Adaptive Understanding and Management for Floods

- Jan Sendzimir[1], Steven Light[2] and Karolina Szymanowska[3]

1 - International Institute for Applied Systems Analysis, Schlossplatz 1, A-1030 Laxenburg, Austria.
2 - Institute for Agriculture and Trade Policy, 2105 First Ave. South, Minneapolis, MN 55404, USA.
3 -Warsaw University, Dept. of Interdisciplinary Studies for Environmental Protection, Warsaw, Poland

ABSTRACT

Resource management problems have so often defied prediction that surprise rather than certainty has become the common theme for embarrassed managers and theoreticians. The sources of uncertainty derive from our failure to grasp the structure and operation of complex systems: nested hierarchies that generate non-linear dynamics from within-scale and cross-scale interactions. We increasingly recognize that surprise and uncertainty are inevitable given that nature and society are moving targets with very complicated interactions at multiple scales. How can we practically address this uncertainty? We describe a process, Adaptive Environmental Assessment and Management (AEAM), that has developed over 30 years of experiments as a test of our abilities to integrate inquiry, understanding, and action in the face of surprising shifts in evolving resource systems. AEAM has been applied to resource management problems such as tourism, fisheries, forestries, mining and agriculture. We consider briefly AEAM's application to river management problems in North America and discuss the potential to experiment with AEAM to address the interplay of ecological and economic problems in European river basins with a history of flooding.

Keywords: Adaptive management, resource management, flooding, complexity, hierarchy, scale

INTRODUCTION

The speed and extent of change in natural and human systems are accelerating at unprecedented scales, forcing managers to make a qualitative leap and look over their conceptual horizon to find the sources of change. The qualitative difference in our appreciation of change is more than multi-disciplinary or multi-sectoral; it challenges the foundations of most models of the world as a continuum of various attributes. The qualitative leaps needed to understand the new dimensions of change seem to reflect a hierarchical world in which a few sets of processes control operation and structure over limited ranges of scale. If change is not occurring uniformly everywhere, but only over specific ranges of scale, then understanding must jump from the local to the regional and global strata of the world hierarchy. Our failure to appreciate hierarchy is often compounded by ignorance of the unexpected and non-linear dynamism of human and natural systems. Profound surprise and uncertainty are the result, and they are replacing stability and predictability as the common themes to managing change.

The degree and quality of uncertainty inherent in the dynamics of ecological, social and economic change can be classified as statistical uncertainty, model uncertainty, or fundamental uncertainty (Hilborn 1987). Lay discourse about change may acknowledge the shallowest level of uncertainty, statistical uncertainty, wherein one may not know the condition of a variable at any one point, but the overall chances of its occurrence (probability distribution) are known. An example of this might be the chances of being struck by lightning. More profound kinds of uncertainty are currently encountered at the frontiers of science and practice. For example, the depth of surprises occurring in natural and human systems are forcing us to reexamine our most basic ideas about how variables are connected in a model (model uncertainty) or whether we can conceive of any model at all that applies (fundamental uncertainty) (Peterson et al. 1997). In the case of model uncertainty one still can predict outcomes but have no idea of their likelihood. For instance, evidence from periodic drops in Europe's temperatures are best explained at present by the switching off of a deep ocean current, the Atlantic Conveyor, yet we have little idea what processes combine to toggle these systems on and off and less of an idea of their likelihood (Broecker 1996). Fundamental uncertainty applies to situations so novel that no current model applies. The discovery of the atmospheric ozone hole exemplified such profound novelty; we couldn't even bring up a cast of characters let alone a set of relationships between them. One begins to appreciate the complexity of systems when one realizes that, as our Earth is increasingly connected by ecological and human processes, all three levels of uncertainty can apply at any one place.

Uncertainty challenges more than our need to understand, because the responsibility to manage systems of humans and nature creates a tension between the need for useful simplifications that allow discussion (theory) and the need for effective action (practice). This tension increases as the uncertainty springing from Nature is compounded by that contributed by society's attempts to learn and manage. Both natural and human systems are constantly changing and evolving, sometimes in synchrony and sometimes not. If our appreciation of uncertainty in the face of evolution forces us to admit that there are no "truths" which persist, and that no person or group is the guardian of such truths, then we can recognize the importance of discussion between a variety of competing ideas. In this paper we confront the question, "If we admit that we cannot eliminate uncertainty, then what means are available to reduce it when we try to understand and manage unpredictable disruptions such as floods?" We will first discuss briefly some of the sources of uncertainty in nature and society, then we will introduce a process of democratic dialogue, Adaptive Environmental Assessment and Management (AEAM), that attempts to practically address the tension between theory and practice by deepening understanding even as the system is managed. We will conclude by suggesting ways AEAM could be applied to enhance the understanding and management of floods.

Sources of Uncertainty in Nature and Society

Natural Systems

The unpredictable ('non-linear') behavior and surprisingly stratified ('hierarchical') structure of natural systems contribute greatly to uncertainty. Natural systems rarely remain on a constant, predicable course; their behavior can erupt in episodes of transformation, recognized in antiquity in biblical terms: plagues, pestilence, fire, and flood (Holling et al. 1995). Forests may appear to grow at a reassuring pace for decades only to be consumed in outbreaks of insect pests or fire. Rare events, such as storms, floods or biological invasions, can radically and unpredictably restructure systems with effects lasting for long periods. For example, the U.S. Army Corps of Engineers will not guarantee the flow of the Mississippi River through the city of New Orleans, because it is finally recognized that no practicable level of engineering can prevent certain hurricanes from redirecting the Mississippi down the Achafalaya basin. Such infrequent episodes can also cause systems to jump irreversibly to new states; forests become grasslands, grasslands become shrublands or deserts.

Surprise from natural systems comes partly from our failure to recognize the hierarchical pattern of their behavior and structure. Briefly, ecosystems are not uniform or continuous in space or time, an assumption about pattern that has made predictions much easier to make in the past, but has lead to tragic and unforeseen consequences. Natural systems are patchy and heterogeneous in space and discontinuous in time. Forests are not uniform mono-cultures but mosaics of patches of different trees and groups of trees. The processes that give these systems their architecture or structure do not operate uniformly at the same time and space scales. They have different "footprints " because they function at radically different rates and over vastly different spatial extents, often differing by orders of magnitude in time (seconds to millennia) and space (centimeters to kilometers). For example at micro-scales the competition for sunlight and water and nutrients results in plant architecture and operates over square meters in spurts of seconds to hours. Medium scale processes (fire or flood) create and maintain the patchwork of the landscape, operating over square kilometers in episodes that occur every 10 to 50 years. And macro-scale processes, such as geomorphology, structure the landscape over hundreds of kilometers, returning periodically over millennia. Therefore, each stratum (range of scales) in the landscape hierarchy is dominated by a different set of processes; no process is dominant at all scales.

