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Integrating Water-Quality into a Water Resources Research Agenda

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A 20-year agenda for water resources research will need to dedicate substantial attention to water quality and assimilate water quality into traditional concerns about water availability and allocation. Water quality is inseparably linked to the utility of available water and to the viability of social and environmental systems. Unfortunately, water quality has received relatively little consideration in water resources research relative to water quantity and has been treated in isolation of other aspects of water resources. At the global scale, a water resources research agenda should address the threats that poor water quality makes to global water resources and ecological sustainability and, conversely, the adverse effects that poor environmental management can have on water quality. At the local scale, water resources research should adopt methods of integrated watershed management to ensure that water quality is included in management and planning. At all scales, water resources research must be cognizant of the threat that poor water quality imposes on human health and the quality of life. Fundamental changes have taken place in resource and environmental management with regards to global environmental change and sustainability, integration of systems and management activities at the small watershed scale, and the potential for ecological damage and threats to public health from modern and legacy sources of contamination. These changes require that water quality be a central concern incorporated and fully integrated into a vibrant 20-year water resources research agenda.

A recent study of water resources research needed in the U.S. for the coming century (National Research Council 2001), concluded that 20th century water resources research focused too narrowly on water quantity, took a short-term view, failed to afford adequate consideration of water quality, and tended to treat water quality in isolation. The study called for a holistic view of water resources research with more consideration of environmental contaminants and their effects on water quality. They recommended a broader framework for water resources research that incorporates water quality data acquisition, recognizes legacy pollution, and acknowledges the vulnerability and resilience of environmental systems to non-point source pollution loadings.

> …the legacy of pollution that has already occurred must be addressed, in addition to the new sources of pollution that are currently going unabated. In particular, greater research is required on nonpoint source pollution, which accounts for nearly three quarters of the contaminant loading to surface water and groundwater in the United States… More knowledge is needed about the susceptibility and resilience of terrestrial and aquatic environments to contaminant loadings, as the long-term impacts of contaminant accumulation may eventually undermine overall ecological function. The successful management of water quality in the twenty-first century will require a more comprehensive understanding of the ways in which the environment processes contaminants, how those processes vary, and their robustness as contaminant loads grow… (National Research Council 2001:14-15).

The Context of Global Environmental Change and Sustainability

A 20-year vibrant agenda for water resources research should be compatible with rapidly evolving needs to address global environmental change. Long-range water quality planning should reflect global change initiatives owing to the close ties between water quality and environmental quality and ecosystem viability. Rapid population growth and the need to increase irrigation to produce ample food to support this growth, will drive the need to protect water quality. Projections of global agricultural impacts estimate that ~10^9 hectares of natural ecosystems will be converted to agriculture by 2050 more than doubling eutrophication of terrestrial, freshwater, and coastal marine ecosystems by nitrogen and phosphorus and similar increases in pesticide use (Tilman et al. 2001).

Water quality can threaten water supplies and *vice versa*. Serious water quality disasters resulting from poor water management include the shrinking of the Aral Sea (Micklin 1988), and mingling of sewage with water supplies beneath Mexico City (Cisneros-Iturbe and Domínguez-Mora 2005, Edmunds et al. 2002, Gonzalez-Moran et al. 1999). The water resources research agenda should recognize the dangers to water availability imposed by poor water quality and the importance of water quantity management to water quality.

Sustainability is an essential goal for viable long-term water-resources planning in general and is specifically applicable to developing a water quality management agenda for the next 20 years. *Sustainability* refers to rates and methods of resource use that can be maintained for long periods without substantial depletion or damage to resources or social and environmental systems. Sustainable development concepts began to be applied globally early in the 1980s as a means of protecting life-support systems of the Earth while ensuring human needs (National Research Council 1999a). They were initiated from a social and political perspective, gained scientific and technological backing as *sustainability science* (Clark and Dickson 2003, Kates et al. 2001), and have now achieved widespread acceptance. Sustainable development was formally recognized as a guiding principle for international policy formulation at the Rio de Janeiro *Earth Summit* Conference in 1992. The *Rio Declaration* includes 27 principles in support of global sustainability principles (Quarrie 1995). Water-quality elements of the water resources research agenda will be essential to and should adopt a long-term, sustainable vision of resources management.

The Context of Integrated Watershed Management for Local Water Quality Management

The old adage "think globally but act locally" applies to water resources research. At the local scale, water quality is controlled by watershed conditions, so watershed management can be the first line of defense. A water resources research agenda for the next 20 years should encourage integrated watershed perspectives that consider systems as integrated and highly inter-dependent (National Research Council 1999b, U.S. Environmental Protection Agency 1993, 1996). Similarly, integrated approaches to water resources management that promote consideration of water systems as highly inter-related are recommended (United Nations 1992: Section 18.36). No consensus exists about precise definitions of integrated watershed management or integrated water resources management, but certain goals are implied including interagency coordination, public involvement, consideration of interactions between physical, biological, and social systems, and spatially distributed methods of characterizing these processes. Watershed management does not necessarily require a centralized watershed program emphasizing science, planning, a formal public participatory process, and detailed management plans. It has been argued that all watersheds are managed to some degree by a range of governmental and non-governmental agents and that watershed management programs should seek to coordinate these efforts; that is, watershed management can be seen as a form of intergovernmental management (Imperial and Hennessey 2000). Watershed management approaches are essential to water quality management because watershed processes – including human and biological interactions – are translated to the quality of water passing through the watershed by surface and subsurface pathways. The success of watershed approaches, however, should not be measured solely by overall environmental outcomes owing to other factors controlling environmental change (Born and Genskow 2000).

