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Sustaining the benefits of integrated watershed management: coping with climatic variability and change

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A key challenge confronting people of the world in the near future is likely to be centered on developing strategies to cope with the inherent climatic variability and climatic change. One concern of the managers of land and natural resources is retaining the multiple benefits of integrated watershed management (IWM) such as sustainable use of water, wood, forage, and wildlife resources while sustaining food production in the face of future climatic variability. IWM is a managerial framework for sustaining the use of natural resources and environmental services that a watershed can offer. We consider how people can sustain the multiple benefits of IWM while coping with future climatic variability and change in this paper. We outline the tenets of IWM and then suggest that the benefits of IWM can be sustained into the future through a participatory, highly coordinated, and flexible planning process. Applying tools such as dendrochronology, also known as tree-ring analysis, can help in structuring stochastic models to simulate future IWM benefits. Insuring that these benefits are sustainable in the face of climatic variability and change can require increased technology development, institutional innovations, and increased investments in land stewardship. Importantly, people need to understand how their use of land and water affects and can sustain natural resources and food production under climatic variability and change.

Key words: Climatic variability and change, natural resources, integrated watershed management, sustainability**.**

INTRODUCTION

Paleoclimatology tells us that periodically—about every 250 million years or so—ice has covered as much as 40 percent of the earths' surface, spreading from the polar regions (Sellers, 1965). There were at least four glacial ages and three interglacial ages during the Pleistocene epoch when global temperatures averaged 6^{o} C below and 3^{o}C above the worldwide temperatures of the 1990s, respectively. Although currently we are within an interglacial period, one might expect that such long-term changes in climatic conditions would occur regardless of what people do. Some people indicate that the climate is getting warmer [34,35], others suggest that the climate is becoming drier [37], and still others believe that the recently observed climatic changes are part of the natural variability of longer-term climatic conditions [24]. While there is increasing evidence that we are undergoing a warming trend across the globe, the extent to which this warming is human induced, an acceleration of natural warming trends, embedded in natural climatic variability and change, or a combination of all of these factors has become a controversial issue among climatologists, resource managers, and concerned lay people. There are suggestions that warming is causing precipitation to increase and intensify in some parts of the world, while elsewhere there are suggestions that precipitation is decreasing and possibly leading to more pronounced droughts. Climate change, therefore, is one of the more challenging concerns currently confronting the people of the world at this time.

It is not our intent to enter into the ongoing and often contentious debate on whether climate change is human induced or what kinds of climatic changes are actually occurring. Some investigators, for example Kerr [27], have suggested that a decade-long stagnation in earlier global warming has taken place since the late 1990s, although many of these same researchers also believe that this pause in warming is only temporary. They argue that a natural swing in climatic conditions to the cool side has been holding greenhouse gasses back, but that such swings do not last forever. The debate on climatic change will continue regardless of the perspective taken [29]. We do know, however, that the world's climate has always been highly variable and largely unpredictable. Historical climatic records and analysis of annual growth rings of older trees show considerable variability in temperature and precipitation regimes over time and space. A key challenge in our option, therefore, is to be able to cope with climatic variability and the uncertainty of future climatic changes.

We believe that it is reasonable to consider that past, present, and future climatic changes are embedded in the long-term (historical) climatic variability and change for a geographic region. It will be necessary, therefore, that watershed managers develop an effective strategy and planning process to cope with climatic variability and possible changes in climatic conditions while sustaining natural resources for commodities and amenities. More specifically, we will consider how people can sustain the benefits obtained through integrated watershed management (IWM) regardless of how future climatic variability might be defined. We will outline the tenets of IWM in this paper and then suggest that the benefits of IWM can be sustained into the future through a participatory, highly coordinated, and flexible planning process. Linking of people to their natural resources and the effects that climatic variability and change can have on these resources is considered initially to place our discussion in perspective.