Figure 1 shows such a discontinuous world by diagramming the space and time dimensions of different elements of a forest and climate hierarchy. Each polygon shows the minimum resolution (left for space or bottom for time) at which the phenomenon is perceivable, and the horizon (right for space and top for time) over which the phenomenon is replaced. For example, a forest stand is visible on a screen with pixels 10 meters on a side, and most stands are less than 5 kilometers in extent. Similarly, forest stand dynamics can be captured at a minimum time step of a year and a time horizon of a century. These polygons attempt to map out the dimensions at which the processes that create forest stands (or any other element in the hierarchy) operate. In a sense, each polygon is a "footprint" in space and time of the set of processes that dominate at that scale. This diagram pictures the hypothesis that there is no overlap between the scale ranges at which different sets of processes dominate. Sunlight may be omnipresent, but the process of competition for energy, nutrients and water that result in a plant do not dominate at the scales of kilometers. At that scale, processes such as fire, flood, human agriculture and forestry dominate to give the meso-scale patterns of the landscape mosaic. Like a Chinese puzzle, the domain of micro-scale processes fits within those of the meso-scale, which in turn fit within those of the macro-scale.

What are the consequences of such a novel world that is not continuous in its behavior or its appearance? These disjunctions in space and time force us to radically revise how we build our understanding up to predict what will happen in systems as large as nature. They mean that traditional methods of extrapolating from the small to the large, from the present into the future, do not work. Namely, one cannot extrapolate understanding of microscopic phenomena (that which we can most easily observe and test) and scale it up to understand the functioning of the environment at larger scales (forests, towns, regions, states). The local control offered by one dam gives little power to predict the behavior of water over an entire river basin. We must observe and test the processes and phenomena at the appropriate scale, and at larger scales experimental replication and control are often not practicable or possible.

Systems do not remain the same but shift or jump between states. Systems that from a human bias appear stable actually are changing slowly within some limited domain of behavior. Leaps to new domains are the surprises that embarrass theorists and managers. We now recognize from such reversible and irreversible jumps that systems do not have one single balance point or equilibrium. They are often multi-equilibrial, and jumps between different states are increasingly recognized (Holling et al. 1995) for their contributions to diversity, structure and resilience of these systems. What have been labeled as ‘disturbances’, with the connotation of degradation from an ideal state, are now seen more as ‘envigorating’ gymnastics that bolster the long-term integrity of the system. These new insights do not disparage the concept of stability as some source of unhealthy stasis; stability is recognized for its contributions to productivity and bio-geochemical cycles. Therefore, it is not disturbance or stability but the cycling between them that now appears to be the engine of evolution and resilience.

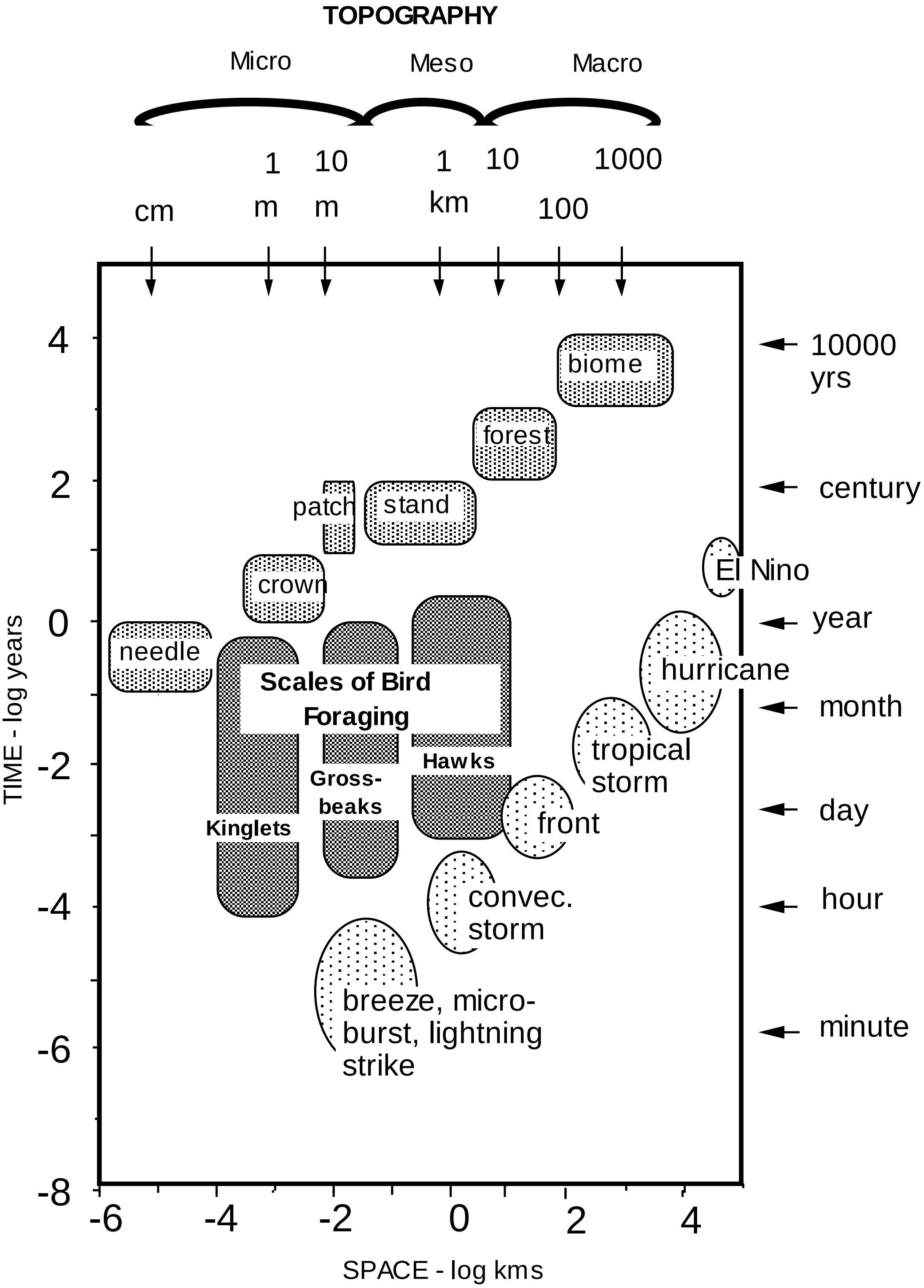

Figure 1: Model of discontinuous distribution of space/time dimensions for operation of atmospheric processes, forest structures and bird foraging scales

Human Systems

Like natural systems, human systems are also moving targets that occasionally jump erratically in shifting between system types. The uncertainty inherent in shifting natural systems can be amplified by interactions with dynamic human societies that are also disjunct in geographical distribution and behavior. Many societies have moved forward in leaps in terms of technology and/or social institutions, and attempts to understand and cope with nature's variability have quite often built up from initial success to catastrophic collapses. For example in some fisheries' early harvests spurred successive bursts in capital and technology that eventually ratcheted harvest efforts up and fish stocks down to levels requiring possibly a century for recovery (Walters 1986). Below we briefly discuss how our confidence in dealing with natural catastrophes has been eroded by the mixed success of some institutions and facets of society.

