Finally, we would like to acknowledge CSIRO Sustainable Ecosystems for its strong support and for hosting David while the book was being written. Gungahlin Homestead, the division's headquarters and formerly a grand farm house, was a stimulating and fitting place in which to write about the resilience of social-ecological systems and sustainability.

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October 2005

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Living in a Complex World:
An Introduction to Resilience Thinking

Life is full of surprises. Sometimes we take them in stride; some times they trip us up.

Consider these questions: In business, why is a competitor's new product sometimes only a minor hiccough but at other times a major shock that can destroy an enterprise? In industry, how is growth sometimes unaffected by medium interest rate rises but at other times the smallest change brings things crashing down? Why is it that the same drought that causes serious degradation of resources on one farm has little effect on another?

The response of any system to shocks and disturbances depends on its particular context, its connections across scales, and its current state. Every situation is different; things are always changing. It's a complex world.

We are all managers of systems of one type or another. That system might be a home, a company, or a nation. You might have responsibility of caring for a nature reserve, developing a mining operation, or planning fishing quotas. Be it a farm, a business, a region, or an industry, we are all part of some system of humans and nature (social-ecological systems).

How do you approach the task of management in this complex world? Do you assume things will happen in much the same way tomorrow as they did yesterday? Are you confident the system you are working in won't be disrupted by little surprises? Do you appreciate what's needed for a system to absorb unexpected disturbances?

All of these questions relate to *resilience*, the ability of a system to absorb disturbance and still retain its basic function and structure. They also relate to concepts of sustainability and the challenge of servicing

current system demands without eroding the potential to meet future needs. We live in a time of growing population coupled with a declining resource base and great uncertainty about a range of environmental issues such as climate change. How can we make the systems that we depend upon resilient?

But before we address issues of resilience, stop and consider for a moment our current practices of resource management.

The Drivers of Unsustainable Development

Our world is facing a broad range of serious and growing resource issues. Human-induced soil degradation has been getting worse since the 1950s. About 85 percent of agricultural land contains areas degraded by erosion, rising salt, soil compaction, and various other factors. It has been estimated (Wood et al. 2000) that soil degradation has already reduced global agricultural productivity by around 15 percent in the last fifty years. In the last three hundred years, topsoil has been lost at a rate of 300 million tons per year; in the last fifty years it has more than doubled to 760 million tons per year.

As we move deeper into the twenty-first century we cannot afford to lose more of our resource base. The global population is now expanding by about 75 million people each year. Population growth rates are declining, but the world's population will still be expanding by almost 60 million per year in 2030. The United Nations projections put the global population at nearly 8 billion in 2025. In addition, if current water consumption patterns continue unabated, half the world's population will live in water-stressed river basins by 2025.

The Food and Agriculture Organization of the United Nations (FAO) 2004 Annual Hunger Report estimates that over 850 million people suffer from chronic hunger. Hunger kills 5 million children every year.

The most famous fisheries in the world have collapsed one after the other, including those managed with the explicit aim of being sustainable (like the cod fisheries at Grand Banks, Newfoundland in 1992). Productive rangelands are turning into unproductive expanses of woody shrubs. Half of the world's wetlands have been lost in just the last century. Lake systems and rivers everywhere are experiencing algal blooms and a raft of problems associated with the oversupply of nutrients.

The World Wide Fund for Nature's (WWF) Living Planet report

BOX 1 A Few Stats on a Shrinking World

As far as humans are concerned, Earth is shrinking. The human population is growing but the resource base required to feed, clothe, and house this growing number of people is not. Indeed, in many instances it is declining. Here are a few numbers extracted in June, 2005 from the recently released Millennium Assessment, (www.millenniumassessment.org), and from the EarthTrends website, (http://earthtrends.wri.org.), maintained by the World Resources Institute.