LINKING PEOPLE TO THEIR NATURAL RESOURCES

Linking people to their natural resources is paramount in effectively managing these resources into the future regardless of the climatic conditions encountered. The ways that people use land, water, and other natural resources can satisfy their needs for food, fiber, forage, and other ecosystem benefits when these uses do not impact adversely on the sustainability of natural resources or quality of the environment in which these natural resources are found. This balance must be appreciated by both the people using the resources and the people responsible for planning and managing for the proper use of these resources on a sustainable basis [22,21]. Transforming this knowledge into sustainable uses of their natural resources is guided by management practices that enable people to develop, sustain, or increase:

Water supplies

- Food production through cropping systems that are in concert with the environmental conditions confronted
- Wood for people's uses and trees for environmental values
- Livestock production
- Combinations of these and other welfare goals

Two questions that might be asked at this point are (1) who are the managers of watersheds and their natural resources (2) what are their specific tasks and responsibilities in satisfying the objectives of managing these natural resources? In some instances, there are technically trained people with the title of "watershed manager" who have responsibilities for managing watersheds to provide water to people. The emergence of watershed management councils and other quasi-governmental organizations to resolve the continuing conflicts over water issues among people, municipalities, and regions also represent institutions with watershed management authority. In the majority of cases, however, the management of watersheds resides largely in the hands of the users of the natural resources on the watersheds—that is, water managers, foresters, livestock producers, farmers, recreationalists, urban developers, and so on. While one might encounter someone with the title of "agronomist," "forester," "engineer," "forester," "livestock specialist," or agronomist," all of the users of natural resources should be aware that they also play the role of watershed manager.

People's Response to Climatic Variability and Change. Actions taken by people to cope with the vagaries of climatic variability and change can be grouped generally by adaptation or mitigation [36,20]. *Adaptation* refers to changes in natural or human systems that enable people to moderate the impacts of climatic variability or, in some cases, exploit the benefits of climatic variability and change. *Mitigation* refers to actions that, for example, can reduce climatic warming by decreasing emissions or enhancing the sinks of greenhouse gasses. We stress adaptation in this paper, although both types of actions are integral components of managing natural resources on watersheds; this is where IWM becomes relevant.

Impacts of Climatic Variability and Change on People. How climate variability and change might impact on people and their use of natural resources in the future is difficult to determine because the array of possible impacts is not always known. However, questions that people might ask about these possible effects include:

- Will climatic conditions in the future be warmer or cooler or drier or wetter?
- Will there be lower or higher flows of water from upland watersheds into rivers and downstream reservoirs?
- Will flooding be less or more frequent?
- Will droughts be longer or shorter, more intense or less intense?

Climatic variability and change also can impact economic and financial infrastures and the commodities and amenities that are derived from natural resources and made available to people in varying combinations and magnitudes [45,3,26]. Climatic variability and change can have a broad effect on people, including:

- Human health through changes in waterborne diseases causing hazards to human life and well-being because of long periods of low flows, or more frequent flooding,
- Availability and sustainable use of energy, for example, as a result of changes in the output of hydropower because of a lowering or increasing of water flows.
- Commercial navigation and transportation of goods and services to consumers because of declining levels of rivers and other water-bodies.
- Agriculture and forestry interests can be impacted detrimentally if changes in the timing of rainfall delay spring planting of agricultural crops, or if warming temperatures cause earlier snowmelt in the spring that affects the ability to store water for dry season demands, or that alters soil moisture that influences the occurrence and severity of forest fires.
- Infrastructure damages in urban areas from the effects of increasing rainfall causing more frequent flooding.

Minimizing the detrimental effects to these and other sectors that can be caused by climatic variability and change must consider both the technical and socioeconomical feasibility of proposed managerial actions.

Impacts of Uncertainties in Climatic Variability and Change. The competition for natural resources by different economic sectors is often exacerbated by extremes in water availability. Lazarus [29] discusses the water-energy-food nexus that confronts planners and resource managers and, in doing so, threatens the sustainability of agricultural production for future generations. Most types of energy production (coal, natural gas, nuclear plants) require water as do all food production systems. For example, recent development of corn ethanol as a biofuel has resulted in increased competition for water to grow corn for energy or for food. Lazarus also stated that there is a need for conjunctive management of multiple resources and, importantly, a need to integrate water resources planning and management at the watershed or larger river basin scale with energy resources at the grid scale. We suggest that IWM provides an effective context for planning and managing these resources to cope with climatic uncertainty in the future.