Government, commerce and science are three broad vehicles for managing uncertainty inherent in complex human and/or natural systems. The constraint of law, the discipline of the market, and the scientific method are all means which partly serve to minimize variability of certain behaviors of people and/or natural resources, or the supply and flow of money that tracks these behaviors. The mounting scope of resource management failures has caused widespread loss of confidence in these institutions, both individually and in concert. Governmental failures to understand or manage resources have emerged most strikingly in command-and-control approaches of centralized authority. Such approaches ignore further experimentation or local wisdom as they lock in to one most efficient means of production, and often continue to roll forward on political momentum long after local economies and ecologies have been devastated. The Soviet management of Eastern Europe is one of the most extreme examples of central control resulting in some of the most patent failures to understand or respond to evolving ecosystems or societies. However, non-socialist examples abound because authority is often concentrated in industry and/or government. And the current trend toward globalization of economies can be criticized as an unhealthy concentration of power whose attempts to minimize variability at global levels makes the system more brittle and vulnerable to collapse at world scales.

Sometimes governments and private industry work as partners to try and guarantee smooth and steady economies by suppressing variability and uncertainty of natural variables. Predictable availability of electricity or transport are created by steadying river flow with dams, and dependable deliveries of food result from pesticide use to eliminate sudden outbreaks of insects or microbes. Many of these dual efforts have resulted in massive failures of such shared resources as fisheries, farms and forestry, or in catastrophic releases of toxic materials. Often government and/or industry have distorted science through clumsy attempts at information manipulation in order to cover the fact that management actions have no real basis in knowledge. Management agencies often suppress scientific dissent in order to present a unified, "certain" front to the outside world, thereby consolidating the political power of the agency (Walters 1997).

For many, science has lost the aura of a compelling tool for understanding or prediction for a number of reasons. The fact that the same data can legitimately be interpreted in radically different ways is at first baffling and then increasingly ridiculous to the popular mind. One might expect the confusion over science to increase as the scale of disturbances increases, because science loses the ability to replicate and control experiments as their scale expands. While this is true, in addition science suffers from a reputation inflated by revisionist histories that filter out the original controversies surrounding scientific discoveries. In a sense, science is falling from a pedestal created by idealized visions of a history of "strong" science, replete with clean breakthroughs that could relieve us of confusion and uncertainty by dramatic and unassailable demonstrations of causation. Actually, such demonstrations are very rare, and the actual importance of many famous discoveries is only recognized in hindsight. Rutherford's dramatic 1920 "vindication" of Einstein's theory of relativity was actually not a very clear demonstration at all, and was challenged for years by other interpretations (Collins and Pinch 1993). The problem for science as a tool for exploring uncertainty is that few but scientists have the tools, the discipline or the patience to wade through the controversy and see the real and compelling patterns of evidence emerge over years. And as larger economic/ecological experiments occur in the biosphere, the increasing number of interrelated causes will not clarify the picture sooner, rather the signals and evidence found will be murkier than before.

The challenge of usefully applying science emerges clearly in some attempts to understand and manage complex systems by quantifying indices of system "integrity." These attempts assume that complex systems are composed of components with relatively constant and tight relationships that consistently behave in a certain way, and, hence, have a 'normal' state against which to compare transient states. Actually, such systems are "open, loosely defined assemblages with only weak evolutionary relationship to one another" (Levin 1992) and their constant change makes it very hard to define what 'normal' is (De Leo and Levin 1997). Consistent local disturbance (tidal flux) may allow highly competing species to coexist, or catastrophes (fire, floods) may periodically reset the clock by eliminating most species. While separating the effects of human from natural disturbance is difficult, these problems are compounded by the variety of connections between different components resulting in different functions. Therefore, what 'health' an index reveals is related to which components and which functions are present and measurable at that point in the cycle of change in the system. Quantification may give one a 'spurious sense of certainty' because components have been reduced to numbers and are more easily communicated so as to make a convincing scientific or political statement. As DeLeo and Levin (1997) conclude:

> "A more promising approach to ecosystem management is to recognize that various genetic, competitive, and behavioral processes (rather than states) are responsible for maintaining the key features of observed ecosystems, and that the dynamics of these processes vary with the scale of description."

Opportunities to Integrate Understanding in the Face of Uncertainty

If our initial successes in eliminating variability and uncertainty have lead to more profound catastrophes, how can we responsibly engage or embrace uncertainty and effectively respond to change? The challenge for society is that not only must understanding be consistently pursued and deepened to appreciate dynamic and evolving systems, but that one must take action in the midst of this effort. In other words, coping with novelty and surprise requires the sustained capacity to learn and to flexibly manage. For thirty years a decision making process has been evolving to address the twin challenges of learning and management. This process, Adaptive Environmental Assessment and Management (AEAM), has been refined in a series of on-the-ground applications in problems of forestry, fisheries, national parks, and river systems. It is currently being applied in two North American river systems, the Mississippi and the Colorado, and offers opportunities to address the development of society on flooding riparian systems. We will describe with examples some of the theory and operation of the AEAM process.

ADAPTIVE MANAGEMENT

Underlying Assumptions

As previously discussed, the driving assumption underlying AEAM is that uncertainty is inevitable, because the behavior of natural resource systems is only partly knowable. Therefore, as ecosystems and societies evolve, so humans must adapt and conform as systems change. However, the challenge of environmental problems denies us the luxury to constrain our focus simply to understanding. Society must respond at a number of levels that include both understanding and management. Historically, the understanding that was developed in isolation from the discipline of reacting to and managing a changing system has often proven shallow and of limited use. Therefore, AEAM is not about learning before one can manage, rather it is learning while one manages (Gunderson, 1998).

How can management and learning be coordinated? Based on the assumption that structured learning is better than trial and error, AEAM is based on a process of Integrated Learning (Figure 2). As Gunderson (1998) notes, “The process is structured for learning by systematically probing uncertainties of resource issues, continually assessing, postulating, testing and re-evaluating.”

If evolving complex adaptive systems are fountains of uncertainty, and surprise is inevitable, then structured learning is the way that uncertainty is winnowed. Surprise is never eliminated, but we may reduce the consequences of the way our understanding lags behind evolving systems by embracing uncertainty, deepening understanding and adaptively responding to system changes. Adaptive responses and management actions must meet social objectives, such as protecting people or resources, but learning must continue as policies are modified to adapt to surprises. And therefore, a second function of management is to probe the system, perturbing it slightly to provoke some minimal, safe response that gives an indication of the working and true structure of the system (Walters, 1986). In this way, AEAM views policies as hypotheses, therefore management actions become treatments in an experiment.