- Worldwide, humans have already converted nearly a third of the land area—almost 3.8 billion hectares—to agriculture and urban or built-up areas. Most of the remainder is too dry for agriculture.
- Between 1960 and 2000, the demand for ecosystem services (benefits provided by ecosystems) grew significantly as world population doubled to 6 billion and the global economy increased more than six fold. To meet this demand, food production increased by roughly 2.5 times, water use doubled, wood harvests for pulp and paper production tripled, installed hydropower capacity doubled, and timber production increased by more than half.
- Global grain production, currently 1.84 billion tons annually, will need to increase by around 40 percent to meet demand in 2020.
- The average annual growth rate of cereal production in developing countries has dropped from 2.5 to 1 percent per year over the past 35 years. Water scarcity and land degradation are already severe enough to reduce yields on about 16 percent of agricultural lands, especially cropland in Africa and Central America, and pasture in Africa.
- In the last few decades approximately 20 percent of the world's coral reefs were lost, an additional 20 percent were degraded. In the Caribbean, 80 percent of coral has been lost in recent decades. Additionally, approximately a third of the world's mangrove areas were lost.
- The number of species on the planet is declining. Over the past few hundred years, humans have increased the species extinction rate by as much as 1,000 times over background rates typical over the planet's history. (The background extinction rate is the relatively constant rate—excluding major extinction events—at which organisms have been disappearing from the fossil record over the course of geological time.)
- Since 1750, the atmospheric concentration of carbon dioxide has increased by about a third (from about 280 to 376 parts per million in 2003), primarily due to the combustion of fossil fuels and land use changes. Approximately 60 percent of that increase (60 parts per million) has taken place since 1960.
- The use of two ecosystem services—capture fisheries and freshwater—is now well beyond levels that can be sustained even at current demands, much less future ones. At least one quarter of important commercial fish stocks are overharvested. From 5 percent to possibly 25 percent of global freshwater use exceeds long-term accessible supplies and is now met either through engineered water transfers or overdraft of groundwater supplies.

analyzes the eco-footprint of 150 countries around the world every two years. In its 2004 report it estimated that the average eco-footprint around the world was 2.2 global hectares per person (a global hectare is a hectare of biologically productive space with world-average productivity). However, there are only 1.8 global hectares available per person. This ecological overshoot means we are using the equivalent of about 1.2 planets or it takes 1.2 years to regenerate what humanity uses in one year. We are using nature more rapidly than it can regenerate.

Regrettably, like a cracked record, the story goes on and on, disturbingly repetitive (see also box 1, "A Few Stats on a Shrinking World").

You've seen or heard these claims before and it is not our intention to add to doom-and-gloom publications. Rather, this book is about options and hope based on a different way of doing things through understanding how the world really works. But we do need to keep in mind what is happening to the world. The imperative message is that the world is shrinking: the human population is growing while its resource base declines.

What lies behind this decline? There is, of course, no single underlying reason; instead, there is a broad spectrum of causes. But they can be grouped into three categories: in some situations people have no choice but to overuse their resource base; in others the decline is allowed to occur willfully; and the third driver of unsustainable development is misunderstanding—the application of inappropriate models of how the world works.

The first category (no choice) relates to problems associated with large populations coupled with poverty. In this case, no other option exists than to overuse resources. It's simply a matter of survival.

All too often, however, there is a choice, and a resource is allowed to decline or is purposely driven down. Sometimes rules and regulations encourage people to overuse resources, this is the case of subsidies for drought-stricken farmers. Often these farmers are either operating on marginal land or mismanaging resources but their operation is propped up by government payments designed to protect people from hardship. In other cases, tax breaks or industry support can lead to rapid loss of a forest or a fishery. These are what are known as "perverse incentives" (McNeely 1988). Furthermore, people sometimes deliberately choose to degrade a resource because they believe science and technology will always be able to come to the rescue.

In many cases, however, resource degradation is simply the result of humankind's insatiable desire to produce and consume, leading to

willful short-term greed and corruption with no heed for the future. Some suggest this is just the way humans evolved—in a world without limits where success was based on maximizing your return. Human behavior is shaped strongly by drives from our evolutionary past (competition, territory, and power) without which we would not be here as a species or as the cultures we now have. Such evolutionary antecedents made sense when the human population was small and the world was seemingly endless but this is no longer the case. In today's world such behavior has begun to turn on us and will deprive future generations of the opportunities we enjoy.

But there is a third driver as well. Our environmental problems can't all be blamed on greed and overexploitation. Ignorance and misunderstanding also play a central role in the decline of our resource base. In many instances, such as in all of the case studies in this book, it's clear that in developing a resource or a region we have not understood well enough the functioning of the ecosystems involved. The people involved were not being greedy, there was no willful destruction. Many ecosystem collapses are occurring in places where enormous resources are being invested in understanding the system and where significant effort is being made to be "sustainable."

