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When the thirsty Ancient Mariner is stuck in the middle of the ocean with an albatross around his neck, he makes this profound observation "Water, water everywhere, nor any drop to drink" (Rime of the Ancient Mariner by Samuel Taylor Coleridge). Many of us may sometimes wonder if the same applies to some fields of science, particularly Earth and environmental sciences. For the sake of argument, let us confine the analogy of the Ancient Mariner to the field of water resources, which is the study of water as a resource to make the world a better place. Idealistic as it may sound, there is nothing wrong in believing that the scientific research should be primarily driven by the need to serve society [1]. Food would have been the other good example considering that we produce today about 2,800 kilocalories of food per capita daily, which is enough to feed the world, and yet hunger and famine still exist [2]. However, this article focuses on water as an example, although the solutions proposed could apply to many other fields.

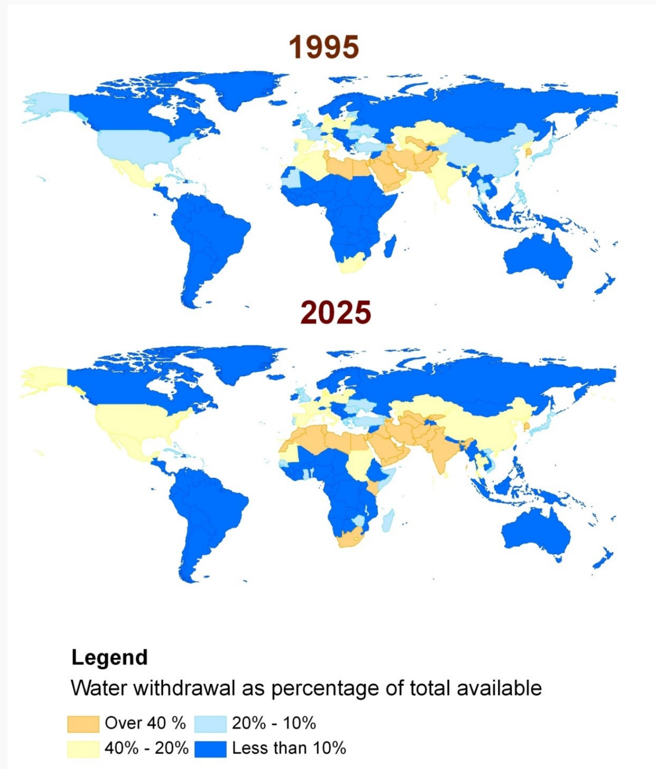

Figure 1. Uneven distribution of water stress projected in the future based on human demand and natural availability. Image Credit: United Nations Environmental Program (UNEP) and American Society of Civil Engineers.

For centuries, the importance of water as a resource has been highlighted very clearly. It's fair to say that we have been raising the alarm of declining water or its skewed distribution for our civilization for as long as we can remember (Figure 1). The rhetoric hasn't really changed in modern times after modern measurement techniques came into being. For example, since the 1980s, we have been reading how floods kill and damage infrastructure and economy (Figure 2). We've been reading in numerous peer reviewed papers how increasingly more destructive floods have become. Often the trends are rightfully (or wrongfully) attributed to a variety of stressors such as climate change, landscape change, urbanization, floodplain encroachment, poor water management or inadequate land zoning and management. There are other confounding factors like policy, planning, social perceptions, and competing interests that are beyond the realm of science.

Yet, how often do we read in papers and reports that we, as a scientific community, are making systematic progress and winning the battle to minimize flood damages and saving more lives? If there has been so much research accumulated over the years, peer-reviewed science papers published and phenomenal scientific breakthroughs made on our understanding of flooding, should we not become gradually more confident in marginalizing the flood problem? Should we not be making less of an alarm in time as decades of peer-reviewed scientific research on water resources has piled up? These set of questions could apply to a lot of other water or environmental issues. If we take a look at any of the premier journals that publish water-relevant research, one will notice a prolific number of peer-reviewed publications that have been printed over several decades. An online search of the American Geophysical Union (AGU) publications with the keyword "floods" in abstract reveals 2,364 peer-reviewed papers. Have those 2,364 science papers led to 1 percent (~23) success stories, tools or improved practices that the world is actually using? Most likely they have. However, we do not seem to hear much about them among the research community. If one assumed polio vaccination and flood research to be interchangeable, then the situation we are currently faced with today in the scientific world could be akin to polio not getting completely eradicated as fast in the United States despite decades of repeated mass immunization programs.