We shall now discuss in turn the functioning of the different phases of AEAM, how uncertainty is confronted by formulating hypotheses, how management actions test these hypotheses, and how learning integrates assessment and management. We shall then describe one example of AEAM as applied in a wetland savanna ecosystem in Florida.

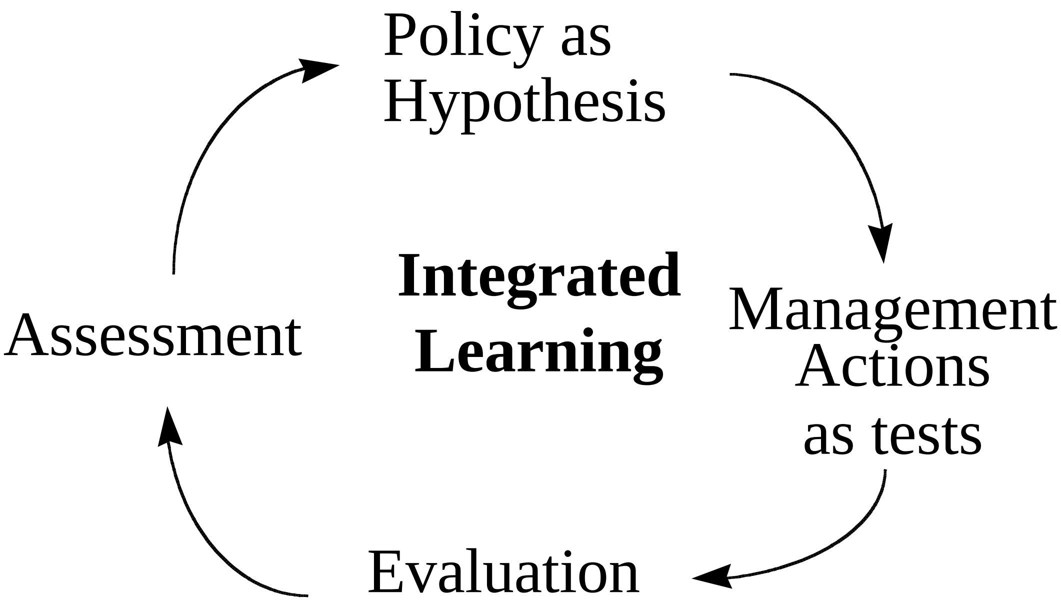

Figure 2. Key ingredients contributing to structured learning in the AEAM process.

Assessing the Known and the Uncertain

The assessment phase simultaneously engages two apparent opposites, integrated understanding and uncertainty, and counter-poses them in ways that are revealing to both. Rather than dodging uncertainty with simplifying assumptions or rationalizations, the AEAM process focuses on uncertainty from the very beginning, utilizing disagreements to reveal and highlight gaps in understanding and other sources of uncertainty. The adaptive process identifies new bases for sharing understanding when gaps or uncertainties are recognized as common to all the different disciplines, sectors, occupations, trainings and experiences represented in the discussion.

The common gaps and links in understanding can bridge the various backgrounds present and establish a foundation of trust that may eventually unlock information and experiences that were previously unshared. This trust is one way in which the AEAM process addresses the refusal to share information, a frequent source of gridlock in environmental decision processes. Another way is to select representatives of various backgrounds based on competence, respect within their group and the willingness to cooperate. Participants are given to understand, that a great potential for communication can emerge if only each person “leaves his/her gun at the door”, be that gun an opinion, a philosophy or a mandate from one’s organization.

The assessment phase aims to initiate and foster discussion by using an informal workshop setting and computer models. Care is taken to introduce and use computer models simply as translators and integrators of people’s understanding, not as technically superior vehicles of “truth.” If dialogue begins where there was none before, then the computer model has succeeded. If people begin to seriously reassess their assumptions because model output based on their ideas seems questionable, then important and novel insights are possible.

The goal of the assessment phase is to integrate understanding and ponder uncertainties to the point that they can be clearly stated as hypotheses about how the system works and what effects interventions (management or uncontrolled human actions) might produce. Complexity in adaptive systems is partly the result of the diversity of causes, and the alternative explanations that address these causes can become the basis for policy in the next phase.

Policies as Hypotheses

Policies are the governing plan, the question set based on experience that sets the stage of further action. Policies range from the formal (government acts, laws, administrative code, legal contracts) to the informal (understandings and shared views among groups). Instead of pursuing the 'correct' policy as a solution to problems, AEAM differs from traditional engines of policy by looking for policy that addresses other social objectives as well as the need to learn in the face of uncertainty (Gunderson 1998). In this light, policies are not magic bullets that address the right mix of objectives to solve a problem, rather they are astute hypotheses about how the world works or "Questions masquerading as answers" in the words of Steve Light. AEAM embraces uncertainty by trying to find the best questions, and thereby tries to dodge the trap of assuming certainty by rallying around 'solutions.'

Management Actions as Tests

Many environmental problems stem from administrative pathologies that narrow policy to achieve efficiency at the expense of awareness about where the system is going. For example, if initial policies achieve high production, one could bank on maximizing the profit of such success by cutting research costs, but only if one was sure of where the system is going. The AEAM process strives to avoid this pathology by broadening implementation to mean the testing and evaluating of hypotheses (policies). This prevents the intent of policy from being changed during implementation, and shifts the search for efficiency from cost reduction to checking whether management actions were executed as anticipated (Gunderson, 1998). This gives implementation a disciplinary rigor of consistency in execution, because otherwise the test of the policy becomes meaningless, and one has loses the power to gain new information about the system.

Integrative Learning

Amassing information does little to help anticipate surprise and uncertainty. Projections based on previous system behaviors have limited utility in the face of true novelty. Integration of the information gained in policy probes has little to do with data quantity and everything to do with quality. To what extent have we winnowed uncertainty and closed the gap on these elusive and dynamic systems? Enhancing understanding through integrated learning is a second loop type of learning that is fundamental to adaptive management in several ways. First, it integrates across multiple disciplines and backgrounds. Second, the focus group, and the community at large, learns by doing. In this way understanding deepens by probing the workings of ecosystems and society and by considered and thoughtful sharing of new ideas and previous experiences. Such inquiry is structured by expert facilitation of discussion, summing up new insights and consolidating gains before reformulating the questions at hand. Finally, this understanding often builds from ground made more fertile by complete re-inspection of assumptions and conceptual frameworks (Gunderson 1998).

The Everglades: An Example of AEAM Applied

One of the key objectives of adaptive assessments of a resource issue is to highlight uncertainties and generate a number of plausible hypotheses about the issue. The AEAM process develops these hypotheses as a suite of alternative explanations about the behavior of the resource. The process of considering the suite of competing ideas helps to integrate concepts about ecology, economy, or politics and to weigh the various policy options. Therefore, the hypotheses link our understanding of the issue with the range of possible outcomes that management actions might produce (Gunderson 1998). We illustrate this below using the example of wading bird declines in a wet savanna known as Everglades National Park in Florida.

