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EXECUTIVE SUMMARY

Investigating ecosystem dynamics at a watershed level

A White Paper produced from a conference sponsored by the Soil and Water Conservation Society held in Athens GA, April 13-16, 1997

Jean L. Steiner, Alan J. Franzluebbers, L. Mark Risse, Philip A. Moore, Jr., Charles A. Francis, Joyce Scheyer, Cornelia B. Flora, Rhonda R. Janke, William G. Deutsch, Stephen Gasteyer, Judy A. Tolk, William Upshaw

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1) Provide a forum for research scientists, land owners, agricultural advisors, policy makers, and others to discuss issues surrounding the topic "ecosystem dynamics at the watershed level."

2) Identify research, information, program, and policy needs at local, regional, national, and international levels to support this approach to land management.

The program included a mix of plenary sessions that highlighted issues to be addressed; poster sessions that gave examples of current projects, approaches to integrated team projects, and findings from diverse environments; facilitated breakout sessions for idea generation and synthesis of issues raised in the plenary and poster sessions; and conference tours that highlighted research, education, and agricultural activities within Southern Piedmont watersheds. Each breakout team included a writing team member who was responsible to capture key ideas and help incorporate those ideas into this white paper. The white paper is an integrated product of all who participated in the conference. Because the conference attracted participants primarily from the USA, that perspective predominates throughout the white paper. Still, the ideas and concepts have relevance to systems in many environments.

The conference was sponsored by the Soil and Water Conservation Society, and cosponsored by Soil Science Society of America, USDA Natural Resources Conservation Service (Watershed Science Institute, Grazing Lands Technology Institute, Social Sciences Institute, and Soil Quality Institute), USDA Agricultural Research Service, Tennessee Valley Authority, Cooperative Research Education Extension and Economic Service, Monsanto, US Environmental Protection Agency, Conservation Technology Information Center, Georgia Chapter of the Soil and Water Conservation Society, Univ. of Georgia College of Agricultural and Environmental Sciences, and Oconee County (Georgia) Chamber of Commerce. The financial and organizational support of conference Sponsors is gratefully acknowledged.

Jean L. Steiner, conference organizer

Ecosystem analysis at a watershed level

Healthy ecosystems require that economic, environmental, and social outcomes be adequately addressed, periodically reevaluated, and kept in balance. To develop and manage sustainable landscapes with multiple uses we need systems approaches that address dynamic characteristics of people and their environments as a whole and includes multiple feedback loops as integral to the process.

A watershed provides a practical scale for systems research and management, because boundaries can be defined and participants recognize their interrelatedness with others who share a water supply. It is essential to identify broad-based stakeholders, get them involved early, and maintain an open process so additional stakeholders can become involved. In holistic approaches to management, plans and actions are rooted in stakeholders' values and must address their highest priority goals. Time required to build participation, communication, and trust pays off through efficient solutions to shared problems.

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Research needs. Traditionally, animal scientists have studied animals, soil scientists have studied soils, plant scientists have studied plants, limnologists have studied water, atmospheric scientists have studied air; seldom have natural resource scientists collectively studied the whole system. Integration of natural resource with socioeconomic sciences is even rarer. Although we are obtaining increasingly detailed information on components of ecosystems, we need to comprehensively understand the structure of agriculture and effects of management on the entire ecosystem.

Economic theory as a whole is insufficient when dealing with things that have non-monetary value. We need an economic theory that balances (i) the value of ecological services of a watershed, (ii) environmental improvement, (iii) societal/cultural needs, and (iv) the ability to achieve financial goals. Although difficult, analyses that document inputs and outputs across political and watershed boundaries are needed to determine if practices are "good" for society as a whole and to determine types and quantity of incentives that could be provided.

Models provide a way to organize and communicate current understanding of key processes and interactions in a system. We need more complete conceptual and mathematical models that describe watershed processes and support informed decision making by stakeholders, but our understanding and data bases to construct such models are sparse and can only be addressed by comprehensive studies of ecosystem and watershed processes. Baseline data that measure quality of life, environmental quality, and ecosystem health are needed to provide indicators based on outcomes of an investment or action.

Education needs. Information concerning natural resources and ecosystem functions must be addressed to a broad-based community of stakeholders, including non-traditional audiences such as urban and suburban homeowners, the elderly, small businesses, and others. Knowledge needs to be packaged in practical ways such as "best management practices" for households, communities, agricultural lands, and forestry to encourage people to consider change

We need watershed-level educational programs to provide a critical link between research and application. This should include curricula for (i) lifelong environmental education, (ii) training the trainers on how to motivate a community to action, and (iii) a watershed and ecosystem focus for K-12 and university students.

Policy needs. Stakeholders of the system being managed should have primary responsibility to define goals and develop policies. While broad national policies for ecosystem protection are needed, successful implementation depends on stakeholders' values that may differ among regions.

