Watershed Management in the United States in the 21st Century

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Abstract.—Views of watershed management in the 21st Century are presented in terms of concept, status, progress and future of watershed planning. The watershed as a unit will increasingly be the basis of planning because the concept is widely understood, many state and federal laws require such a focus, and watersheds are a logical entity for monitoring purposes. Impediments to watershed planning remain, but progressive and effective policies are evolving in response to public demand that diverse land uses and users protect the watershed resources. Watershed management will be improved by new computer technology tools, more effective integration of social sciences capabilities, and advanced legal and institutional incentives for landowners and users. Research needs identified include better integration of computational capabilities with spatial and temporal information, watershed monitoring capabilities, mechanisms for evaluating watershed policies and programs, and better understanding of basic hydrology and the effects of multiple land user disturbances on water resources on a large scale.

Introduction

Watershed management policies and practices in the United States 21st century will be largely driven by a growing human population and the associated commodity and non-commodity demands placed on natural resource systems. The U.S. population now exceeds 270 million. A "medium" projection estimate for the year 2050 is 348 million people (Gardner-Outlaw and Engelman, 1997). Whether this projection is proven correct or not, the certainty is that the U.S. will have a much larger population in the 21st century than at present. The concentration of population in and around urban settings will also influence future watershed management policies and practices. Settlement patterns in the U.S. are concentrated around coastal areas including the Great Lakes, with the east and west coast being the most densely populated. Interior spaces of the U.S. are also under the influence of population expansion as exemplified by Denver and Phoenix. In addition, other urban areas are sprawling outward from city centers, as illustrated by Seattle and Portland.

This mix of concentrated settlement patterns and sprawl, in combination with overall population growth, is putting stress on natural systems. However, these demographic patterns describe only part of the issue. Increasing rates of land and water consumption in areas of low renewable water resources, especially in the western states, adds to the complexity of our national problem. The competitive demands for wildlife and fish habitat, clean water, food and fiber production, living space, transportation and utility corridors, scenic and recreational environments, and other natural resource-based attributes are growing dramatically. A major challenge for natural resource managers of the next century will be how to address these intensely competing demands imposed by a growing and increasingly consuming population, and at the same time protect and preserve natural systems on a sustainable basis.

One of the most central issues in the management of natural systems in the 21st century will be the demand for water, for endangered species, such as fish and other species, and for human consumption and use. The availability, characteristics, and behavior of water in natural systems are largely a cumulative function of the basin or watershed from which the water is derived (in addition to climate, of course), and land use practices. Thus, watershed management will become increasingly significant as a means to ensure adequate supplies of appropriate quality water for a variety of uses. High quality water in adequate quantity for human use will increasingly become a prominent and, in some cases, a dominant consideration in land management, and will be viewed as a human health and security issue. This will precipitate more national conflicts over water "rights" as opposed to water "privileges".

Through examination of the concept, status, progress, and future of watershed planning, we present here our views of watershed management in the U.S. in the 21st century. This is followed by discussion of a number of research issues that will impact efforts to plan and manage on a watershed basis.

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Watershed as a Planning Unit

As competition for natural resources, including water, intensifies to unprecedented levels, careful planning will become increasingly important. Watersheds are a logical unit for unifying the planning process and for producing the desired outcomes such as improved water quality and habitat for fish and other species. Several factors—the concept itself, evolution of federal and state laws, and monitoring issues—support the watershed concept as the basis for planning.

Concept

First, people can understand the concept of a watershed. For example, they understand the physiography in which the ridge lines of a watershed can be defined, as well as the downward cumulative flow of streams, rivers and ground water, and the general relationship between precipitation and high and low streamflows. This widespread understanding may be greatest where topographic relief is well defined as in the West, but even elsewhere the concept is appreciated.

Federal and State Laws

Second, federal and state laws are both forcing and encouraging watershed planning. The Endangered Species Act (ESA) requires adequate habitat conditions to ensure the survival of endangered and threatened species such as certain salmonids on the west coast. The survival of such species is dependent on many factors including ocean and near ocean conditions (National Research Council, 1996), but clearly habitat conditions in watersheds play a major role. Another federal direction is The Federal Guide to Watershed Analysis under the President's Northwest Forest Plan (Regional Ecosystem Offices, 1995).