Wading bird populations have declined dramatically (as much as 95 percent) over the past 70 years in South Florida (Bancroft 1989). The Everglades National Park provided a primary nesting site for millions of birds at the beginning of this century, and these numbers have declined to the tens of thousands. An AEAM process, convened in 1989, a number of alternative hypotheses were posed to explain these population declines (Light et al. 1995). We briefly paraphrase each alternative explanation below.

- Shrunken Habitat: The conversion of portions of the Everglades by agriculture and urbanization has decreased the original area to half its size. This area has low biological productivity per unit area, so loss of productive habitat has lead to lower nesting populations.
- Decreased Flow: The development of the Everglades involved drainage and diversion of much of the water in south Florida to the extent that much less water flows through the park. These lower water flows have caused dramatic declines in biological productivity at the estuarine fringe of mangroves, a border area that used to hold the densest nesting colonies.
- Damped Fluctuations of Water Level: Water levels fluctuate seasonally in South Florida, driving the ecology of the Everglades. These fluctuations provide the means of food production and delivery. Fish populations thrive and reproduce in times of flooding and are concentrated by lowering water levels to the point where wading birds can easily feed on them. Water management schedules for canals in the Everglades have changed these hydrological patterns to the point where they are not synchronized with wading bird nesting cycles.
- Distant Magnet: The decreases in nesting populations in the Everglades are matched by increases in other parts of the Southeastern United States, Louisiana and the Carolinas for example. Population declines in the Everglades may not wholly reflect lowered ecological conditions there so much as better or improving conditions elsewhere that have drawn the populations to distant sites.
- Mercury: Mercury concentrations have increased in the atmosphere over this century, and many wetland soils absorb and concentrate deposition from the air. Anaerobic water conditions can mobilize this metal from the soil, and it can pass up the food chain to wading birds. Over time the latent toxic effects of mercury have decreased the nesting success of wading birds.
- Parasites: Increased agriculture upstream of the Everglades has released progressively larger amounts of nutrients into the surface water, and populations of parasites have thrived and increased as a result. The increased

> burden of parasites has diverted metabolic energy normally given to reproduction and thereby lowered the success of nesting of wading birds.

Passive and Active Adaptation

How can understanding of these alternative explanations be integrated at the same time that one must manage the system? Walters (1986) introduced three concepts of how to structure management approaches in the AEAM process: (1) *Evolutionary* ("trial and error") which starts with a haphazard set of choices and progressively winnows these down to a better subset to improve results; (2) *Passive Adaptive* which utilizes historical data to select or construct the a response model ("single best estimate"), and the management decision is made assuming this model is correct; (3) *Active Adaptive* which uses historical data to establish a suite of competing hypotheses or response models, and the manager's policy choice reflects a balancing of anticipated performance in the short term with the longer term advantage of knowing which hypothesis is most correct (Walters and Holling 1990).

Two problems arise with passive adaptive approaches. First, the effects of management interventions are confounded with effects of the environment. This is evident in the long and bitter debates about whether fishing effort or environmental effects (climate, watershed habitats lost to silt from logging) are primarily to blame for collapsed fisheries (Walters and Collie 1988). A second, and more fundamental, problem is that passive adaptive policies may allow us to miss opportunities to improve the performance of system. This might occur if the 'right' model and the 'wrong' model both predict the same response pattern, and the system is managed as if the wrong model is correct (Walters and Holling 1990).

So what should a manager do in pursuing an active adaptive approach so as to properly engage a suite of alternative explanations? No hypothesis has an exclusive lock on the truth, and each is to some degree plausible. The answer lies in balancing between two areas: 1) considering the policy implications of the entire suite of hypotheses, and 2) developing a process to sort between all the hypotheses. (Gunderson 1998). In the first case, if all hypotheses point toward similar policies, then one can proceed and manage in a flexible way. In the Everglades example above, if all hypotheses pointed toward water dynamics as the reason for nesting loss, then a set of management experiments could be developed to test these ideas. One set of tests would address most or all hypotheses at the same time. If the suite of hypotheses do not point toward the same policy implications, then any policy that is firmly and irreversibly established would be doomed from the outset. For example, if the Distant Magnet hypothesis were closest to the truth, then any water-based policy would not only fail to achieve the conservation goal but would erode the trust of stakeholders who are participating in the AEAM process (Light et al 1995).

The second approach, sorting between competing hypotheses, is generally done in the assessment stage of AEAM. In the case of the Everglades, an active adaptive approach might have recommended a policy of monitoring wading bird populations at much larger scales while experimenting with a qualitatively different set of manipulations (water flow, periodicity, or nutrient removal) to try to tease out which of the competing explanations holds the most promise. The AEAM process counters the tradition of casting a policy into concrete through law by iteratively testing these sets of hypotheses through the years and making recommendations to adapt as results and understanding develop.

ADAPTIVE PROCESSES APPLIED TO RIVER FLOODING

Adaptive Practices for River Flooding in North America

The United States has a 150-year history of federal programs assuming responsibility for flood control and risk management that emphasized structural flood control, such as levees, channels and dams (Faber 1997). But all that has begun to change with the Great Mississippi River Flood of 1993. In fact a rash of major floods (Galloway 1998) have hit the nation during the 1990s including: in California (1995,1997,1998), Georgia and Alabama (1994) Texas (1995), Red River of the North (1997) and now the massive flooding in North Carolina associated with Hurricane Floyd (September 1999). When adjusted for inflation, since 1951 flood losses have tripled to over $4 Billion per year.

While Adaptive Environmental Assessments have been applied in a number of major river basins over the past 20 years in the United States including the Truckee-Carson, San Joaquin/ Sacramento Bay-Delta, the Colorado, the Upper Mississippi and Platte rivers, most of these assessments have dealt with fish and wildlife issues and not flooding directly. However, efforts are currently underway exploring the possibilities for developing AEA assessments in some of the watersheds in the Red River of the North.

But that is not to say that more adaptive management strategies are not becoming part of flood management programs. The results of the Great Mississippi River Flood of 1993 and the subsequent White House Task Force review attest to the fact that thinking and actions are changing. It was “The Great Flood of 1993” that seriously touched nine Midwest states along the upper Mississippi River and pushed the decision-makers to reconsider the floodplain management issues. The moment arrived to choose between the management focused on the economic development and the endeavor to balance economic and environmental outputs of floodplains.

