Evolution of Urban Water Systems Analysis[1]

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DOI: 10.1061/(ASCE)WR.1943-5452.0000400

First, thanks to Wayne Huber for his generous introduction. Much of what I have been able to accomplish since 1968 has been due to our collaboration on a variety of water resources methods and applications to significant urban water problems including national assessments of combined and sanitary sewer overflows in the United States and Canada, restoration of the Kissimmee River and the Everglades, and national studies of the potential of low impact development for urban storm water systems. Second, I am honored to join the distinguished group of Julian Hinds Award winners who have made major advances in the water resources field. Ironically, my interest in rational optimization methods to inform decision making runs counter to my personal experience of a series of serendipitous events that have resulted in major opportunities. My interest in civil engineering was nurtured by personal experience growing up on the west side of Chicago adjacent to the Eisenhower Expressway that was under construction during most of my childhood years. I witnessed several major changes in my neighborhood including moving houses out of the right of way, and sophisticated construction techniques to fit an expressway and mass transit railroad into a narrow right of way. The "Ike" was finished when I was a senior in high school, and transformed my neighborhood into a traffic congested area with high levels of noise and air pollution.

I learned of a co-op scholarship opportunity with the Metropolitan Sanitary District of Greater Chicago (MSDGC) to study civil engineering at Illinois Institute of Technology through my little league baseball coach a few weeks before the beginning of classes. Without this scholarship, I would have been unable to attend college. MSDGC is a national and international leader in wastewater and storm water management and their co-op program provided invaluable experience in several aspects of sanitary and civil engineering. My co-op experience in sanitary engineering helped me get selected to satisfy my military obligation as a U.S. Public Health Service (PHS) officer studying salinity problems on the Colorado River Basin. This work introduced me to the major water issues of the western United States and their link to economic development with irrigated agriculture being the predominant water user. However, our progress was slow because we had to rely on slide rules and simple calculators.

My wife and I missed our families and decided to return to Chicago with our two young children after fulfilling my two-year service obligation in the summer of 1964. Fortunately, the PHS offered graduate traineeships in water pollution control, and I was selected to attend Northwestern University for a one-year master's degree program. My introduction to water resource systems came from Professor Bob Gemmell, a recent Harvard graduate who had participated in the seminal Harvard water program. Shortly before finishing my master's degree, Professor Gemmell asked me if I was interested in staying at Northwestern to pursue a Ph.D. As a father with two small children, I had not considered this option. My wife generously agreed to my continuing graduate school. By then, I was familiar with the doctoral work of Walter Lynn on optimizing wastewater treatment plants, and Rolf Deininger on regional water quality management. Both of them studied with Professor Abe Charnes, an applied mathematician and a pioneer in optimization methods whose major theoretical advances came from solving real problems. I took both of Professor Charnes' courses and he agreed to be a member of my Ph.D. committee. This was the beginning of a close relationship that lasted many years. Professor Charnes had a gift of convincing his students that they knew more than they thought. This kept us working hard to live up to our undeserved reputations. The major intellectual breakthrough in my research was seeing the relationship between the dual variables of linear programs and economic theory. For my research, this link provided the marginal value of water in the Colorado River Basin, which turned out to be quite small due to the prevalence of low valued irrigation. In order to supplement my income during graduate school, I worked part time for the American Public Works Association (APWA) on a study of the nature of storm water runoff pollution in Chicago. This study included modeling and field sampling of the nature of urban runoff.

I joined the faculty of the Department of Environmental Engineering Sciences at the University of Florida in the fall of 1968. Wayne Huber had arrived two months earlier. EPA's predecessor was interested in developing a computer simulation model to evaluate overflows from combined and separate sewers. Drawing on my experience with APWA, Wayne and I wrote a proposal to develop such a model. Our proposal was combined with two other proposals to develop the Storm Water Management Model (SWMM) that was released in 1971. Our development group and the sponsor favored an open source model to allow freer exchange of ideas and the ability of users to inspect the code. This open source approach has been a vital element in sustaining EPA SWMM for the past 42 years and continuing to nurture its refinement. I would like to think that our national assessments for U.S. EPA done in the mid-1970s using a combination of optimization and simulation with SWMM had a positive impact in convincing the federal government of the importance of initiating urban storm water pollution control programs rather than committing their resources exclusively to building advanced waste treatment plants for dry-weather flows.

Thanks to insights provided by Professor Charnes, I took an early interest in cooperative n person game theory to address equity issues associated with water resources problems. The optimal solutions to problems often have very undesirable equity characteristics, e.g., group 1 receives the bulk of the benefits whereas group 2 pays the bulk of the costs. A major benefit from using game theory is that it forced us to explicitly consider the winners and losers associated with various scenarios. It also made it evident that some games will be inherently competitive depending upon key initial assumptions regarding ownership of common resources.

