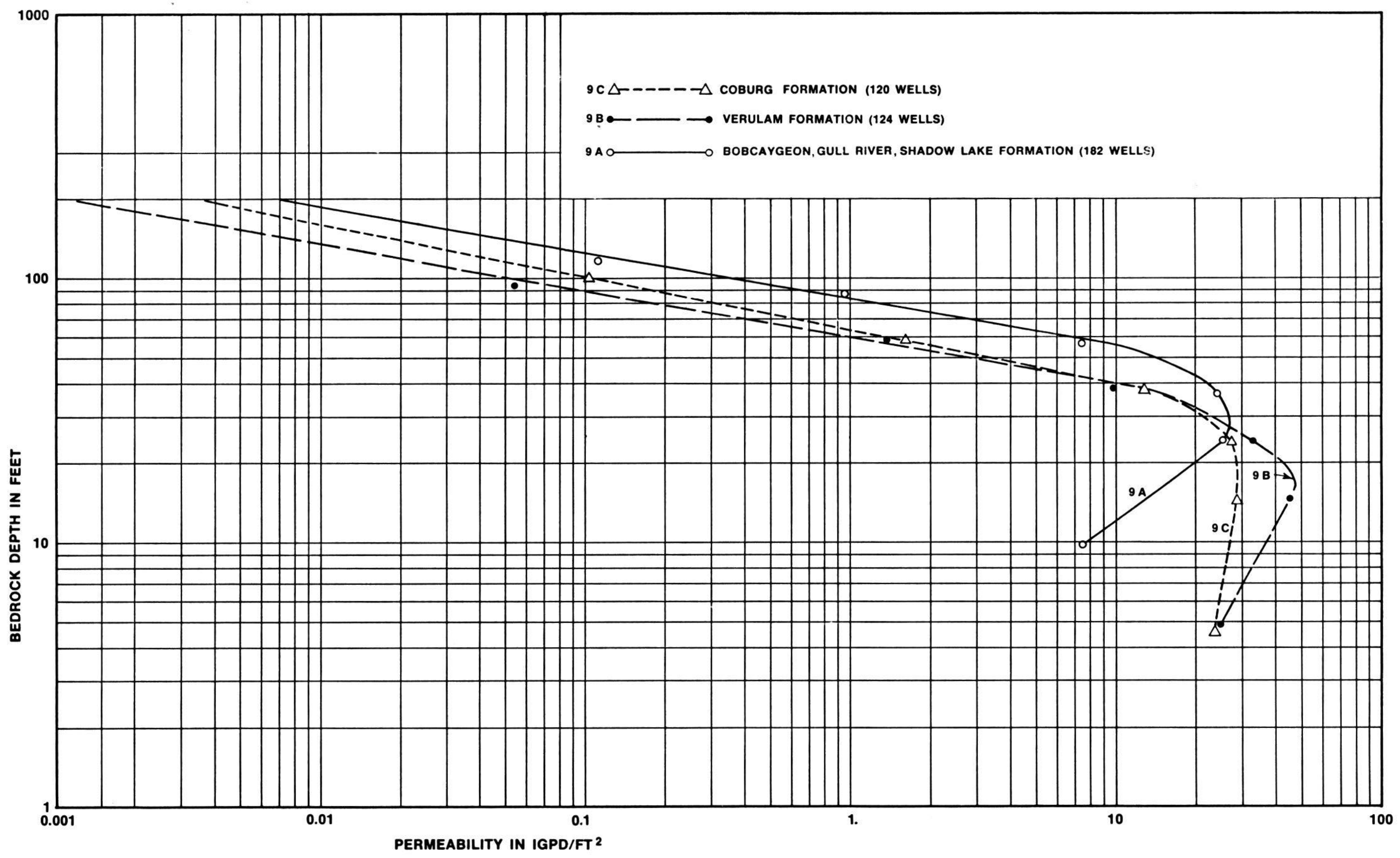

Fig. 1: Average permeability in each depth zone versus the mean penetrated depth of each zone of the Trenton – Black River Group, Middle Ordovician limestone.

