Editor's Message
Thoughts on the evolution of hydrogeologic practice in the USA during the last 40 years

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The intent of this Editor's Message is to (1) review changes that have occurred in the practice of hydrogeology in the USA during the last 40 years, the span of my career in the US Geological Survey (USGS), and (2) appraise how these changes are likely to impact the career of hydrogeologists now entering the field. The review reflects a perspective influenced by the author's personal biases, but the discussion of the hydrogeologic practices of 40 years ago should reasonably represent the then prevailing state of the art. Also, although the many changes that have occurred in hydrogeologic science impact the careers both of the practitioner and of the researcher, the appraisal is limited to a discussion of the effects of change on hydrogeologic practice.

Both the review and the appraisal are deficient in their discussion of international developments and conditions in hydrogeology, and may be considered parochial, particularly in a journal that prides itself on its international outreach. Perhaps this Message will inspire those with a broader international perspective to write of their impressions on the evolution of hydrogeologic practice on an international scale.

Review of Changes

All facets of the practice of hydrogeology have been impacted by rapid change. For brevity, this commentary considers only the aspects of training, hydrologic literature, textbooks and teaching materials, computation, and data collection and analysis. Other topics, such as report preparation, could be discussed, but conclusions regarding the effects of change on the work-life of the hydrogeologist would remain the same.

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Training

In the late 1950s, hydrogeologists in the USA were relatively few, and few of these had formal training in the subject. Instead, new entrants to the field became hydrogeologists through on-the-job training, often in the USGS or in one of a few State Water Surveys, perhaps the most notable of which was the Illinois State Water Survey. Nonetheless, a young person entering the profession, often with a bachelor's degree in geology or in civil engineering, could rely on one of several of the pioneers in the science, such as John Ferris, Hilton Cooper, C.V. Theis, C.E. Jacob, S.W. Lohman, or (my mentor), R.W. Stallman, to provide excellent mentoring. Such mentoring arguably could be as valuable an educational experience as that provided by advanced academic training.

Availability of formal training in hydrogeology in the USA increased rapidly in the 1960s as universities began to recognize the field as a distinct science, and to offer advanced degrees in hydrology. Schools that pioneered in developing curricula in hydrology include the University of Arizona, New Mexico School of Mines and Technology, and the University of Illinois. Now, schools offering degrees in hydrology are almost too numerous to count, and most new entrants to the field of hydrogeology have at least a master's degree, and many a doctorate, in the field.

Literature

Journal articles on hydrology were few in the late 1950s. Of professional societies, only the AGU (American Geophysical Union) recognized hydrology as a distinct discipline, and most of the technical articles on hydrology appeared in the *Transactions of AGU* and in AGU's *JGR* (*Journal of Geophysical Research*). Some papers appeared in the ASCE (American Society of Civil Engineers) *Hydraulics Division* and *Irrigation and Drainage Division Journals*, and occasional papers appeared in other journals, such as *Soil Science*, *Soil Science Society of America Journal*, and *Journal of Geology*. Relevant papers regarding flow through porous media appeared in the petroleum literature, but petroleum engineers and hydrogeologists tended to ignore each other. Also, the International Association of Scientific Hydrology published proceedings of annual specialty conferences that provided a valuable literature source. The total number

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of journal papers published each year in the USA probably numbered in the several tens.

This situation changed rapidly during the 1960s, however. The journals *Ground Water* and *Journal of Hydrology* started publication in 1963, and AGU began publishing *WRR* (*Water Resources Research*) in 1965. Additional new journals devoted to hydrology appeared at irregular intervals thereafter, including *Advances in Water Resources* in 1976, *Journal of Contaminant Hydrology* and the journal *Hydrologic Processes* in 1986, *Hydrogeology Journal* in 1993, and ASCE's *Journal of Hydrologic Engineering* in 1995. (Note that this is an incomplete and perhaps biased list.) Not only did the number of journals increase substantially during the last 40 years, but the number and length of papers in each journal also grew significantly. For example, the number of pages per volume of *WRR* (adjusted for page size) grew from 366 in 1965 to 3,770 in 2000, a tenfold increase or a growth rate of about 6% per year. Other journals exhibited similar growth, and with a combination of more and larger journals, newly produced literature appears at a rate tens of times faster than in 1960. Even more daunting, the volume of accumulated literature has expanded perhaps a 1,000-fold since then.