Everyone supports ecosystem protection in some way, but individuals differ on points such as who should pay the costs and how much negative economic impact can be tolerated at the expense of ecosystem protection. We need "accounting" systems to compare monetary and non-monetary values, and to balance short-term and long-term economic or ecologic benefits.

Societal response to uncertainty about impacts has been to accept risks of negative impacts that we might be able to get by with. An alternative proposal based on the "precautionary principle" recognizes that there will always be uncertainty in quantifying impacts of pollutants within ecosystems, and that uncertainty should move us, as a society, to act with caution in protecting ecosystem function, rather than risking what we might be able to get by with.

Setting the direction for integrated natural resource systems management. In defining an agenda to support integrated ecosystem and watershed management, it is important to assess (i) what we know and the impacts of what we do; (ii) what we do not know but need to know to develop more sustainable systems; and (iii) what elements are important but inherently unknowable. We know that a factory model of production has caused many problems when applied to agricultural systems and that there are examples of more ecological approaches to farming that have succeeded in all parts of the world. We do not know how to implement and assess environmental quality impacts of agricultural systems using outcome-based, rather than design-based, standards. We will never be able to forecast future societal preferences, surprises, or the future "vision" that will drive agriculture or other production systems. To prepare for the "unknowable", we need strategies for a diversity of possible futures with adaptability to respond to social and environmental surprises.

Broad-based stakeholder involvement. The power of stakeholder involvement is starting to be recognized and institutionalized in agricultural and natural resource management programs. For emerging problems within ecosystems and watersheds that transcend the agricultural sector, additional stakeholders will need to be brought into the process, representing interests of all impacted by natural resource management. Research and management systems that are designed together should be monitored and evaluated together and stakeholder involvement is required from the outset.

Integrated research, education, and management. A systems approach provides a strategy to cope with ecosystem dynamics within watersheds. Such programs have high start-up costs, particularly in the time involved in establishing a stakeholder network, building trust that allows the group consensus process to succeed, and compiling baseline information. Monitoring impacts of change is also expensive. Concurrent research and education within natural resource management efforts could leverage limited resources for maximum impact and effectiveness. Institutional leaders should develop reward systems that encourage, rather than penalize, risk-taking researchers, educators, and practitioners who act "outside the box."

Hierarchical research programs. Just as ecosystems are hierarchical, there is a need for hierarchical research programs. Shorter-term studies to address different questions can often be embedded within long-term experiments. When the goal is to study the system as a whole, but there is a critical lack of understanding of a particular process within the system, it may be efficient to design a component study within the larger integrated study. A key is to ensure appropriate linkages within hierarchies.

Interagency cooperation and communication. Problems addressed within a watershed exceed the scope and mandate of any single local, state, or federal agency, so communication is needed across societal and agency lines. While many people work hard to achieve cooperation, there is so much information coming from so many different places that a systematic approach is needed to enhance quick and complete communication about diverse activities within a given watershed.

For a copy of the full text of this white paper contact SWCS, 7515 NE Ankeny Road, Ankeny, Iowa 50021-9764, attention Charlie Persinger.

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Jean L. Steiner

Conference Organizer

November, 1997

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Agroecosystem research using a holistic approach

Increased Environmental Awareness. Food and fiber production in the USA has never been greater and the retail cost of these products to consumers has never been more affordable than during the past three decades. Agricultural scientists have made enormous contributions to this phenomenal accomplishment. With less labor and fewer people directly involved in food and fiber production, more of the average American's time and money can now be spent on non-subsistence activities, including recreation such as water sports, appreciating nature and its beauty, and traveling. Ironically, because of the changes in agricultural and natural resource management practices and liberation from subsistence living, there is now an increased awareness of negative impacts of high-input farming, clear-cut forestry, mining of natural resources, industrial development, and urbanization on the water, air, and soil resources that all people depend on to maintain high quality of life. Degradation of water, air, and soils has occurred because environmental outcomes were not recognized as essential parts of the agronomic and economic objectives to produce more food and fiber for greater profit.

Increased environmental awareness is an important learning step toward people's acceptance of the concept of holism and the need to balance production and resource conservation. An ecosystem is a discrete unit that consists of living and non-living parts, interacting to form a stable system. The idea of holism recognizes that important properties of a system emerge from interactions among components, and therefore, you can not understand how a system functions by simply focusing on the components.

This is sometimes expressed as “the whole is more than the sum of the parts.” Ecosystems exist at many hierarchical scales and the boundaries are often difficult to delineate. Ecosystems function through distinct processes such as flow of energy through food-chains and cycling of nutrients. An important type of ecosystem is an agroecosystem, in which agriculture is an important component. In an agroecosystem, as in other systems with high levels of human management, economic productivity and processes become important in additional to the biological productivity and processes important to all ecosystems. Healthy, diversified agroecosystems require that economic, environmental, and social outcomes are adequately addressed, periodically reevaluated, and kept in balance. The merit of resource use for human purposes needs to be assessed by all interested parties in terms of social goals and the fate of resources.