Let me clarify the above with a caveat. We actually have been quite successful in understanding the science of flooding and learning from it to save lives, at least in Europe and the U.S. As an example, the 1976 Big Thompson Flood in Colorado killed 144 while the recent 2013 Boulder/Lyons Flood killed eight (thanks also to improved forecasting and communication technology). Similarly, comparisons between two major floods a decade apart (1988 and 1998) in Bangladesh reveal that the number of deaths from flooding are declining despite a larger and longer duration flooding. During the 1998 floods, 110,000 square km was inundated compared to 90,000 square km in 1988, while the flood lasted 20 days more in 1998. Yet, flood casualties declined from 2,400 (in 1988) to about 900 (in 1998). The statistics for Bangladesh are particularly impressive when one normalizes the damage as a function of population density and lanc encroachment (population has increased by another 60 million from 1990 to 2010). For every big mistake we have made (e.g., in the U.S., this could be the Teton dam failure), we have indeed learned from it and made things better in practice later.

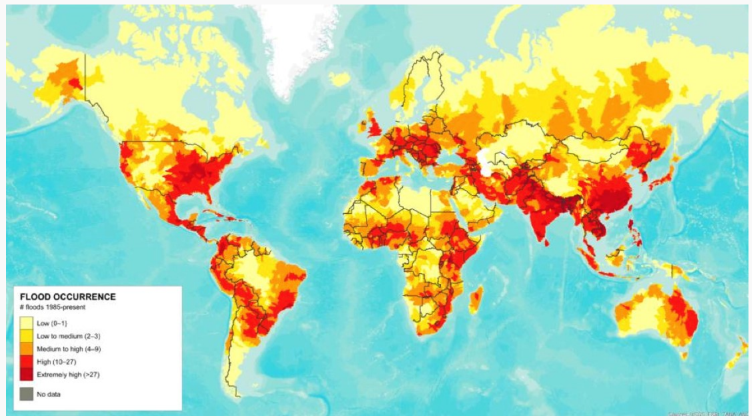

Figure 2. Global occurrence of floods since 1985. Image Credit: World Resources Institute

However, the progress we have been making seems to be getting slower by the day. Science on Earth and environmental topics seems to take long (or longer) to reincarnate as a societally beneficial tool and deliver quick returns on the scientific funding. The examples listed above all took decades to happen and a tremendous amount of non-scientific effort in the field. The scientific research on Earth and environmental sciences has become completely digital and exploded by a few orders of magnitude compared to the 1980s. Yet, we have not been able to take advantage of the good and prolific science that is coming out rapidly and convert it into tangible products at a much faster rate.

A good reason for this is that we may be living in a broken system where the applications framework for converting science into tools remains an analog one. This system has not updated itself to handle the huge bandwidth required to absorb research that has expanded many folds. Thus, there is the feeling of Ancient Mariner that many of us feel today.

We have already heard about some of these issues of science not delivering the value to people for water resources. Let's be clear. The problem is not a problem with science per se. It is how we leverage the science to deliver the benefits to society. Terms like "Valley of Death" that first appeared in a National Research Council (NRC) report in 2000 (on weather satellites not having made as much an impact as it should have on society) have raised this issue more prominently more than a decade ago [3]. A few years ago an article appeared titled "Have We Dropped the Ball on Water Resources Research?" in the Journal of Water Resources Planning and Management (a publication of the American Society of Civil Engineers). Therein, one of the leading hydrologists of today chastised the community of having taken their eyes off of training the next generation of problem solvers for water resources [4].

I would like to talk about three potential solutions to fix this broken system that could give our Ancient Mariners the life-saving water we crave. The first solution would be to enforce a stronger sense of accountability. Accountability might be a strong word. We are certainly not referring to putting scientists in jail when an earthquake happens (as we have seen recently in Europe). However, when the science fails to deliver the purported (printed) benefits for society as claimed in our research papers, we as a scientific community could do a better job of tracing the paper trail of scientific development to figure out what went wrong and why. In professional engineering practice, analysis of design and construction is traced back to identify the person and flaw responsible for a failed construction so that it can be corrected for future reference. A similar sense of accountability could bring a greater sense of responsibility to package science that can actually ‘deliver’ more to society.

