GUNDERSON: **(SLIDE 1)** Wow, thank you. It's always interesting to start off – any kind of conference. I was a bit surprised when Ian asked me to kick things off here. So, I'm not sure what to tell you in advance, other than it's been about 35 years since I finished my masters and took a job with the National Park Service in South Florida with this naive idea that better science would help solve these big environmental issues. Now I get to talk to undergrads and grad students in environmental science at Emory University. And so, I'll jump right into it. I was asked to talk about uncertainty and shooting the rapids, which came from the name of a paper that I co-authored a couple of years ago.

(SLIDE 2) I wanted to start off with a general statement that we daily and over longer terms really confront, I think, qualitatively different types of uncertainties-- that range from things that are moral in nature (what's good what's bad,) to thinking about how the impacts of what we do are going to play out, how we make decisions about that—all the way to what scholars call epistemic uncertainty. Epistemic means knowledge and how we come to understand and think about the world that we live in. And that is the type of uncertainty that science addresses. So, part of what I'd like to say is that we have to deal with not just one type of uncertainty but with multiple types of uncertainty that are really, really different in nature.

(SLIDE 3) A connection to the title about uncertainty and shooting the rapids, links in my mind this idea that most of the way in which we try to manage uncertainty is throughout time, in a temporal domain going from now into the future or extrapolating from the past into the future. And one of the things about this sort of river rafting metaphor is that it also links in with some famous work by economists in terms of how people make decisions, especially under situations of uncertainty. I am referring to work by Daniel Kahneman, he's got a book out now called *Thinking, Fast and Slow*, and he says that our minds work on those two speeds, and that we work both; slowly, kind of logically and consciously to work out problems, but we also think very fast, automatically, like when river

runners have to hit the rapids. And a lot of that thinking is quite subconscious. It's built upon practice and experience.

Another concept that I wanted to kind of introduce is the notion of working across scales similar to how we think across time. We have to work in different time domains in terms of trying to confront uncertainty.

(SLIDE 4) Some organizational literature and organizational theory, proposes how groups undertake collective action to deal with uncertainty. Businesses and governmental agencies like the US National Hurricane Center seem to follow a set of steps in trying to confront or cope with uncertainty, predict where major storms are going to show up. And they go through these kinds of steps of trying to reduce that uncertainty—that is, what do we know about it, what information can we gather, how does that fit with our mental models, our assumptions, our reasoning, about how the world might play out.

We all use models, models whether they are conceptual models or complex mathematical models, and we don't just use one. We use a variety of them in terms of trying to figure out what these outcomes might be. And I think it's true. So, the National Hurricane Center, when they have to predict where these storms are going to be, they don't just use one model. They use a bunch of models that range from statistical models about where these storms have been, experienced forecasters who've watch these cyclones spin across the tropics for years, to really complicated three-dimensional equation continuity type models, all of them having a piece. And then they look at the alternatives, what are these various ranges of outcomes, and then they make a decision in terms of how to proceed. That decision may include something like, "I'm going to deny it. It's not going to happen." I might seek some kind of false certitude about it. They may hedge their bets, and then they make a decision. A sort of simple example about this is that every morning I look at The Weather Channel or Weather Underground website and look to see

what the probability of rain is going to be. That's me trying to reduce my uncertainty about weather. I weigh my alternatives. Should I put my umbrella in my book bag? Should I wear a raincoat? I may say, "Forget it. I'm in too much of a hurry, I'm just going to run out without my rain coat or my umbrella today," or I'm going to hedge my bets and stick my umbrella in my book bag and carry it just in case it does rain, those sorts of things. So, people assess uncertainty and act on that assessment every day. And again, it's a combination of these slow thinking processes and fast thinking processes.

(SLIDE 5) Now, one thing that I've come to realize is that we all have these constructs or models in our head. We make decisions based upon how we think the world works. About 25 years ago, I met this fellow, Buzz Holling, who sort of changed my life and the way I think about these things. A lot of these ideas are in collaboration with or from Buzz's really creative mind about dealing with understanding complex ecological systems, and moreover, how we act in them. And he says that there are at least four or five different of these sort of – we call them myths, right? These myths are assumed general structures that are used to understand how this complicated world outside us works. They range from things like a random world to a balanced world to a resilient world and those sorts of things, and I'll talk a little bit about each one of these and why they're important.

