PARADIGM CHALLENGE: INTEGRATING FRESHWATER RESEARCH AND EDUCATION

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Water resources decision makers face constant challenges and frustrations in satisfying their societal constituencies while making wise decisions in the face of a variety of uncertainties. Environmental imperatives are among the most difficult of these challenges, incorporating as they do elements of human health and safety, resource availability and distribution, intergenerational equity, intercultural justice, and sanctions on ecological systems. These decision makers must simultaneously balance risk and valuation in many dimensions and across an array of spatial and temporal scales. How they do this —and how well they do this— are the subjects of many scholarly and popular publications. I will not review these here. My concern is with the scientists and engineers whose inspiration, analyses, syntheses and hard work help to reduce uncertainties and enable more informed decisions. These researchers are, in my opinion, investors in the decision matrix. How can their investment be maximized? This essay proposes that one way is through the integration of research and education.

I am employed by the National Science Foundation (NSF), a $3.2B federal agency which is well-known for funding research. Less well-known perhaps, is NSF's support for education and human resources. The NSF has identified the *integration of research and education* as one of its strategic objectives, and many of us have given a lot of thought to what this might mean. From my perspective there are very natural connections between research and education because both are focused on enlightenment, discovery and understanding. Both also must embrace the concepts of knowledge as a mountain — requiring the mastery of facts; and as a stream — requiring problem-solving skills.

Water resources concerns are a crucible of thorny issues. The distribution of water on earth is not even: Less than 3% is fresh water, and the majority of that is tied up in ice caps and glaciers. Ground water represents the bulk of the remainder, with lakes and soil moisture representing a smaller volume. The water in the atmosphere, rivers, and biota is a tiny fraction of the water on the planet. I think that there are three overarching — and somewhat overlapping — freshwater issues. These are 1) water availability, involving the quantity, location and timing of water supplies and demands, 2) human health and safety, involving effects of flooding, waterborne disease and water quality, and 3) aquatic ecosystem integrity, involving threats to ecosystem functions, biological diversity and habitat including exotic species, dams and diversions, and pollution.

The water availability issue is defined on the human end by water withdrawals and consumption. Withdrawals are concentrated near population centers and agricultural regions and are greatest where irrigated agriculture is pursued in arid lands. More than three-quarters of the withdrawals in the United States are from surface water and less than one-third of this water is dedicated to consumptive use. Worldwide, water withdrawals have grown more than five-fold over the last century. By far the majority user is agriculture, with industry, and municipal supply smaller fractions of the total (Shiklomanov 1993). Irrigated agriculture is tremendously important, accounting for 16% of the cropland that is irrigated globally but much higher percentages in some countries than others. There are large regions in the United States where the water availability issue is at the center of virtually all planning and development decisions.

The human health and safety issue is hugely important economically. The loss of life and property due to flooding this year and in the recent past have driven home the power of water to disrupt lives. But when most people think of health and safety they are thinking about disease. Gastroenteritis was the third-leading cause of death in the United States in 1900. It is no longer on the "top-ten" list due to medical advances and water treatment. Water-related infections are by no means insignificant globally: ~250 million new cases are reported annually, 10 million of which result in death. The outbreak of Cryptosporidiosis in Milwaukee a few years ago was a chilling reminder of the vulnerability of even advanced water supply systems to pathogenic organisms under certain conditions. Water quality concerns are another part of the human health issue: For organics alone, ~100,000 synthetic compounds are currently in use, all of which have different solubilities, different derivatives and different persistence (Nash 1993). These are derived from virtually every human activity, from decaffeination of coffee to dry cleaning to fossil fuel combustion to the production of plastics and explosives.