Developing a new research paradigm. Traditionally, research has been implemented through a linear process consisting of basic research through applied research leading to technology transfer and education. There is little intrinsically wrong with this approach, but the process is often slow and tends to be narrowly focused, with collateral issues of substance receiving little attention. Complex problems often need simultaneous focus on basic and applied research and application across diverse disciplines. The public is demanding that research results be applied to problem solving more quickly than was common in the past. If we want to develop and manage sustainable landscapes with multiple uses we would be better served with a systems research approach that focuses on interactions. This strategy addresses dynamic characteristics of people and their environments as a whole, and includes multiple feed-back loops as integral to the process. Linear and systems approaches lead to different interpretations of reality that greatly influence the types of research questions. They need not be mutually exclusive, but could be complementary.

There are diverse approaches to systems research, but, in general, broader-based systems research is quite different from the linear model of research, particularly in (i) problem identification, (ii) partnership building and goal setting, (iii) communication, and (iv) participatory challenges. As discussed in another section, stakeholders must be identified and involved in identifying problems and potential causal relationships as well as setting priorities in what to address and envisioning the outcome. State-of-knowledge and available technology must be adequately evaluated in the quest to decide on priorities. Once researchable questions of high priority and concern to stakeholders have been developed, research goals must be implemented. This requires evaluating available resources, defining roles and responsibilities of participants, and setting timelines. A participatory approach that links multiple, specific research components to a common theme can help to divide responsibilities into manageable elements within the framework of defining and achieving goals.

Because research and its application continually unearth new questions, communication within the team must be an ongoing and evolutionary process. Problems, team building, and goal setting are periodically evaluated and prioritized in order to address relevant issues. Related ideas can be clustered and acted upon in unison to optimize the use of scarce resources. To derive the most impact and support from concerned stakeholders, consensus-building should be a key component of the systems approach of conducting research to help solve problems.

Important challenges face those using a systems research approach. Cross-disciplinary communication and understanding is required for effective collaboration. Issues of spatial and temporal scales are important when transferring knowledge from one hierarchical level of an ecosystem to another. Processes interact, but the points at which they have the greatest influence on the ecosystem need to be understood. Often, processes or factors that remain unknown are treated as "black boxes," yet understanding them may be the key to much greater system-level advances. Because stakeholders are numerous, the diverse objectives they bring can result in conflict, leading to the need to establish priorities while building consensus among participants.

Recognizing ecological principles. Ecosystems are composed of organisms (humans, large and small animals, plants, and microorganisms) assembled together within their environment. In general terms, the environment is composed of matter and energy. Matter is never lost, only recycled from one form to another. Depending upon the boundaries, matter can be transported in or out of the system, and continually flows among system components as the ecosystem functions. Energy, however, flows through the system unidirectionally from solar radiation to chemical storage via photosynthetic organisms and later is released after use by animals and microorganisms. In some cases, the ultimate release of chemically-stored energy may be much later, e.g., fossil fuels. In many cases, energy leaves the system in a bound form, such as exported agricultural or forestry products, and some ends up in landfills for future archeologists to discover.

Healthy, functioning ecosystems are composed of a multitude of interactions among the biotic and abiotic components. Organisms continually respond to and alter their environment. These evolutionary facets of ecosystems defy the concept of equilibrium; i.e., in the long-term, change is inevitable. Steady-state conditions can be realized only in relatively short time frames, with the time frame lasting a few seconds for some processes to millennia for others. Humankind has always changed its environment, but attention to ecological principles when addressing human goals can help avert disasters and lead to long-term sustainability of earth's resources.

Because matter is never lost, but merely transformed and relocated within the environment, several ecologically-based concerns about current land management deserve attention. Concentration of industries and farm animals into limited geographic areas without adequate attention to the build-up of by-products results from a short-term vision that does not recognize the implications of these accumulations. For example, feed grain is produced in midwestern USA, shipped to large-scale animal operations in surrounding regions, meat shipped primarily to urban centers in the eastern USA, and the manure left in the hands of animal producers who have often limited land available to redistribute the nutrients and no economic incentive to do so. Nutrient losses from surface runoff and leaching can then lead to eutrophication and contamination of water supplies. Export of grain from midwestern USA requires replenishment of nutrients to the soil, which could have been supplied, at least in part, by animal manure if animal feeding operations were integrated into the local economy, rather than separated geographically.

