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Observatories, think tanks, and community models in the hydrologic and environmental sciences: How does it affect me?

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[1] Multiple issues in hydrologic and environmental sciences are now squarely in the public focus and require both government and scientific study. Two facts also emerge: (1) The new approach being touted publicly for advancing the hydrologic and environmental sciences is the establishment of community-operated "big science" (observatories, think tanks, community models, and data repositories). (2) There have been important changes in the business of science over the last 20 years that make it important for the hydrologic and environmental sciences to demonstrate the "value" of public investment in hydrological and environmental science. Given that community-operated big science (observatories, think tanks, community models, and data repositories) could become operational, I argue that such big science should not mean a reduction in the importance of single-investigator science. Rather, specific linkages between the large-scale, team-built, community-operated big science and the single investigator should provide context data, observatory data, and systems models for a continuing stream of hypotheses by discipline-based, specialized research and a strong rationale for continued, single-PI ("discovery-based") research. I also argue that big science can be managed to provide a better means of demonstrating the value of public investment in the hydrologic and environmental sciences. Decisions regarding policy will still be political, but big science could provide an integration of the best scientific understanding as a guide for the best policy.

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1. Introduction

[2] Over the past 50 years, the hydrologic and environmental sciences have matured through the research of (primarily) individuals who have observed the natural world and addressed its complexity with a primarily reductionist approach in the tradition of Bacon and Descartes. This reductionist approach separates the component processes of the environment, evaluates their individual mechanistic processes, rates and dependencies; and enables science to posit how these components contribute to and influence the complexity of the environment. This separation of components is readily apparent in the organizational structure of most universities as well as science funding agencies. There is also an idealistic and general belief that these individual process components would someday be assembled to examine the holistic operation of the hydrological/environmental system. Individual scientists have made important contributions to our understanding of holistic, coupled systems (e.g., CO_2 and climate, vegetation and water balances in arid regions, flooding and land use, eutrophication dynamics and ecosystem resilience). However, the new approach being discussed publicly and being proposed to advance the hydrologic and environmental sciences is the establishment of community-operated "big science" (observatories, think tanks, community models and data repositories). This approach is being developed in parallel across several agencies and multiple divisions of single agencies too numerous to list and I do not offer an opinion on their scientific worth or their scientific justification. I ask: How could those new approaches serve the science in the current political arena for research in the United States? How could those new approaches impact the individual scientist?

2. Scientific Productivity and Accountability

[3] The ideal of discovery science [*Bush*, 1945] is no longer the primary operating principle for federal science funding in the United States [*Guston*, 2000]. In the 1980s, two important changes significantly influenced the business of science [*Guston*, 2000] but not necessarily the practice of science. First, the Office of Technology Transfer (1980, within the NIH) was created and charged with tracking the productivity of nationally funded science in terms of innovations and patents. This created a mechanism by which to assess a "cost effectiveness" of federal funding and productivity in (for this case, NIH) the sciences. This concept has been expanded to other agencies (e.g., within NSF, it is emphasis on "broader impact") and by the Bayh-Dole Act regarding technology transfer policy. Second, the Office of Research Integrity (~1989, within NIH) and the Inspector

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General's Office (within NSF) were established to evaluate questions of ethics and falsification of data under a guiding principle that "QA/QC" of science is best discovered, viewed and judged by the community of scientists. Thus, by the early 1990s, the political context for research in the United States had changed considerably [*Guston*, 2000] and specific questions of productivity, accountability and trust had become a significant part of the political landscape of science. Confusing the issue is the observation that such judgmental measures have been applied inconsistently in time and across agencies.

[4] Several examples can be cited of technological spinoffs that demonstrate (after the fact) productivity and accountability in the "value" sense of this Congressional effort and as a contribution to the gross national product (GNP): (1) Satellites and space probes contributed to the growth of the communications industry, the electronics industry and personal GPS technology. (2) Space exploration vehicles contributed to new robotic capabilities, Velcro, miniaturization and the personal computer industry. (3) Biomedical research contributed to new drugs and new therapies.

[5] Yet these examples also illustrate that the hydrologic and environmental sciences lack a significant means of demonstrating a contribution to the GNP. Satellites and space exploration are particularly illustrative because the original justification was "to beat the Russians to the moon." That effort has left us with a large inventory of "space junk" because there was no stakeholder with a vested interest in space. As we now grapple with aging satellites in decaying orbits plummeting to Earth, some with nuclear power modules, we define a parallel to many current and pressing hydrologic and environmental issues. Certainly, 1930s U.S. policy could have defined the value of dams in the western United States in terms of (e.g.) agricultural production. However, current issues often focus on the assessment of damage resulting from dams. Times have changed.