The Mississippi River begins in north central Minnesota and flows 2,350 miles to its mouth in the Gulf of Mexico, falls 1,463 feet and drains 1.25 millon square miles or 41 percent of the continental United States. The Upper Mississippi River basin drains approximately 714,000 square miles above the confluence of the Ohio River. The Upper Mississippi River basin is composed of many smaller sub-watersheds that vary widely in physical characteristics such as topography, land use, soil types. The upland watershed characteristics across the upper basin have changed considerably over the past 100 years significantly increasing runoff with the conversion of tall-grass prairie wetland and oak savannas to agricultural land and urban uses. The upper Mississippi River System floodplain is mainly used for agricultural purposes (68.8% of the floodplain). The lands used for crops and small farm communities are protected by the agricultural levees. There are several residential, industrial and commercial areas of bigger urban concentrations (5% of the surface) behind the urban levees. In addition the runoff is controlled in great measure by regulation of large dam and reservoir projects on the main stem. Reservoirs, like levees reduce the flood threats to many downstream communities but at the same time create a false sense of security encouraging many people to settle riverbanks and become victims of major floods.

In all the impacted area over 20 million acres (8.1 million ha) (Wright 1996), more than 35 million farms were flooded, 12.7 million acres (5.1 million ha) of corn and soybeans, which is 8% of the total for nine Midwestern sates, were not harvested (IFMRC 1994). It was a huge catastrophe from human perspective, 100,000 residences were flooded (source Disaster Housing Program), 52 people killed, 74,000 became homeless, 30,000 jobs were disrupted (Wilkins 1996, Wright 1996). In the lower part of Upper Mississippi River this Flood was estimated to be a 500-year event.

The Great Flood of 1993 has had both immediate and longer-term adaptive influence on floodplain management in the United States. The flood did result in the immediate, voluntary relocation of more than 8,000 homes and business or 10% of all structures damaged (Faber 1997). The false sense of security offered by dams and levees has been dealt a significant blow. An ongoing potentially escalating sense of vulnerability to flooding is being recognized and the United States' approach to floodplain management is moving in a new direction. In January 1994 the Interagency Floodplain Management Review Committee (IFMRC) was directed to assess the causes and impacts of the Midwest flood and to propose the recommendations for policy changes. Basically, the report called for sharing the challenge emphasized the need for responsibility and accountability for floodplain management to be distributed among various levels of government and with the citizens:

- Avoidance of unwise use of the flood plain;
- Minimization of vulnerability when floodplains are used;
- Increased education and the outreach to people in flood prone areas;
- Mitigation of damage when floods do occur; and
- Protection and enhancement of natural resources and the functions of floodplains. (Galloway 1998)

A movement to reduce flood damages through nonstructural means, such as limiting the irresponsible development of floodplains or evacuating those at most risk, slowly has become the alternative to the construction of dams, levees and floodwalls. An alternative vision in which the frequently flooded communities would become river-focused parks and recreational areas, their former occupants would be relocated to safer areas on higher grounds is taking shape in Grafton, IL where 900 people, 262 structures were moved to relocation site above the floodplain. A large part of St. Charles MO was also relocated (Faber 1997). Federal disaster laws were changed to encourage these actions such actions by setting aside of 15% of all disaster relief for relocation, land acquisition and other forms of hazard mitigation. It was followed by 20 million US dollars annual program to support such projects. In addition the insurance reform in October 1994 made it possible for the flood insurance to help pay the costs of elevating or relocating damaged buildings. On the other side the new constructions were strictly controlled by state and local officials by requiring them to be at elevation well out of harm's way. In the Midwest the increasing cost in meeting the more severe floodplain management requirements is discouraging people from floodplain development.

To preserve and enhance natural resources of floodplains the environmental interest in some lands are being acquired from the willing sellers. That simplifies the restoration of bottomland and related upland habitat and flood storage. On the other hand the pressure is put on changing land uses behind the levees and in the upland areas. Some of the owners choose to convert from row crops to alternative crops or silviculture or return their lands to natural state under many kinds of possible easements. As of 1997 more than 50,000 acres of Midwest floodplain farmlands were put into federal easement programs. In addition Congress and Clinton Administration increased funding for the small-scale restoration projects of the Mississippi River floodplains and the 1996 Farm Bill included provisions for the farmers to increase conservation activities in floodplain environments.

The importance of sharing the responsibility and accountability for accomplishing floodplain management among all levels of government and with citizen participation is working according to Galloway (1998):

"Many state legislatures and executive agencies have examined their flood management policies and moved toward tighter controls. Federal and state government have relocated…25,000 families nationwide. State and federal agencies have acquired interest in over 250,000 acres of flood-prone land."

While the Great Flood of 1993 has not resulted in a new National Floodplain Management Act, the nation is clearly moving away from federally dominated structural solutions to increased flood risk. Clearly there is more involvement of the states, bottom-up public involvement process and community-based floodplain management.

The nation is moving away from fragmentary approach to floodplain ecosystems in which each levee, each dam was a separate project; it becomes replaced by the systems approach. A Minnesota mediation plan worked out following the disastrous floods of 1997 in the Red River of the North (RRN) show promise of taking watershed approaches in which flood-damage reduction and restoration of ecosystem services are being given separate but equal consideration. The Wild Rice Watershed District in the RRN has developed a "systems approach" framework paper that sets forth a collaborative watershed approach much as would be incorporated in an AEA effort. The framework paper sets up interdisciplinary groups, in partnerships of federal and state agencies, tribes, local governments, and private organizations to problem solving and broaden the set of alternative solutions. A watershed-level hydrologic model to help evaluate alternatives in the decision making process is under development.

In dealing with increased incidents and cost of flooding, the United States during the 199s has slowly begun to shift its fundamental strategy of federal flood control and prediction. Learning to live with and profit from rivers' variability is starting to make sense economically and ecologically. This is Adaptive Management. Currently, most approaches to addressing the aftermath of the devastating floods seem to be small and limited in scope, not basin-wide and multifunctional in design. This trend seems to part of a much broader based movement in the United States for increased grass-roots efforts to redefine the way water and land-related resources are managed. With patience and perseverance future decades will bring opportunities to scale up these more adaptive approaches to basin and landscape levels of management.

AEAM Initiatives in European River Basins

Many factors contribute at different scales to the integrity of systems of man and nature, such as river basins. Besides the surprising dynamism of systems, one reason that “solutions” to resource management problems are short-lived is that they are incomplete; they address one set of factors, either ecology, economics, or politics, or they address more than one set but only at one scale. For example, long time practitioners, such as J. Korman (pers. comm), have pointed out that dialogue-based management efforts such as AEAM can stall because of failure at the local, political level to find “local champions.” Initiatives directed at regional and national efforts may founder if no locally respected people are persistently keeping the dialogue process on the agenda or rallying local participation. Alternatively, political organizing might unify local populations around their own experience but wither in the face of macro-scale dynamics, such as global economics or regional climate change. How can understanding and policy be functionally and flexibly integrated and then harnessed to address a problem from all disciplines, sectors and scales that pertain?