INTEGRATED WATERSHED MANAGEMENT

Adapting to the effects of climatic variability and change on sustainability of natural resources requires a combination of traditional and innovative methods of managing natural resources and ecosystem services that are more resilient under varying climatic conditions. In the following, we outline the tenets of IWM and indicate how this more holistic strategy contributes to a more sustainable approach for planning, managing, and using natural resources that helps people cope with future climatic variability and change [8, 6, 22]. It is necessary that people recognize that managing natural resources and the environments in which people live is increasingly challenging as human populations increase worldwide (see Box 1). The demands by people for land, water, and other natural resources become more difficult to meet on a global basis as a consequence. At the same time, we believe there is growing awareness that institutional mechanisms to meet this challenge are effective only when they are grounded in the technical and socioeconomic realities that connect people to their natural resources.

Box 1

A Worldwide View of Managing Natural Resources and the Environment. The logic of The World Commission on Sustainable Development dictum to “Think Globally but Act Locally” has become increasingly clear and more urgent to people in coping with climatic variability and change. People are learning that management activities that appear initially to be isolated in their impacts frequently interact closely with each other through time [22}. People have also learned that what they do to vegetation, soils, and water on upland watersheds can impact on the people living downstream and their uses of the natural resources. A reality of the world is that different people and different political entities such as states (provinces), cities or villages largely determine what happens within their jurisdictions and that these jurisdictions are almost always situated within the boundaries of a large watershed or river basin. Planners, managers, and other stakeholders must appreciate the fact that water flows downstream and, therefore, that most of the natural resources associated with flowing water occur without regard for political boundaries. This means that all people must work together to plan and act on a broad basis for good land stewardship of a watershed or river basin to be realized. IWM facilitates this necessary collaboration.

Tenets of Integrated Watershed Management. The basic tenet of IWM is that it incorporates land, soil, and water conservation and appropriately planned land-use activities involving the use of these natural resources into a broader and more logical managerial framework [6, 22]. In essence, IWM is a formal process of organizing and guiding the uses of land, water, and other natural resources on a watershed to provide a diversity of goods and services to people without harming the basic soil and water resources available. This strategy encompasses the inherent interrelationships among varying uses of land, soil, and water resources and explicitly recognizes the linkages between uplands and downstream areas.

IWM practices are planned changes in land use, vegetative cover, other nonstructural, and structural actions that are taken to achieve IWM objectives such as:

- Sustaining or enhancing the quantity and quality and water resources.
- Providing flood protection throughout a river basin.
- Protecting the available soil and water resources for the production of fiber, forage, and food.
- Rehabilitating degraded lands to obtain a more productive condition.

People are affected both positively and negatively by the interactions among land, water, and other natural resources and in turn people influence the nature, severity, and duration of these interactions by the ways in which they manage and use these natural resources. The effects of these interactions follow watershed boundaries not political boundaries (Box 1). Because these interactions cross political boundaries, what seems to be sound use of natural resources from the viewpoint of people in one land or political unit might not be sound use of these resources from a societal point of view. A consequence of this spatial viewpoint is the possibility of undesirable downslope or downstream effects. The IWM approach to land stewardship brings these off-site effects into the analysis and planning of future management options by considering watershed boundaries.

A IWM strategy offers a framework for attaining the sustainable use of the natural resources and environmental services that a watershed can offer, while IWM practices provide the tools for making this framework operational [6, 22]. What distinguishes IWM from other approaches to the management of land, water, and other natural resources is its holistic consideration of providing people with varying combinations of benefits, for example:

- Water resources for human consumption, irrigation of agricultural crops, generation of power, fisheries, and maintaining minimum flows for aquatic ecosystems.
- Wood fiber for processing into primary and secondary products including bioenergy.
- Fodder and forage for livestock production.
- Habitats for wildlife populations for purposes of consumptive and nonconsumptive uses.
- Protection of soil resources to sustain agricultural production.
- Land and water resources for recreational and tourism opportunities,
- Sustainability of ecological diversity and ecosystem services.

Benefits of Integrated Watershed Management. IWM takes place within the reality that watersheds and river basins largely function in response to climate and to natural-resource capacities and land use patterns of that are independent of boundaries delineated by their respective ownership or control. The benefits of IWM vary widely and can be found on a diversity of landscapes (see Box 2), however, the implementation of IWM practices depends not only on the physical and biological conditions of the watershed, but also by appropriate regulations, controls, market incentives, and investments.

