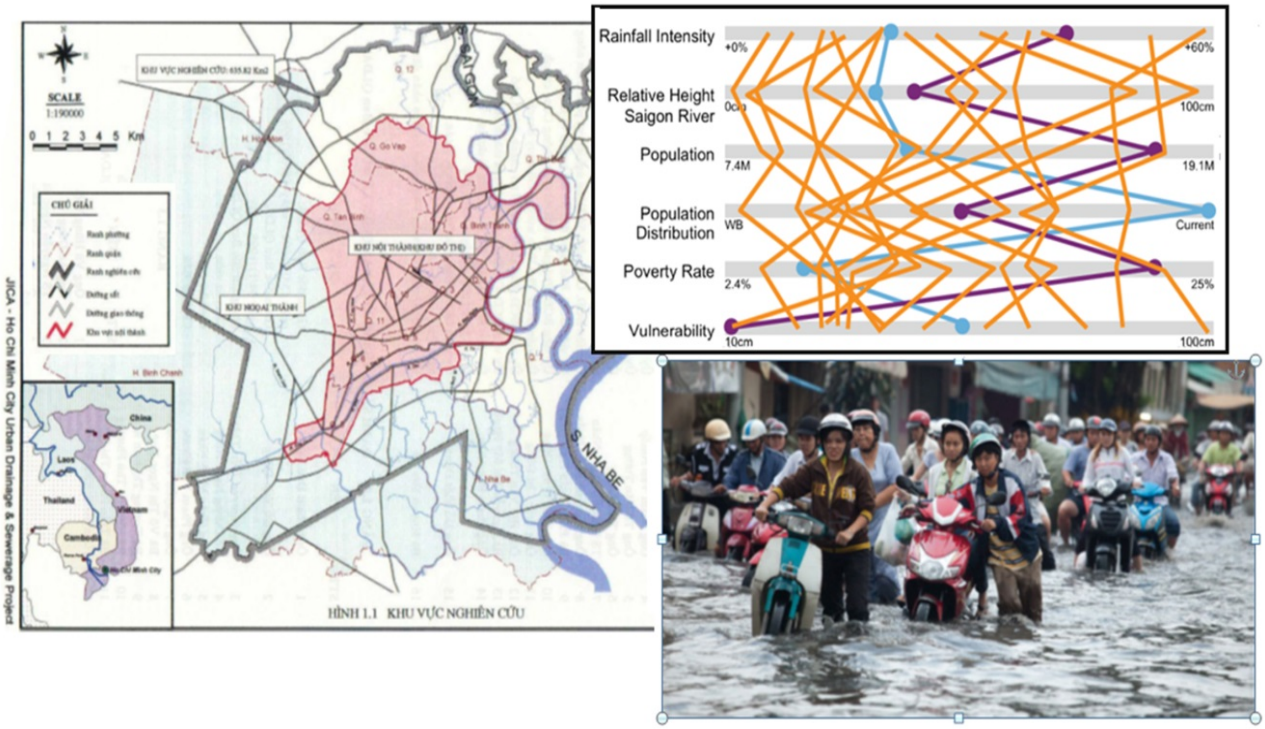
Workshop on Robust Decision Making Under Deep Uncertainty

September 5, 2014

South Florida Water Management District



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PURPOSE AND SCOPE OF WORKSHOP

Background

Alternative futures which may include changing rainfall patterns, sea level rise, and rapidly expanding socio-economic conditions present a significant planning challenge for water management agencies in South Florida. Projections of future stressors, particularly those associated with climate change and sea level rise, inherently possess deep uncertainties. Sea Level Rise along with changing precipitation and temperature patterns have the potential to disrupt infrastructure and communities, water supply, flood control, and environmental restoration efforts over the coming decades, but the precise timing and extent of these impacts remain deeply uncertain, complicating decisions on needed investments in infrastructure and other system improvements.

Adaptive strategies represent an obvious solution in principle, but are often difficult to develop and implement in practice. Dr. Robert Lempert (RAND Corporation) has been instrumental in helping agencies to develop adaptive policies to respond to climate change and integrating these policies into the organizations' long-range planning processes. He has been invited to present his experience in dealing with situations of Robust Decision Making under Deep Uncertainty.

The analysis employs Robust Decision Making (RDM), a quantitative decision- analytic approach for supporting decisions under conditions of deep uncertainty. RDM studies use simulation models to assess the performance of agency plans over thousands of plausible futures, use statistical "scenario discovery" algorithms to concisely summarize those futures where the plans fail to perform adequately, and use these resulting scenarios to help decision makers understand the vulnerabilities of their plans and assess the options for ameliorating these vulnerabilities.