(SLIDE 6) So, a lot of simple statistics are based upon a mental model that much of what we perceive of the world is random, that things happen out there in stochastic ways. In this myth, some of the system dynamics can be controlled by large-scale processes, whether they're storms or tsunamis. And moreover, there is little or no feedback within the system to stabilize it, that it's sort of subject to the vagaries of what's going on around it.

(SLIDE 7) I would argue that certainly, in the middle to the latter part of the 20th century, a lot of resource management is based upon a notion that ecological systems or natural systems operate around a global equilibrium. Examples include a classic logistic curve model, which drives fishery harvests or at the bottom, water regulation. This model of nature suggests that whatever happens to this system, whether we take fish out of it or we move water around, it's going to recover or come back to an equilibrium state. And the hope is that it's going to return to such a state, whether we know it will or not.

(SLIDE 8) One of the other models of nature makes assumptions that policy affects are predictable. That is, if we know if we pull lever A over here, then consequence B is going to happen. There's another view that's emerged around this idea of the precautionary principle that no matter what we do, bad things are going to happen, and there's a lot of uncertainty associated with that that these bad things might happen. And in that case, then the best thing is to be really, really sure about something before we do it. I would argue that probably a lot of the endangered species management in the US falls within this sort of myth in that whatever we do, something bad is going to happen, right? So we try to prevent bad things from happening and buffer the system from disturbances.

(SLIDE 9) Another view of nature came about 45 years or so ago, when Buzz Holling introduced this word "resilience" into the ecological literature. One key thing about this notion in a kind of system sense about a kind of nature-resilient myth is that these systems that we operate in don't have just one single or one kind of global equilibrium value but can operate in very different stable states or regimes. On the slide you'll see an example here of coral reefs that are either in a coral state or an algae state. There have been hundreds of publications over the last 20 to 30 years demonstrating these kind of alternative multiple equilibria. So it's not just a matter of the system sort of returning to where it is but the

system actually flipping into something else. And moreover, this kind of concept introduces a level of uncertainty that's really difficult to deal with, because there is always multiple claims about what led to these states, how stable are these states, and moreover what does it take to transition back from one state to another. Because people generally have choices about these different states, right? So if you're a manager of the Great Barrier Reef, you really do want something that looks like this and not this, right? We rely on these alternative states of nature to provide sets of ecosystem goods or services or conservation purposes; however you want to characterize it. But this idea in the myth of nature resilience – is that resilience is defined by the set of factors needed to flip from one system state into another.

(SLIDE 10) Another idea that has emerged at the end of over the last 20 years or so has been this notion of trying to reunite, I guess for lack of a better word, people and nature, A lot of 20th century resource management was about people controlling nature or thinking about how our actions are or were going to affect nature. Also, social scholars and social scientists were studying and thinking about, the human components of these systems are really what matters. But over the last 20 years or so, many scholars have merged these two perspectives and thinking about resource systems as a type of coupled system – the ecosystem and the human system. On the human side, the institutional preferences, social values, rules, regulations, help to determine how we act and intervene in ecosystems. These ecosystems often respond in ways that lead to structural and functional ecological changes – which can be characterized as a regime shift or change in ecological state. Such changes in ecological state can in turn affect and alter the human sub-system. One example of this move towards merging the ecological and social systems is a center called SESYNC. This stands for the Social-Ecological Synthesis Center, which was established about four or five years ago in Annapolis, Maryland. The center brings scholars and practitioners together to

develop new concepts, methods and ideas about coupled social and ecological systems – not just one system separated from another but how they interact with each other.

(SLIDE 11) Next, I'm going to move on from work on simple mental models and present a more synthetic model of how coupled systems of people and nature change over time. Based on work with Buzz Holling and other colleagues, we see similar kinds of patterns of change over time. It may be a model of classic forest succession or urban development as shown in this slide.

(SLIDE 12) Generally, systems grow and develop over time. Most begin with a rapid growth phase, as shown in the bottom left corner of this slide. In the rapid growth, resources are exploited, and there is intense competition for those resources. But over time, as shown by the rising arrows, systems accumulate structure. Diversity increases, and the system becomes more connected. At some point, the systems reach a different phase, as shown by the yellow box. This is called the conservative phase, conservative in the sense that the focus is on conserving that stored capital. So for example, forests accumulate biomass. You can think about that. And the energy that goes into driving that forest goes into maintaining that biomass.