The Clean Water Act (CWA) is another powerful federal law that has resulted in standards for permissible water quality variation. An overarching goal of the CWA is to maintain or improve the physical, biological and chemical integrity of the nation's waters. For example, the total maximum daily load (TMDL) of sediment in streams may be controlled by regulations resulting from this law. The sediment load at any particular point in the stream is a function of everything that influences sediment dynamics above the point of measurement, including up-stream land uses and practices. The many land uses in the watershed, and their individual and collective influence, will have to be addressed to meet water quality standards resulting from the CWA. But TMDL regulations only correct the problem after it occurs. Management practices are increasingly being stipulated in regulation, in the few states that have been aggressive, and other states are seeking either regulatory or voluntary Best Management Practices.

Protection and mitigation for threatened and endangered species will require that land users, including those in forestry, agriculture, utilities, range management, and urban and exurban development, deal with their own and their combined impacts within the watershed. If planning is not coordinated across ownerships and land uses, protection efforts by one land use or ownership group could easily be defeated by activities or practices in other parts of the watershed. Even disturbances on small areas of the watershed can have adverse downstream consequences for water quality and quantity. Desired outcomes cannot be achieved if the major factors influencing water quality or species survival within the watershed are not addressed. Obviously, improving and coordinating management practices across watersheds with multiple and fragmented ownerships will present a major challenge.

State laws and regulations that support watershed planning are also emerging. In 1998 the Washington State legislature passed Engrossed Substitute House Bill 2514, with overwhelming bipartisan support. The law establishes a watershed management planning process to develop standards for in-stream flow levels, water quality, and habitat plans for defined watersheds. A primary purpose of the bill is to address fish listings under the ESA and the needs of those who rely on out-of-stream uses of water. The provisions of the bill are voluntary and call for pluralistic representation from state agencies, local government entities, general citizenry and representatives of major interests in the area. The goal is to collaboratively develop integrated watershed management plans for the planning areas. Up to 500,000 dollars in grants per defined watershed can be provided by the state to support the process. A companion bill, Substitute House Bill 2496, instituted a "systems" approach for salmon recovery, and stipulated that a local planning process must occur in order to obtain state grants. A subsequent 1999 bill stipulated that a new planning entity, appointed by the Governor, should direct the flow of money to projects for salmon recovery.

Of course, all of these more recent watershed planning efforts were preceded by earlier efforts such as the old river basin studies of the 1960s, the Tahoe Regional Planning Agency (TRPA) and the Tennessee Valley Authority (TVA), for example.

Monitoring

A third reason that watersheds are a logical basis for planning is that monitoring for compliance with federal and state laws may be more easily achieved at the watershed level, if appropriate coordination mechanisms are in place. Runoff and water quality, traditionally monitored at gaging stations on rivers and tributaries, provide measures of compliance with regulations and serve as an indicator of responses to policy changes if measured carefully and over long time periods. Information from gaging stations provides an integration of all land use practices upstream and an indication of cumulative effects of these practices within the watershed. More sophisticated technologies are being developed to track movement and changes of particulates, pathogens, fish, and other elements of the watershed that in turn are indicators of overall environmental health.

Challenges related to monitoring remain, however. The watershed has been described as the "canary in the coal mine" since the 1960s, when river cleanup programs were begun. Monitoring may be able to pinpoint sources of pollution, with newer technologies, but it is more important perhaps that watershed monitoring will help individuals and communities understand the ambient health of their environment and the impacts of their own growth patterns. If monitoring is conducted, there is great variability in the types of biological, physical and chemical measures currently used to monitor, as well as uncertainty surrounding which indicators are appropriate. Questions also remain as to whether monitoring data is actually used by resource managers and policy makers to evaluate and adapt programs and policies. There is also variability in who monitors what variables and for what purpose. Further, monitoring may be resisted by those who may not wish to grapple with the findings that result.