Textbooks and Teaching Materials

Textbooks were also limited in number before about 1960. Tolman's text (1937) *Ground Water*, John Ferris' (1949) chapter *Ground Water* in Wisler and Brater's *Hydrology*, and Butler's (1957) *Engineering Hydrology* come to mind. The mimeographed notes for the USGS Ground-Water Short Course, taught mainly by John Ferris and S.W. Lohman, provided an important tool for training new hydrogeologists. Again, the situation rapidly changed. Todd's text, *Ground Water Hydrology*, came out in 1959 (Todd 1959), as did perhaps one of the most important reference works on solutions to groundwater hydraulics problems ever to become available to hydrogeologists – Carslaw and Jaeger's (1959) *Conduction of Heat in Solids*. A year later, another valuable source book, *Transport Phenomena*, by Bird et al. (1960) was published. John Ferris' *Theory of Aquifer Tests*, compiled from his lecture notes for the USGS short course, was published in 1962 (Ferris et al. 1962). Roger De Wiest's (1962) translation of Polubarinova-Kochina's *Theory of Ground Water Movement* made some of the Soviet literature on groundwater hydraulics available in English for the first time. Since that time, several new texts on groundwater hydrology have been published, perhaps the most notable being Freeze and Cherry's (1979) text, *Groundwater*.

Computation

In 1960, the hydrogeologist's computational tools, aside from hand calculations, consisted of slide rules and electromechanical calculators. Numerical evaluation of published equations for aquifer-test analysis, needed for the preparation of a family of type curves, required many hours of slide-rule computations and hand calculations. Multiple-regression problems required the retention of more significant digits than was possible with a slide rule, and even relatively small problems (by modern standards) required numerous hours of evaluation using an electromechanical calculator. Groundwater-flow simulations were performed using electric analogs, either resistor–capacitor networks or conductive-paper analogs.

Rapid change resulted from the appearance of electronic calculators and the increasing availability of access to digital computers. Computer usage progressed from batch submissions of card decks to a mainframe computer, to remote terminal access to a mainframe computer, and now to the use of personal desktop computers (PCs or Work Stations). The rapidly increasing availability of graphical user interfaces for many computational tasks and simulation codes has further enhanced computer accessibility to even the novice computer user. This rapid evolution has advanced to the point that computational problems that once took hours to days to overcome are now solved in seconds, and numerical models of groundwater flow can be set up and run in hours, rather than weeks to months.

Data Collection and Analysis

All facets of data collection and analysis have undergone profound change in the last 40 years. Aquifer tests, in common use both then and now, have been analyzed in several ways. Before 1960, the principal tools of analysis for aquifer tests included the Thiem equation, the Theis equation (and the Cooper-Jacob approximation), and the Jacob-Hantush leaky-aquifer equation. Hantush's (1960) *Modification of the Theory of Leaky Aquifers*, which accounted for the effects of storage in the semiconfining beds, represented a significant breakthrough. A plethora of analytical equations for aquifer and slug-test analysis that covered a wide range of aquifer situations soon followed. As examples, solutions were developed for effects of well partial penetration, well-bore storage, water-table conditions, and multiple aquifers. Complete slug-test solutions were developed for confined aquifers – both for the underdamped case (monotonic water-level response) and the overdamped case (oscillatory water-level response) – and for a partially penetrating well tapping a water-table aquifer. A literature review (Weeks 1978) conducted in 1977 identified 50 papers on aquifer-test analysis published between 1961 and that time.

Similar rapid advances could be enumerated for most other facets of data collection and analysis, including, for example, water-level and soil-moisture data collection, geophysical logging, water-chemistry analyses, and modeling of groundwater flow and transport.

Assessment

How has 40 years of rapid change impacted the work-life of the practicing hydrogeologist? Clearly, he/she

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spends less time hand-plotting data, preparing hand-contoured maps, making numerical computations, or formulating and building analytical, analog, or numerical hydrologic models than in the not-too-distant past. One might assume that with so much erstwhile busy work now automated, the hydrogeologist should be able to work at a slower pace, spend more time formulating an understanding of the hydrologic system under study, and pursue research interests sparked by unexpected findings during the applied study. Instead, the pace of work has accelerated, and most journeymen hydrogeologists have less, rather than more, time to adequately formulate their conceptual models, prepare their reports, and pursue research interests. This is true despite the fact that the typical hydrogeologist is more diligent in his/her work habits than was the case 20–40 years ago. Years ago, coffee-breaks tended to be lengthy, and extended casual lunches were not uncommon among many in the hydrologic community. Now, most hydrogeologists, including a majority of those once less diligent, drink coffee at their desks and, typically, rarely go out to lunch.

So why the more hectic work pace? Many, if not most, hydrogeology projects are now scheduled for shorter duration than was typical in the past; from 3–4 years then, to 6 months to 2 years now. However, conceptual model formulation at the start of the project remains a trial-and-error process that perhaps requires as much time as ever. At the end of the project, composing a well-written report is as difficult and time consuming now as it ever was. Thus, many hydrogeologists today spend most of their time on study plans and on report preparation, with much less time spent conducting the study.

Perhaps the most important question raised by this appraisal is whether a career in hydrogeology might be as rewarding and enjoyable for the entry-level hydrogeologist as it was for those who started 40 years ago. Based on the above analyses, it seems likely that the young hydrogeologist indeed may have as happy a career as have many of the “old-timers,” but to do so must both train and work more diligently than the young hydrogeologist of the past.

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