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THE 2000 C.V. THEIS AWARD

The American Institute of Hydrology (AIH) established this award in 2986 to honor the charter member of AIH, C.V. Theis – the founder of modern ground-water hydrology. The award is presented annual, on the recommendation of the AIH Awards Committee, for a major contribution to the field of ground-water hydrology. The first C.V. Theis Award was presented to Roger J.M. DeWiest at the AIH Conference on Application of Recent Advances in Hydrosciences in San Francisco on March 26, 1987.

Citation— *Chunmiao Zheng*

"The C.V. Theis Award" recognizes individuals who have made outstanding contributions in hydrology. Mary Anderson is most deserving of this honor for her numerous achievements as a researcher, educator and leader.

Mary has played a central role in leading the evolution of groundwater modeling from an esoteric plaything into a fundamental tool of practicing hydrogeologists. Since receiving her Ph.D. in hydrogeology from Stanford in 1973, Mary has worked on all aspects of computer modeling of groundwater systems, and has made significant contributions to the science of hydrogeology in many areas. Among these are the interaction between groundwater and lakes, the characterization of geologic heterogeneity for purposes of groundwater investigations, the quantification of groundwater recharge, and philosophical issues of model application. Since it would be too numerous to describe everything Mary has accomplished, let me briefly highlight a few of her scientific contributions.

Soon after arriving at University of Wisconsin-Madison in 1975, Mary began studying groundwater-surface water interaction at several lakes in northern Wisconsin, which would become part of the NSF's Long Term Ecological Research program. At a time when quantitative analysis was the exception rather than the rule, Mary realized the power of groundwater modeling and used it as a primary tool in her research. Since then, this line of research has provided invaluable insights into the role of groundwater in controlling the hydrological, geochemical and ecological evolution of lakes and wetland systems. Equally important, her work has established a quantitative and multidisciplinary framework for studying groundwater-surface water interactions which combines computer modeling with field measurements of hydrological and geochemical data. A geochemist colleague of mine recently pointed to Mary's work as providing some of the best available studies on lakes.

Mary had the vision to begin studying the influence of aquifer heterogeneity on groundwater flow and contaminant transport early in her career, well before it was recognized as a central problem in hydrogeology. Her landmark paper "Using models to simulate the movement of contaminants through groundwater systems" published in 1979, pointed out many of the conceptual and numerical pitfalls associated with modeling contaminant transport in heterogeneous aquifers. This paper continues to be cited in journal articles as a framework for the study of contaminant transport. Many of the points discussed in the paper are as applicable today as they were 20 years ago. In 1989, Mary published a now well-referenced paper entitled "Hydrogeologic facies models to delineate large-scale spatial trends in glacial and glaciofluvial sediments". Mary's articulate description of sedimentary facies models as the conceptual foundation for defining the internally consistent hydraulic conductivity distributions in sedimentary systems represents one of the finest examples of ingenious thinking on how to deal with aquifer heterogeneity. Later, Mary and her students continued research in this direction and developed concepts and techniques for integrating facies architecture descriptions with numerical simulation. These pioneering efforts have had an enormous impact on much on-going research and paved the way for exciting applications in this rapidly evolving field.

Mary writes beautifully. The name "Mary Anderson" has become synonymous with "groundwater modeling" because of her two popular textbooks on groundwater modeling, *Introduction to Groundwater Modeling: Finite Difference and Finite Element* first published in 1982 with Herb Wang, and *Applied Groundwater Modeling: Simulation of Flow and Advective Transport* published in 1990 with Bill Woessner. The exemplary clarity and the clever mixture of concepts and short computer codes in the first book have helped thousands learn the fundamentals of groundwater modeling, while the lucid presentation and careful synthesis of a vast amount of information have turned the second book into the standard reference work for conducting groundwater modeling studies. Her writings on more philosophical issues of groundwater modeling, such as an editorial entitled "Groundwater modeling — the Emperor has no clothes" published in 1983, have also had lasting influences and helped establish a sound footing for groundwater model applications.