(SLIDE 13) But the longer these systems are in this sort of development process, they become subject to different kinds of disturbances. Some are external changes, exogenous crises like the hurricanes or tsunamis that can create both a crisis in the sense that it's a surprise, something that hadn't been expected before is going to happen.

(SLIDE 14) There are other classes of crises or surprises that are associated with a loss of resilience. As these systems mature over time, they become more connected. They become more vulnerable to things that are happening. I guess a good example of that now is this sort of increased cost of extreme weather events, not just in US but across the

world. It's not that these events are getting any stronger. It's that the system has become more vulnerable to weather events. It's become more costly to deal with these sorts of things.

(SLIDE 15) This leads to the next phase of system change; one that accounts for crises or instabilities. Shown as a release phase or pink box in the lower right, structure that had been accumulated in the prior phases collapses.

(SLIDE 16) Many systems go through a quick reorganization phase, as shown by the blue box in the upper left of this diagram. As ecological systems or social systems develop over time, that's a slow process. It can unfold over decades to centuries, whereas these disturbances and instabilities are rapid, and so are periods of reorganization. And then the system can start again.

(SLIDE 17) I've used this kind of heuristic with colleagues to look at histories of these complex social ecological systems, like Everglades Water Management. Over a century water resource development has shown at least four management eras, each one triggered by a crisis. Earlier on, those crises were unforeseen variation in weather events – too much rain, too little rain. Later, on they were nutrient-induced crisis that have to do with the sort of effects or latent effects of land use changes within South Florida.

(SLIDE 18) Each new management era has led to changes in the infrastructure. The plumbing in Everglades now consists of 1,500 miles of levees and canals, huge pumps to move water around the landscape. But another form of adaptation has come in the human side of the equation. There have been these sort of institutional changes in which new institutions were created, reformed, reworked, whether it was in the 1920s, the presence of the federal government; or in the 1980s, in which these much more collaborative stakeholder type groups were formed over time.

(SLIDE 19) You can in this diagram how the adaptive cycle has been applied to interpret the history of the Everglades. It shows how ecological and social components go through these phases of increasing development and vulnerability facing crisis followed by reformation and changes – resulting in different management eras.

(SLIDE 20) A revised version of the adaptive cycle model that emerged from these studies came from consideration of cross-scale influences. I tell my students, I said, "You know, one of the best things about being a professor is you get to make stuff up." And so, this is one of those things that we made up. Instead of calling the adaptive cycle of change we gave it the name of "panarchy," which refers to nature's rules rather than sort of hierarchy theory, which was dominant in ecological and a lot of the social literature as well. But the point here is, again, these fast and slow dynamics. And, moreover, the recognition that there are things that are slower and larger that influence both how these systems organize and that can influence these kinds of crisis periods. And moreover, that there are key times for innovation and the introduction of novelty in new and different ways of trying to deal with these chronic problems.

I've spent a lot of time on simple heuristics that people use to explain how people make sense and act in complex dynamics of systems of people and nature. Moreover, these models/constructs help us think about and manage uncertainty.

(SLIDE 21) A colleague of mine, a social scientist, Francis Westley, introduced this idea that probably most of the folks in this room can relate to – that managers have to confront and manage different types of uncertainty. That is, many folks have to deal with different types of problems or problem domains. Managers must deal with different problems -- ones that aren't just science, but ones that involve the kinds of organizations, whether they're formal organizations (such as federal or

state agencies) or issues of community, to overarching problems that involve politics.

This gives me a chance to tell a bad joke I heard about the etymology or the source of the word "politics," – *poly* meaning "many," and *ticks* are blood-sucking arachnids. I'll move on and talk a little about how we deal with complexities and uncertainties of science and organizations.

(SLIDE 22) While science is an institution that confronts and resolves uncertainty, it can be applied in many different ways. I think it's a lot of what folks are struggling with in these kinds of meetings are these different cultures or approaches in science; one is analytic. It is narrow in the kind of questions it can answer, uses types of standard statistics, and is very common. Another, more integrative type of sciences, acknowledges multiple causation, multiple hypotheses. I would argue that most of us tend to be trained in the analytical approach to science, and struggle to apply this to real world problems that are much more integrative in nature.

(SLIDE 23) As indicated in prior slides, many managers have to deal with problems of institutions and stakeholders and advocacy groups and epistemic groups and problems of collective action.