A number of public and private institutions are currently discussing how to test AEAM as a public learning and management tool in various river basins in Europe. Such tests would aim to probe AEAM’S capacity to embrace a more comprehensive group of factors acting over a wider range of scales. We describe below how we might use AEAM to address flooding within the context of a wider set of factors that interact to affect the integrity of a river basin in Central Europe. Opportunities that AEAM might exploit became apparent during participation [Sendzimir] in the Czech Republic with a similar dialogue process, Landscape Stewardship (Lucas 1992, Endicot 1993, Western and Wright. 1994, Mitchell and Brown. 1998) a highly cost-effective way to get a quick overview of a complex management problem while initiating an open discussion in the region. In Moravia it was applied as a brief, intensive survey of all the factors that contributed to flood risk and damage on the Morava river in 1997 by a multi-disciplinary “expert” team over one week’s time. Specifically, we hope to clarify how the openings created by effective probing processes such as Landscape Stewardship could be built upon by the longer-term capabilities of AEAM. The capabilities we discuss here include the capacity to add scientific rigor to the process of posing and testing questions at a number of scales, to help lay and professional people to visualize the consequences of their assumptions as they affect the complex dynamics of floods, and to sustain a dialogue that transcends the limited horizons of politics or funding institutions.

Landscape Stewardship does bring distant and local experience to the same arena, namely, the public inquiry and final report put out by the outside team. During these public hearings one could compare local, regional and continental responses to flooding in terms of dike location and farming practices. For example, local Czech farmers complained that dikes magnify the damage of large scale (dike-breaching) floods by retaining water on fields long enough to kill biological activity in the soil, thereby prolonging the recovery period to several years before planting could resume. However, downstream on the same river we learned that the Austrians have experimented with moving dikes uphill to increase the water volume the floodplain can accommodate, removing row crops and using the floodplain as a wet meadow for grazing (Umweltbundesamt 1999). The Czechs admired how the Austrian portion of the Morava river absorbed with no damage the same volumes that flooded upstream portions of Moravia and how quickly flood waters receded without the dikes. They did point out, though, that Austrian farmers on the Morava depend on EU subsidies to market their floodplain cattle. In this case, the scale mismatch between local Czech economies and EU continental subsidies closed the discussion on a point of frustration. If an AEAM process could reframe this dialogue as a search for alternative hypotheses to test about what makes a river community vulnerable to flooding, perhaps the Austrians could be constructively used as an outside lesson on how to approach the problem at more than one scale. This and other hunches could be tested in local experiments with dike relocation coupled with innovations on national policy on agricultural subsidies.

Our landscape stewardship discussion in Moravia brought to light similar interesting experiments in the Netherlands. Centuries of Dutch experience in flood control have lead them to an impasse where further technical solutions do not add much to their capacity to absorb the effects of future floods on the Rhine. They conclude (T. Smits, Rijkswaterstaat Nederlands , pers. comm.) that their history of technical applications was based on a mistaken premise that river basin morphometry and land use should be modified solely for human uses. Specifically, over centuries they had changed the shape of river basins to accommodate the size and shape of transportation vessels (channelizing) and the needs of habitation and row crop agriculture (diking at the lowest possible elevation on the floodplain). Their new program "Room for the River" (Middelkoop and de Boo, 1999) reflects a new philosophy that human use functions should be adapted to the shape of river basins that naturally result from flooding histories. This program is currently being translated into land use change and relocation of inhabitants and dikes on certain floodplains. Row crops are being converted to forest, marsh or wet grazing meadows. Inhabitants are being relocated, with compensation, to higher elevations, and dikes are being relocated back from the main channel such that the entire floodplain cross section can accommodate a much larger volume of water.

It is difficult, however, to learn from foreigners or to experiment with your own intuition or the hunches of your neighbors when the flood aftermath is strained by mistrustful casting and/or avoidance of blame. Such an atmosphere can't be dispelled in a week. Longer time periods are needed under a structured framework where one feels safe to guess, safe to play with novel combinations of ideas. But the grace of sufficient time is rarely granted, because the scale of processes that cause crises is usually much larger than that of election cycles or funding horizons. One of the key political engagements of this era is to help political and funding agendas to match their cycles of operation and conceptual horizons with the scales at which problems develop. New decision mechanisms must be introduced if politicians, insulated from long term consequences by short (2 – 6) year election cycles, cannot appreciate such larger scale processes as flood frequencies, dam basin sedimentation rates, fish migration cycles and climate change. AEAM provides a transparent mechanism whereby professionals that are normally constrained by their organization's time horizon can safely consider policy consequences at a multitude of time scales.

At the outset AEAM addresses mistrust head-on by building consensus around what we agree that we do and don't know. Scientific discipline allows lay people to add their experience to the discussion and pose their questions in ways that are testable. This also coaxes policy specialists (corporate or government bureaucrats) to reframe their policy solutions as useful questions for testing. The tension of avoiding blame is really part of the general fear of being pinned or locked into a bad solution, particularly those from outside one's own school of thought. AEAM works to defuse this fear by encouraging multiple interpretations and then repeatedly testing the best candidate hunches. The danger of locking into one solution is minimized by capacity to test and then reassess. This is done in an iterative cycle of understanding enriched with multiple views, followed by testing and monitoring, that is fed back into a new round of understanding and testing.

In any discussion a key difficulty in building consensus is for all participants to see the consequences of their own assumptions or those underlying any other alternative hypotheses. The number of varying inputs to flooding make this especially difficult in managing a river valley. The combined variabilities in time and space of climatic inputs and river basin morphometry make it virtually impossible for any person to visualize the space/time dynamics of flooding. For example, precipitation, whether rainfall or fallout from Chernobyl, is no longer considered regionally homogenous; locally patchy models of precipitation are now sought for prediction. And it is very hard to assess the consequences to flooding of adding or removing or changing channels, dikes, wetlands or land uses. AEAM can abet such visualization by making sophisticated hydrological modeling accessible to anyone through computer interfaces. The various effects to flood behavior or the economy that result from such policy choices as changes in dike location, land use practice, transportation routes, lock and dam operation, can all be explored in parallel using computer simulation within the guided discussion framework of AEAM.

As with the Everglades, a disciplined discussion of the sources of flood risk that threaten the integrity of river valley ecosystems and society starts to become practical when a number of plausible and testable hypotheses can be posed. Then the various philosophical and political factions can unite around a test of the best group of these hypotheses, and the community can come together in the monitoring and re-evaluation of our understanding. We list below some potential examples, with caricature titles, of hypotheses about sources of flooding risk, though an actual AEAM process would probably use local and distant experiences to generate far more:

1. Engineered Security: Technical means (channels, dikes and locks) are inadequate and have to be changed (modified and/or increased) to meet future flooding potential.
2. Landscape Sponge: Land use change is reducing water storage capacity and increasing run-off speed faster than any technical, commercial or ecological response can remedy and must be halted, modified or reversed.
3. Innovative Enterprise: Commercial and/or agriculture practices need to be changed such that the needs of transportation and agriculture require less investment in anti-flood defenses such as technology or land use change.
4. "Room for the River": Flooding results from inadequate capacity of the floodplain to accommodate flood volumes because basin morphometry has been excessively modified to serve human use functions.

