Regarding INTERA and its Founders' Contributions to Digital Computer Modeling in Hydrogeology

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After reading a recent article in the journal *Groundwater* by Molz (2017) that details the history of digital computer modeling of groundwater systems, I realized part of the story was missing. In Molz's article, he correctly cites the contributions by many early icons in our industry's pursuit of digital simulation capability including Paul Witherspoon, John Phillip, Al Freeze, John Bredehoeft, George Pinder, Tom Prickett, and others. He also admirably tackles some of the contributions of the private sector in the development and application of numerical models, notably Stavros Papadopulos, Steve Larson, Jim Mercer, Charlie Faust, and Peter Huyakorn. He also poses the question "So how did the petroleum engineering and soil-physics-based numerical methods move into hydrogeology?"

Notwithstanding Molz's coverage of these topics, there is more to the story regarding the influence of the petroleum and private sectors that I would like to offer. The missing backstory relates to the significant contributions of the INTERA corporation and its founders Drs. Ronald Lantz and Suresh Pahwa as well as principal technical staff members that include Mr. Gerry Grisak and Drs. John Pickens, Mark Reeves, Robert (Bob) Andrews, Banda RamaRao, Richard Jackson, and John Wilson. Their mention is warranted because of the pivotal role they played in bringing petroleum reservoir numerical modeling technology into hydrogeology, and their contributions are briefly described here.

INTERA was started in 1971 by Ron Lantz as an environmental modeling division of INTERCOMP Resource Development and Engineering Inc. (operated today as Scientific Software-INTERCOMP Inc.), a recognized leader in petroleum reservoir simulation headed by Drs. Keith Coates and Harvey Price. In the early seventies, INTERCOMP had the most sophisticated petroleum reservoir engineering software in the world (Price and Coates, 1973). Prior to joining INTERCOMP, Ron was part of Esso's (Exxon) Production Research Company and already well known for his research in numerical model stability criteria (Lantz, 1971). Ron's contributions to hydrogeology began in 1974 when, under John Bredehoeft's leadership at the USGS, INTERCOMP's environmental group (now INTERA) won a project with the USGS to develop a three-dimensional coupled ground-water flow and transport model for energy and contaminant transport. The resulting code, SWIP (INTERCOMP, 1976) was regarded by the USGS, academia, and the private sector as a significant

achievement and used by many USGS staff (e.g., Merritt, [1984]). Some years later, Ken Kipp of the USGS used the SWIP code as the basis for the development of his HST3D program (Kipp,1987). INTERA's work in numerical dispersion, field tests to measure dispersivity, and the 'Intera finite difference model' were cited by Anderson and Cherry (1979) in a CRC Critical Review article on the state of the science of groundwater flow and transport processes and technology.

In developing SWIP, Ron leveraged his knowledge of advanced reservoir numerical methods developed in the petroleum industry. SWIP was the first ground-water code to couple flow, energy transport, and contaminant transport in three dimensions, accounting for density and viscosity effects (INTERCOMP, 1976). At the completion of the SWIP code development project, Ron and Suresh conducted a three-day SWIP course for the USGS's Denver office where attendees included most of the prominent USGS hydrogeologists from across the US such as Lenny Konikow, John Bredehoeft, Jim Mercer, Charlie Faust, Stavros Papadopulos, and Steve Larson. This initial contact led Ron Lantz and INTERA to later partner with Charlie Faust and Jim Mercer to found GeoTrans as an INTERA subsidiary in 1979. INTERA later sold its interest in GeoTrans to Charlie and Jim in 1983.

In 1976, the Nuclear Regulatory Commission (NRC) contracted Sandia National Laboratories (SNL) to develop a groundwater flow and nuclear transport model. Based on a recommendation from the USGS, the SNL technical leads contracted INTERA to support this effort. Later that year, INTERA modified the SWIP code to include radionuclide transport resulting in the widely used code called SWIFT (Figure 1).