In addition, the ecological principle of capturing energy from sunlight and storing energy and nutrients within plants has not been utilized to its fullest in modern agroecosystems, which have relied on fossil fuel inputs to generate high productivity. For example, cover crops offer great potential to store energy and excess nutrients during winter, but are not widely used in USA agriculture. This leaves nutrients susceptible to leaching into groundwater where they may contaminate drinking supplies. Maintaining vegetative cover on the soil decreases soil erosion, increases soil microbial activity and conserves nutrients within the active organic-inorganic cycle, and reduces runoff of water, nutrients, and pesticides, all of which contribute to sustainability of the soil resource.

Balance is critical for ecosystems to survive and to be sustainable. Contamination of the environment changes the type and quantity of organisms that are able to function within the ecosystem, whether such contamination is from nutrients and sediment in water, heavy metals and pesticides in soil, or smog and trace gases in air. Because organisms cycle matter in the environment, human-induced environmental limitations contribute to the excesses of matter that, for example, shift aquatic biologic activity toward lower trophic level organisms.

Suitability of ecosystem analysis at a watershed level. Ecosystems can be defined at many scales, i.e. a soil pore, a field, a farm, a watershed, a geographic region, a continent, or the earth. A watershed level is often an appropriate scale for natural resource management and research. Water flows along channels within a watershed and converges at a common mouth. People and other organisms within the watershed are more commonly affected by activities of others within that watershed than within larger areas. At a watershed level, impacts of land management on water quality can be identified in the water leaving the watershed. A watershed exhibits a range of land uses that also typically interact at larger scales. Mutual interdependence is clear within watersheds, although specific interactions differ for each farm, industry, or consumer.

For some natural resource problems, watersheds may not be the most appropriate scale. Watersheds often cross political and social boundaries and this must be accounted for. Some problems of nutrients, odors, and water transfer can be addressed at the farm level, but interactivity with neighboring land uses that impact, but are not controlled by, the farm need to be addressed. Some issues, such as massive nutrient transfers between regions inherent to agricultural production systems that are dominant in the USA and many other countries, should be addressed at the regional, national, or global scale.

Approaches and tools

Initiating ecosystem projects at watershed scales. When the watershed is selected as an appropriate and preferred unit of ecosystem management, a broad base of stakeholders must be involved from the inception. A stakeholder is any person or group with an interest or a stake in the health of the watershed or ecosystem being addressed. Some stakeholders live in the watershed, some do not. Some earn their living in the watershed. Stakeholders may have an interest because they own land; because of ancestral links; because they value the recreational, wildlife, or aesthetic aspects of the watershed; because they consume food produced in the watershed; or because they have commerce impacted by the watershed. Other species and future generations of humans are also stakeholders in today's management systems; their interests are addressed because a living, human stakeholder deeply believes in the value of their interests. A key requirement for success is identifying stakeholders, getting them involved early, and maintaining an open process so that persons not initially identified as stakeholders have the opportunity to become involved. Participation of land owners as key stakeholders is essential, since management decisions about a specific parcel of land are linked to land ownership.

It is essential to clearly define the boundaries of the system to be managed; key land uses, communities, and activities included in the watershed; and major factors that influence or are influenced by the condition of the watershed. The entire process must be iterative since physical or biological features may change or may not readily be recognized as important. Additional stakeholders may be identified who need to be engaged at various stages.

A key characteristic of holistic approaches to management, and also research, is the recognition that plans and actions are rooted in the values of the stakeholders and address their highest priority goals within limitations of available resources. Stakeholders come to the table with diverse and sometimes conflicting perceptions, values, and objectives. However, there are common values among stakeholders that make it possible to identify shared goals and move forward. Respect for individuals with different views is key to the success of this process. At the beginning, issues to be addressed should be brought into the open, often through brainstorming sessions where all ideas should be accepted and recorded without judgement. The next step is to cluster and identify common threads among stakeholders. As the boundaries of the system increase from relatively local to regional, national, or global levels, common values generally become broader (e.g., the well-being of grandchildren now and into the future, good health, a safe and secure food supply).

Many projects fail as a result of improperly handled controversy arising from lack of communication and cooperation among stakeholders. A common error that leads to controversy is categorization of stakeholders. Stakeholders "defined" as part of an interest group are more apt to recognize common values within that group rather than realizing that many other groups hold common values. For instance, an agricultural stakeholder may appear to have goals that conflict with those of an environmental stakeholder, when in fact, both want to protect water quality, even though they may disagree on the degree, method, and reasons for protecting water quality. Broad-based values, problems, and goals of the group as a whole should be developed through a consensus process as the basis for research or management activities. This being said, it should be recognized that this is not an easy process, but takes the form of a negotiation.