T may be converted into coefficient of permeability, K, by dividing it by the aquifer thickness, m. However, there exists not only a groundwater flow through exploitable waterbearing formations or aquifers, but also through any strata of any permeability. Therefore, to obtain an average coefficient of permeability of an entire formation the whole waterbearing section and not only its most permeable part has to be considered for the thickness, m. K obtained by dividing T by the average well length (below static water level or piezometric surface) may be rather accurate since the bedrock wells are usually constructed as open holes. However to find out any relation between K and bedrock depth, it is more appropriate to divide the bedrock into depth zones, as described previously, and to consider m as the average well length in each zone. In figures 1 and 2 the average permeability versus depth was plotted logarithmicaly. Two relations are remarkable. The highest permeability at depths 15–40 feet is seen to have a decreasing trend to the bedrock surface; and at greater depths it has a strong linear decrease with depth showing only a small variation between similar lithologic units. A similar logarithmic decrease in the well yield with depth was observed in crystalline rocks by Davis and Turk (1964).

Usually it is expected that the weathering of bedrock increases its porosity. In coarse-grained rock, a relatively high permeability may result from the weathered zone. In very fine-grained or rather soft rocks which are covered by glacial deposits the conditions seem to be different. The decreasing permeability trend towards the surface of the limestone and shale formations might result from plugged fractures which are clogged by