Status of Planning on a Watershed Basis

Watershed planning in which the cumulative influence of all land uses and practices can be assessed and managed will require the involvement of all land ownerships and resource users in the watershed. The legal demands in the 21st century will not allow single landowner planning, or planning that assumes landowners will voluntarily participate on their own to achieve watershed objectives. Rather, landowners will be compelled by a combination of regulations and public sentiment regarding expectations for the watershed, as was the case for air quality management in airsheds in the 1970s. The laws (ESA and CWA), standards (TMDLs), and expectations (adequate quantity and quality of water) are clear. Further, the results of planning and implementation of plans can be continuously monitored to assess success or failure. We might argue that the state of the art of assessing success or failure has advanced far more rapidly than planning. Public access to information and consequent usage of information to coalesce public sentiment is almost unlimited, as the world wide web allows almost universal access to GIS and other information. Ultimately, successful planning and implementation will require public processes transparent to all and data bases that can be integrated. However, quality of access is a function of bandwidth, a phenomenon that was virtually unheard of five years ago. This means that rural and less wealthy areas will be more challenged for information, until bandwidth access is provided.

As early as 1992, Washington's Forest Practices Board provided an option in its regulations for watershed planning by landowners, which was generally supported in theory, but not implemented in any meaningful way. We believe that landowners initially waited for one another to lead the way with these "alternate plans," and no one led. Then the concept was supplanted by ESA-driven Habitat Conservation Plans.

Although the Washington policy was not implemented as intended, some forest landowners have begun to quietly address watershed planning, either as part of their habitat conservation plans to conform to ESA requirements, or for setting ISO (International Standards Organization) 14000 standards for their land management. These efforts have not deliberately attempted to achieve the cross-boundary, cross-ownership goals that watershed management contemplates, however.

In Oregon, Governor John Kitzhaber appointed a Willamette Restoration Initiative board, to follow a long-standing citizen-driven effort to focus on planning for the Willamette River Basin. Clearly, the Willamette, the major "gathering place" of water and people in Oregon, will be a model for planning and perhaps successful social engagement around a critical set of natural resources.

However, impediments to successful watershed planning remain, including: landowners with different objectives that may conflict with public watershed goals; years of regulatory behavior that has not rewarded collaborative planning; overlapping state and federal agency responsibilities; incoherent and disparate data collection; multiple political jurisdictions; undirected funding; distrust of data sets not one's own; models that have not been validated or linked; funding cycles that are too short to address the problem or long-term monitoring needs; and incomplete understanding of watershed processes.

Progress in the 21st Century

Notwithstanding the challenges described above, the 21st century will bring progress in watershed planning. The changes in policy and practice will not be revolutionary, but rather evolutionary and increasingly progressive and effective. We further posit that the trend of the last 200 years, of pushing one use or user aside as a new and presumably more valued land use emerges, will become more rare in the next century. Public sentiment is demanding that more uses coexist, and that users find ways to adjust to one another's needs in a more pluralistic way. Forestry is a case in point. Although not without difficulty and cost, forestry, as a watershed practice, is adjusting its ways of management around urban boundaries, as agriculture has done. Forest companies and some other large land users, like utilities, manufacturing industries, airports, municipalities, and in some cases, agriculture, have donated land, provided streamside buffers of consequence, invested millions of dollars in fish habitat restoration, and otherwise mitigated practices to gain wider public acceptance of their activities. None of these individual acts should be construed as watershed planning, even though they might be consistent with a plan.

Role of Technology

The expected improvements in watershed planning in the 21st century will be aided by significant new technical tools. GIS, highly sophisticated remote sensing capabilities such as hyper-spectral and laser imaging, large scale computer modeling, visualization technologies, and no doubt other developments, will make it easier for watershed managers to characterize, predict and assess watershed conditions and behavior. Perhaps more importantly, these tools will help both the public and landowners to better understand what proposed policy changes may look like on the ground and what the costs and benefits are likely to be. As information sophistication increases, the application of that information will increase as well. Sharing data across agencies and land ownerships will be essential, and organizational impediments to shared data and shared decisional tools will need to be overcome. The institutional and cultural shifts that are being surmounted in many technological industries will need to be addressed by resource managers and regulators.

The World Wide Web and internet are sources of vast information that nearly anyone can access. These tools and associated technologies have already revolutionized watershed planning in the 21st century by providing data and information to a wide audience. For example, U.S. EPA's "Surf Your Watershed" site (*http://www.epa.gov/surf/*) is a Web-based service designed to help users locate, use and share environmental information for their watershed. The state of Washington has a "Watershed Home Page" (http://www.wa.gov/ecology) that focuses on issues specific to the state. Oregon's state agency (http://waterquality.deq.state.or.us/wq/default.htm) provides information as well, as do many other state water quality agencies. The Web can help level the playing field by conveniently providing information in interactive form, and assisting all users to gain a better understanding of trade-offs and alternatives, possible courses of action and consequences, and what is known and is not known. These advances should make it more difficult for the selective use of information in achieving policy goals by any sector. An informed and involved public is necessary for a democracy to succeed and thrive, and this is no less true for the watershed planning process.