Purpose

The workshop will provide an introduction to the philosophy and methods of the RDM approach with special emphasis on deep uncertainty, some examples of other areas where this approach has been applied, and some consideration of the information needs and effort that might be required to apply these methods to South Florida.

Workshop content

The workshop began Dr. Lempert's overview of RDM concepts, methods, and case studies, followed by a brief questions and answers session. The program continued with a presentation from the Netherlands covering the Dutch experience in applying RDM and ended with a panel composed of several key managers from South Florida that discussed the challenges of developing decision strategies and a potential path forward.

Dr. Robert Lempert works for the RAND Corporation and is director of the Pardee Center for Long-Range Global Policy and the Future Condition (PCLRGPFC).He has a PhD in physics and works on long term policy analysis related to climate change. Dr. Lempert served on NAS panel dealing with climate change and was an author of the section of the recent IPCC report –Workgroup #2 Decision Support. He has also written a book on Extreme events and disasters – the Next 100 years. More about Dr. Robert Lempert at: http://www.rand.org/about/people/l/lempert_robert_j.html

More than 50 participants (some via WebEx) attended the workshop. The workshop included a panel with senior staff from SFWMD, U.S. Department of Interior, Miami-Dade County, Broward County and the cities of Miami Beach and Fort Lauderdale.

ACKNOWLEDGEMENTS

This workshop was organized by SFWMD staff. Dr. Jayantha Obeysekera, Chief Engineer, developed the workshop, established the agenda and recruited speakers and panel members. Jeff Kivett, Division director was the Executive Manager who provided guidance and sponsored the event. **Robert Lempert**, Ph.D., Director, Pardee Center for Long Range Global Policy and the Future Condition, RAND Corporation and Dr. **Joseph Arts**, Strategic advisor and Professor, Infrastructure and environment, Rijkswaterstaat & Wageningen University, The Netherlands, were the principal speakers. We especially thank the panel members who took time form their busy schedules to participate in this workshop:

Shannon Estenoz

Director, Office of Everglades Restoration Initiatives, U.S. Department of the Interior

Jennifer Jurado

Ph.D. , Director, Natural Resources Planning and Management, Broward County

Hardeep Anand

P.E.,Director, Public Works, City of Fort Lauderdale

Eric Carpenter

P.E., Director, Public Words, City of Miami Beach

Virginia Walsh

PhD., P.G., Chief, Hydrogeology, Water & Sewer, Miami Dade County

Nikki Spencer from the SFWMD Communication Unit assisted with coordination and workshop logistics. Rick Miessau provided technical assistance with computer resources. Rick, Martha Nungesser, Jenifer Barnes and others took additional notes on the presentations and reviewed this report. Suzana D. Mic, a Doctoral student at Florida International University and Joel VanArman, a retired SFWMD scientist provided volunteer services to take detailed notes on the workshop, prepare summaries and compile the document.

Workshop Report by Robert Lempert

On Friday, September 5 the Southern Florida Water Management District held a workshop at its West Palm Beach headquarters entitled "Robust Decision Making Under Deep Uncertainty." SFWMD staff, local decision makers, and other members of the community attended the workshop. The workshop had four main sections: an overview presentation of RDM, a presentation on stakeholder participation, a presentation of RDM methods and case studies, and a stakeholder panel.

I presented the morning and afternoon RDM talks. Jos Arts, Strategic Advisor and Professor, Infrastructure and environment, from the Rijkswaterstaadt and Wageningen University in the Netherlands talked about his organization's work with stakeholders. My morning talk offered a general overview of RDM, using as examples RAND's work with the US Bureau of Reclamation on the Colorado Basin Supply and Demand Study and with the State of Louisiana on their Master Plan for a Sustainable Coast. My afternoon talk presented RDM in more detail, with a particular focus on RDM's use of scenarios, some RDM software tools, and robustness criteria used. Prof. Arts talk focused on the Dutch practice of participatory, "fast and better" process of stakeholder engagement, which can improve treatment of uncertainties. Arts also mentioned the Adaptive Delta Management and Shared Vision Planning approaches.