[6] The hydrologic and environmental sciences have made significant contributions to the science upon which national policy and environmental policy were enacted (e.g., creation of the EPA, regulation of Freons (atmospheric ozone), regulation of phosphates in detergents (lake eutrophication), CO_2 and climate, control of suspended sediments during road construction, improved waste management protocols, etc.). However, as the multiscale (time and space) dependencies and coupled component systems behavior of the environment (complexity) became more evident, this original mechanism of contribution to society (e.g., guidance to government with regard to regulation of Freon, phosphates, arsenic in the water supply, etc.) has been supplanted with the need to address more complex questions. For example, What is the impact of large-scale agricultural fertilizer use on the water quality of streams and lakes? . . .on coastal ocean hypoxia? What is the impact of Mississippi River channelization on the ecosystem services of the Mississippi Delta? . . .on flooding potential along the Mississippi River? What is the danger from channelization and increased hurricane activity? What is the impact of dam construction on the salinity of the Colorado River and ecosystem function within the Grand Canyon? What is the impact of climate change and industrialization on the water resources of the nation? This newer type of question raises the important question of "How can the hydrologic and environmental sciences best provide Congress and the public with a rationale for continued and enhanced research to address this newer type of question?"

[7] In this new context, the existing mechanism of accountability (OTT-like offices) does not serve the hydrologic and environmental sciences well; it does not provide a good measure of (after the fact) "success" and value to the nation with respect to the investment in the hydrologic and environmental sciences because these sciences rarely produce "things". When Congress/public asks "What have you done for me lately?", the hydrological and environmental sciences have inadequate means by which to provide specific information pertinent to the questions asked. Consequently, individual scientists are left to explain their individual research which often fails to address any specific public policy question because it contains only a part of the system within which the publicly or Congressionally defined question operates. The hydrologic and environmental sciences need of a mechanism by which to demonstrate their productivity and the value they bring to the nation.

3. Observatories, Think Tanks, and Coupled Hydrologic, Environmental Systems Models

[8] In order to answer the multiscale, multidisciplinary hydrological and environmental complexity questions of the present, which have the potential to specifically address questions of "What if . . .?" and "What is the impact of. . .?", big science has been proposed for the hydrologic and environmental sciences. Here I do not evaluate the scientific merit of this effort; I consider its potential impact on the individual scientist and its capability to provide some of the rationales that need to be made to, e.g., the public, Congress and the Office of Management and Budget. Big science is typically envisioned as community-built models designed to couple the disciplinary, component sciences into systems science often including an ability to interact with stakeholder-posed scenarios (see Figure 1). In addition, they include observatories to test those "molecular to basin scale" models of the environment on the multiple scales of the prediction (e.g., hydrologic observatories, LTERs, NEON, ORION, etc.) and to identify missing couplings, components, and scaling relations of those models. (Observatories will require new and patentable instrumentation, but such instrumentation does not provide a significant contribution to the GNP.) Big science is also assembling extant watershed measures and "context data" in a common format that should enable access to information on a time and space scale heretofore unrealized. Big science also includes a community-operated synthesis center or think tank (e.g., NCEAS, http://www.nceas.ucsb.edu; NCHS, http://nchs.berkeley.edu) that (1) assesses components for inclusion in the community model(s), (2) ensures access to the model(s) (e.g., for testing newly quantified/identified coupled, component process functionalities), (3) ensures comparison of the model with observatory data and archived data, (4) recommends modification to observatory design to adequately test knowledge of the environment, and (5) ensures access and availability of observatory data to the individual PI.

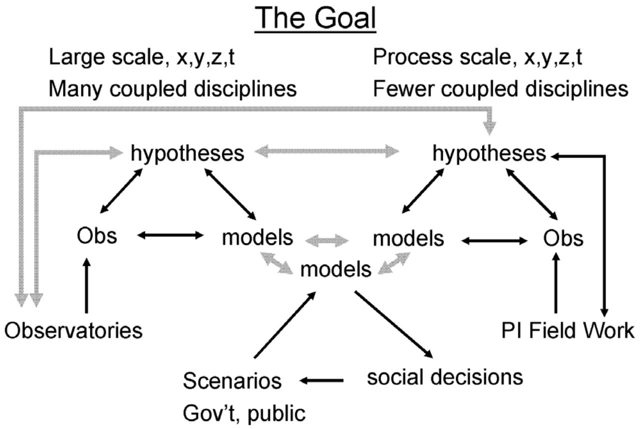

Figure 1. The big science approach builds on the tradition of individual, discovery science and builds models over multiple time and space scales and with multiple, coupled disciplinary components. Observatories serve to test these models and identify knowledge gaps. Together, others have argued that they offer a pathway to advance science. Critical to successful implementation of big science are the linkages (1) among the single-PI, the community model, and community observatory and (2) between the observatory-tested, multiscale, multidiscipline best science systems models and government- or public-posed scenarios. The first critical linkage is necessary for the success of science; the second critical linkage is necessary to help define value for justification of continued federal investment in the field.