Box 2

Benefits of Integrated Watershed Management: Two Examples Arizona. The Beaver Creek Watersheds were established in the ponderosa pine forests of Arizona to study and quantify the multiple resource benefits obtained by IWM practices. One of the practices was a combined stripcut-silvicultural thinning treatment to increase water yields while sustaining timber production and enhancing other ecosystem services. A water-yield increase of almost 25 percent was observed annually until the re-establishment of vegetation in the strip-cuts [2]. While the practice removed trees in the stripcuts, a mosaic of even-aged stands of trees was retained in the leave strips to sustain the integrity of residual forest on the watershed [16]. Livestock forage increased in response to elimination of trees in the stripcuts and a reduction in stocking conditions in the leave strips [5]. Habitats for wildlife species improved as a result of the increase in forage plants, retainment of protective cover in the leave strips, and creation of the edge effect (ecotone) between the stripcuts and leave strips [15]. Soil losses following implementation of the stripcut-silvicultural thinning practice was minimal, and, therefore, sustainability of the benefits of IWM was retained.

Minnesota. In the example of the Minnesota River Basin (MRB), IWM provides a framework for addressing several unintended environmental consequences of agricultural development. Over a century and a half of agricultural development in the Minnesota River Basin has resulted in one of the most productive agricultural areas in the world. To expand agricultural production, wetlands have been drained and converted to agricultural crops with a resulting extensive tile drainage network and ditch system that more efficiently move water off the land and into stream channels [30]. Annual crops have largely replaced native prairie grasses in the uplands, and replaced many native riparian forests along streambanks and in the floodplains. Stream channels have been modified to convey flood water in an effort to reduce recurring flood damages to roads and farming communities. The cumulative watershed effects of these activities have altered the hydrology of the Minnesota River Basin and, in doing so, contributed to channel instability, excessive sediment loads, and impaired water quality. Pilot watershed projects to rectify these problems are underway in the Elm Creek watershed in the Blue Earth Basin, a major contributor of nutrients and sediment to the Minnesota River Basin [32,31,38]. An array of land-use practices is being evaluated as alternatives to row crops that can provide viable financial options for land owners while reducing downstream loading of sediment and nutrients to meet water quality standards. Perennial prairie grasses and trees are being evaluated as potential bioenergy crops along riparian corridors and on hillslopes in conjunction with restoration of wetlands and rehabilitation of stream channels. Peak stormflow from cropped field and loading of nitrogen and sediment have been reduced [30]. In addition to improved water quality and habitat, increased carbon sequestration and reduced energy use can potentially reduce atmospheric carbon. Importantly, increased wetlands and perennial crop cover should provide greater resilience than annual cropping systems to increased stormflow peaks and to changing climatic conditions. The key to sustainability of such efforts will be largely dependent on providing viable economic options for landowners that would likely require some form of payments for environmental services.

PLANNING CONSIDERATIONS FOR INTEGRATED WATERSHED MANAGEMENT

Sustaining the benefits of IWM in the face of climatic variability requires a highly coordinated, participatory, and flexible planning process that identifies the most appropriate practices for implementation. While a number of protocols are available to integrate climatic variability and change into planning, the uncertainty of future climatic conditions needs to be appropriately considered in the planning process [20]. Flexibility is paramount in the planning process because of the risks and uncertainties associated with forecasting future climatic variability and change. Identifying the economic, environmental, and social costs associated with changing climatic conditions is also required. Understanding the linkages among people, their natural resources, and the institutions responsible for planning and managing these natural resources is necessary. Therefore, the planning effort for IWM needs to consider:

- The holistic considerations of the interactions among land, water, and other natural resources currently on a watershed and expected to be available to people into the future.
- The organizational capabilities and institutional arrangements necessary for managing the array of natural resources on a watershed basis for sustainable use in the long term.
- A recognition of the risks of failure in achieving the goals and objectives originally specified in the planning process.

Alternative courses of action should also be specified if it is determined that the IWM practice initially selected for implementation by planners is shown subsequently not to be feasible or that it fails to meet its stated goals following implementation.

Role of Stochastic Models. Stochastic models can play a key role in selecting IWM practices for implementation under conditions of climatic uncertainty by providing a set of scenarios of climatic conditions that have some probability of occurring in the future. Stochastic models can estimate the probable distributions of future climates (outcomes) by allowing for random variation in one or more of the climatic inputs through time. This random variation is derived from observed and projected fluctuations in historical climatic data by applying time-series techniques [18]. The distributions of these future outcomes are based on a large number of simulations called stochastic projections that reflect the random variation in the specified input(s).

