Groundwater

Wolfgang Beyer: A Groundwater Scientist from Dresden

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Wolfgang Beyer was a groundwater scientist in Dresden, whose work on the permeability of sediments is cited the world over, but who is otherwise little known. This article is to commemorate him on the occasion of his 90th birthday. He was born on June 17th, 1929 in Breslau (today Wrocław in Poland) and died in 2003 at the age of 73 in Dresden. Following high school and an apprenticeship in masonry, he studied civil engineering at the Technical University (TU) of Dresden from 1949 to 1953. As a young graduate he quickly became scientific assistant at the Institute for Soil and Water Resources at the TU Dresden in 1955. He directed the teaching and research laboratory for Prof. Zunker. In 1964 he completed his doctoral dissertation titled "Contribution to the determination of crucial groundwater flow velocities." In 1972 he obtained his teaching qualification in the subject of hydraulic soil physics and took on more responsibilities in lecturing and the training of young researchers (Figure 1). Through his development of teaching and lecture materials he influenced the education of both local and long-distance students. Due to the onset of illness, Wolfgang Beyer concluded his work at the TU Dresden at the age of 60. He is fondly remembered by many of his former students as a kind, though scientifically meticulous teacher.

Wolfgang Beyer's life's work is best represented by the fact that the "Beyer method" has been and continues to be referenced in thousands of datasheets, reports and publications. The determination of hydraulic

Figure 1. Wolfgang Beyer in 1972. *Source:* Archive of K.-D. Beyer.

conductivity K for gravel and sand based on the grain-size distribution (sieve analysis) using Beyer's empirical formula remains standard practice in the German-speaking region and is internationally renowned. The original results were published from 1964 to 1969 in the journal WWT "*Wasserwirtschaft Wassertechnik*" as well as in the Scientific Newspaper of the TU Dresden (Beyer 1966). Had the formula been presented in english-language publications in the 1960s, it may well have displaced the Hazen (1892). Kerry F. Paul, expert for well screen design and advocate for a more sophisticated grain size analysis, rightly points out that A. Hazen originally developed his formula for wastewater and water filters with artificial grain mixtures, while Beyer developed his

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formula for natural sediments. He recommends using the formula according to Beyer and Schweiger (1969) (Paul 2010). By accounting for nonuniformity and the bulk density, the Beyer method yields better agreement with the conductivity values obtained using more labor-intensive lab and field pumping tests for natural quaternary sediments, for example, glaciofluvial sand and gravel. Noteworthy is the clear delineation of the limits of the method's application. The determination of K using the Beyer (1964) formula is accurate for a moderate bulk density, a silt content (0.06 mm) of less than 10% and a uniformity coefficient C between 1 and 20. In case of a differing bulk density, the publication by Beyer and Schweiger (1969) should be cited.

The sieve analyses and lab experiments were conducted in the laboratory for hydraulic soil physics (Figure 2). A cylindrical permeameter (inner diameter 8.1 cm, height = 12 cm, with water deaeration though boiling and cooling, flow from top to bottom) was used for the lab experiments.

How long did Wolfgang Beyer work on his calculation method and what was special about it? It took more than 8 years and 1500 grain size distributions and hydraulic conductivity tests along with numerous pump tests. The study areas were located in the regions of large water supply companies in the German states of Saxony, Saxony-Anhalt, and Brandenburg.

Against the backdrop of today's time and cost pressure, it is scarcely imaginable to put in this level of effort, not even within multiyear research projects. The discrepancies between the mean hydraulic conductivity determined using grain size distributions from various depths and pump test results were usually less than 30%. Beyer (1964) himself wrote: "Not all authors have investigated such a large number of samples in deriving their formulas. Frequently these resulted by generalizing the rules gleaned from the experimental results of idealized soils or soil fractions." This assessment can be readily applied to many contemporary publications.

In the meantime many calculation methods have been proposed to determine the hydraulic conductivity based on grain size analyses. Numerous publications (e.g., Rosas et al. 2014) compare selected formulas from Hazen (1892), Slichter (1899), Krüger (1918), Terzaghi (1925), Kozeny (1927), Zamarin (1928), Zunker (1930), Sauerbrey (1932), Krumbein and Monk (1942), Loudon (1952), Beyer (1964), Shepherd (1989), Alyamani and Sen (1993), Barr (2001), and Chapuis (2004). Recommendations on the use of certain formulas are provided based on statistical evaluations and the consideration of lab tests, pump tests, slug tests, new measurement methods and model calculations. The literature review for this paper revealed that between 2015 and 2019 at least five review articles were published that compare different existing methods. It is worth noting that the Beyer method was listed in several of these papers among the preferred methods (e.g., Lopez et al. 2015; Fuchs et al. 2017; Urumovic and Urumovic 2017) and was found to

produce the best correlation in investigations with highly heterogeneous soil samples (e.g., Odong 2007).

Some authors, however, call the use of empirical formulas entirely into question, for example, Storz et al. (2017) for industrial sand and Diem et al. (2010) for naturally deposited sediments. Beyer would undoubtedly have no issue with this, being a proponent of lab and field experiments. It should be kept in mind, however, that permeameter and pump tests are often not practical for lack of time and funds. Furthermore, those using empirical formulas should assume a possible error of up to 30%, as noted by Beyer (1964). Figures such as 1.8×10^{-4} m/s or even 1.83×10^{-4} m/s might be correct as calculated mean values, but make little sense when considering this margin of error. Rather, good practice according to Beyer would be reporting a mean value of 2×10^{-4} m/s and honestly communicating the uncertainty in the determinaton of the hydraulic conductivity. As always, the accuracy of a correlation-based determination depends on the measurement of the input parameters, in this case on the meticulous sample collection from the borehole for the determination of the grain size distribution.