However, we must also observe that the usefulness of the Web for collaborative watershed planning may be limited by the lowest common denominator among the collaborators, as inequalities in Web access will dictate. Band width problems in rural areas, underfunded agencies or Indian tribes, or under-trained staff will inhibit mutual access to information. Applying advanced technologies to watershed planning will be a great challenge to social scientists and planners, as they work to obtain access for groups who might be left behind. Information management decisions will be critical, as government agency funding is always subject to funding cutbacks that might imperil a well-developed data system. Keeping systems updated, as new information is developed, will require strategic decisions about long term funding and maintenance capabilities.

Regardless of these complications, for natural resource land and watershed planning, the organizations that recognize the empowerment value of the internet will be most successful. They will create constituencies for their plans and goals, and they will experience, we believe, much more stability in their external relations as a result.

Role of Social Sciences

We posit that social science and natural science research will have to more closely integrate their emphases including interdisciplinary approaches in order to provide the comprehensive tools necessary for effectively understanding and managing watersheds well into the next century. This integration is critically important, as humans influence resource systems, decisions about resource planning and management, and the means to engage in both the planning and the evaluation of its consequences.

Social science research will bolster not only process, but behavioral, regulatory, and policy improvements in wa-

tershed management planning well into the 21st century. The 21st century will also bring more refined social mechanisms for the interchange of ideas in watershed planning. In addition, there is likely to be broader understanding and acceptance of landowner responsibility for environmental outcomes of land use. We believe this development will not only be national in scale but international as well. A companion development will be well-established technical capabilities within landowner communities and more sophisticated and well-informed local agencies and publics.

Impressive progress has already occurred. As long as 15 years ago, natural resource managers were stimulated to negotiate settlements of disputes and regulatory standards. Now watershed interests have been advancing similar processes, starting with vigor less than 10 years ago. The collision of economic and social interests with the requirements of the ESA and the CWA is accelerating the number and types of collaborative processes. People are becoming increasingly adept at these efforts, and agencies are adopting facilitative processes all over the country at all levels of planning. The negotiations have not been all successful, nor are they without challenges, but some have succeeded, and people at least have begun to better understand the multiple viewpoints on a number of different issues.

As we move ahead, everyone will have to develop a greater understanding of the role of the social and natural sciences in policy-making. Although today's resource managers are often involved in research, and scientists are helping design management techniques and prescriptions for social action (a significant change from traditional roles), policy processes and scientific processes are, in fact, very separate. There is considerable disappointment and disillusionment when science-intensive policies "fail" to "solve" problems.

One reason for this disappointment can be traced to the fact that there is a vast "culture gap" between "policy" people and scientists. Simply providing managers with results from scientific studies is inadequate for policy development and implementation. This is a two-way problem: lack of scientific training for policy-makers, plus inability, and occasionally unwillingness, of scientists to understand policy processes and pressures, or to explain their science in terms usable by policy-makers. Science is incomplete, fragmentary, and hard for non-scientists to understand and use. A major problem is the high level of uncertainty in much of the science needed for policy-making. Unlike scientists, most policy makers are not trained to deal with and act upon fragmentary knowledge and high degrees of uncertainty.

Often, scientific information is in greatest demand when cause and effect relationships are most obscure. It is difficult to identify the scientific information needed to make good policy: if the information does not yet exist, it is routinely impossible to do the research to produce it on policy-makers' time-scales. As a consequence, many resource management decisions are made in the face of fundamental uncertainty. Science, which cannot predict a "specific" outcome, needs to relate to the need to predict the range of possible consequences.

Another challenge we face is that science-based solutions to environmental problems often fail primarily because the policy is not implemented appropriately or effectively, if at all. In fact, because of the failure of science-policy communication, policy decisions often are not implementable. Examples include (1) federal mandates on water quality that require analysis of contaminants far beyond scientific capabilities, and (2) the federal listing of west coast salmon runs as endangered, which will force local and state governments to design and implement costly remediation plans of unknown utility.