Over the last two decades, Mary has served as mentor to a generation of students at UW-Madison, many of whom have become industry leaders and productive researchers. The success and prominence of UW's hydrogeology program is a direct result of Mary's vision and leadership in many research areas, and a unique style of working with graduate students that encourages independent thinking and inspires in students a deep-rooted passion for solving real-world problems. On the occasion of her 25th year of teaching at the UW-Madison, many of Mary's former students will get together this fall at the GSA annual meeting for a research symposium in her honor. This is testament to the deep appreciation and affection Mary's former students have for her.

Mary has also given her time unselfishly to numerous professional services activities, including serving as the Hydrology Section President of the American Geophysical Union and a councilor of the Geological Society of America, and service on a large number of committees, panels, and editorial boards. In addition, Mary has always been very generous with her time helping aspiring young scientists from this and other countries. I remember when I was looking for a graduate program in 1983, I sent letters in broken English from China to several U.S. universities including Wisconsin. I was so surprised and moved by Mary's quick and warm response that I applied for admission to Wisconsin only. What a lucky break for me!

C.V. THEIS AWARD

President Seaburn, ladies and gentlemen, it is indeed a privilege and honor to present my teacher, mentor and friend, the recipient of the 2000 C.V. Theis Award, Mary Anderson. Mary embodies all that we associate with C.V. Theis, outstanding scientist, inspiring teacher, and unselfish services to the profession. Congratulations!

Dr. Chunmiao Zheng
University of Alabama
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C.V. THEIS AWARD

Response- *Mary P. Anderson*

In accepting the C.V. Theis Award, I am extremely honored to have my name and achievements linked in some small way to this great man, who was "recognized by all of his associates as having no peers" (White and Clebsch, 1993). I am also honored to be linked via the Theis Award to all of the illustrious scientists who have previously received the award.

I was privileged to meet C.V. Theis for the first and only time on the occasion of his receiving the American Geophysical Union's Horton Medal for outstanding contributions to the geophysical aspects of hydrology. This was in 1984, just three years before his death. In his acceptance speech, Theis (1984) reminisced about his interactions with Horton and with Meinzer and also offered some thoughts for the future, noting that emphasis on transport of solutes in groundwater had forced researchers to come "... full circle from the assumption of homogeneity" to the realization that "heterogeneity characterized all known water-bearing formations."

Theis had an uncanny ability to foresee the problems that would face future generations. In a little known paper presented in 1967 at a conference of the American Water Resources Association, he correctly attributed the cause of field scale dispersion to the presence of heterogeneities in the subsurface. The man who had realized that the equivalent homogenous porous medium was conceptually important to transient aquifer test analysis was probably the first person to appreciate fully the relationship between geological heterogeneities and macroscopic dispersion. Theis called for a new conceptual model to replace the equivalent homogeneous porous medium and also anticipated the need for tracer tests to measure dispersion:

> ...although I consider it certain that we need a new conceptual model, containing the known heterogeneities of the natural aquifer, to explain the phenomena of transport in groundwater, no certainty exists that the details here discussed are dominant. Even if these should be of major importance, the quantitative expression of the mixing techniques and the possible correlation of these with types of sedimentation and other phases of the geologic history of a formation must await many more detailed tracer studies in the field. (Theis, 1967)

These were startling statements back in 1967. The significance of his observations almost certainly was not appreciated by the audience. No one asked Theis a single question on dispersion during the discussion period at the end of the session.

In his acceptance of the Horton Medal, Theis remarked that advances in the theory of groundwater hydrology have occurred in pulses, citing contributions by Darcy, Dupuit, Forchheimer, Wenzel, and Hubbert. Theis himself, of course, had found the key that enabled researchers to quantify heterogeneity for water supply problems. His work (Theis, 1935) spawned a multitude of research contributions by others who built on his work. The publication of this paper in 1935 revolutionized groundwater hydrology and recognized, however, that the concept of the equivalent homogeneous porous medium was inadequate when applied to problems of contaminant transport. Had he been cloned to live another generation, Theis may well have found a way to quantify heterogeneity for use in contaminant transport problems.