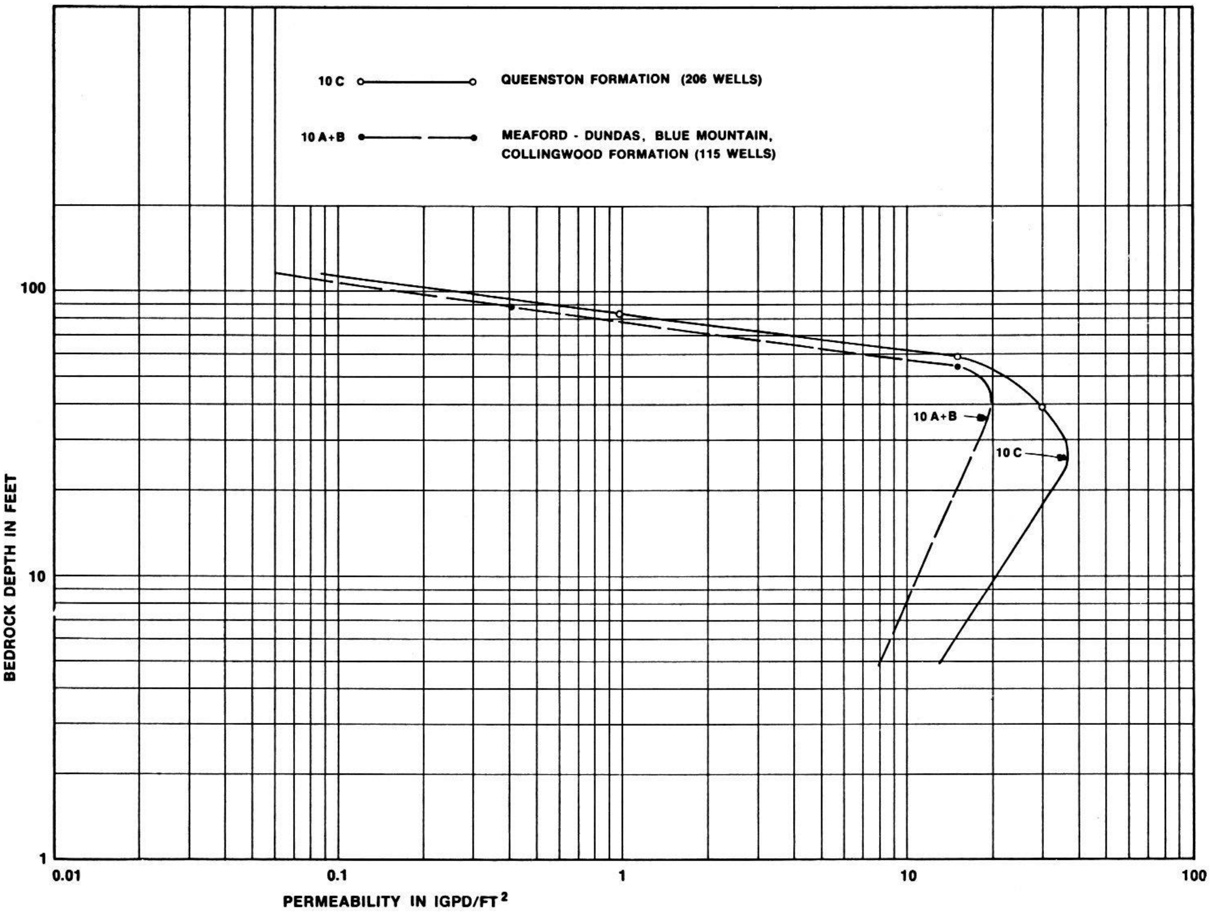

Fig. 2: Average permeability in each depth zone versus mean penetrated depth of each zone of the Upper Ordovician shale.

argillaceous material originating from overlaying till deposits. This trend might also be slightly influenced by the manner of sampling. DAVIS and TURK (1964) and SNOW (1968a) noted that the distribution of specific capacities in fractured rock is always skewed to the right. The mean is larger than the median, so for a large number of wells, a greater capacity can be expected than for a single well. SNOW (1968a) conducted studies to assess the effect of sample size. The reason for the increasing permeability with increasing size of sample or for an increasing number of wells is the fact that the fracture apertures are not all alike. The distribution of apertures is probably skewed to the right. In the present study where the sample size varies from 12 to 59, the largest number of samples is in the group 31–50 ft. deep, which coincides in some cases with the depth of the highest permeability (Fig. 1 and 2). Still another influence of the trend might result from cased wells through the weathered zone. This would, however, indicate a low water production in the upper part of bedrock.

The widening of the fractures in the limestone due to dissolution

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca\,(HCO_3)_2$$

seems not to be important in the shore belt area. The results do not show any evidence. This may be because the low permeability of the glacial deposits reduces the recharge and the low hydraulic gradient causes a very slow groundwater flow. In fact an aerial photographic survey showed almost no karstic phenomena occuring at the surface.