The aquatic ecosystem integrity issue is based on the idea that rivers, lakes, wetlands and aquifers are more than just bodies of water. They provide essential goods and services, including self-purification, flood control, aesthetic and recreational opportunities, fish and waterfowl habitat and many more. The web of life in these systems is intricately connected to the physical environment, just as each aquatic system is part of the catchment or watershed surrounding it. I have been involved for several years in the NSF/EPA Water and Watersheds research grants competition, aimed at research that takes a systems approach to watershed ecosystems, including the physical and human dimensions of these issues. The many forcing factors that affect aquatic ecosystem integrity include habitat loss due to sedimentation, dams and diversions, introduction of exotic species, overfishing, and water pollution. According to the U.S. EPA, about 40% of the Nation's surveyed rivers, lakes, and estuaries are not clean enough to meet basic uses such as fishing and swimming. The leading sources of pollution are: agriculture, municipal sewage treatment plants, hydrologic/habitat modification, urban runoff, resource extraction, and nonpoint sources (U.S. EPA 1997). Water quality effects on aquatic ecosystem integrity cannot be blamed on villainous big polluters: it is not an "us versus them" issue, it is an "us" issue.

Let me summarize by saying that water resources education is enormously important because we have these big, interconnected issues and we need the finest professionals in order to deal with the problems that we know about now as well as the problems that will undoubtedly emerge over the next decades. But in my opinion, to maximize the translation of today's research findings into judicious decisions tomorrow, the education of future water resources professionals must be integrated with the finest research now underway.

Now I would like to step back from water for a bit and address the question from a slightly different perspective. The issues of water are really only a piece of a larger issue that many people are grappling with: Sustainability. How do we meet the needs of the present generation without compromising the ability of future generations to meet their own needs?

The sustainability issue is a direct byproduct of the human population issue. For most of the time humans have been on the planet the population has been $\leq$ 1 billion. We have, in less than a century, increased to nearly 6 billion. Some projections indicate that the human population will crest sometime in the next century at about 10 billion, at which time half of the people will live in urban centers like the ones lighting up this nighttime view of the planet. That alone is significant to water resources issues because urban water needs come with a great deal of political clout.

There are also what might be called external forcing factors that can affect sustainability. Climate is one. At the end of the last ice age 11,000 years ago, a massive ice sheet covered much of Canada and the northern tier states in the East and Midwest. A lot more real estate was available in Florida because the sea level was down. Only 5°C of global warming later, the present ice cap has retreated far into the Arctic. There is scientific consensus that humans are changing the atmospheric composition in a way that might lead to climate warming. The timing and magnitude are not yet certain, but the issue is worth attention because of the potential for profoundly significant consequences. The kinds of effects that climate change will have on water resources will be familiar ones: droughts, storms, floods, disease, exotic invasions, biotic impoverishment. Where, when and in what combination these will emerge are the real unknowns.

The point I would like to make is that in the context of these large issues, freshwater research and education is important to everyone, not just future water resources professionals. There are a couple of problems that I would like to speculate about and perhaps give you some food for thought at the symposium here. The first is what might be called the "Nerd Herd" problem. As Gregory Van der Vink[2] so eloquently put it, you have the scientifically illiterate vs. the politically clueless. According to Van der Vink, bright students do not see science as a way to reach positions of leadership, and science suffers because those in leadership positions have little experience with science. In my opinion, unless and until technically knowledgeable experts fully infiltrate the ranks of political and institutional leadership, the education of *everyone* regarding environmental concerns such as water resources will continue to be critical.

While I am on the subject of leadership I would like to return briefly to the issue of decision making that I mentioned earlier. Figure 1 shows what might be some of the drivers and limits of decision making superimposed on an amoeba. If you have seen an amoeba moving under a microscope you know that it sends forth several pseudopods and then gradually oozes in the direction of one of them, drawing its body up behind it. An amoeba can only follow one pseudopod at a time. This might be a model for environmental decision making where the different drivers and limits help to direct which pseudopod is followed and which ones are drawn up behind. The drivers and limits include politics, where perceived crises and risks point the way; public concern and stakeholder values; technological capabilities; budgets and, usually a relatively small part of the mix: scientific uncertainty. An excellent reference which greatly influenced my thinking on this subject is Barnaby (1995).