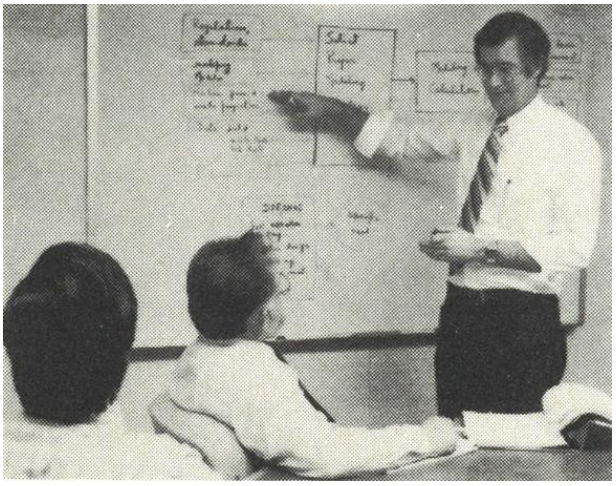

Figure 1. INTERA's Ron Lantz (standing), Suresh Pahwa (left) and SNL's Pat Brannen (center) discussing SWIFT code development in 1975.

Some years later, the NRC wanted to add dual-porosity flow and transport capabilities to enable the evaluation of radioactive waste storage in fractured media. Since INTERA was working on a major code development project for the U.S. Department of Energy (DOE) at the time, the company could not work directly for NRC to support the development of this new code. Therefore, an INTERA Principal Scientist, Dr. Mark Reeves, was loaned to INTERA subsidiary GeoTrans to lead the SWIFT II code development project team. Collaboration with David Ward at GeoTrans led to the completion of SWIFT II in 1984 and Mark returned to INTERA where he worked until retiring in 1998.

Another contemporary development in the private sector was the DYNSYSTEM series of codes at what is now CDM-Smith in Boston, Massachusetts. These codes originated at the Massachusetts Institute of Technology (MIT) with John Wilson's 1979 AQUIFEM two-dimensional finite element groundwater flow code, which he developed with grad student Lloyd Townley who soon after went to the Commonwealth Scientific and Industrial Research Organisation in Australia. Consulting with CDM in 1980, Wilson and colleagues built a quasi- three-dimensional version of this code, called AQUIFEM-N, then designed an entirely new, fully three-dimensional finite element groundwater flow code called DYNFLOW, which is still used today. Looking at alternatives for mass transport solutions without numerical dispersion issues, this team also developed the random walk code DYNTRACK. A few years ago, serendipitously and 40 years after his work on AQUIFEM, Lloyd Townley joined CDM-Smith.

The impact of Ron Lantz's contributions to groundwater modeling and the environmental and petroleum reservoir industries are many. The companies he started from 1976 to 1983 (Figure 2) include GeoTrans, TECHLAW, and reservoir modeling companies such as INTERA Petroleum Consultants, PetreSim, and J.S. Nolen and Associates. During the late 80s and early 90s, INTERA also purchased and revived the UK consultancy ECL, the firm that developed the well-known Eclipse reservoir software which INTERA later sold and is now part of Schlumberger. Geologic Testing Consultants Ltd (GTC) was an INTERA subsidiary that Ron started with Gerry Grisak and John Pickens after recruiting them from Environment Canada in 1981. Gerry was the Head of Contaminant Hydrogeology and John was a member of the Contaminant Hydrogeology team at Environment Canada in Ottawa, Ontario. There they conducted foundational research on scale-dependent dispersion. GTC was the first hydrogeology company to develop aquifer interpretation software, called GTFM, capable of incorporating borehole history and its related affects into well test analysis (Pickens et al., 1987). Gerry and John later relocated to Texas to join the INTERA team and GTC became an INTERA branch office in Ottawa. Collaboration with Richard Beauheim at SNL at the DOE's Waste Isolation Pilot Plant in New Mexico led to enhancing the GTFM software with petroleum industry well-test interpretation techniques (pressure derivative analysis), a first in the hydrogeology community (Beauheim and Pickens, 1986).

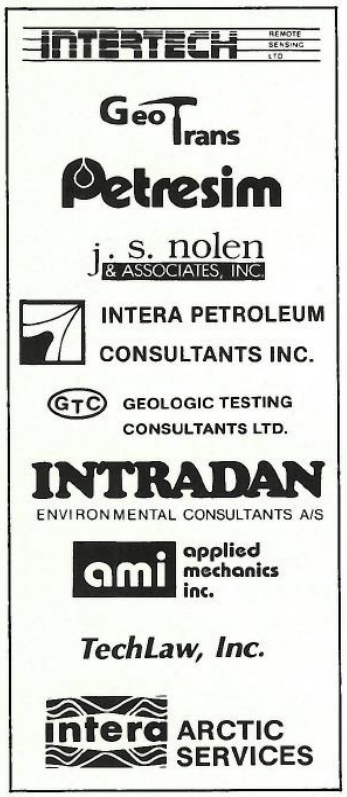

Figure 2. Logos of INTERA's subsidiaries and affiliated companies from 1976-1983.