Overall, the 1960s and 1970s can be viewed as the golden days of water resources systems analysis. Mainframe computers opened up a new world of powerful analytical tools that forever changed how we address problems. Federal support for major interdisciplinary initiatives reached all-time highs with a variety of major research initiatives, e.g., NSF's Research Applied to

[1]This lecture was given by James Heaney after receiving the 2012 Julian Hinds Award.

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the Nation's Needs (RANN), major public works initiatives (e.g., EPA's wastewater treatment program that affected virtually major city in the United States), superb support for graduate students, and the dawn of the environmental protection era beginning with Earth Day in 1970.

The major technological advance of the early 1980s was the introduction of personal computers and much friendlier software. The IBM PC was released in August 1981 and the Lotus 1-2-3 spreadsheet followed shortly thereafter in January 1983. Fortuitously, I was on sabbatical in AY 1982–83 and immediately turned my attention to using spreadsheets on microcomputers as an option to the still unwieldy mainframe computers. I reworked my graduate class in water resources systems analysis to use spreadsheets. I proudly presented this new software to the class in fall 1983 with a step-by-step lecture on how to solve a problem using the spreadsheet. Then, I assigned a problem to be solved using my step-by-step approach. Somewhat to my chagrin, none of the six students followed my instructions but all of them got the correct answer using a variety of procedures that matched their personal learning styles. Then I realized the power of this new tool in not forcing students to follow a specific algorithm. PCs provided the basis for many innovations in teaching, research, and outreach that will continue indefinitely. One potential negative effect is that current student thinking is perhaps too unstructured.

Two major research themes dominated my time at the University of Colorado from 1991 to 2003: (1) data-driven methodology for forecasting urban water demand and conservation effectiveness; and (2) decentralized urban storm water systems for the 21st century. The catalyst for revisiting the urban water demand problem was the need to quantify the water savings associated with conservation best management practices. Our initial efforts using aggregate regression and time series analysis were unsuccessful. This led us to embark on a bottom-up approach to evaluating parcel level water use for selected single family residences using 10-second data and software to convert this data into individual water using events. The success of this initial effort led to funding from AWWA Research Foundation for a national study of 1,200 homes in 12 cities that has provided the foundation for reliable estimates of indoor and outdoor water use. In the late 1990s, Wayne Huber (then at Oregon State University) and I received funding to develop innovative approaches to deal with urban storm water. One emerging trend was to use decentralized systems with an emphasis on infiltration on site or in the surrounding environs. Such approaches came to be called low impact development (LID). This effort showed the need to jointly evaluate outdoor water demand and storm water runoff control using infiltration since they are competing objectives.

In 2003, I accepted an offer from the University of Florida to "return home" as Chair of the Department of Environmental Engineering Sciences. Florida experienced serious droughts in 1991–2001 and had set up a statewide committee to develop a plan to devise quantitative water conservation programs and plans. An important part of this program was the establishment of the Conserve Florida Water Clearinghouse. Our success in Colorado with bottom-up water demand management helped my group get selected to host this clearinghouse beginning in 2006. Florida mandates government in the sunshine that allows public access to water and demographic data. The five water management districts and several state agencies had been developing this essential data so it became feasible to attribute GIS data for every one of Florida's 9 million land parcels grouped into 64 land use categories. Similarly, monthly water production data are available for every water utility in the state from 1999 to the present. We compiled this data into our clearinghouse database. Also, we initiated benchmark studies with select utilities wherein customer monthly billing data were linked with the parcel attribute data. These benchmark studies provided the basis for estimating end use water demand coefficients for the 64 land use sectors. Water conservation models need to include water audit information to estimate unaccounted for water and site-specific information on water reuse and private wells. A key element in our analysis is to calibrate water use analysis for the entire utility for a recent year in order to explain how the water is being used and the expected impact of conservation BMPs. Finally, the evaluation model needs to look at cost effectiveness and prioritize investments. The resulting online model, called EZ Guide, is available for use by any Florida utility. The bottom-up methodology uses concepts from production economics and simple optimization techniques to find the optimal mix of end uses for a given utility as viewed from various perspectives. Working in such data-rich environments requires a paradigm shift for the research community to more fully recognize the value of data-driven research that focuses on bottom-up evaluations that better predict the behavior of the customer-specific attributes and historically observed water use behavior rather than simple top-down generalizations that have limited value for prioritizing demand management programs.

In closing, I want to once again thank the many members of ASCE that have inspired me over the years for this honor. A special thanks to my students, children, and grandchildren who have taught me more than they will ever know by providing new perspectives on life. Most importantly, serendipity blessed me many years ago when I met my wife Diane. We celebrated our 50th anniversary in August 2012.

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