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The evolving world of soil physics

Rien van Genuchten

This short essay is about the discipline of soil physics, how I became part of it, and where I think we are heading. First, let us look at the term "Soil Physics", which has been defined in different ways. One standard (but circular) definition refers to soil physics as the application of physical principles to soils, while others suggest that soil physics should refer to the state and transport of matter and energy in soils (e.g., Hillel, 1971). Whatever the exact definition, different topics have been associated with soil physics, starting with the early view that soil physics is an inherent part of the agricultural curriculum with a focus on both laboratory and especially practical field-scale applications. This would include soil textural analysis, soil density and permeability measurements, water retention, and horizontal or vertical water flow (including capillary rise). This early focus certainly is understandable since soil management, crop production and irrigation were the initial themes when agricultural operations started several thousand years ago. Excellent overviews of early soil physics from the 18th century and later are by Philip (1974) and Swartzendruber (1977). While the initial focus was on agricultural issues, starting in the 1960s and 70s the focus broadened increasingly to more environmental issues involving protection of our soil and water resources and global climate. This included then also more emphasis on the physics part of "soil physics", leading to more fundamental descriptions of soil as a living porous medium in which water, heat and solutes operate, with or without vegetation (e.g., Sposito, 1986; Raats, 2001; Raats and van Genuchten, 2006). Several textbooks at that time very much influenced my work, the most important being books by Kirkham and Powers (1972), Nielsen et al. (1972), and Taylor and Ashcroft (1972).

My own involvement with soil physics started in the late 1960s when I attended Wageningen University in the Netherlands to study irrigation and drainage, leading to a MS research report on drip irrigation (van Genuchten, 1971). I remember being very proud about that report and still refuse to delete it from my publication list, even though I do not have a copy anymore. The report documented some drip (trickle) irrigation experiments carried our using a fine- and a coarse-textured soil, along with analyses of the developing moisture distributions using analytical solutions of the Richards equation as derived by Philip. Not sure what to do next, I went to Las Cruces, New Mexico, where Peter Wierenga convinced me to do a PhD with him in soil physics. There I learned about chloride, pesticide, boron and pesticide transport processes in laboratory soil columns, and how physical (e.g., aggregation) and chemical (e.g., kinetic sorption) nonequilibrium processes affect observed breakthrough curves. The PhD work resulted in several papers published in SSSAJ, the leading soil physics outlet at the time (e.g., van Genuchten and Wierenga, 1976; van Genuchten et al., 1977).

After graduating in 1975, I spent 3 years as a postdoc with George Pinder at Princeton University looking at finite element solutions of the Richards equation using Hermitian (smooth cubic) finite element basis functions. There I initially struggled with the numerical solutions when using Brooks and Corey (1964) type formulations of the unsaturated soil hydraulic functions, which were not first-order continuous at the air entry value. This caused me to look at alternative formulations, leading to a Princeton research report (van Genuchten, 1978). I thought that that report was the end of it. But I had shared a card-deck copy of the optimization program (SOHYP) I used for this work with several, including Jacob Dane which was impressed and urged me to publish a paper about it. I initially hesitated, but finally submitted a paper to SSSAJ in 1980 when I had accepted a position at the U.S. Salinity Laboratory in Riverside, California. The paper was returned by SSSAJ for major revisions: they told me the material was marginal, and that even the title was not original. I nearly gave up, but in the end still revised things and resubmitted. The resulting paper (van Genuchten, 1980) became very popular later on, and very much changed my career; I became the presumed expert about multiphase soil hydraulic properties, Pc-S curves, residual water contents, pore-size distribution models, and so-on (which I never felt relative to the

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Department of Earth Sciences, Utrecht University, Utrecht, Netherlands.
Department of Nuclear Engineering, Federal University of Rio de Janeiro, Brazil.

pesticide transport work I did for my PhD). In any case, the hydraulic functions are now used in many unsaturated flow studies, in environmental and global climate research, in studies about fuel cells, fabrics, bio-membranes, ink infiltration processes, and other studies, gathering some 30,000 citations or more at present. My goodness!!