Thorough and creative evaluation of available resources (natural, human, financial, and social) to address problems is needed (Figure 1). It takes time to build community participation, communication, and trust, but once that has been achieved, solution of problems through voluntary approaches, based on mutual self-interest and respect within the community, reduces the cost compared to regulatory or judicial approaches. Participatory monitoring and evaluation, with clearly identified indicators of success or lack of success will allow for real time changes as needed.

Tools for ecosystem analysis at watershed scales. Much information and many tools are available to support natural resource management, but may not be easily adapted to watershed-based systems. For instance, extensive soil data exist, but in the USA, soil maps are established on a county or political boundary basis. Numerous data are available on population, demographics, agricultural production, forestry, nutrient use, irrigation, and other important information, but such data are organized along county and state lines. Watersheds often cross jurisdictional lines, such as county, state, or national boundaries, and considerable effort is needed to compile data from numerous sources. The data may have been compiled differently within adjacent areas, causing apparent discontinuities at borders. Most data are not available in electronic geo-referenced formats, which would provide a powerful information management tool. The result is that considerable expense is incurred to prepare data overlays for a given watershed. Information about organisms within watersheds is usually much less complete than information about the physical resource base. Organisms are always changing, they are seasonal and often mobile, and we haven't devoted the same systematic approach toward inventory of species and habitats as we have to inventory of weather, soils, and geology.

We have several tools to assess resource conditions and their trends, e.g., the National Resources Inventory. However, such tools may not be well-suited to the desired analysis. Most tools and models are not balanced across all aspects of the system. In some, biophysical relationships are detailed, but socioeconomic relationships are simplistic or lacking and *vice versa*. In agricultural models, ecologic aspects such as spatial variability, competition, succession, and population dynamics are often lacking. Ecologic models frequently lack a human management component.

There are numerous approaches to experimental design and statistical analysis that are seldom applied to natural resources and agricultural research. Individual researchers tend to use only a few of the designs available. As we use different approaches to design research around larger and more complex systems, we will often have to accept and learn how to interpret less precise answers that have greater levels of uncertainty associated with the answers.

Watershed projects can help bridge between those who do research and stakeholders who may have limited knowledge of the concepts behind research. A stakeholder's belief in the value of the ecosystem, to them personally and as part of a larger society, precedes the stakeholder's commitment to protect or rehabilitate the natural resources. Monitoring effects of management changes and conservation investments often requires volunteer workers and local donations of funds. Unfortunately, community involvement and motivation techniques seem to alienate some scientists, and scientific models of ecosystem dynamics or biodiversity appear to challenge laypeople.

Research, education, and policy needs for ecosystem management

Research needs. Traditionally, animal scientists have studied animals, soil scientists have studied soils, plant scientists have studied plants, limnologists have studied water, atmospheric scientists have studied air; seldom have these natural resource scientists collectively studied the whole system. Integration of socioeconomic sciences with natural resource sciences is even rarer. Many scientists hesitate to venture beyond their field of specialization, mainly because reward systems within university, government agencies, and businesses support the *status quo*. In addition, specialists are often given greater respect than generalists. As a result, people usually only examine one or two aspects of extremely complex systems. This myopic approach to research in natural resource management often results in more questions than answers when the research is complete.

Although we are obtaining increasingly detailed and needed information on specific effects of management on components of the ecosystem, there is still a great need to comprehensively understand the structure of agriculture and effects of management on the entire ecosystem. Benefits of a particular management strategy to one component of an ecosystem may be detrimental to other components. Yet, we have not devised approaches that allow us to evaluate diverse criteria that are important to different stakeholders.

Comprehensive analyses of costs and values are needed on several scales, such as the farm, the watershed, and the ecosystem. Economic theory as a whole is insufficient when dealing with things that have non-monetary value. We need an economic theory that balances (i) the value of ecological services of a watershed, (ii) environmental improvement, (iii) societal/cultural needs, and (iv) the ability to achieve financial goals. Research is needed on the ecosystem value of improved water, soil, or environmental quality to communities or regions, rather than just focusing on costs and benefits to the individual who implements management practices.

Although difficult, analyses that document inputs and outputs across political and watershed boundaries are needed to determine if practices are "good" for society as a whole and to determine the type and quantity of incentives that could be provided by local, state or federal agencies. Incentives could include cost-sharing programs that have commonly been used to support natural resource conservation goals, but we also need better understanding of the complex mix of factors that motivate individuals to change their ecosystem management practices.

Site-specific, quantitative baseline data that measure quality of life, environmental quality, and ecosystem health are needed provide indicators based on outcomes (change in baseline criteria) of an investment or action. Few data exist to quantify acceptable amounts of pollutants entering watersheds or interactions among air, soil, and water. How can limits be developed for non-point source pollution when the acceptable levels may be unknown? A prime example of this problem is phosphorus. Each year, millions of dollars are spent on research to reduce phosphorus runoff from agricultural fields; yet there are few guidelines, goals, or targets on the levels of phosphorus that specific aquatic systems can assimilate without causing problems. Scientists who study sustainable agriculture typically measure amounts of pollutants in streams or in runoff water, but rarely measure impacts of pollutants. There needs to be more research where cause and effect relationships are established that show the impact of the pollutant in question in the system of interest.