(SLIDE 24) Perhaps one of the best scholars in this area was Elinor Ostrom, the only woman to win a Nobel Prize in Economics. She studied how people manage natural resources and came up with these sort of empirical ideas and principles about what makes for successful resource management institutions, but also that there's no panacea, there's no cure-all, there's no one-size-fits-all for these kinds of institutional settings and configurations as well.

(SLIDE 25) Moving back into the realm of how natural resource managers have sort of dealt with uncertainty brings us to the idea of adaptive management. About 40 years ago—a group of scientists, Buzz Holling, Carl Walters, and others, proposed adaptive management. As shown in this flowchart, it is a process to confront the uncertainty of these

resource problems, saying that there's an inherent unpredictability, an inherent uncertainty around any one of these linking what we know about these problems to acting on these problems. One part of adaptive management is to view of policies as hypotheses. Or, as a friend of mine says, “Most policies are really questions disguised as answers." If these are questions, then management should try to test those ideas in a kind of quasi-experimental setting. There is a large and growing body literature on adaptive management. One of the big first case studies that came out was Kai Lee's work on the Columbia River and trying to apply these ideas of adaptive management to the river just outside the door.

(SLIDE 26) I'm going to quickly talk about two cases that I've been involved with, one in the Everglades in South Florida; the other is adaptive management in the Colorado River South of Glen Canyon.

(SLIDE 27) Everglades is a poster child for bad environmental management. While it has a national park at the downstream end of the system, conservation of natural resources has not been successful even though it is part of a complex water delivery system designed to support conservation. As a result largely due to water management, there are more than 20 endangered species, collapsed wading bird nesting, many invasive species and a decline in water quality.

(SLIDE 28) In an attempt to undo environmental declines, the US Army Corps of Engineers in 2000 presented a plan to Congress to try and restore these lost values. The plan came after 10 years of study, and is an attempt to undo many years of unsuccessful conservation management. The comprehensive Everglades restoration plan was passed by congress with the stipulation that ecosystem restoration would use adaptive management to try and resolve uncertainties associated with how this plan might unfold. Well now, 15 years later, there haven’t been any experiments done. There has been a lot of planning, of experiments. Every time they try to do something, something happens and somebody complains. And

so, in my mind, it's not that we don't know enough about the system in terms of what to experiment with and how to conduct these experiments but really, the sort of social capacity that's required. And that's where I use this word "adaptive governance," to view that sort of context. And I'll expand upon that in a minute.

(SLIDE 29) On the other hand, downstream of the Glen Canyon Dam, there are, again, a whole bunch of resource issues in terms of water going through the national park, endangered species, sediment transportation, power generation, invasive cultural claims, issues of water law. And it's not any more institutionally complex than the Everglades. Yet for some reason – and I think it has to do with lots of leadership – they've been able to pull off a lot of experiments, actually, both in terms of flow experiments and [predator] control experiments over time. **(SLIDE 30)** And they've learned a lot by doing these experiments. In fact there's a new recent paper that documented benefits of active experimentation in numerous river rivers systems around the world.

(SLIDE 31) Mangers in the Grand Canyon know how much experiments cost, money has not been an obstacle to experimentation. The scientists in the system say that the experiments have really changed the way in which they understand and manage the system. As I said earlier, it required a lot of leadership – not just the Secretary of the Interior, Bruce Babitt, saying this is going to happen, but leadership throughout across the institutional setting as well. And in spite of that, there's been as far as I know – although I think they're working on it now – no long-term experimental strategy. All these experiments have been short-term experiments. So, this kind of adaptive management is applied in many resource systems, and become the standard in the US Dept. of Interior. I apologize for another bad joke, but it sums up the state of adaptive management in the US and probably around the world: "Everybody says they're doing it, but, actually only a few people are doing it. And the ones who are doing it are doing it poorly." There are many reasons why that happens and I would

argue that one of the big things – and again, this is nothing particularly new – has been the sort of process of adaptive governance. So I have a few more minutes. I'll try and finish up on that note.

(SLIDE 32) So what is it? Governance is not management, and governance is not government, right? Governance talks about both the formal structures and the sort of laws, legal regulations, power policy, informal institutional settings, but also the role of collaboration and informal kinds of institutions. Ron Bruner in his book from about 10, 12 years ago talks about that as well, the sort of emergence of these both top-down and bottom-up institutional settings around these complex systems.

And it's really one of these governance that allows for adaptive capacity, to deal with flexibility for learning and dealing with change rather than managing against change. And I think also, one of the key things about it is that it always keeps uncertainty front and center. It's part of trying to understand how these systems work, and in a kind of collective way.