Linkages between watershed management and water quality underlie the rationale for much spatially distributed water quality modeling that simulates pollution-reduction, crop management, or ecological enhancement to reduce damages associated with sedimentation and contaminant releases (Zhang et al. 2009). Moreover, watershed-based management has been institutionalized by U. S. regulatory procedures. The U. S. Environmental Protection Agency (EPA) spent approximately $204 million in fiscal year 2006 alone on Section 319, Clean Water Act, grants to reduce nonpoint-source pollution, and much of this effort focused on watershed-based plans (Hardy and Koontz 2008). An example of watershed management aimed primarily at domestic water quality protection is provided by the Croton watershed, which serves water supplies for New York City (National Research Council 2000).

Legal justifications for incorporating water quality protection in a U.S. agenda arise from federal legislation. Water quality is directly linked to congressional acts such as the Clean Water Act and Safe Drinking Water Act as well as to broader environmental legislation such as the National Environmental Policy Act and Endangered Species Act. The Clean Water Act requires protection of the chemical, physical, and biological integrity of the nation's waters by the EPA. Among other provisions, the Clean Water Act requires states to identify problem watersheds and to estimate the maximum sum of point and nonpoint-source loadings that these sites can assimilate as *total maximum daily loads* (TMDLs). Technical manuals to assist with TMDL procedures for nutrients, sediment, and pathogens review monitoring and assessment procedures (USEPA 1999a, 1999b, 2001). The TMDL program has greatly encouraged watershed planning for protecting water quality in the U.S.

Management of ground water quality in the U.S. differs from surface water because planning units are not defined by watersheds. Sources of ground water pollution include landfills, buried tanks, salt water intrusion, and pesticide applications. In addition to dissolved solids and pathogens, dense and light *non-aqueous phase liquids* (DNAPLs and LNAPLs) and pharmaceuticals have been of growing concern to ground water quality (Fetter 1993). The Safe Drinking Water Act established maximum contaminant loads and other standards for drinking water supplies, and the 1986 amendments (PL 99-339) added three ground water protection programs. As pressure mounts on ground water supplies, the 20-year water resources research agenda should include vigilant maintenance of the viability and enforceability of such laws and support the introduction of additional legislation to keep apace of new pollutants and pollutant pathways. Ground water protections plans should be an essential element of watershed management.

Contaminants in Sediments, Soils, and Aquifers

Water quality is driven by exchanges between water and its surrounding media. Thus, more needs to be known about the potential toxicity of biologic and geologic materials in the beds and banks of lakes and rivers and in ground water aquifers. Vast repositories of legacy sediment contain high levels of hazardous or toxic materials that may be subject to remobilization. In the U.S., contamination from legacy materials is an important concern; the need to remediate hazardous waste sites led to the creation of EPA Superfund program (Daley and Layton 2004). Unfortunately, the geochemistry of sediment varies greatly at the local scale with geology, biology, climate, topography, land-use history, and point-source discharges, so extensive sampling, laboratory analyses, and data cataloguing are needed to locate and characterize areas of concern. The EPA established *Sediment Quality Guidelines* to measure the extent of contamination and to limit additional contamination (McCauley et al. 2000). The Guidelines provide a comprehensive catalogue and analysis of sediment geochemistry and related biological data in the U.S. (EPA 1998 a, b, c). They describe where contaminants reach potentially harmful levels in river, lake, ocean, and estuary sediments and the potential for adverse effects on human and aquatic life. Volume 1 (EPA 1998a) describes the likelihood of adverse effects of contaminated sediment on human or ecological systems, Volume 2 (EPA 1998b) provides maps of sampling stations and chemical and biological data summaries for watersheds containing *Areas of Probable Concern*, and Volume 3 (EPA 1998c) identifies likely point-source sediment pollutant contributions. The agenda should advocate the maintenance and extension of this database and its integration with policy.

At all scales, a standardized assessment and synthesis of sediment quality data is needed to identify problem areas and allow study of process linkages such as aquatic responses and resilience. This assessment should employ standardized methods to provide comparable data between studies. It should also include methods that will reflect the reactivity of substances in sediment with water and aquatic biota. Total digest methods can be useful to water quality studies, but future research on contaminant uptake will need to shift emphasis from total elemental concentrations to the solubility and bioavailability of toxic substances. The bulk composition of sediments, soils, and aquifer materials is usually dominated by elements locked up inside mineral grains and not readily available for uptake. From a water quality perspective, the toxicity of thin outer coatings on mineral grains that are actively exchanged with surrounding fluids and micro-organisms may have greater relevance than total sediment chemistry. Concentrations in coatings can be measured by weak acid extractions (Loring and Rantala 1992). The position of sediment also plays an important role in the transfer of contaminants to water supplies and aquatic organisms. For instance, toxicity in the hyporheic zone of rivers and lakes and near well-heads of domestic water supplies is of greater concern than in sediments at a greater distance from ecologic activity or points of water extraction. The agenda should seek and adopt standardized sediment-sampling protocols that consider these methods and site locations.

Conclusion

Water quality is inextricably tied to the viability of water resources availability and resilience. Incorporating water quality into a holistic management scheme is essential for sustainable water resources management, so a vibrant water resources research agenda must account for interdependencies between the quality and quantity of water. This greatly increases the complexity of water-resources planning because it requires consideration of water quality over broad scales of time and space and the interactions with ground water aquifers, legacy river and lake sediment, and biologic systems. The water quality aspects of the agenda must be sustainable and should include consideration of maintaining and developing a viable legal system of regulations and incentive programs.

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