We have limited understanding of how management practices perform during episodic weather events and over long time periods. If a management practice does not work during critical periods, such as a big thunderstorm, its value is limited. Likewise, the life expectancy of a management practice should always be evaluated. A constructed wetland may remove phosphorus from swine lagoon effluent extremely well for the first few years, but what happens after 20 years? Also, when a management practice is implemented in a biological system, we must assume we might have made the wrong decision and monitor for the result (e.g., introduction of kudzu or multi-flora rose had many unintended effects that weren't identified until their distribution was wide-spread).

There is a need to develop better tools to study interactions within ecosystems, as well as conceptual and mathematical models that describe watershed processes to support informed decision making by the stakeholders. Models provide a way for systems scientists to organize and communicate current understanding of key processes and interactions. Compared to models currently available, future models need to be more balanced across disciplines and be able to deal with extreme events, issues of scale, and transport and feedback across boundaries. Impacts predicted by the models should include not only chemical and biological effects, but economic and social impacts, and should be able to support multiple-objective problem solving (e.g., decisions that meet economic as well as environmental and social goals; decisions that meet current as well as future needs). Our understanding and data bases to construct such models are very sparse and can only be addressed by comprehensive studies of ecosystem and watershed processes. In this process, it is necessary to realize and define what questions and data requirements are actually necessary. We need to ensure that models are developed and data collected only to meet clearly defined objectives. We should not collect data for data's sake, nor build models, for modeling's sake.

Education needs. Development of effective ecosystem management and policy can be enhanced through education and communication. Letting people know what has worked or failed in other areas, what new technology has been developed recently, and what the status of their ecosystem is will contribute to the quality of policy making and decisions about ecosystem management. Bringing natural resource management to the community level will encourage greater stakeholder participation, show stakeholders how they affect the ecosystem, and promote informed decision-making about natural resources and ecosystems.

Consumer education is needed regarding environmental impacts of production practices. In today's production systems, costs are often externalized to achieve profitability. Many consumers choose to pay more for products where costs are not externalized. For example, organic fruits and vegetables cost more, but consumers are often willing to pay increased prices either out of concern for their health or that of the ecosystem. If enough people make similar choices then the market can help bring about change. To do this, the public must have knowledge of different production practices and impacts of these practices on the environment. Individuals also need to be aware of how their own lifestyles impact shared resources within their watersheds (e.g., how their communities handle waste disposal and alternatives for minimization of waste and improved cycling of wastes). Knowledge needs to be packaged in practical ways such as "best management practices" for households, communities, agricultural lands, and forestry to encourage people to consider change.

Information concerning natural resources and ecosystem functions must be addressed to a broad-based community of stakeholders, including non-traditional audiences such as urban and suburban homeowners, the elderly, small businesses, and others. In addition, education of traditional audiences must change as user needs change. While the Internet provides an opportunity to reach diverse audiences, do many educators know how to use it to communicate information in a format that meets diverse user objectives? It is important to develop more effective connections between the knowledge base and the communication base. As one participant stated, "... is research on best communication and environmental education approaches a valid research agenda?".

In spite of a stated emphasis by many state and federal agencies on whole-farm and large-scale plans and programs, we are only entering the frontier of basic understanding of landscape and watershed function. We design financial support packages and multi-farm activities to promote improved agricultural practices and watershed function, yet these programs are often designed with incomplete data bases.

Strong research-application linkages are needed to meet the needs of field technical assistance people. In addition, to facilitate stakeholder involvement and communication, public servants need to learn how to promote communication among people with diverse values, perceptions, and learning styles.

There is a clear need for watershed-level integration in formal educational programs at all levels to provide a critical link between research and application. This should include curricula for (i) lifelong environmental education, (ii) training the trainers on how to motivate a community to action, and (iii) a watershed and ecosystem focus for K-12 and university students. Beyond the current strong interest in components of the science curriculum that focus on ecology and environment -- promoting recycling, protecting biodiversity, planting trees -- there is a need to help students understand the fragility of ecosystems and the complexity of human roles in ecosystems. Agroecosystem performance is especially important to human survival because of the need for food in a world with increasing population and decreasing arable land. The lack of understanding of where food comes from, and how this depends on the health of agricultural production ecosystems, provides a substantial challenge to educators planning curricula into the next century. Those with awareness and concern about education on watershed diversity, function, and health have a special obligation to take this special knowledge to the general public, and to promote a stronger emphasis on this topic in our future curricula.