The workshop closed with a panel discussion, in which decision makers presented challenges and opportunities relevant to the case studies and methods presented earlier in the day. The panel participants included:

- Jeff Kivett, Director, Operations, Engineering and Construction, SFWMD
- Shannon Estenoz, Director, Office of Everglades Restoration Initiatives, US Dept of the Interior
- Jennifer Jurado, Director, Natural Resources Planning and Management, Broward County
- Hardeep Anand, Director, Public Works City of Fort Lauderdale
- Eric Carpenter, Director, Public Works, City of Miami Beach
- Virginia Walsh, Chief Hydrogeology, Water & Sewer, Miami Dade County

The day's discussion, in particular those surrounding the panel session, suggested several areas where the methods highlighted at the workshop might make useful contributions. In particular:

- Recent work examined the sensitivity of the greater Florida Everglades ecosystem to climate change using the South Florida Water Management Model. But because this initial work included only an initial sampling of scenarios, some of the vulnerabilities may be over-estimates, for instance because they neglect the potential for adaptation, and some be under-estimates, for instance because they neglect interactions among potential

stressors. An RDM analysis could build on this work by expand the consideration of socio-economic assumptions and consider more systematically adaptive management strategies. Such an analysis might focus on exploring the vulnerabilities of and robust responses for the comprehensive Everglades Restoration Plan (CERP).

- Miami Dade County and the City of Miami Beach are currently upgrading much of their water supply, drainage wastewater, sewage, and related infrastructure. An RDM analysis could help develop designs more robust to climate change. Such analyses might examine the regrets of alternative infrastructure investments over a range of climate futures, and suggest designs with low consistently low regrets.
- Developing longer-range management plans in the face of a changing climate may require stakeholders to recognize, understand, and be willing to move beyond consideration of the current set of tradeoffs. Otherwise, it may prove difficult to make anything other than incremental adjustments, which in the longer-term may prove insufficient. An RDM analyses, in particular with its focus on scenarios that illuminate vulnerabilities, might help communicate such tradeoffs, by linking them both with the strengths and weaknesses of current plans and with specific options for addressing any weaknesses. Such options might include those that are able to exploit a wide range of co-benefits.
- Currently plans such as the current Everglades Restoration Plan include adaptive management, but only in an ad hoc manner. An RDM analysis could suggest how to more explicitly include adaptive management in such plans. A systematic analysis of adaptive management plans might also contribute to infrastructure plans in cities such as Miami Beach.
- Southern Florida has made impressive gains in regional collaboration. But uncertainties in the future actions of other jurisdictions remain an important uncertainty in the planning of some agencies. RDM analyses could help improve regional collaboration by enhancing the ability to include such uncertainty in plans and enhance coordination among planning activities.
- Some agencies make flood risk management decisions while balancing among competing and uncertain threshold responses. On the one hand, too much intervention to reduce flood risk may reduce business activity, for instance by inhibiting easy street access to businesses hardened against flood. On the other hand, too much flood risk may drive businesses away. RDM analysis could help develop plans that appropriately balance between such risks.

Workshop on

Robust Decision Making Under Deep Uncertainty

September 5, 2014

AGENDA

Morning Session 9 am – 12:30 pm

0900-0910 Opening Remarks (Jeff Kivett, P.E., Director, Operations, Engineering & Construction, SFWMD)

0910-0930 Logistics & Introductions (Jayantha Obeysekera, Chief Modeler, SFWMD)

0930-1030 Robust Decision Making under Deep Uncertainty (Dr. Robert Lempert, Director, Pardee Center for Long Range Global Policy and the Future Condition, RAND Corporation.

10:30-10:45 Break

10:45-11:45 Stakeholder Participation on Deep Uncertainties about Future Developments: Dutch perspectives (Dr. Jos Arts, Strategic advisor and Professor, Infrastructure and environment, Rijkswaterstaat & Wageningen University, The Netherlands)

11:45-12:30 Lunch break

WORKSHOP AGENDA (Cont.)

Afternoon Session, 12:30 – 3:45 PM

12:30-2:00 Case Studies and Tools (Dr. Lempert)

2:00 – 4:00 Panel with managers on challenges in decision making under uncertainty and the potential application of RDM

Panel:

Robert Lempert, Ph.D., Director, Pardee Center for Long Range Global Policy and the Future Condition, RAND Corporation.

Jeff Kivett, P.E. , Director, Operations, Engineering & Construction, SFWMD

Shannon Estenoz, Director, Office of Everglades Restoration Initiatives, U.S. Department of the Interior

Jennifer Jurado, Ph.D. , Director, Natural Resources Planning and Management, Broward County

Hardeep Anand, P.E.,Director, Public Works, City of Fort Lauderdale

Eric Carpenter, P.E., Director, Public Words, City of Miami Beach

Virginia Walsh, PhD., P.G., Chief, Hydrogeology, Water & Sewer, Miami Dade County

0400 Closing

Robust Decision Making Under Deep Uncertainty

Workshop Notes

INTRODUCTION

The workshop opened with Jeff Kivett thanking everyone for attending. He reminded everyone that the workshop is part of the MOU, following the Saltwater Intrusion Workshop held earlier this summer. He noted that the District has still much to learn about decision-making, and that an important aspect is the recognition of uncertainty as a different way to approach water management. Quality of life is one major aspect that needs to be considered, and new ways of thinking about the future need to be part of decision-making today. He further argued that the regional collaborative framework of work, exemplified by the Climate Change County Compact is a good way to start.