It isn't just the amount of knowledge—details about species and ecosystems—it's also the kind of knowledge. It's the way we conceive of resource systems and people as part of them. The way we currently use and manage these systems (which we describe in the following section as "business as usual") is no longer working and yet what we hear most of the time is that the solution lies in more of the same.

This book focuses on this third driver of unsustainability. The first driver (poverty) will only be resolved when the world has addressed the other two. We return to the second driver (willful excessive consumption) in the final chapter because our best hope for dealing with it also lies in a philosophy of resilience.

Despite Our Best Intentions

Why is it that, despite the best of intentions (and in contrast to the one or two recent books telling us that "everything is okay"), many of the world's productive landscapes and best loved ecosystems are in trouble?

Current "best practice" is based on a philosophy of optimizing the delivery of particular products (goods or services). It generally seeks to

maximize the production of specified components in the system (set of particular products or outcomes) by controlling certain others. Those components might be grain yields, fish catch, or timber harvest. Or, if conservation is the goal, optimization might be aimed at preserving as many species as possible in a national park or reserve. In the case of grain crops it might entail planting all the available land with a single high yielding variety and then maximizing growth with chemical fertilizers and pest control, and using large-scale cropping machinery. Production is maximized by tightly controlling each aspect of the production process.

Optimizing for particular products has characterized the early development of natural resource management, particularly in agriculture. Initially, it worked. Indeed, it resulted in enormous advances in resource productivity and human welfare. Now, however, those initial successes are bedeviled by a variety of emerging secondary and highly problematic effects on all continents and in all oceans. As Ogden Nash writes, "Progress might have been alright once, but it has gone on too long."

An optimization approach aims to get a system into some particular "optimal state," and then hold it there. That state, it is believed, will deliver maximum sustained benefit. It is sometimes recognized that the optimal state may vary under different conditions, and the approach is then to find the optimal path for the state of the system. This approach is sometimes referred to as a maximum sustainable yield or optimal sustainable yield paradigm.

To achieve this outcome, management builds models that generally assume (among other unrecognized assumptions) that changes will be incremental and linear (cause-and-effect changes). These models mostly ignore the implications of what might be happening at higher scales and frequently fail to take full account of changes at lower scales.

Optimization does not work as a best-practice model because this is not how the world works. The systems we live in and depend on are usually configured and reconfigured by extreme events, not average conditions. It takes a two-year drought, for example, to kill perennial plants in tropical savannas, and it takes extreme wet periods for new ones to be able to establish. The linkages between scales and sectors (agriculture, industry, conservation, energy, forestry, etc.) often drive changes in the particular system that is being managed. And, very importantly, while minor changes are often incremental and linear, the really significant ones are usually lurching and nonlinear—like mouse plagues in Australian wheat crops,

insect pest outbreaks in forests in North America, and the sudden change from a clean, clear lake to one dominated by an algal bloom.

The Paradox of Efficiency and Optimization

"Efficiency" is a cornerstone of economics, and the very basis of environmental economics. In theory, an economy is efficient if it includes all the things that people want and value. An efficient economy, in this sense, is therefore a good thing and efficiency has become to be regarded as a laudable goal in policy and management. The paradox is that while optimization is supposedly about efficiency, because it is applied to a narrow range of values and a particular set of interests, the result is major inefficiencies in the way we generate values for societies. Being efficient, in a narrow sense, leads to elimination of redundancies—keeping only those things that are directly and immediately beneficial. We will show later that this kind of efficiency leads to drastic losses in resilience.

Optimization does not match the way our societies value things either. It promotes the simplification of values to a few quantifiable and marketable ones, such as timber production, and demotes the importance of unquantifiable and unmarketed values, such as the life support, regenerative, and cleansing services that nature provides (collectively known as "ecosystem services"). It also discounts the values placed on beauty or on the existence of species for their own sakes. Whether they realize it or not, societies depend for their existence on ecosystem services. And societies also value their ability to pass these things to future generations. Optimization, however, distorts this. It reduces time horizons to a couple of decades—the limit of the time horizon for most commercial investments. Values that do not have property rights or are publicly owned are not marketed, do not generate wealth, and gain little support, even if they involve critical ecosystem services. Often not enough people understand the criticality of the life support systems—the ozone layer and climate regulation are examples.