Incentives for Landowners and Water Users

Legal and institutional incentives for encouraging landowner and water—user involvement in a watershed planning process are relatively undeveloped. Our society is still largely focused on command and control intervention and penalties. Further, agencies arguably are still advised by risk-averse legal counsel, and many interest groups capitalize on risk-averse publics to advance single-purpose causes. This is a litigious society, and the natural resources sector is no exception. Legal challenge continues to be a course of action for many people. While not a useful device for solving complex, natural resource problems, litigation has been used effectively for halting actions within watersheds that plaintiffs wished stopped. There is a large amount of current litigation based on federal environmental laws, suggesting that the courts are believed by some to be the most effective redress for their convictions and values. This reality results in risk and uncertainty for the regulators and the regulated alike, and it constitutes a challenge to the effectiveness of consensus forums for resolving differences and gaining understanding of physical and biological relationships on watersheds. Nonetheless, within our democracy there is no avoiding the use of multiple forums, consensus processes or the courts. However, we note the continuing gridlock in national forest planning as a result of various opportunities for vetoing any proposed action through litigation. If the same pattern should carry over into watershed planning, all the possibilities for planning across multiple ownerships and land uses could come to naught.

All of these legal realities can be a significant impediment to advancement in collaborative watershed planning. Several newer approaches include Habitat Conser-

vation Plans between landowners, utilities, municipalities, and the federal government, conservation easements purchased with public funds, and conservation purchases with private funding in which owners or operators are compensated for alternative or modified uses of their land. In addition, proposals for tax concessions or credits to provide incentives for watershed and habitat improvements made by owners and users are being considered more seriously. We believe that incentives will gain a much stronger standing in the 21st century. Sequestration of carbon will likely be a major focus for forestry policy in the next century, and landowner and utility incentives for climate enhancing management should be on the agenda as part of watershed planning science and economic tradeoff analysis. Debate about how much owner/users should be compensated for costs they absorb in implementing watershed measures desired by the public, versus how much they should be willing to absorb under the mantle of environmental stewardship will move into the more sophisticated arena where people will confront compromises between the command and control approach and an incentive-centered approach. If we could wish our way into the 21st century, we would advance multi-resource, multi-ownership cooperation on watersheds that would accrue to the advantage of the public and owner/users alike. Arguably, the Forest and Fish Module, which was recently approved in Washington State and is described below, is a step in this direction, and may be an approach that other states would find useful.

Forest and Fish Module: An Experiment in Watershed Planning at the State Level

A 1997-1998 Washington State land use planning process involving diverse and sometimes adversarial interests in a consensus forum is called the Forest and Fish module. This effort was intended to set the stage for the next generation of forest practices on non-federal land in the State and involved 15 months of intense negotiations between industrial and non-industrial forest land owners, the State Department of Ecology and Department of Fish and Wildlife, the U.S. EPA, Fish and Wildlife Service, and National Marine Fisheries Service, counties, and treaty tribes. Although environmental interests participated in the early negotiations, they ultimately left the process and are extremely critical of the agreement. The process continued nonetheless and eventually resulted in a "Forest and Fish Plan" that was submitted to the legislature as Engrossed Substitute House Bill 2091. The proponents of the plan expect to provide functioning fish and wildlife habitat, and flexibility for landowners to sustain economic competitiveness for the life of the plan, which is expected to be on the order of 50 years. The plan includes only one principal watershed use, namely forest management.

Complexities ahead notwithstanding, the 1999 Washington State Legislature passed and the Governor signed into law the Forest and Fish Plan with bipartisan support, and included financial provisions for landowners to help meet conservation objectives. The principle of negotiated solutions between many widely diverse interests has been demonstrated and reinforced by the process, but one must ask whether there will be a newer model of engagement that replaces this often drawn-out and exhausting procedure. Environmental critics are particularly exercised at the science underlying the agreements. We posit that science must be transparent and even more integrated into the process in the next model, in order to both keep the parties at the table, and to help create a structure within the agreement that can be readily evaluated and monitored over time.

Research Needs

It is apparent that watershed planning is in its infancy, in part because it is complex owing to the interaction of physical, biological and social factors. Our knowledge base is limited in each of these areas, largely because of the scale at which planning in the coming century needs to be done. The stakes are high for our society and having good information will be an important key for successful policies and watershed plans. Societal investment in research is badly needed.