[9] This big science approach to the hydrologic and environmental sciences has troubled the community and raised questions about the future role of the individual scientist and the funding of traditional "discovery" science. Some scientists are very welcoming of this change in the research process and will make the transition with ease. However, not all will make this transition; but, not all need to make this transition. As a scientific community, we need to expand the integration in our sciences by utilizing our diverse disciplines and individual expertise. Observatories and synthesis models are an obvious direction, but they need to be conducive to individual participation and to provide synthesis responsive to scientific, regulatory, and public policy questions.

[10] I suggest that addition of big science with more management, more infrastructure and more cost, does not mean a reduction in the importance of single investigator and discovery-based science. Rather, if the think tank management truly represents the community, it must ensure a specific linkage (Figure 1) among the large-scale, team-built, community-operated observatories, context data files, coupled models, synthesis centers and the single investigator. The big science approach could therefore provide a continuing stream of hypotheses for discipline-based, specialized research and a strong rationale for continued and well supported individual PI research. Furthermore, big science could provide a better mechanism for demonstrating "the value of public investment in hydrological and environmental science" by providing a better linkage between the best science, concerned stakeholders and government.

[11] Many hydrologists and environmental scientists already build (coupled, systems) models to assess/assemble/assimilate research on time and space scales that can be handled by their laboratory and the skills of the individual and his/her team. However, the constraints on the individual PI in terms of (more important) time, money, and (less important) skill are also limitations on the science as a whole. Single PI and small team models may lack important couplings and components necessary to be responsive to public- and government-posed scenarios upon which best science input to policy can be made. Through cooperative- and community-managed data files and the inclusion of individual scientist components/contributions within a larger and more complex, coupled multidisciplinary model (a system of connected modules), we can better develop the large-scale, systems-level environmental models that will best define the current state of knowledge and the best defined science input for policy decisions. Additionally, it is the operation of observatories on multiple time and space scales that will generate community-based data sets and context data archives that enable us to compare the model of "what we think we know" to the reality of nature and thereby define "what we don't know." This capability should provide a continuing series of specific hypotheses for the individual and discovery-based science. These hypotheses can be discovered by community operation of the community model, by the individuals operating the community model, and/or by investigation of community context data files or mining the publicly available data from observatories. The large community models, data files and the observatories (big science) do not remove the individual specialist and traditional science from the field; the community models and the observatories of big science could provide a prioritized assessment of the specific science that needs to be discovered and a strong database and rationale for continuing discovery-based science.

[12] Potentially of additional importance is the critical need for the community to provide the public and government with better answers to pressing scientific and policy questions. Because (in my opinion) the hydrologic and environmental sciences do not produce a product that can be easily equated to a GNP value, we will be advantaged well if we are able to demonstrate how advances in the hydrologic and environmental sciences could be used to improve use/management of land, water, industry, etc. The construction and operation of community models and observatories, and the availability of watershed measures and data files (big science); could provide the context, expertise and the capability to respond to "What if..." scenarios as posed by government and by the public. Some scientists will prefer to maintain a strong connectivity in the science loops (across multiple time and space scales and multiple disciplines) and less in the policy loop (see Figure 1). Others may choose to become actively involved in the policy loop and could serve as the public face of the science. Big science may enable greater discovery from the single investigator and offers more opportunities than limitations if outreach and management of big science is appropriately designed and inclusive.

[13] I am of the opinion therefore that big science (community-operated models, observatories, watershed

measures and data files and think tanks) can offer advantages to the individual scientist in the hydrologic and environmental sciences and to the scientific community as a whole. (1) Under appropriate operating principles, big science could provide a steady stream of hypotheses for testing by the individual investigator. (2) Big science could provide a mechanism by which to demonstrate the value of public investment in hydrological and environmental science by providing a place and a capability to run "What if..." scenarios that become the currency of value. (3) Big science moves the hydrological/environmental sciences forward into understanding the complexity of the science in a manner that was the original motivation of discovery science and all of us as individuals. What we need to ensure, however, is that the goals are clearly understood and the ideals are properly incorporated within the platforms that are being proposed.

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