Robust Decision-Making Under Deep Uncertainty By Dr. Robert Lempert

Presentation Link:

ftp://ftp.sfwmd.gov/pub/jobey/RDM_Workshop_Presentations/RD_workshop_morning_090514.pdf

Dr. Lempert's presentation focused on proposing a new method for dealing with climate change uncertainty in a diverse political context. He argued that traditional methods of addressing uncertainty in the context of long term planning oftentimes do not correspond with the ways in which people, particularly in diverse stakeholder contexts, use information. There are a variety of new tools that allow us to better understand and think about future situations. Climate change is challenging for many reasons, but one defining characteristic is the fact that knowledge about climate change is changing rapidly; at the same time the decision-making/planning contexts asks us to make robust, well-defined decision. The traditional models of dealing with uncertainty often underestimated what is known about risk, and led to gridlocks as it allowed for competing stakeholders to argue based on their various visions about the future. The four tenets of RDM are 1. use a multiplicity of scenarios to think about the future 2. focus on a robust as opposed to an optimal (compromise between stakeholders) strategy 3. have strategies that are adaptive and 4. use the results to facilitate discussion. The RDM method starts by proposing a strategy or the policy goals, continues by modeling all the possible futures, looking at the acceptable models based on the parameters set from the beginning (such as costs involved) and then based on these scenarios it ends in a discussion on the trade offs of all these scenarios and decide on the best course of action.

To better explain the RDM approach, Dr. Lempert used the example of Ho Chi Minh City (from now HCMC). The city, facing extreme vulnerability from flooding, used a SWIM model to

understand what the future might bring. The RDM model starts by organizing the parameters of flooding risk in a simple framework that looks at hazard components, who and what is exposed to these hazards and vulnerability. In the case of HCMC, six risk parameters were identified, such as rainfall, population growth, poverty rates, etc. A traditional risk modeling approach takes the six risk parameters and comes up with a best estimate scenario, the RDM approach looks at a multiplicity of plausible scenarios and analyzes how the infrastructure would hold in all of these cases. It then looks at which of the six deeply uncertain parameters are most important in terms of infrastructure vulnerability. In the case of HCMC, rainfall, river level (a result of both subsidence and SLR) and poverty rates proved to be extremely influential. The analysis continues by looking at what levels the infrastructure would fail. At this point this level becomes the base level on which projection for these parameters are analyzed. Dr. Lempert argued that the clarity with which the model introduces the future, leaves little room for debate, prompting towards a discussion about how much robustness can the city afford, rather than discussing what the future will look like. It is at this point that decision-makers can start looking at the tradeoffs.

In the case of the contentious Colorado River Basin long term planning, the RDM approach helped decision makers particularly because it showed in a very organized and easy to follow way (see slide 46) the actions that needed to be taken in the near future and which actions can be deferred for ten or twenty years. In the end the RDM approach helped decision-makers in several ways, like identifying key vulnerabilities to future uncertainty, highlighted key tradeoffs among adaptive strategies, and defining near-term actions for implementation.

Dr. Lempert used another difficult case that benefited from the RDM approach – The Louisiana Coast Case, where in the aftermath of Hurricane Katrina, the coastal managers began investing time and resources to study and propose solutions in view of the loss of land. Decision makers were flooded with a number of proposals that were costly, diverse and conflicting. In addition decision was difficult because of the lack of science about the future of coastal change and uncertainty. The RDM approach categorized all the projects proposed and came up with several scenarios that showed what would happen if each category of proposals would be considered both together and separate. In the end decision-makers were able to use an iterative approach to decide on what projects would be most beneficial given the available budget.

Discussion.

Akin – what about the modeling tools, was there disagreement?

For the Colorado River system, there was an existing agreed-upon model. In Louisiana, modeling tools were developed during the process. Multiple models were evaluated to determine the best approach. When using models, it is important to have an agency or team of impartial experts with convincing authority to support the models and defend their validity.

Dave – How does model complexity come into play?

This is a black box issue. Not everyone understands what's inside the model and therefore we need a trusted party that can provide some confidence that the model is appropriate. There is also the computation issue. The Colorado River model took one month to run approximately1 million cases. The Louisiana Model took much longer. A major part of the response was based on attempts to make the model run faster.