The danger of flooding does not remain constant but changes with time due to the evolution of society and such shifting environmental processes as climate change. To sustain a focus on this shifting flood risk, some sort of dialogue such as AEAM needs to continue the effort to understand and respond to all the critical sources of change. If we can develop such a capacity for enlightened dialogue, the critical information needed to face a crisis may not be hidden in libraries or the collective intuitions of bureaucrats or academicians; it may be floating on the crest of a rich discussion that is in the public domain. And such discussion may be the soundest platform for anticipating and adapting to crises, however inevitable they may be in a warming climate.

CONCLUSIONS

The policy-based experimentation advocated by adaptive management is essential to reduce the ecological, social, and economic costs of learning. Adaptive management focuses upon developing alternative hypotheses, identifying gaps in knowledge, and assessing what knowledge would most effectively distinguish alternative hypotheses and, therefore, could be most useful in setting and updating research and action priorities. As Peterson et al (1997) state:

> “Rather than simply testing and rejecting individual hypotheses, scientists and decision makers must consider diverse sets of alternative hypotheses. Alternatives need to be continually revised, modified, and discarded, based upon how they fare in tests against empirical data (Hilborn and Mangel 1996). Maintaining the status quo must be explicitly examined as one alternative among many, with its attendant consequences, benefits, and costs. More often than not, policy decisions have multiple dimensions that are difficult, if not impossible, to convert into a single metric. In these cases, techniques such as multi-attribute utility analysis, wherein tradeoffs between alternatives are evaluated using multiple metrics, may be necessary. In either case, such methods of analysis are best viewed not as authoritative objective procedures, but as modeling processes that provide a means of making underlying valuations open to scrutiny, discussion, and sensitivity analysis.”

In order to exercise reasonable caution we should recognize that the greater our uncertainty, and therefore the less our capacity to precisely define risk, the more considered and "reversible" our management actions should be. Data accumulation and analysis may narrow our sense of uncertainty, but our capacity to predict risk is persistently undercut by the scale of our actions in creating new uncertainties. Adaptive processes provide one of the most prudent frameworks for assessing and addressing the multiple scales at which flooding risk and damage emerge.   The laboratory for the theory and practice about floods has to be wider even than society; it has to span the range from local village experience to global sources of weather processes. The hard lessons of the last 40 years mandate that we learn to address all these scales, flexibly and repetitively, so that the most important question is always at hand.

BIBLIOGRAPHY

Bancroft, G.T. 1989 Status and conservation of wading birds in the Everglades. American Birds 43: 1258-1265.

Broecker, W. S. 1996. Thermohaline circulation, the Achilles heel of our climate system: will man-made CO2 upset the current balance? Science 278:1582-1588.

Collins, H. and T. Pinch (1993) The Golem: What You Should Know About Science. Cambridge University Press.

De Leo, G. A., and S. Levin. 1997. The multifaceted aspects of ecosystem integrity. Conservation Ecology [online]1(1): 3.
Available from the Internet. URL: http://www.consecol.org/vol1/iss1/art3

Endicot, Eve (ed.). 1993. Land Conservation Through Public/Private Partnerships. Lincoln Institute of Land Policy. Island Press, Washington, DC.

Faber, S. 1997 Flood Policy and Management: A Post-Galloway Report. *River Voices* Vol. 8, No 2, p.1.

Galloway, G., Cunniff, S., Kelmelis, J. Robinson, M. Shoudy. H. 1998 What's Happened in Floodplain Management Since the '93 Mississippi Flood? Natural Hazards Observer, Vol. XXII, No. 5.

Gunderson, Lance 1998 A Primer On Adaptive Environmental Management. Arthur R. Marshall Laboratory, Department of Zoology, University of Florida, Gainesville.

Hilborn, R. 1987. Living with uncertainty in resource management. North American Journal of Fisheries
Management 7:1-5.

Holling, C.S., Schindler, D.W., Wlaker, B.W., Roughgarden, J. 1995. Biodiversity in the functioning of ecosystems: an ecological synthesis. IN Biodiversity Loss: Economic and Ecological Issues. C. Perrings, K-G. Maler, C. Folke, C.S. Holling, B-O. Jansson eds. Cambridge University Press, Cambridge, U.K.

Levin, S. A. 1992. Orchestrating environmental research assessment. Ecological Applications 2(2): 103-106.

Light, S., Gunderson, L., and C. S. Holling 1995 The Everglades: Evolution of management in a turbulent ecosystem. IN Barriers and Bridges to the Renewal of Ecosystems and Institutions. L. Gunderson, C.S. Holling, and S. Light eds. Columbia University Press, New York.

Lucas, P.H.C. 1992. Protected Landscapes, A Guide for Policy-Makers and Planners. Chapman and Hall, London.

Middelkoop, H. and de Boo, (Eds.). 1999. Twice a River; Rhine and Meuse in The Netherlands, RIZA Report. Ministry of Transport, Public Works and Water Management. pp. 127. ISBN 90 369 52 239.

Mitchell, Brent A., and Jessica L. Brown. 1998. Stewardship: A Working Definition. Environments 26(1):8-17. Heritage Resources Centre, University of Waterloo (Canada).

Peterson, G., G.A. De Leo, J.J. Hellmann, M.A. Janssen, A. Kinzig, J.R. Malcolm, K.L. O'Brien, S.E. Pope, D.S. Rothman, E. Shevliakova, and R.R.T. Tinch. 1997. Uncertainty, Climate Change, and Adaptive Management. Conservation Ecology [online] 1(2): 4.
Available from the Internet. URL: http://www.consecol.org/vol1/iss2/art4

Sharing the challenge: Floodplain Management into the 21st Century. Report of the Interagency Floodplain Management Review Committee to the Administration Floodplain Management Task Force. Washington D,C. June 1994.

Umweltbundesamt 1999 Fliessende Grenze: Lebensraum March-Thaya-Auen. Umweltbundesamt, Vienna, Austria.

Walters, C. J. 1986. Adaptive Management of Renewable Resources.; McMillan, New York, New York,
USA.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology [online]1(2):1. Available from the Internet. URL: http://www.consecol.org/vol1/iss2/art1

Walters, C.J., and J.S, Collie 1988 Is research on environmental effects on recruitment worthwhile? Canadian Journal of Fisheries and Aquatic Sciences 45: 1848-1854.

Walters, C. and Holling, C.S. 1990 Large-scale management and learning by doing. Ecology 71 (6): 2060-2068.

Western, David, and R. Michael Wright. (eds.). 1994. Natural Connections:
Perspectives in Community Based Conservation. Island Press, Washington, DC.