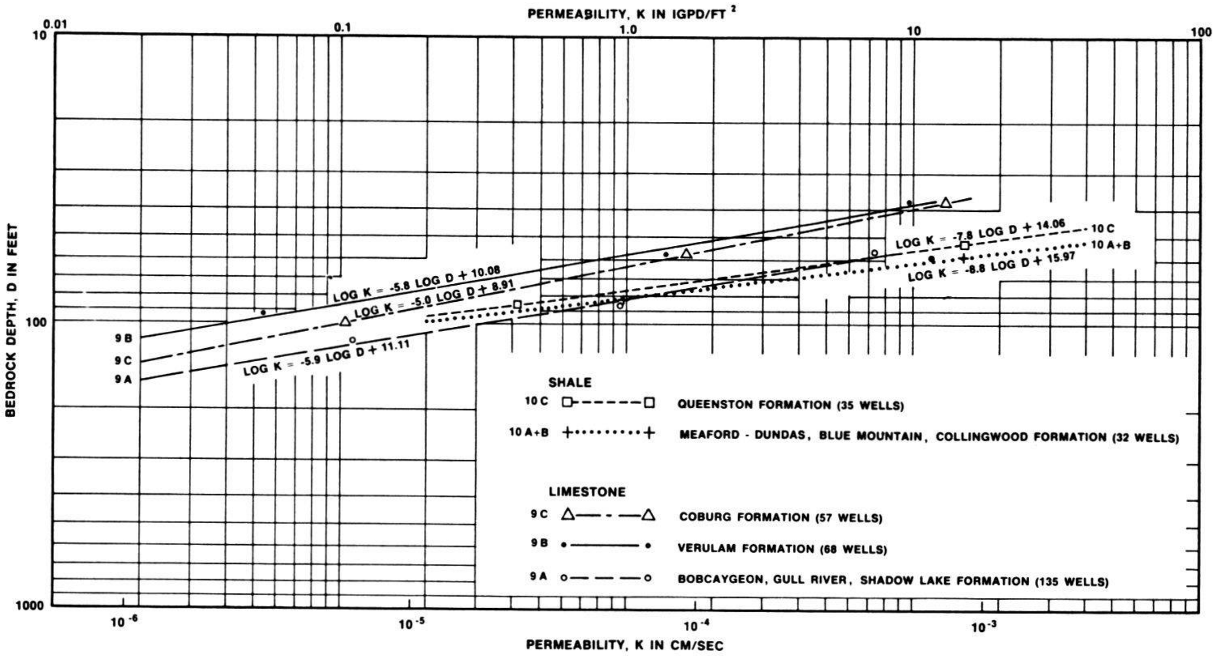

Fig. 3: Mean permeability in each depth zone below 40 feet, versus the mean penetrated depth of each zone of the bedrock formations bordering Lake Ontario (equations for K in Igpd/ft.^{2})

For comparison the part below 40 feet with the linear relationship is shown in Fig. 3 for the different limestone and shale formations. Their means (Fig.4) are compared with the permeability/depth relationship of crystalline rocks of Colorado (SNOW, 1968a).

The equations of best fit for K in Igpd/ft^2 (1 Igpd/ft^2 = $5.66 \cdot 10^{-7}$ m/sec) are:

Shale	$\log K = -\ 8.3 \log d + 14.90$
Limestone	$\log K = -\ 5.6 \log d + 10.08$
Crystalline rocks	$\log K = -1.67 \log d + \ 3.28$