Though efficiency, per se, is not the problem, when it is applied to only a narrow range of values and a particular set of interests it sets the system on a trajectory that, due to its complex nature, leads inevitably to unwanted outcomes. The history of ecology, economics, and sociology is full of examples showing that the systems around us, the systems we are a part of, are much more complex than our assumptions allow for.

What it all adds up to is that there is no sustainable "optimal" state of an ecosystem, a social system, or the world. It is an illusion, a product of the way we look at and model the world. It is unattainable; in fact (as we shall see) it is counterproductive, and yet it is a widely pursued goal.

It is little wonder, then, that problems arise. And when they do, rather than question the validity of the model being applied, the response has been to attempt to exert even greater control over the system. In most cases this exacerbates the problem or leaves us with a solution that comes with too high a cost to be sustained.

In the real world, regions and businesses are interlinked systems of people and nature driven and dominated by the manner in which they respond to and interact with each other. They are complex systems, continually adapting to change. Change can be fast or slow—move at the speed of viruses multiplying or of mountains rising. It can take place on the scale of nanometers or kilometers. Change at one level can influence others, cascade down or up levels, reinvigorate, or destroy.

The ruling paradigm—that we can optimize components of a system in isolation of the rest of the system—is proving inadequate to deal with the dynamic complexity of the real world. Sustainable solutions to our growing resource problems need to look beyond a business as usual approach.

As failures mount, and as more and more people become aware of them, there is a growing dissatisfaction with the ways in which natural resources are managed. What are the important qualities of a system that need to be maintained or enhanced for a system to be sustainable? Resilience thinking is an approach (part philosophy, part pragmatism) that seeks answers to these questions.

The Key to Sustainability?

What is your version of sustainability? Is it summed up by the catch phrase "reduce, reuse, and recycle" (reduce your waste, reuse what you have, and recycle everything else)? Are you impressed by notions of ecological footprints and living within the carrying capacity of the land? Are you striving for a "factor four" improvement for the future in which we double the production from half of the input? Or maybe we should be aiming for a factor ten?

These approaches encapsulate some of the more mainstream thoughts on sustainability, and they all revolve around the notion that the key to sustainability lies in being more efficient with our resources. If we can be clever enough with the way we do things we can live within the carrying capacity of our environment.

Of course, this kind of efficiency will always be an important part of any approach to sustainability. But, by itself and of itself it is not the solution. Indeed, as we will show, by itself it has the potential to actually work against sustainability. Why? Because the more you optimize elements of a complex system of humans and nature for some specific goal, the more you diminish that system's resilience. A drive for an efficient optimal state outcome has the effect of making the total system more vulnerable to shocks and disturbances.

While that might sound counterintuitive, it is the inevitable conclusion reached by many studies investigating how social-ecological systems change over time. This book aims to explain the logic behind this seemingly perverse outcome.

By way of example of the tension between resilience and efficiency, consider the rise of the "just-in-time" approach where manufacturers dispense with big stockpiles of materials. Instead, parts and supplies are delivered to a factory at the exact moment when they are needed. The system, deemed to be efficient and optimized, yields big savings in inventory expenses but is very sensitive to shocks and has resulted in some severe industry dislocations when problems up the line with materials or staff have resulted in critical supply shortages.

The bottom line for sustainability is that any proposal for sustainable development that does not explicitly acknowledge a system's resilience is simply not going to keep delivering the goods (or services). The key to sustainability lies in enhancing the resilience of social-ecological systems, not in optimizing isolated components of the system.

The debate on sustainability has come a long way in recent decades. But if we examine it through a resilience lens, it's clear that we still have a way to go.

Embracing Change—The Heart of Resilience

At the heart of resilience thinking is a very simple notion—things change—and to ignore or resist this change is to increase our

vulnerability and forego emerging opportunities. In so doing, we limit our options.

Sometimes changes are slow (like population growth); sometimes they are fast (like exchange rates, or the price of food and fuel). Humans are usually good at noticing and responding to rapid change. Unfortunately, we are not so good at responding to things that change slowly. In part this is because we don't notice them and in part it's because often there seems little we can do about them. The size of the human population is a key slow variable, for example. So too is climate change. But few people believe there is anything they can do directly to influence either.

In and of itself, change is neither bad nor good. It can have desirable or undesirable outcomes, and it frequently produces surprises.

