ground water

Historical Note/

# Jacob Bear: An Autobiography

by Jacob Bear[1]

It is not easy to write about myself, as requested by the history editor of *Ground Water*, especially when the request includes the explanation: "A hundred years from now, people will want to know what sort of person you were: This is your opportunity to tell them." I told him that, so far, whenever I wanted to say something to the scientific/professional community, I did so through my papers and books. Nevertheless, I agreed to try.

I was born in Haifa, Israel (then Palestine), in 1929. My parents immigrated from Russia and Poland to Israel in the early 1920s, as Zionists driven by the urge to participate in the establishment of a homeland for the Jews in their ancestral land so that Jews will have at least one place in the world to where they can flee whenever persecuted. I married my wife, Siona, in 1951. We have three children and six grandchildren.

Being a member of the underground HAGANA (defense) units since the age of 16, it was natural that when I graduated from high school, I joined the PALMACH (the Israeli underground fighting units) and fought in the War of Independence (1947–1948). In 1949, following a short period in a kibbutz, I started my studies of civil engineering at the Technion-Israel Institute of Technology, Haifa. In my senior year, I elected to graduate in the option of water resources, realizing that water—in fact, the scarcity of water—would, no doubt, be a central issue and a limiting factor in Israel's development. I liked the challenge. Also, by watching my professors, J. Breuer (water works) and S. Irmay (hydraulics) and their activities, I was convinced that this was an exciting field in which I'd be able to combine theory and practice. I liked that, too.

I received the B.Sc. (summa cum laude) in 1953, and the Dipl. Engenieur (equivalent to a P.E.) degree in 1954, both in civil engineering. I started to work as an engineer in the Planning Division of TAHAL-Water Planning for Israel Ltd., the government (now private) company in charge of water resources planning and development in Israel.

A couple years later, I was awarded a scholarship by the Dutch government and spent a year with the Government Institute for Water Supply in Scheveningen, Netherlands, studying ground water hydraulics, seawater intrusion, and the use of laboratory models as tools for solving ground water problems. My supervisor was Professor Krul of TUDelft. I learned a lot also from Mr. Santing, an excellent engineer and wonderful person.

One of the main models that I learned to use was the Hele-Shaw (parallel-plate) model (Figure 1). During the 1960s I used this model extensively to investigate seawater intrusion (in the vertical cross section) into layered coastal aquifers, under the sharp interface approximation. To remind you, this was before the era of computers when no other tool was available for solving regional ground water problems with a phreatic surface and/or a (assumed) sharp freshwater/seawater interface (Stefan problems). Within the framework of cooperation between the Delft Technological University and the Technion, I developed the Horizontal Hele-Shaw model that enabled investigations of seawater encroachment into (horizontal) regional coastal aquifers. For this research, I received my M.Sc. in civil engineering from the Technion in 1957.

Returning to Israel from the Netherlands, I started to work in ground water hydrology. In Israel, ground water, primarily from the coastal (sandstone) aquifer and the (limestone) mountain aquifer, constitutes the major source of water. However, the total available annual sustainable water yield is rather small, to the extent that it seriously

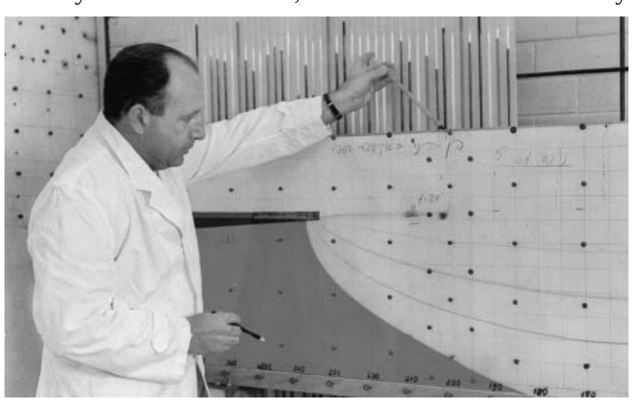

Figure 1. Investigations of seawater intrusion using a Hele-Shaw model, 1963.

[1]Jacob Bear, Professor Emeritus, Department of Civil and Environmental Engineering, Technion-Israel Institute of Technology, Haifa, 32000 Israel; 972-4-8292290; fax 972-4-8228898; cvrbear@tx.technion.ac.il; www.technion.ac.il/~cvrbear/; www.heath-hydrology.com/cmdl/.

constrains development. In addition, weather fluctuations are large, and several successive drought years are common. The problem of droughts is exacerbated by the lack of surface water storage capacity, due to the geological structure. Seawater intrusion, as a consequence of excessive pumping, has always been and still is one of the main issues that I had to deal with when returning to Israel.