Embedded in the formulation of stochastic models are statistical properties (means, standard errors, etc.) of the available data sets for the climatic conditions of a watershed or river basin and the laws of probability that are the foundation for generating the sequences of data sets representing the probabilities of future climatic events [14,18]. The climatic event(s) with the highest probability of occurring in the future then becomes a basic input(s) to the general planning process. Stochastic models can be applied to estimate sequences of increased or decreased rainfall events, warming or cooling temperature regimes, or prolonged drought conditions. Information obtained through dendrochronolgy (see below) can be especially useful in applying stochastic models to assist in the planning process to sustain future IWM benefits.

Dendrochronology. Dendrochronology, also known as tree-ring analysis, was developed by Andrew E. Douglass, founder of the Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona, in the early 20th century. Dendrochronology is a set of measurement and analytical techniques by which the annual growth rings of a tree are referenced to the respective years of their formation and the history of changes in the growing environment of the tree are then reconstructed from interpretations of the morphological or chemical properties of the growth rings such as their width, cell size, or trace-element composition [41,19].

The analysis of tree-ring series has been useful in generating scenarios of future climatic variability. These scenarios can be incorporated into stochastic models structured to utilize a statistical time series such as that represented, for example, by a reconstruction of historical rainfall events from a tree-ring series [43]. Tree-ring series have also been used in reconstructing other patterns of historical climatic variability in many regions of the world [46,9,42]. Knowing these patterns helps to explain the effects of climatic variability on historical spatiotemporal drought and streamflow regimes (see Box 3).

Box 3

Reconstruction of Historical Climatic Events: Two Examples Spatiotemporal Drought in Northwestern Africa

Northwestern Africa has been suffering drought conditions for more than 30 years that have impacted economic and social structures of countries already reeling from acute water shortages. Future use of the limited water resources in the region requires a more efficient planning process to implement long-term management actions and other intervention strategies. However, effective planning is limited by a lack of historical climatic data to place the current drought conditions into perspective. To overcome this deficiency in the available instrumental record, Touchan et al. [44] prepared a comprehensive tree-ring network for the region; applied this network in reconstructing the variability of historical drought in the region with the Palmer's drought index as a basis; and analyzed the spatiotemporal features of this historical reconstruction back to 1179 AD. Touchan and his colleagues determined that on a broader regional scale, the most recent decades of the 20th century emerged as a period of highest drought frequency since the 13th and 16th centuries. Furthermore, they determined that one of the driest periods in the last nine centuries was the last half of the 20th century. A significant shift toward drier conditions in the most recent decades was also revealed. This finding is consistent with projections of circulation models indicating that emissions of anthropogenic greenhouse gas were likely to result in imminent climatic drying of subtropical regions.

Streamflow Regimes of the Colorado River in the Western United States. One of the more outstanding examples of the lack of historical information of streamflow regimes was the over-allocation of water resources of the Colorado River Basin in the western United Sates. Planners met in 1920 to agree on allocation of the rights to the water flowing from the upper basin into the lower basin. The planners estimated that the annual streamflow volume at the point of allocation averaged 19,985 billion cubic meters. This estimate was derived from the available streamflow records spanning the period of 1906 to 1922. To place this relatively short-term instrumental record into a longer-term perspective, Stockton and Jacoby [40] reconstructed a historical streamflow pattern with a time series for the previous 450 years derived from a chronology of annual tree rings. Their analysis showed that the streamflow volumes estimated from the available record represented the longest period of sustained high streamflows in the previous 450 years. The limited record of streamflow volumes available to the planners in 1920, therefore, was not representative of the historical streamflow regimes of the river and that the allocation of water into the lower basin of the Colorado River had been based on an anomalously high value of streamflow volumes. As a consequence, severe shortages of available water has often resulted when all of the entities involved demanded their share of the water originally allocated to them.

Early in the planning process, reconstructions of historical patterns of climate can be incorporated into stochastic models to obtain the probabilities of occurrences of specified climatic events in the future such as minimal rainfalls necessary for implementation land or water development practices. If the determined risks are considered too high that a deficiency in rainfall might occur in the future, appropriate lower risk alternatives can be considered to achieve the goals specified in the initial planning process.