I am reflecting on all this in that one never knows (at least I did not) how well one's research may fit into the broader picture. In that sense soil physics has changed tremendously the last 30 or 40 years. Change has come in several aspects, especially the need to address environmental challenges, soil and groundwater pollution, the lack of fresh water, soil salinization, climate change, and many other issues. Contaminants include a range of agricultural and industrial pollutants, pollutants generated by mining and milling operations (including radioactive materials), viruses and bacteria, and a suite of emerging chemicals (pharmaceuticals, disinfection byproducts, nanomaterials, microplastics, PFAS, personal care products, microplastics, and more). This has caused soil physicists to focus on a much broader array of problems than the narrow field of "soil physics". The soil physics field certainly has become much more multidisciplinary. Moreover, research includes now spatial scales covering molecular scales, pore scales, core scales, plot scales, field scales, regional scales and even global scales. I have certainly seen this in my own activities. In that sense I am not sure anymore if I should call myself a soil physicist, a soil scientist, a soil hydrologist, an agricultural or civil engineer, or maybe just a hydrologist.

Publications by soil physicists now also appear in a much broader set of outlets, changing from mostly soil science journals (e.g., SSSAJ, Soil Science) to journals organized by other societies (AGU, GSA, EGU, ASCE, ACS, ···), and journals operated independently by such publication companies as Elsevier and Wiley, including to me far too many new open-access journals outside the publication mainstream. The number of papers now being published is truly astonishing, and to me nearly depressive. So many papers are now being published each year that you must be a full-time reader of thousands of papers in hundreds of journals, or you have to limit yourself to only a few and concentrate on doing your work and writing it up. It seems that one cannot be both (reader and writer). In that sense everything is accelerating, the bad versus the good: the environmental problems this planet faces, versus the number of scientists that work on the problems, their creativity and their enormous output. Still, one thing that worries me is the stress that all this causes on especially young scientist in the academic world. When I started my career, one good peer-reviewed publication per year was thought to be sufficient in many places. Now researchers are expected to have several (three, four, five, ...) papers to be published in high-impact journals, with the publications needing to have many citations. Beginning academicians are at the same time often pressured to submit research proposals and have them approved. This even though the success rate at present is often less than 25 %, while the proposal sometimes also needs to include enormous overhead costs. Additionally, beginning scientists often are expected to serve as editor or associate editor of one or more journals, serve on a range of internal and/or external committees, and show activities across disciplinary, cultural and socio-economic boundaries (with which I actually agree), all this often at a time in their life when many start a new family. Clearly the pressure to perform must be overwhelming.

Because our planet is faced with so many environmental problems, which area is best to address in one's research? I regularly get questions about this: what topics should I study to have impact; where to begin? My answer is simple: Do the things you enjoy most, albeit of course within the structural boundaries of your department of employer. And interact with your friends and colleagues that pursue the same topics and possible solutions. In this sense I was extremely fortunate in that I could work nearly always on the conceptual-mathematical part of things, with lots of help from others. I enjoyed things so much that there was no difference for me in working and studying a particular topic at work, or playing with the problems at home on my free time. There were no boundaries in this. For example, I could work on analytical solutions, alone or with my friends and colleagues (e.g., Leij and van Genuchten, 2002; Toride et al., 1999; van Genuchten and Wagenet, 1989; van Genuchten et al., 2012, 2013), or do the same for numerical solutions addressing variably-saturated flow and contaminant or heat transport problems (van Genuchten et al., 1977; Šimůnek et al., 2008, 2009, 2016), The latter included documentation of the codes into user-friendly software, notably the RETC, STANMOD and HYDRUS codes (https://www.pc-progress.com/en/Default.aspx).

Looking back now on these publications, it may seem to have all been relatively straightforward; but they were not! Last month I scanned through some of my old notes on deriving the analytical solutions. I would not have the patience anymore to do this again. For example, some of the solutions contained unusual functions, such as complementary error (erfc) functions with complex arguments (van Genuchten, 1985) or modified Bessel (K_0, I_0, K_1, etc.) and Kelvin (Ber, Bei, Ker, Kei, etc) functions (van Genuchten et al., 1984). I remember needing a lot of time and patience to mathematically verify and program those functions correctly. This since I noticed that several standard textbooks at the time, such as the popular text by Abramowitz and Stegun (1970) I often used, sometimes contained small errors or misprints. Lots of patience and persistence were indeed needed to derive the solutions and associated computer programs. But then, patience and resilience are generally needed with any research project, whether mathematically as I always enjoyed, or experimentally, or otherwise.

To conclude, I want to thank the many giants in the field with who I could work and interact over the years. My ultimate advice to beginning scientists and engineers: Do the research you enjoy most within the confines of your assignment as a student or scientist in your department, or as a professional at work, collaborate as much as possible with others, and freely share your work if possible. But if you do not enjoy your work, give it up and change to another path in life.

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(Most of our papers can be downloaded from the personal pages on the HYDRUS website, http://www.pc-progress.com/en/Default.aspx?rien-van-genuchten)