As I have already mentioned, assuming a sharp interface, I used the Hele-Shaw model, or analog, to investigate this problem and provide forecasts for the extent of seawater intrusion as affected by pumping. However, field measurements showed that the approximation of a sharp interface, or narrow transition zone, was not always justified. How do we take into account the transition zone when modeling seawater intrusion? A literature survey indicated that the same problem of seawater intrusion was also investigated in California, where similar problems were encountered.

A scholarship from the Technion and from the Hebrew Technical Institute, New York, brought me to the University of California at Berkeley in 1958. There I spent the next two years under the supervision of Professor David K. Todd[2], investigating seawater intrusion into coastal aquifers without the assumption of a sharp interface. To understand how the transition zone develops, I had to investigate the spreading of a solute, referred to as "dispersion." At that time, I could already find some works on dispersion, or miscible displacement as it was called then. I would like especially to mention the works of P.G. Gerard de Josselin de Jong (1958) of TUDelft and Saffman (1959) in the United Kingdom. Professor Todd had a number of students before me, including M.N.E. Rifai and Steve Law, who also worked on miscible displacement. As part of my Ph.D. research, I developed the concept of dispersion as a second rank tensor and the dispersivity as a fourth rank tensor. These results (Bear 1961), which formed the basis for understanding mechanical dispersion and the role of diffusion, still serve as a basis for our work on hydrodynamic dispersion. I now had the tools for dealing with dispersion phenomena, as encountered in seawater intrusion and in artificial recharge of aquifers for storage purposes.

At UC Berkeley, I was lucky to meet Professor de Josselin de Jong, who spent a sabbatical there. I learned to love and admire him as a wonderful person, an excellent scientist (not only in his field of specialization, which is soil mechanics), and an excellent artist (painter). His insight into the physics of phenomena, and his ability to express them in simple words and in freehand sketches, also made him a first-class educator. We developed a friendship, which I cherish to this day. I dedicate this autobiography to him.

In 1960 I joined the academic staff of the Department of Civil Engineering at the Technion, teaching and conducting research in engineering hydrology and ground water hydrology, and later in modeling phenomena of transport in porous media. I was promoted to the rank of professor in 1970. Over the years, I served in a few administrative positions at the Technion, including vice president for academic affairs (1970–1976), director of the Neaman Institute for Advanced Studies in Science and Technology (1978–1981), dean of the graduate school (1983–1986), and dean of civil engineering (1995–1997). In 1980 I was appointment to the Albert and Anne Mansfield Chair in Water Resources, at the Technion. In 1997 I formally retired from the Technion.

Over the years, I have enjoyed the combination of teaching, research, and consulting, which has kept me involved with the practice. For 30 years, beginning in 1960, I served as a consultant on ground water to the Hydrological Service and to TAHAL, under the wonderful leadership of Eng. Aaron Wiener. Through numerous national projects and committees, I was deeply involved in the development of water resources in Israel, educating hydrologists and introducing scientific and modeling approaches to the practice. I gained a lot of practical experience, which I then incorporated in my lectures.

In the early 1960s I was involved in two large projects conducted by TAHAL, both sponsored by the Food and Agricultural Organization of the United Nations. One was on the management of the coastal aquifer, which enabled me to cooperate with Santing and de Josselin de Jong, in which we developed a methodology on how to manage a coastal aquifer while controlling the extent of seawater intrusion. The other was on artificial recharge and storage of water in phreatic aquifers.

In both projects, we could write models, whether with sharp interfaces or with a transition zone, but we could not solve these models. Numerical solutions and the use of computers in hydrology did not significantly arrive until the early 1970s. In the meantime, we used the Hele-Shaw model for seawater intrusion and the passive resistance capacitor (RC) electric analog to study regional flow in heterogeneous aquifers. I designed and ran for TAHAL at the Technion large Hele-Shaw models and RC-networks, which enabled us to forecast the behavior of aquifers under planned flow regimes. In the early 1970s we junked all the laboratory models and replaced them with computers and computer programs. With codes and computers, do we now have more fun?