Incorporating Impacts of Climatic Variability on Future Rainfall Events and Available Water Resources Planning and management for the sustainable use of land, water, and other natural resources in the face of varying climatic conditions is a theme of future IWM activities. Determining the amount and distribution of available water is a critically important component in the planning process.

Fortunately there are numerous computer simulation models that can be used to provide estimates of the future availability of water resources for a wide range of climatic conditions to help in meeting this challenge [17,23,12,13,47]. Among the hydrologic changes that are simulated in many of these models are water yield responses to changing rainfall amounts, temperature regimes, and evapotranspiration demands. These changes can affect dramatically the future availability of water resources to people. One such model is TOPMODEL that simulates the responses of water resources to a time series of rainfall and temperature regimes [4]. These time series can then be incorporated in a stochastic generator when the simulation goal is forecasting the availability of future water resources within a framework of the estimated variability to be encountered.

A time series of rainfall regimes can be studied by applying TOPMODEL and calibrating observed rainfall events against historical rainfall events estimated by a tree-ring analysis. A long-term data set of future rainfall events can be generated with a stochastic model and thereby help forecast the impacts of climatic variability on the availability of future water resources. TOPMODEL must be calibrated to local heterogeneity and anisotropic conditions even when a stochastic generator is available. Once these requirements have been satisfied, simulations of future rainfall events and water flows can be incorporated into the planning process to select the most suitable IWM practice(s) to implement.

CONSIDERATIONS FOR SUSTAINING INTEGRATED WATERSHED MANAGEMENT

Insuring that the benefits of implementing IWM practices are sustained while coping with the uncertainty of climatic variability and change and that suitable practices are selected for implementation requires a combination of technological development, effective institutional arrangement, and increased investments in land stewardship for success.

Technological Development. Technological development necessary to sustain the benefits of IWM often centers on methods of increasing the availability of the land, water, and other natural resources to meet people’s present and future needs. With respect to water resources, obtaining “new water supplies” with present technologies seems unlikely. The amount of water available to people at the present time is realistically all of the water that people will have available to them in the future. However, future technological development may be able to find more efficient delivery-systems of water to a site, improving techniques of harvesting rainwater, or improving the treatment of “brown water” that has previously been considered to be unusable. Artificially recharging aquifers during wet periods can help offset groundwater mining that occurs during dry periods. Increasing the water flows from upland watersheds by changing vegetative cover with the intent of delivering increased flow to downstream users has been a long-term focus of IWM practices in many regions of the world [6]. Unfortunately, these increases are not necessarily sustainable without repeated treatments and, as a consequence, temporally limited.

Other approaches for increasing the availability of water resources include reducing the demands for water resources through pricing mechanisms (see Box 4) or altering the ways that people utilize their water resources. In terms of the latter approach, reducing the large amounts of water consumed in the agriculture sector to free-up water for other uses is a possibility for improving the future availability of water resources. More than 75 percent of the water resources of the world is consumed currently in the production of agricultural crops [33] with most of this water applied to irrigation.

Box 4

The Pricing of Water Resources. Water is often considered a public resource that people have a basic right to its use. The general Assembly of the United Nations voted unanimously to affirm this right in 2010. However, at this time, methods of increasing supplies are becoming so expensive, that many government institutions are not able to shoulder the costs for these services alone. Markets by themselves have not been able to balance these competing realities. With the necessary incentives, however, appropriate technologies might be developed to obtain and deliver water to users in a more cost-effective and environmentally sound manner. In the United States, for example, investing as much money in water infrastructures as the federal government invests in other public-work programs could alleviate some of the financial pressures for obtaining and delivering water to people. Many state and municipal governments are increasingly dependent on private entities for this financial assistance [25]. It is further clear that in the final analysis, public and private sectors must work together to achieve the needed infrastructures. Otherwise, no pricing mechanism or management scheme will completely resolve this growing concern.

In lieu of—or in addition to—measures aimed at increasing water availability, an alternative watershed management approach entails the adoption of land-use practices that couple natural resource and food production needs of people in face of the conditions of precipitation variability and water scarcity. For example, agroforestry practices have been implemented by farmers faced with low precipitation and the uncertainty of drought conditions that limit the sustainable production of annual crops. Agroforestry options can provide alternatives to annual cropping systems that are susceptible to low rainfall regimes or prolonged drought, and, as a consequence, dependent on irrigation to successfully grow these crops [7]. Agroforestry systems comprised of woody and herbaceous species can provide more agricultural production such as a variety of forage, food (fruits, nuts, etc.), and fuelwood sources.