Notwithstanding his knack for recruiting talent from government agencies for startups, Ron Lantz also recruited several of the top university researchers in numerical modeling to spend extended time in INTERA's hallways in Houston in the 1970s and 1980s to collaborate with the INTERA code development team. He would typically pick them up at the Houston airport for their first visit to INTERA in his DeLorean which added to the mystique of the team he was building at INTERA. Noted collaborators included John Wilson (MIT and New Mexico Tech), Jon Sykes (Waterloo), Al Freeze (University of British Columbia [UBC]), Leslie Smith (UBC), Pat Domenico (Texas A&M), and many others.

In the early 1980s, both INTERA and CDM were charged with developing "competing" groundwater flow and transport models for the Atomic Energy Canada Limited's (AECL) proposed underground research laboratory at Pinawa, Canada. Despite using very different modeling codes (SWIFT v. DYNFLOW/TRACK), and absolutely no collaboration during the process, the two teams produced remarkably similar three-dimensional models. It was at one of the research meetings for this project that Ron Lantz invited John Wilson to come to work with INTERA in Houston.

While working at INTERA in the early 1980s, John Wilson and INTERA collaborators Jon Sykes (on sabbatical from Waterloo), Banda RamaRao and Bob Andrews (Figure 3) developed and applied groundwater adjoint sensitivity methods to ascertain the most sensitive groundwater model parameters in a single computer run, a breakthrough in groundwater model sensitivity analysis (Sykes et al., 1985). Adjoint methods had been applied to reservoir modeling in the mid 1970s by French mathematicians Chavent et al. (1975). Later in the early 1990s, collaboration between Dr. Ghislain DeMarsily and INTERA staff led to significant advancements in DeMarsily's pilot point inverse method (RamaRao et al., 1995) by locating pilot points using the adjoint sensitivity techniques developed by Wilson, Sykes, RamaRao, and Andrews a decade earlier. The pilot point inverse method has become the industry standard today due to its incorporation into the PEST code (Doherty 2015). Interestingly, since the late 1990s, the petroleum industry has also adopted the pilot point method for reservoir history matching (Oliver et al., 2008) due to the success of the method in groundwater modeling.

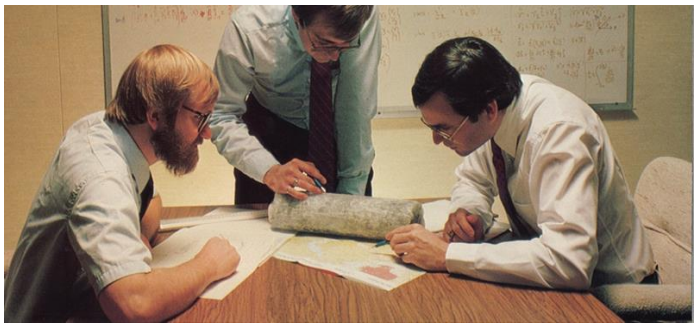

Figure 3. Bob Andrews, Doug Metcalf, and John Wilson at INTERA in the early 1980s in INTERA's Houston office.

Lastly, the contributions to groundwater modeling by the team at Geraghty and Miller (now Arcadis) in the 1980s and 1990s must be mentioned. Dr. David Buss, Glen Duffield, and Jim Rumbaugh were GeoTrans staff that migrated to Geraghty and Miller. They were among the first to recognize the need for commercial groundwater modeling software and developed tools for the practicing hydrogeologist. These early tools led to Groundwater Vistas and the AQTESOLV pumping test analysis software which are in wide use today.

Figure 4. Ron Lantz today in Austin, TX

Today, INTERA is a 180-person international consulting firm with offices in the US and Europe. The company maintains a reputation as a leader in groundwater consulting. INTERA is involved in some of the most challenging projects around the globe, a testament to the company that Ron built. At the age of 82, Ron Lantz (Figure 4) still provides tremendous support to INTERA as a Director Emeritus on INTERA's Board. While not a hydrogeology household name, his many significant contributions to our industry merit this response to Molz's Historical Note.

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