Over the years, I was lucky to have a number of excellent Ph.D. students. I can mention (the now professor and well-known) Gedeon Dagan, who worked on interface problems using small perturbations theory. For a while we experimented with the hodograph method as a tool for solving sharp interface problems (de Josselin de Jong developed a multi-layered hodograph), but we soon reached the conclusion that this approach is very limited and the amount of required mathematics makes it very impractical. I'll also mention Dr. Yehuda Bachmat (with whom I worked on a general theory of macroscopization by averaging over an REV), Professor Carol Braester (who worked on multiphase flow in fractured rocks, and became a world-known expert on this subject), Dr. Brian Berkowitz (transport in fractured rocks), Dr. Fuli Wang (now in Christchurch, New Zealand), Dr. Yunwei Sun (at Lawrence Livermore National Laboratory, who worked on optimization of the pump-treat-inject technique), and Dr. Quanlin Zhou (now at Lawrence Berkeley National Laboratory, who worked on modeling flow and solute transport with density effects). I could mention others, but I'll mention here only one more, the late Dr. Oded Levin (who fell in the defense of his country in 1969), who worked on optimal management of an aquifer—combining ground water hydrology with optimization theory.

In 1964 I was approached by UNESCO to write a 100-page manuscript on the physical principles of percolation and seepage, as part of their Arid Zone Research Series. Together with two colleagues, Professors S. Irmay and D. Zaslavsky, in 1968 I completed a comprehensive 465-page volume. As I continued to work on ground water flow, drainage, contamination of aquifers, modeling migration in oil reservoirs, and similar subjects, I realized that all these engineering disciplines are actually applications based on a single fundamental theory that deals with phenomena of transport (movement, accumulation, and transformation) of extensive quantities (such as mass, mass of chemical components, momentum, and energy) in the special domains referred to as porous media. I started to write and lecture on this unified approach.

In 1967 I established a section of flow through porous media within the framework of the International Association for Hydraulic Research, and served as its chairman for four years. In 1969 I convened the First International Symposium on the Fundamentals of Transport Phenomena in Porous Media. It brought together professionals and scientists from many disciplines, all working in and making use of the same fundamental theory. A second conference with the same objectives was convened a few years later in Guelph, Ontario.

These ideas brought me to write the book *Dynamics of Fluids in Porous Media* (Bear 1972). In it I presented a unified approach and a theory that is applicable to many disciplines, starting from the definition of a porous medium. Obviously, the volume contained a comprehensive chapter on the use of laboratory models, but it also presented, among other topics, the concept of an REV, which I started to promote in papers published since the mid-1960s, a systematic approach to two phase flow, and the theory of dispersion and solute transport. The emphasis in this book was not only on the description of phenomena, but also on the use of well-posed mathematical models as a tool for describing the phenomena of transport in porous media, and for forecasting their behavior in response to excitations. The computers and computer programs that started to appear provided the solution tools that made such models practical tools and not merely scientific exercises. I was glad to note that the book was very well accepted and, in fact, even today, 30 years later, is still considered as "the Bible of Hydrological Sciences . . . heavily referenced by both academics and consultants" (*Eos*, November 26, 2002). By the way, the book was translated into Chinese; in China, it is used as a major text on ground water.

The ideas of a unified fundamental theory underlying the description and modeling (also a term that gradually entered our vocabulary in those days) of phenomena of transport in porous media, with applications in many disciplines, led me in 1985 to establish the journal *Transport in Porous Media*, aimed at bringing scientists and professionals from many disciplines under the same roof. I have served as its editor since then.

In 1979 *Hydraulics of Groundwater* (Bear 1979) was published, in which I tried to bring the comprehensive approach and mathematical modeling of flow and contaminant transport to the field of ground water hydrology. I wrote this book because I was convinced that mathematical models were a tool that should be available to and used by ground water consultants and professionals, and not only by scientists and special experts. The book contained a chapter on flow in the unsaturated zone (usually treated by soil physicists), which I realized was going to play an important role in modeling subsurface contamination originating at ground surface, and a chapter on ground water management in which the flow and transport models serve as constraints.

I coauthored *Modeling Groundwater Flow and Pollution* (Bear and Verruijt 1987), combining the same approach with the presentation of a simple computer code that enabled every student to actually solve problems of practical interest. I also coauthored *Introduction to Modeling of Transport Phenomena Porous Media* (Bear and Bachmat 1990), a comprehensive, unified approach to modeling phenomena of transport in porous media, from the microscopic to the averaged continuum level. Nowadays, models are accepted as fundamental tools in practice, but not long ago the question of whether models should legitimately be used as a prediction tool was still being debated. (e.g., the International Ground Water Modeling Center was established in 1987 to promote the use of models. For some years, I served on its International Technical Advisory Committee.)