A second problem that you might think about is what I call the Rodney Dangerfield problem. This is speculative. The problem in my view is that until relatively recently, environmental issues seem to have had a difficult time competing for stage time compared with other global issues. In thinking about this problem I have come across lots of possible explanations, and I am still open to the possibility that my perception might have been flawed and there never was any such problem! But consider the juxtaposition advanced by Nelson (1997): The dualisms influencing the western conception of the order of the world are presented as man/woman, reason/emotion, culture/nature, mind/body, and so on. The fact that we refer to nature as Mother Nature is no accident. Could our social system be wired to respect "culture" above "nature" just as it seems to value "reason" over "emotion"?

Whether or not the Rodney Dangerfield problem is a problem, it is imperative that educators present an unbiased and balanced view of the issues. Water resources, climate change, biodiversity loss, pollution, technology, population, lifestyle: All are potentially volatile because of their implications for socioeconomic disruption. Scientists and engineers must recognize that decisions are made regardless of whether scientific consensus has ripened. Decisions are made based on beliefs and values and the facts that seem to be at hand — including economic ones. Education, integrated with research, is the only framework I know of that has and will continue to provide a sound underpinning for the decision making process. The credibility of the educational effort is therefore critical. Credible education is not lobbying, it is not politically reactive, and it is non-partisan.

An educated citizenry is less likely to fall prey to what might be called sound-bite channelization. You are familiar with the appearance of a braided river: all of the channels carry some water, there is a lot of wood around, the system is a complex set of interacting parts. That is how real-world environmental issues are. When complex issues are reduced to simplistic phrases or sound bites, it is as though you channelized the river. Much information and many options are lost.

The final context point that I want to make has to do with demographics, economics and power. According to Dent (1994), all human generations go through predictable patterns of innovation, spending, and power. The influence of a generation is in direct proportion to its size. The Baby Boom generation, born mostly in the 1950s and 1960s, is the largest generation in the history of the U.S. As a generation enters early adulthood (age 19 or so), it spawns innovations in technology, social values, lifestyles etc. When the generation grows a little older, the people tend to get married, buy a car, buy a house, buy furnishings and appliances, have children, buy a bigger car, buy a bigger house, put the children through college, and so on until the kids are off the parental dole. The peak spending usually occurs when the generation is in its mid 40s. As the generation matures it no longer spends as much: the parents may move into a smaller home and start actively saving for retirement. But this is the beginning of what Dent calls the Power Wave: When the generation passes the Spending Wave it begins to control investments and corporate and political power, which it uses to change organizations and institutions.

The importance of this to freshwater research and education is that in the next century we will likely see two large power waves beyond the Baby Boom power wave as the children and grandchildren of the Boomers mature. Although re-tooling is always a possibility, and public outreach is always desirable, the bottom line is that the people entering the Baby Boomer power wave have pretty much had their education: Their lifestyle, technology and values innovations are already in the hopper and they are in the midst of an enormous spending wave. Innovations and spending are both influential, of course, but it is the power wave where education will be exhibited and applied with the greatest leverage.

The 21st century world will be full of exciting ideas and an immense diversity of talent and capability. Cognitive revolution, defense reinvestment, shared wealth, infrastructure renewal, global competition, data explosion, environmental crises: These terms will be replaced with other terms, and perhaps newer concepts, in the next decades. I have often said that I think information is data that has been synthesized and communicated, and that knowledge is information that has been embedded into someone's brain or the collective intelligence of a people. Wisdom tempers knowledge with experience. We need wisdom. That is the challenge, the opportunity, and the importance of integrating freshwater research and education for the next century.

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ENDNOTES

1 The opinions in this paper are those of the author alone and do not necessarily represent the positions of the National Science Foundation.

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BIOGRAPHICAL SKETCH

Penny Firth is a bureaucrat who evolved from a swamp ecologist. After coming to the National Science Foundation in 1991, she served as the executive secretary of the interagency Committee on Earth and Environmental Sciences before becoming involved in several NSF programs and cross-agency activities. She was one of the architects of the NSF/EPA partnership for environmental research and has managed the NSF/EPA Water and Watersheds competition since its inception in 1995. Dr. Firth is presently a Program Officer in the Environmental Biology

Figure 1. Drivers and limits of decision making.