Effective Institutional Arrangements. Much of this paper has dealt with biophysical issues of IWM within the context of climatic variability and change. Equally important, however, is consideration of the institutional situation, the policies confronted, the planning process followed, and the economic and financial issues faced in implementing IWM practices. Furthermore, sustaining the benefits of

IWM requires a participatory, highly coordinated, and flexible planning process.

More effective policies to link people and their use of land, water, and natural resources with the institutions responsible for implementing the management of these natural resources are vital. Policy issues differ from technical management issues in terms of how they are addressed by people. Technical experts often analyze the management situation confronted and make recommendations to policymakers to help in the resolution of problematic issues through formulation of the necessary policies [7,22]. However, there can be disagreement among people on technical management issues or a lack of incentives that result from conflicting or otherwise ineffective policies. These differences should be addressed in the process of formulating effective and necessary polices for coping with present and future climatic variability. A high level of interaction and communication among policymakers and all stakeholders is necessary to achieve effective policies for this purpose.

Improved marketing incentives throughout the financial and economic flows involved in trading the commodities and amenities obtained on watersheds and river basins can represent a viable approach for distributing the benefits of IWM more equatability to people confronting climatic variability and change. Marketed commodities (such as food and wood) and nonmarketed amenities (reduced sediment, improved water quality, enhanced habitat, and so forth) must both be included in the development of innovative market outlets sensitive to climatic variability and related uncertainties.

Increasing incentives for the trading of carbon credits in a marketplace could evolve into a reduction in the emissions of greenhouse gasses through carbon sequestration [10] and, as a consequence, mitigating the possibility of future climatic warming. Because nearly one-half of the terrestrial carbon in the world is stored in forests, the world could become a much warmer place with a reduction of these forest covers [1,11]. Therefore, implementing IWM to sustain or increase the capacities of the world's forested watersheds to sequester carbon could be a significant contribution to coping with climatic variability and especially climatic warming.

Increased Investments. Increased investments can be needed in many instances to sustain the flows of commodities and amenities obtained through IWM management practices. Sustaining these benefits into the future often depends on the availability of increased investment opportunities and related employment opportunities as a result of this investment. Much of the investment made in the management of land, water, and other natural resources in the United States is public-sector investment because water and the involved landscapes are most often found in the public domain [22]. The level of this investment is reflected largely by the operational budgets of the governmental agencies responsible for management of the natural resources on these lands. Investment by the private sector also occurs with much of it administered through governmental agencies and nongovernmental organizations. Increased investment in nonmarket amenities such as clean water and enhanced outdoor recreational opportunities is also frequently needed but these benefits are difficult to value in financial terms.

There currently are gaps between what is needed and what is forthcoming in the level of investments made in attempting to cope with impacts of climatic variability and change. Therefore, increased levels of investments are needed in both research and operational endeavors to achieve sustainable IWM under conditions of climatic variability and change.

SUMMARY

Developing effective managerial strategies to cope with future climatic variability and change will be a challenge confronting people throughout the world. The authors of this paper propose that the use of land for production of food, forage, water, wood, wildlife, and other benefits can be sustained though integrated watershed management that takes into account climatic variability and possible future climatic changes. A participatory, highly coordinated, and flexible planning process to select the most appropriate IWM practice(s) is paramount in achieving this goal. Applications of stochastic models that generate scenarios of climatic conditions having a possibility (probability) of occurring in the future can play a role in implementing this planning process. Information obtained through analyses of the annual growth rings of a tree facilitates projection of historical trends in climatic variables affecting IWM benefits into the future. If the future climatic conditions are deemed not to be suitable for the successful implementation of an IWM practice selected initially in the planning process, an alternative practice might be a better choice for implementation even if the management goals are not fully satisfied. Varying combinations of increased technological development, effective institutional arrangements, and increased investments will be necessary to insure that these benefits remain sustainable. Developing policies that encourage sustainable land and water use to cope with the uncertainty of future climates requires a clear vision of what stakeholders need and want from watershed landscapes.

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