Policy needs. Development of management policies to protect regional ecosystems and their critical functions is needed in a sustainable society. But, who's role is it to define and develop these policies and what should these policies entail? Participants in the conference felt that stakeholders of the system being managed should have primary responsibility. It is important that stakeholders participate in policy development at early stages. While broad national policies for ecosystem protection are needed, successful implementation depends on stakeholders' values that may differ among regions. Clearly, more policy needs to be implemented at the local level, and public agencies should work as partners or facilitators rather than regulators to ensure that all the stakeholders are represented. Although everyone in a watershed is affected by ecosystem dynamics, those who are directly affected are most prone to act. Locally led conservation requires that interests of all key stakeholders be addressed and that the group be focused on win-win solutions. Public servants need strategies that encourage stakeholders to be pro-active in policy development, rather than developing policies and waiting for the stakeholders to react.

Regulation will be needed in some cases, but it should come from local societal pressures in support of the broad principle of "polluter pays". There have been success stories whereby volunteer citizens were able to positively influence water-quality policy at the local and state level.

Everyone supports ecosystem protection in some way, but individuals differ on points such as who should pay the costs and how much negative economic impact can be tolerated at the expense of ecosystem protection. We need policies that address socioeconomic and natural resource costs and values, and that identify who benefits and who pays. This is required to determine returns on environmental investments and would influence how we finance and support watershed and ecosystem protection practices. If individuals are expected to make management changes that provide benefits to society at large, then equitable compensation should be ensured. The traditional cost/benefit analysis approach has failed to support sound ecological management, because the system allows individuals or groups to realize the economic benefits of an action while leaving society at large to absorb some of the financial and environmental costs of that action. We have no effective system to compare monetary and non-monetary values, and short-term economic benefits have been given far greater weight than long-term economic or ecologic benefits.

Our response to uncertainty about impacts has been to accept risks of negative impacts that we might be able to get by with. An alternative proposal based on the "precautionary principle" recognizes that there will always be uncertainty when we try to quantify impacts of pollutants within ecosystems, and that uncertainty should move us, as a society, to act with caution in protecting ecosystem function, rather than trying to risk what we might be able to get by with.

The right to drink clean water, breath clean air, and enjoy a healthy environment is valued by individuals. As one conference speaker stated, "Everyone has the right to not be poisoned". Effective policies should reward and promote activities that ensure environmental quality while achieving a diverse array of goals. Many times people believe that to do something in an environmentally "friendly" way will hurt them economically. Before individuals voluntarily change their practices, they must be shown that they will not suffer the anticipated economic loss, that they will gain environmental or social benefits worth the economic cost, or that others who benefit from the environmental gain will help bear the economic costs. In some cases, stakeholders may be willing to invest resources into "ideal" systems that would be highly sustainable, but require major social or cultural changes. In other cases, changes that temporarily prevent some problems but do not provide long term solutions will be the only option that all stakeholders can agree upon. Policies need to be analyzed to determine if they are treating causes or symptoms.

Stakeholders must realize that effective policies and ecosystem improvement are not developed overnight. In an iterative process, we make changes in the system in response to a problem, we monitor and evaluate these changes, and from this, future improvements are proposed. New knowledge and technological advances may have a profound effect on the way a system functions and on the program needs. Public awareness and communication are essential feedback loops in the iterative process.

Setting the Direction for Integrated Natural Resource Systems Management

In defining a research, education, and policy agenda to support integrated ecosystem and watershed management, it is important to assess (i) what we know and the impacts of what we do; (ii) what we do not know but need to know to develop more sustainable systems; and (iii) what elements are important but inherently unknowable. Many current agricultural systems have not achieved the goal of sustainability and in many cases we know the principles of how to solve major problems. For instance, we know that soils erode when exposed to high intensity rainfall and that crop residues or growing plants protect the soil surface from erosion by from high intensity rainfall. We know that nutrients applied to agricultural fields move across or through soils and contaminate water sources and that these losses can often be reduced through the use of nutrient management plans. We also know that the industrial or factory model of production has caused many problems when applied to agricultural systems and that there are many examples of more ecological approaches to farming that have succeeded in all parts of the world.

There are many things we do not know about ecosystem dynamics at the watershed level. As one Conference speaker said, "What we don't know is the full range of species richness that exists in any given watershed, nor do we fully understand how such species richness could be applied to the production goals of an ecologically based agriculture." For instance, an important research and technology development focus has been the search for biological solutions to many agricultural production problems that are now approached with chemical and engineering solutions. We do not know how to solve some very large problems, such as how to control erosion from infrequent, high-impact storms or how to balance nutrient budgets of large animal production units within small geographic regions. We also do not know how to implement and assess environmental quality impacts of agricultural systems using outcome-based standards rather than design-based standards.