These broad statements, when applied to interacting systems of humans and nature (social-ecological systems), take on special meanings with important consequences. Resilience thinking presents an approach to managing natural resources that embraces human and natural systems as complex systems continually adapting through cycles of change.

Most of the concepts in this book are not new. Concepts of resilience and changing ecosystems have been around for decades. However, only recently have interdisciplinary groups of scientists begun to tackle the problem in earnest. The Sante Fe Institute, for example, is one well-known group that has spawned ideas about chaos theory, network dynamics, and, latterly, robustness. Another such group is the Resilience Alliance, a collection of researchers who have pooled their insights to develop a framework for understanding change in social-ecological systems. Through the efforts of groups like these, resilience thinking may provide valuable insights to sustainability.

A Roadmap to this Book

There are many ways to present a framework for resilience thinking. We have chosen to approach it by taking three steps. The first lays down a foundation for understanding, the second outlines the core of the approach, and the third begins to explore how resilience thinking might be applied to addressing challenges in the real world.

The first step involves considering a systems perspective of how the world works:

- We are all part of linked systems of humans and nature (referred to throughout this book as social-ecological systems).
- These systems are complex adaptive systems.
- Resilience is the key to the sustainability in these systems.

A traditional command-and-control approach to managing resources usually fails to acknowledge the limits to predictability inherent in a complex adaptive system. The traditional approach also tends to place humans outside the system. Resilience thinking is systems thinking, a concept that is more fully explored in chapter 2.

The second step is to develop an understanding of the two central themes that underpin resilience thinking:

- Thresholds: Social-ecological systems can exist in more than one kind of stable state. If a system changes too much it crosses a threshold and begins behaving in a different way, with different feedbacks between its component parts and a different structure. It is said to have undergone a "regime shift." This theme of thresholds and "changing too much" is discussed in chapter 3.
- Adaptive cycles: The other central theme to a resilience approach is how social-ecological systems change over time—systems dynamics. Social-ecological systems are always changing. A useful way to think about this is to conceive of the system moving through four phases: rapid growth, conservation, release, and reorganization—usually, but not always, in that sequence. This is known as the adaptive cycle and these cycles operate over many different scales of time and space. The manner in which they are linked across scales is crucially important for the dynamics of the whole set. These ideas are explored in chapter 4.

The third step is to apply this understanding to the real world:

- How might a resilience approach be put into operation?
- What are the costs of a resilience approach?
- What are the implications for policy and management?
- What might a resilient world be like?

While a framework for resilience thinking provides valuable insights into why and how systems behave as they do, to have policy and management relevance it needs to be able to solve problems in resource management, which is discussed in chapters 5 and 6. In chapter 6 we also discuss how managing for resilience has the capacity to create space in a shrinking world by opening up options rather than closing them down. Resilient social-ecological systems have the capacity to change as the world changes while still maintaining their functionality. Resilient systems are more open to multiple uses while being more forgiving of management mistakes.

While every effort has been made to keep jargon and terminology to a minimum, resilience thinking does contain several concepts that can seem a bit daunting to the uninitiated on first exposure. We encourage readers not to be too worried about understanding every detail on the first reading. Instead, try to take away a general appreciation of what thresholds and adaptive cycles are, while attempting to understand them in relation to the system in which you are interested.

Even if the finer details of some aspects of the resilience approach remain a bit obscure, if you can incorporate the broader themes presented here on living within complex adaptive systems you'll discover you've acquired a powerful set of insights about how the world works. Concepts of sustainability, efficiency, and optimization all begin to take on a new light.

Our hope is that readers will start asking questions about the systems in which they live or in which they are interested: What are the key variables driving them? Is the system approaching a threshold? What management actions do you need to consider in order to avoid such a threshold? What are the dynamics of this system? What are the connections between the scale at which you are concerned and the next level up and down?

These are all big questions that may not be easy to answer. However, the very act of framing them in relation to the system in which you play a role is an important step toward resilience thinking.

Between each chapter a case study on a region illustrates the significance of resilience thinking when applied to real-world situations. They demonstrate its value in interpreting and understanding what lies behind changes being observed in five very different social-ecological systems around the world.