(SLIDE 33) Here's another way of thinking about it that sort of adaptive management – it is part of a larger-scale framework within which adaptive management can occur, as those characteristics of polycentricity, participatory, and then all of that is kind of set into a kind of legal framework. This is just another way of thinking about the relationships between adaptive governance and adaptive management. Adaptive management is about managing the uncertainties in the scientific or ecological parts of the system, adaptive government is about managing the other side – the social system and how it confronts and manages instabilities, crises and shifting social values

(SLIDE 34) All right. So to kind of finish up here, some suggestions in terms of uncertainty, I think one of the big things – and probably nothing new to most the folks sitting in this room – is this idea of adding learning to our all the other things that we have to do in our life. But try to develop

these kinds of institutional-based learning systems. I was talking to a fellow from the park service the other day, and you know, what a lot of folks don't realize is that how many – probably hundreds of years of experience sits in these resources agencies in terms of people's knowledge and understanding of these systems and how that is managed.

Whether that's retained, how that kind of sort of wisdom that's accumulated is used to sort of carry on so that the next generation doesn't repeat the problems of the previous generation. There's an interesting study about how civil engineers went through all these bridge building cycles on a generational basis because people didn't learn from the previous generations.

I would say the other thing that a lot of this sort of managing uncertainty is about is thinking across scales, thinking about how do we link immediate with the future? And moreover, examining things that are often assumed or much more tacit in terms of these kinds of slow-structuring variables that influence the resilience of these systems, their capacity to deal with these kinds of shocks and crises and change.

(SLIDE 35) And then finally, I'll leave it with this, what keeps coming up over and over again—and I'm really arm waving now, if I haven't before—is the need for leadership. We see that over and over and over again. And again, I'm not talking about the sort of people at the top, but really, the folks in this room. That's really where I see leadership, real leadership originates. And with that, I will finish and I am happy to take questions

GUNDERSON: . Yes, ma'am?

GUNDERSON: Yes, so the question was 'could I define epistemic organizations'. So, in my kind of simple Southern mind, epistemic means learning organizations, right? So, organizations that are really set up to try and

learn. You would think that research would be that, but that's really only part of it. So it's kind of a vague term, and some folks question whether or not organizations can learn or collective learning can take place. I happen to think that it does. But it really is just nothing but learning-based organizations that learn well while doing it, and figure out some ways of collecting that. So, things like books that are produced from this group are one way in which that collective learning gets captured and stored. Yes, ma'am?

SPEAKER: Hi, thank you. Law is the great striver for certainty, and it is not in any way a learning-based part of governance. So could you offer a few thoughts on how law can assist in this adaptive management and adaptive governance path we're on?

GUNDERSON: Great question. Part of it is that sometimes maybe there ought not be a law, that sort of the 20th century movement, at least in the US, towards law as prescription, that these define – try to remove uncertainty about a sort of statement of social values, or a statement of how those – I think it forces a certain kind of institutional configuration around resolving those uncertainties. And so, in many of these cases – and again, I'm probably preaching to the choir here – these things end up in court, in terms of the law being used, whether it's administrative or procedure [lax], in terms of trying to influence different parts of this system.

I think a kind of poor response to your question is, one, there is a growing realization. In fact, I think that's one of the reasons why the Glen Canyon Protection Act was passed and perhaps why the Everglades was out of the early '90s, people were realizing that these kinds of uncertainties that are imposed by the laws really cannot be resolved in courts. They really are beyond the capacity of I think – this is probably an extreme statement – of the courts to resolve those kinds of uncertainties. So, the other part of it is that but use those kinds of things in terms of – in my mind, the sort of positive aspects of these laws is that they've often been used to create

these kinds of instabilities or crises, which can cause the system to renew itself in a different configuration, right?

So for example, there are a lot of people who say that the only reason that the Everglades' $8 billion restoration program got passed or even got started thinking about it was at the end of a long, protracted lawsuit that went on between federal and state government suing because of water quality issues within the Everglades. And again, it was this kind of like -- that's not the arena that we want to resolve these issues in. And then the other thing is that the restrictions on the level of experimentation that these laws kind of create. And some legal scholars are dealing with that. There's some recent work on how administrative law is consistent with -- or you could use administrative law in a way to promote interesting probes and experiments within these systems as well, so. That's probably an insufficient response, but that's all I could think of.