Beyer contributed to the good reputation of groundwater research in Dresden through his other work in soil physics as well. Some examples are his work on clogging at bank filtration sites in Saxony, such as Pratzschwitz and Torgau, including the development of exploration methods (Beyer and Banscher 1975, 1976), on seepage of hydraulic structures (e.g., purging dams of the uranium ore processing company Wismut), on the sealing of contaminant deposits, on the execution of tracer tests and temperature measurements in groundwater and even on the development of evaporation pans for the measurements evaporation on the surfaces of reservoirs (e.g., the pumped storage facility Niederwartha in Dresden). The clogging channel developed by Beyer and Banscher (1976) (Figure 3) was replicated many years later by Grischek (2003) and Soares (2015) and used in experiments on the development of external and internal clogging in river and lake beds. In the 70s, Beyer also investigated temperature changes during bank filtration and developed a model to predict the raw water temperature of a bank filtration facility. Practical applications of this included the climate control system of the Semper Opera House in Dresden constructed in 1979.

Work that seems ecologically questionable from today's perspective includes the storage and disposal of contaminants (e.g., refined and natural oil) in open quarries, which was planned and partially implemented as an emergency solution in the 1960s. Beyer dealt with the geohydraulic fundamentals (Beyer et al. 1964; Beyer 1965; Beyer and Schweiger 1967), studied the hydraulic interactions of one such quarry intended for disposal/storage and proved a potential threat to groundwater quality (Beyer and Brauns 1966). He also dealt with seals and suitability tests of earth materials to be used as sealant material in storage basins for refined oil and fuel in Saxony and the Czech Republic.

Wolfgang Beyer developed many practice-focused books as a co-author, such as the "Handbook of Irrigation

Figure 2. Laboratory for hydraulic soil physics in the "Pikardie" building in the Grand Garden of Dresden, a TU Dresden building around 1970. *Source:* **Archive of K.-D. Beyer.**
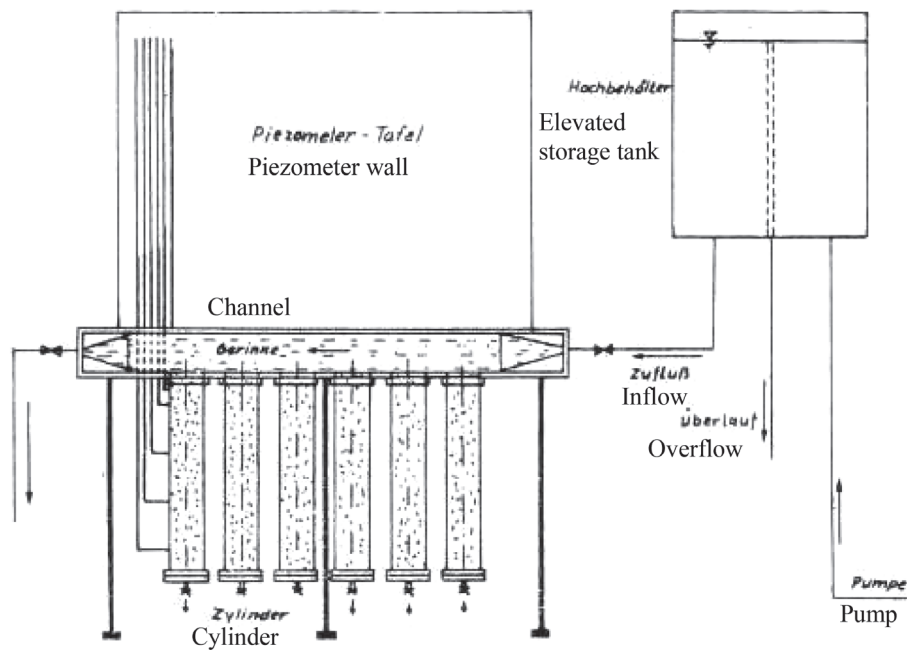

Figure 3. Clogging channel according to Beyer and Banscher (1976).

and Drainage" (1969), the text book "Water Supply for Irrigation" (1972, 2nd ed. 1981) or "Soil Use and Soil Protection" (1990), and at the end of his career the popular science booklet "Water for Home and Garden" with editions in 1986, 1988, and (Beyer 1990). His publications are understandable and clearly worded—a pleasant contrast to modern-day texts with frequently used filler words, unnecessary complications and long, nested sentences.

Continuation of the Scientific Work of Beyer

Digitization leaves (in this case fortunately) no stone unturned, including the work of Beyer and

Schweiger (1969). Houben and Blümel (2017) developed a spreadsheet tool in Microsoft Excel and the Visual Basic program "PoroCalculator," which eliminated the need for the error-prone reading of graphics and tables. The Beyer (1964) has also been implemented in many programs for the evaluation of grain distribution curves, some of which include the expanded version accounting for the bulk density.

In the Division of Water Sciences at the HTW Dresden, time-intensive experiments were conducted from 2017 to 2018 in cooperation with Kerry F. Paul to expand the lower application boundary of the Beyer and Schweiger (1969) method (Grischek et al. 2018),

which remains to be completed. The clogging channel as originally developed by Beyer and Banscher (1976) is planned to be employed in portable form to assess the threat of clogging at potential bank filtration sites in Asia.

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