The second solution, unusual as it may sound, is more of a computer science issue to make the knowledge we generate as scientists more easily accessible to beneficiaries. Science that is properly packaged and delivered should not have the beneficiaries be dependent on scientists all the time.

During recent interactions with computer scientists who address big data, internet mapping, Web security or high performance computing, it has become apparent that software models based on the science of water resources are not professionally programmed. Scientific researchers rarely create software that are vertically integrated to allow scalability, reproducibility or integration with additional data and tools. This is no fault of scientists who are trained to do science and not to build stable software that is scalable. Computer scientists can pinpoint the software flaws of tools scientists build that prevents intuitive design, cross platform interoperability and ease of use. Of course, there are exceptions (the NASA Land Information System is a good example). Overall, the amateur quality of software made by scientists mean that the science on water resources struggles every day to reach out to beneficiaries unless an advanced training is provided.

Figure 3. “Compound Eye” Satellites System for Accelerating Societal Applications of Earth and Environmental Sciences. Image Credit: Faisal Hossain

And then, there is the third solution – using satellite technology for Earth and environmental sciences to accelerate the transitioning of science to societal benefits. From a measurement technology perspective, this is becoming more imperative for water if we consider that we are currently experiencing the Anthropocene of surface water. Surface water is being redistributed and artificially managed to the extent that there is no pristine river basin left today without the human footprint caused by water diversions, barrages, dams and irrigation projects.

For example, U.S. Geological Survey (USGS) records indicate an increase in irrigation acreage from 35 million acres (1950) to 65 million acres (in 2005) in the U.S. alone [5]. Similarly, there are about 75,000 artificial reservoirs built in the U.S. during the last century with a total capacity almost equaling one year’s mean runoff [6]. In most regions of the world, it has become more intractable to have accurate knowledge of the management component of water at space-time resolutions relevant for predicting water availability downstream. For example, water is frequently transferred from one basin to another (in China, the analogy would be the North South diversion project) or heavily regulated through a system of reservoirs. The stand-alone physical models have become increasingly limited in predicting the state of surface water availability without a management component and numerical assimilation of the human footprint. When we cannot figure out what this human management of water is in most regions due to lack of in-situ observations, satellites in space are likely the only platform that offer a routine compound eye on how water resources are being redistributed by rules made by humans and not by nature. A broader example of this Compound Eye concept is shown in the graphic of Figure 1.

For example, a recent study shows that with the synergistic use of satellite missions such as TRMM, AQUA, TERRA, Landsat (7 and 8), Envisat, Jason-2, SRTM and GOES, it is possible to reduce uncertainty by 300 percent in river level simulations of river systems managed by humans and overcome the model limitations [7]. By using satellite precipitation data (microwave and infrared), radar altimeter data (microwave), and visible data together, the flow pattern of the highly regulated Ganges basin can be detected. As another example, the joint use of radar altimetry (Envisat and Jason-2) and Landsat data for river width can help understand the shape of cross section of regulated rivers. This information can then be used directly in river models with satellite precipitation and landcover data to improve water management for society that a stand-alone model could not have done for regulated rivers. If put in context of future or recently launched satellite missions for water (e.g., GPM, SWOT, SMAP, SMOS, Sentinel, IceSat-2), such joint use of many satellites as a ‘compound eye’ (or team) augurs well for solving water resources management problems for society.

Perhaps the biggest issue to making the large body of scientific literature deliver benefits to society is society itself. The above suggested solutions do not directly address the broader philosophical issue of getting society to adopt the science in manner that is practicable and meaningful. When one actually embarks on the journey to make science transition as a durable tool for society, one realizes the many over-looked issues of scale, uncertainty, format and logistics that the above solutions over-simplify. In fact, a similar effort to make scientific research evolve as a tool for operational flood forecasting revealed a surprisingly humbling assessment of how much science can progress without the societal response to an idea [8]. Thus, involving society in the development of every solution up close is important to make sure that the final solutions actually work. A stronger sense of accountability, better-designed software and team work use of satellites (as compound eye) may be able to take advantage of the prolific amount of scientific research that is being produced every day and provide round-the-clock societal benefits. The sum of this surely has to be greater than the whole.

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