Agriculture and natural resource management are strongly influenced by things that are inherently unknowable. We will never fully understand how diversity within an ecosystem - plants, insects, animals, microbes - hangs together, because intricate, complex interactions co-evolve and will always exceed our capacity to comprehend. We will never be able to forecast future societal preferences (e.g., food products, environmental concerns), the future "vision" that will drive development of agricultural production systems (recent examples are precision agriculture or low input sustainable agriculture), or surprises (e.g., ozone hole, Legionnaire's disease, *Cryptospiridium* in public water supplies). To prepare for the "unknowable", we need strategies for a diversity of possible agricultural futures with adaptability to respond to social and environmental surprises. We attempt to control "net community productivity" that is harvested for our use, but, in ecologically-based agriculture, production goals are fit into a specific ecological neighborhood and farmers learn to live with and mitigate risks through diversification, flexibility, and adaptation. The way we adapt to weather and earthquakes may provide a better model for farming than the way we run factories. Complex interactions within watersheds are not predictable or completely controllable, nor is agriculture.

Participatory, holistic approaches allow us to tackle complex issues that we cannot solve through reductionist research. A watershed provides a practical scale for systems research and management, because the boundaries of the system can be defined and participants recognize their interrelatedness with others who share a water supply. It is essential to identify stakeholders who represent a broad array of interests in the system, get them involved early, and maintain an open process so that groups and individuals not initially identified as stakeholders have opportunities to become involved. In some cases leadership in initiating a project and developing a stakeholder group may come from research groups, but in many cases, community education or action agencies are better positioned to build broad-based networks and maintain them over extended periods. In holistic approaches to ecosystem management at the watershed level, plans and actions are rooted in the values of stakeholders and must address their highest priority goals within the limitations of available resources. Stakeholders come to the table with diverse and sometimes conflicting perceptions and values. However, there are common values among stakeholders that make it possible to identify shared goals and move forward. By respecting individuals with different views, it should be possible to identify values, problems, and goals of the group as a whole. The process requires a long-term commitment of individuals and groups because it is an iterative process whereby progress is evaluated and goals are assessed and modified when needed to meet evolving priorities of the group.

The considerable time required to build community-based participation, communication, and trust pays off through efficient solutions to shared problems. Participation in a successful holistic research and management process is satisfying, because the approach is rooted in our societal values of individual autonomy and democratic action.

Recommendations

Broad-based stakeholder involvement. The powerful impact of stakeholder involvement is starting to be recognized and institutionalized, for instance by the USDA Southern Region Sustainable Agriculture Research and Education programs that require a systems approach and farmer involvement in all research and education proposals. The Environmental Protection Agency works through states to implement the Clean Water Act. The state agencies use diverse strategies to gather local input. The 1996 Farm Bill also required that conservation funds be prioritized to the highest priority problems as identified by local work groups convened by Soil and Water Conservation Districts throughout the country. For emerging problems within ecosystems and watersheds that transcend the agricultural sector, additional stakeholders will need to be brought into the process representing the interests of all impacted by natural resource management. Research and management systems that are designed together must also be monitored and evaluated together and stakeholder involvement is required from the outset.

Integrated research, education, and management programs. Systems research and management programs provide a strategy to cope with ecosystem dynamics within watersheds. These types of programs have very high start-up costs, particularly in the time involved in establishing a stakeholder network, building trust that allows the group consensus process to succeed, and compiling baseline information. Monitoring impacts of change is also quite expensive because of the large areas and complex interactions within ecosystems and watersheds. Therefore, concurrent research and education within natural resource management efforts could leverage the limited resources of all for maximum impact and effectiveness. Participants with different perspectives also learn from each other. The shared experiences make the efforts of each more effective in meeting diverse needs of stakeholders. Institutional leaders should develop flexible systems that encourage, rather than penalize, risk-taking researchers, educators, and practitioners who act "outside the box".

Hierarchical research programs. Just as ecosystems are hierarchical, there is a need for hierarchical research programs. Some questions can only be addressed through long-term research, but because it is expensive to establish and maintain long term research sites, agencies that support the research and individuals that conduct the research need shorter-term payoff. Shorter-term studies to address different questions can often be embedded within the design of long-term experiments. Similarly, when the goal is to study the system as a whole, but there is a critical lack of understanding of a particular process within a component of the system, it may be possible to design a reductionist study within the larger integrated study. This should improve the efficiency of interpreting results from reductionist studies within the broader context. A key is to ensure appropriate linkages between hierarchies.

Interagency cooperation and communication. Problems addressed within a watershed exceed the scope and mandate of any single local, state, or federal agency. Therefore, to succeed in watershed research and management, communication is needed across societal and agency lines. While many people work hard to achieve such cooperation, there is so much information coming from so many different places that a systematic approach is needed to enhance quick and complete communication about diverse activities within a given watershed.

List of figures