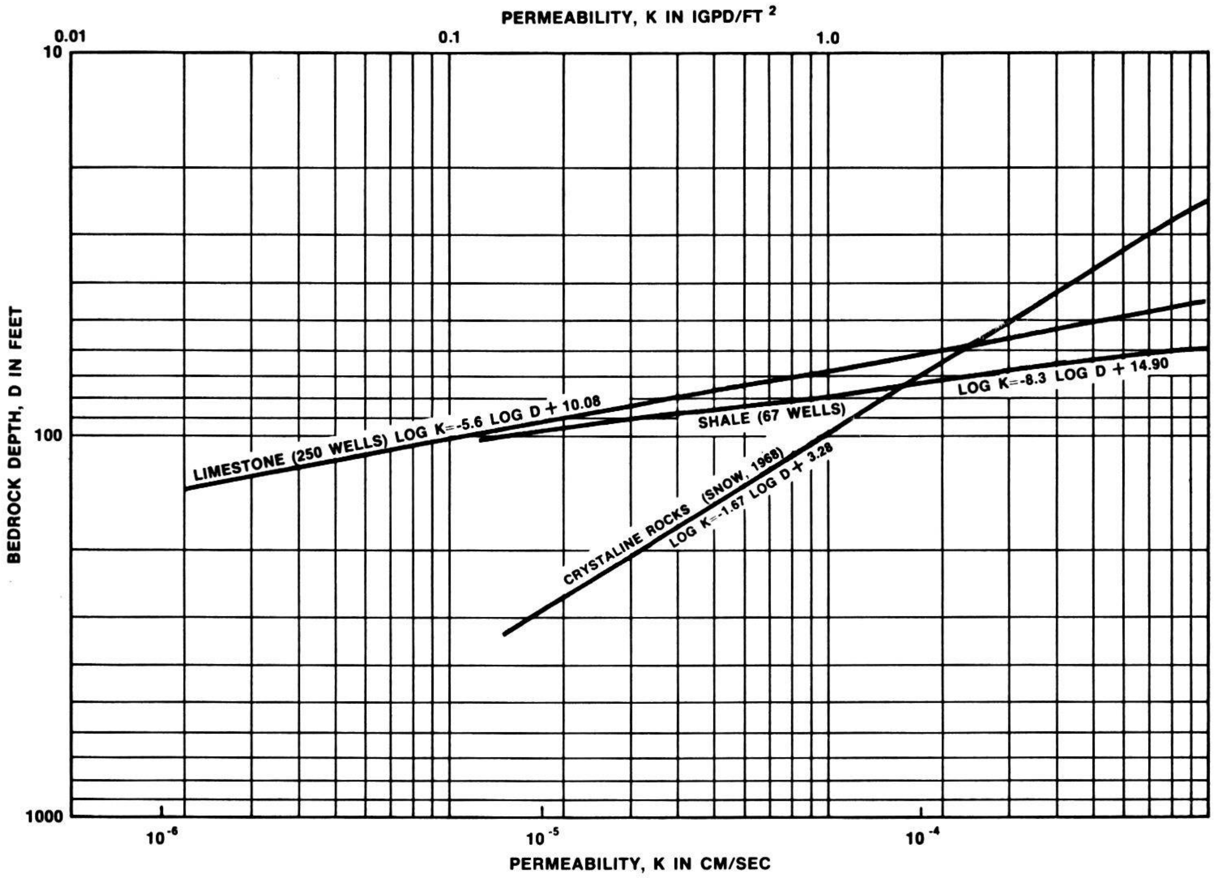

Fig. 4: Bedrock depth versus mean permeability of shale and limestone bordering Lake Ontario (computed from pumping test data) compared with the permeability/depth relationship of crystalline rocks of Colorado (after D. T. SNOW, 1968, computed from injection tests). (Equations for K in Igpd/ft^2.)

Of interest are the slopes of the curves for the different rock types. The rocks with low strength tend to close their fractures quicker with depth and rapidly become less permeable. This relationship was also observed by DAVIS and TURK (1964) by comparing low-grade metamorphic rocks with other crystalline rocks.

It appears as a general rule that the trend of decreasing fracture porosity with depth is valid for crystalline and sedimentary rocks (karst excluded). The best water producing zones are to be anticipated at shallow depths, particularly in rather soft bedrock. The optimum well depth in dense bedrock may vary from area to area. But a brief statistical analysis of existing well data might reveal rather quickly the approximate permeability/depth relationship.

References

DAVIS, S. N. and TURK, L. J. (1964): Optimum depth of wells in crystalline rocks. Groundwater *2*, No. 2, April 1964, pp. 6–11.

HAEFELI, CH. (1970): Zur Abschätzung der Transmissibilität von Grundwasserleitern mit Hilfe der spezifischen Ergiebigkeit. VSP Bull., Vol. 37, Nr. 91.

HAEFELI, CH. (1971): Groundwater inflow into Lake Ontario. Scientific Series No. 9, Dept. of EMR, Inland Waters Br., Ottawa, Canada.

LAWSON, D. W. (1968): Groundwater flow systems in the crystalline rocks of the Okanagan Highland, British Columbia. Canadian Journal of Earth Sciences *5*, 1968, pp. 813–824.

LEWIS, D. C. and BURGY, R. H. (1964): Hydraulic characteristic of jointed rock. Groundwater *2*, No. 3, July 1964, pp. 4–9.

SNOW, D. T. (1968a): Hydraulic characteristics of fractures metamorphic rocks of front range and implications to the Rocky Mountain Arsenal Well. Quarterly of the Colorado School of Mines *63*, No. 1, January 1968.

– (1968b): Rock fracture spacings, openings, and porosity. Journal of the Soil Mechanics and Foundation Division, Proceedings of the American Society of Civil Engineer, Jan. 1968, pp. 73–91.

THEIS, C. V. and BROWN, R. H. (1963): Estimating the transmissibility of a water table aquifer from the specific capacity of a well, in «methods of determining permeability, transmissibility, and drawdown», compiled by R. Bentall. United States Geological Survey Water Supply Paper 1536-I.

WENZEL, L. K. (1942): Methods for determining permeability of waterbearing material, with special reference to discharging well methods. United States Geological Survey Water Supply Paper 887.