Over the years, I observed how the emphasis in ground water investigations (in both research and practice) has been shifting from flow in aquifers, including evaluation of aquifer yield, estimating aquifer properties, and hydraulics of wells, to the current emphasis on contamination (and remediation) of the subsurface. My own work, under the heading of flow and (contaminant) transport in porous media, has been shifting in the same manner. In fact, dealing with contamination of the subsurface requires the modeling of flow and transport phenomena in both single and multiphase flow, with source terms (in the mass-balance equations) that represent homogeneous and heterogeneous reactions. In fact, since 1990 I've had the chance to work on these subjects, in connection with cleanup operations, with a wonderful, experienced, and knowledgeable team at Lawrence Livermore National Laboratory (LLNL)—for which I am thankful to Fred Hoffman of LLNL, and to Richard Weiss of Weiss Associates.

More recently, working with my Ph.D. student Quanlin Zhou and former Ph.D. student Bensabat, I completed the route, which I started in my own Ph.D., to solve seawater intrusion problems in three-dimensional heterogeneous domains, taking into account dispersion and density effects. I recently had the opportunity to participate in the construction of a comprehensive flow and transport model for the coastal aquifer in Israel. Still missing (or does it exist already?) is a practical solution to the problem of optimal management of a coastal aquifer, in which the variable density model has to be satisfied as a constraint.

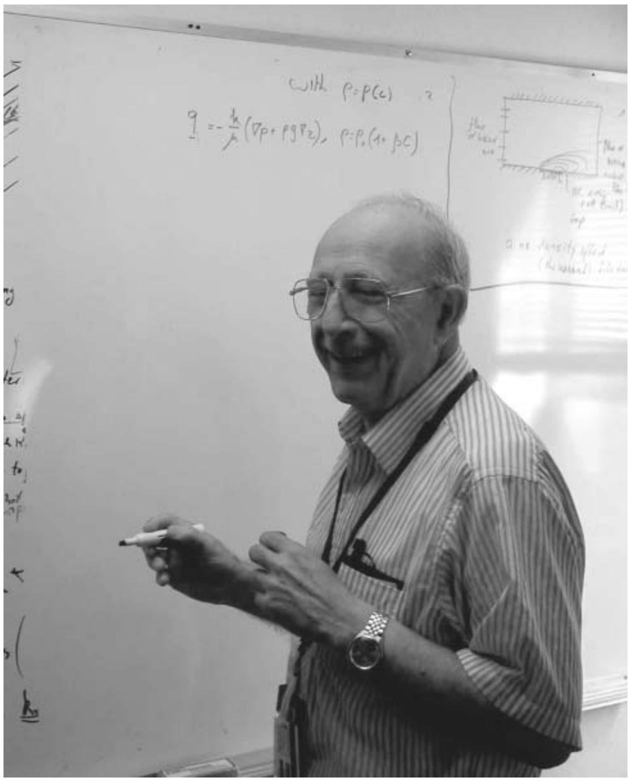

Figure 2. Lecturing at Lawrence Livermore National Laboratory, 2001.

In 1978 I was awarded an honorary doctorate in technological sciences by Delft University, Netherlands. In 1980 I was appointed as the Albert and Anne Mansfield Chair in Water Resources at the Technion. In 1988 I was awarded an honorary doctorate in technological sciences by E.T.H. Zurich, Switzerland, and was elected Fellow of the American Geophysical Union. In 1998 I was awarded the Rothschild Prize in Engineering in Israel.

I have always enjoyed teaching and educating (not a sin, I hope, for a professor) the new generation of hydrologists (Figure 2). I had the opportunity to teach at many universities during sabbaticals. I also have offered (and still do) many short courses for professionals (hydrologists and modelers) at many universities and institutes around the world, presenting the mathematical models of flow and contaminant transport in the subsurface, and emphasizing the importance of selecting the correct conceptual models. In recent years I have become enthusiastic about distance learning through the Internet as an important educational tool for students and active professionals. I am trying to promote this technology and am offering courses via the Internet, trying to pass my experience on to others, especially the younger generation, in an effort to improve our work in this important area.

This is it for now. For me, working in the area of ground water, and in the more general field of modeling phenomena of transport in porous media, has been and still is exciting and rewarding. It is a field that requires teamwork—the cooperation of geologists, hydrologists, chemical engineers, and biologists, to mention but a few. It is certainly a field in which one can contribute significantly to society and the quality of life. To be a good practitioner in this field, one should be able to understand and use models correctly. I have tried to contribute to this exciting field.

**Editor's note:** For an autobiography of David K. Todd, see *Ground Water*, November–December 2001 issue, v. 39, no. 6: 673–675.

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