Five Regions, Five Stories

The five regions we discuss are:

- The Everglades in Florida, United States: Possibly the world's most famous marshland system. Significant parts of the national park have crossed a threshold into a new regime dominated by cattails.
- The Goulburn-Broken Catchment: One of Australia's most agri-culturally productive regions. Saline groundwater now lies just beneath the surface of the region's most productive agricultural zone.
- The coral reefs of the Caribbean: Once one of the most magnificent coral systems in the world and a tourist draw that was the economic lifeblood of the region. In the last thirty years, 80 percent of hard coral reefs have disappeared and the remaining reefs are at risk.
- The Northern Highland Lakes District of Wisconsin, United States: A fishing paradise with an uncertain future. The natural amenity of this much-loved area is slowly being lost as its population grows.
- The Kristianstad Water Vattenrike: An internationally renowned wetland in southern Sweden. Its beloved wet meadows are being lost, water quality is in decline, and wildlife habitat is disappearing.

Why these five regions? To begin with, they are different. They have very little in common, with different levels and types of population engaged in different enterprises coping with a range of different challenges. What they do have in common is that each is confronted with a range of natural resource and social challenges that have major implications for their inhabitants and surrounding regions. And we know quite a lot about them; each has been studied over many years in an attempt to understand the ecological and sociological processes that drive them.

We have chosen case studies at a regional scale because this is the focus of much of the work of the Resilience Alliance. However, as the basis of resilience thinking becomes clear, it should be apparent that it applies to systems of people and nature at all levels: individuals, communities, businesses, and nations.

Of course, there are many other regions around the world facing enormous resource issues that are not discussed in this book. Many

parts of Africa, for example, are suffering chronic food shortages, disease outbreaks, and social instability. Two such regions (in Mozambique and Zimbabwe) are part of the Resilience Alliance's set of case studies and there are many lessons in resilience thinking that are relevant to these regions. However to meet the needs of this book as an introduction to resilience thinking we have chosen to examine five regions that are well studied and that reflect a range of contrasting issues.

Our first case study is the Everglades, a world-renowned wildlife wonderland at the southern tip of Florida in the United States. Attempts to tame parts of it for agriculture and urban settlement over the last hundred years have had mixed results. On the one hand the region supports a lot more people, industry, and agriculture. On the other, its natural qualities have gone into steep decline, including its water quality. Development has resulted in some significant gains but the costs are only now being understood.

Key Points on Resilience Thinking

- Current approaches to sustainable natural resource management are failing us. They are too often modeled on average conditions and expectations of incremental growth, ignore major disturbances, and seek to optimize some components of a system in isolation of others. This approach fails to acknowledge how the world actually works.
- Business as usual is about increasing efficiency and optimizing performance of the parts of social-ecological systems that deliver defined benefits, but fails to acknowledge secondary effects and feedbacks that cause changes (sometimes irreversible changes) in the bigger system, including changes to unrecognized benefits. While increasing efficiency is important for economic viability, when undertaken without considering the broader system's response it will not lead to sustainability; it can lead to economic collapse.
- Resilience thinking is about understanding and engaging with a changing world. By understanding how and why the system as a whole is changing, we are better placed to build a capacity to work with change, as opposed to being a victim of it.

CASE STUDY 1

Carving up a National Icon:

The Florida Everglades

One hundred years of command and control management have exacted a heavy price on the Everglades, possibly the most recognized wetland in the world. Efforts to develop it have involved compartmentalizing it into agricultural, urban, and conservation sections; draining it; and constructing massive infrastructure to control floods and mitigate the damage from hurricanes. The results have significantly reduced the area of natural habitat, created dramatic declines in water quality (for wildlife and humans), and made the region increasingly vulnerable to the shocks produced by extreme weather events.

The Everglades of today is propped up by injections of billions of dollars from the federal government, while being held in gridlock by litigation and a highly adversarial contest between a myriad of players. It is a social-ecological system with a major resilience problem (Gunderson et al. 2002).

For all this, the Everglades is still regarded as an international icon for natural beauty. And yet the very aspects of this region that make it world-renowned are under a serious and growing threat as human development in and around the Everglades has slowly shifted the pattern of dynamics that has crafted the region. And what's at risk is not just the "nature" portions of the system in the national park, but the hydrological changes impact on the economic prosperity and social stability of the broader region that now supports over 6 million people.

The irony is that the very developments that opened up the territory for growth and prosperity, specifically the control of water levels, have