Clearly, we need more sophisticated and transparent systems for monitoring variables of interest to policy makers and the public, including runoff, water quality, fish populations and watershed condition, along with the data archiving, processing, and visualization capabilities that arguably can make these data useful and accessible for many critical groups.

We need to reinvest in basic hydrologic research that will improve our understanding of the linkages between various land uses and the variables of interest at the watershed scale. Understanding the complex pathways by which subsurface water moves on steep hillsides and its interactions with soil strength, erosion and landslide frequency is badly needed. We need to be able to trace the origins of non-point sources of pollution to sub-basins in watersheds and the practices causing them, as well as the incentives (educational, financial, technical, regulatory) that will encourage sources to control them.

Previous watershed studies focused on processes at the small catchment scale (usually less than a few hundred

acres). While such studies are still needed, we also need to understand how multiple land uses interact to affect water resources on much larger scales. We need to understand and predict how large scale disturbances or long-term management policies are likely to affect water resources in larger basins. In the West, perhaps the most important such disturbance is wildfire. Increasing fuel loads as a result of long-term management practices, particularly on federal forest lands, makes this an especially critical issue.

Sensor technology, that measures nutrient demand and stress, should play a much larger role in forestry, as it will in agriculture, for detection and rapid response to disease, insects, fire, and even marketability. Incentive based management and more widespread public acknowledgement of resource goals will help make these investments usable.

Our "watershed" research must be extended to include coastal estuaries and the near shore portion of the ocean that is so important to anadromous fish. In the West, one of the major drivers for managing and regulating land use practices in watersheds, including the urban portions, is the ESA restrictions associated with threatened or endangered runs of anadromous fish. Throughout the world's coasts, the ocean and estuarine conditions that affect fish populations must be better understood in terms of their relationships to other terrestrial conditions. Without this sorting out of knowledge and relative contribution to habitat quality or decline, socio-political decisions about how and where to best apply money for protection and mitigation of environmental conditions will continue to be haphazard and likely unsuccessful exercises. Further, it will be impossible to ascertain whether and how much changes in watershed practices are effective in helping to restore these threatened or endangered populations. Having said this, we also recognize that improved watershed habitat conditions and management practices are essential to the healthy restoration of these fish populations.

We provided examples of watershed planning that involved multiple property owners, operators, and resource users with multiple land uses. Successful watershed planning of this type is currently rare, but such efforts are growing, partly as a result of endangered species issues. We believe the model needs to advance a step, with a more transparent basis in the scientific and other inputs that go into policy decisions. For this to occur, information structures and decision tools must be shared by groups that are not used to sharing. Research can help bridge organizational barriers to information and prevent jurisdictional and institutional boundaries between and within various levels of government from hindering effective watershed management. In the West, for example, it is common to have large blocks of federal land juxtaposed with state and private land in a basin, each with different policies and regulations and limitations on the role of public participation in planning and decision making. These need to be coordinated, and sharing science and knowledge may be the most sure way to span those boundaries.

More research is needed to develop mechanisms for evaluating watershed policies and programs. The evaluation mechanisms must include more than a measure of simplistic outcomes (e.g., "bean counting" the number of enforcement notices, numbers of species listed, and so on). At present, evaluation efforts often result in a determination that policies have "failed" simply because we do not know how to comprehensively evaluate and measure the impacts of those policies and programs. If "adaptive" management principles are to be properly implemented, then a new generation of evaluation technologies must be developed and implemented as a part of policy. Without such evaluation capabilities, the promise of adaptive management as a formal, systematic, and rigorous approach for learning from the outcomes of management actions will not be fully realized. Since many watershed practices and policies are essentially experiments, the reliable feedback that adaptive management is intended to provide is critical for improving subsequent actions and objectives, and accommodating change.

Lastly, we need to increase the public investment in both natural and social science research related to watershed management and water resources. Given the magnitude of the water resources problems we face and the growing value of water as our population grows, the current level of investment at state and federal levels is inappropriately low. If we commit to incentive packages that reward effective planning behavior, devote energy to collaboration, rather than strife, and take advantage of technological advances that will help understand and monitor our natural systems, we may achieve both a more coherent watershed management policy and more effective regulation to boot. But it will take a concerted devotion to research, effective funding, and a new collaboration model to pull it off.

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