In the second half of the 20th century, we can identify several more advances of groundwater theory by pulses. Toth's (1962, 1963) analysis of regional groundwater systems, which built on Hubbert's (1940) earlier work, led to "major breakthroughs in understanding the behavior of groundwater systems" and "provided a guide for the application of numerical models that were soon to transform subsurface hydrology" (Dunne, 1998, p. 22). Freeze's insightful paper on uncertainty (Freeze, 1975) set off a major initiative in stochastic analysis of hydrogeological problems, especially as related to contaminant transport. But it is still unclear whether the voluminous research contributions in stochastic hydrogeology will have the lasting, monumental impact that Theis' 1935 paper had on the future of groundwater science. Stochastic analysis has not yet given us a clear-cut, practical way to quantify geological heterogeneity in problems of contaminant transport.

While advances in theory have occurred in pulses, the topic of groundwater-surface water interaction has formed a running theme throughout the history of groundwater science. Starting with the work of Boussinesq (1877), analysis of the interaction between a stream and a contiguous alluvial aquifer has been a focus of study for more than 100 years (Winter, 1995) and is an active area of research (e.g., see Jones and Mulholland, 1999). Slichter (1899) developed an analytical solution to characterize groundwater flow in the vicinity of a stream. Theis, too, contributed to the literature on groundwater-surface water interaction (Theis, 1938). Kohout's (1960) classic paper analyzed the interaction between the ocean and a coastal aquifer. More recently, investigators have focused on groundwater-lake interactions, the hyporheic zone, and groundwater discharge to wetlands (e.g., see Winter et al., 1998). There is a session on groundwater-surface water interactions scheduled for this AIH conference, as well as a session at the up-coming GSA conference ("Surface Water-Groundwater Connections") and another to be held at the up-coming AGU conference ("Interactions between Groundwater and Surface Water: Bridging the Gap between Theory and Observation").

In spite of all of this attention to both the theory and measurement of groundwater fluxes, there are still many difficulties in obtaining accurate estimates of the spatial and temporal distribution of these fluxes, including fluxes to and from rivers and streams, reservoirs and lakes, wetlands, and the ocean. Similarly, there is a voluminous literature documenting attempts to quantify groundwater recharge (e.g., Simmers, 1988), including work by Theis (1937a, b), who also introduced the concept of "rejected recharge" (Theis, 1940), but there still are no standard procedures for measuring recharge to the groundwater system from precipitation.

The problems in measurement arise in part because of the diffuse nature and spatially large extent of most groundwater discharge and recharge areas. While there are instruments designed to make direct point measurements of infiltration or recharge (e.g., infiltrometers, lysimeters, seepage meters) and discharge (seepage meters), in most cases it is uncertain whether or how these measurements might be extrapolated to larger areas. Indirect methods of estimating fluxes (e.g., using head measurements and Darcy's law; analysis of water-level fluctuations, and analysis of temperature profiles, isotopes and solutes dissolved in groundwater) also suffer from the same limitations. Moreover, integrated estimates of flux (e.g., baseflow estimates used to approximate groundwater discharge to rivers, water balance methods and model calibration to estimate recharge) are also subject to much uncertainty.

Recharge/discharge estimates are of interest at many different scales and for many different purposes. These fluxes affect physical, chemical and biological processes in both the saturated and unsaturated zones. Furthermore, basin scale biogeochemical cycles are determined in part by recharge/discharge patterns and the physiology of vegetation is strongly linked to recharge/discharge zones. Inflow of groundwater to surface water bodies, including wetlands, carries nutrients important to biological communities. Recent work at the groundwater-stream interface (the hyporheic zone) and at the groundwater/lake interface has demonstrated that most of the chemical transformation occurs within a few inches of the interface. Improved measurements of groundwater fluxes and associated biogeochemical processes within these interfaces are needed. Of particular interest are processes involving pathogens and nutrients such as nitrogen.

Estimation of recharge and discharge rates is of paramount importance to the sustainable use and management of groundwater resources because these rates determine the net replenishment of aquifers. At a regional scale, the amounts of total groundwater recharge and discharge are important in water budget analyses for basin management and water supply decisions. At a macroscale, information on groundwater fluxes is used in addressing local water supply issues and groundwater contamination problems. Groundwater discharge is also relevant to mass wasting (landslides) and surface water generation. Thus, accurate estimates of groundwater recharge and discharge are important to groundwater sustainability and the health of ecosystems, as well as in geomorphological processes.

Although much good work has been done on this old yet eternally relevant topic, many questions remain. Estimation of groundwater fluxes across interfaces remains a grand challenge for the hydrological community.

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