What about uncertainties within the observational database, e.g. uncertainties of existing climate data is this an issue?

This was not really discussed explicitly. Uncertainty is likely captured in the range of future climate scenarios, such as was discussed in the Ho Chi Min City example. The forecast of a 5% increase in extreme event frequency in the future, for example, is considered to be a 5% increase above the existing frequency based on historical data

Matahel. What about correlated variables, e.g. river water levels and rainfall?

Correlation analyses can be incorporated into the process. In our case, river height was influenced primarily by events throughout the huge watershed as well as sea level rise and land subsidence. Most of these influences were outside the relatively limited area analyzed for rainfall to determine flooding due to local runoff. Therefore the correlation between rainfall and river water levels was not too high.

Virginia: We generally capture existing uncertainties in data and models and propagate these in future projections. Such analyses provide a sense of what uncertainties are likely to give the biggest differences.

Stakeholder Participation on Deep Uncertainties about Future Development: Dutch Perspectives by Joseph Arts

Presentation Link: ftp://ftp.sfwmd.gov/pub/jobey/RDM_Workshop_Presentations/SFWMD-RWS%20webinar%205Sept2014%20v2_Arts.pdf

Dr. Jos Arts argued that the most important aspect that needs to be addressed in conditions of deep uncertainty is stakeholder and public involvement. He stated that "deep uncertainty requires a deep understanding of stakeholders". Starting in the 1990s, the agency responsible for the three major infrastructure networks in the Netherlands, Rijkswaterstaat (from now RWS), transitioned from a planning process that was based uniquely on expert knowledge to a planning process that was more inclusive of stakeholder's opinions. Yet, even though this process fended some long held criticism, and made the process more inclusive, it remained problematic. The main criticism was related to the failure of dealing with uncertainty; this was particularly because the work

conducted in this context was often giving a "false certainty" about the future, and because it was slow to implement, and often led to litigation. In view of this, the agency conducted a series of studies and found out that early and continuous involvement of stakeholders made a big difference. Yet, even though involvement of stakeholder is a demand during our times, as it has much to do with government legitimacy, it is tough to implement. Old habits are tough to change. There is a culture of data collection, where big data, charts and mathematical models, are much appreciated, while people's needs and opinions are lost in this data. Yet, it is well known that mathematical models have a number of uncertainties, while climate change, challenges even further these well-known uncertainties. In fact, the more climate change impacts are researched, the more uncertain they become.

Moreover, we find that people don't like uncertainty. This is particularly true in the political arena, where politicians rarely want to acknowledge that they don't know everything; and that is because oftentimes, acknowledging such a thing means political death. So, in our experience with uncertainty, we found out that people either ignore the issue of uncertainty to climate change, choose the bottom line of the bandwidth – which is problematic because it does not address the whole problem, choose the upper line of the bandwidth – which is again problematic, because it often becomes too costly to address, and ends up being abandoned. Finally, we see that a compromise figure for SLR, for example is chosen, which does not have anything to do with what is actually expected to happen. In conclusion, there are three general solutions for dealing with uncertainty: maintaining the status quo, postponing the solutions/decisions, and keeping with a false sense of certainty. Dr. Arts argued that there is no one good solution, but in the cases of big agencies, such as SFWMD or RWS, which have a huge societal impact, these issues need to be carefully re-thought.

Some of the ways forward that the RWS is considering, is using the tipping point concept, engaging the public in all stages of planning, combining water management with spatial planning, and keeping the planning process open to change and adaptation. All these processes can, and should be supported by data, scientific tools, and technical experts. In addition we should not only think about what the future might bring, but also what the public is likely and will support.

Discussion

Shannon Estenos: The dimension of water management issues down here that complicated things even further is this issue of ecosystem restoration. There is this assumption that the idea of restoration implies that there has to be a reshuffling of trade-offs. There has been a value shift that says that these trade off are no longer acceptable, for all of these reasons. But when it comes to stakeholder engagement, when we analyze alternative futures, we see that we tend to keep the system that is today, in place. That is the system of costs and benefits – we hold those constant and then we adjust our approach to the future by holding those constant. And I think that's an

incongruity between what it means to look at these alternative futures, and what it is implied by the idea of restoration, which is the fact that those trade-offs that we want to keep constant have destroyed what we are trying to restore now. This is something that we wrestle with all the time. Have you experienced this kind of situation during your stakeholder engagement?

Jos Arts: This is a real issue of deep uncertainty for technical organizations like ours. We were really surprised in the 1970s by the ecological turn and the fact that people were really resisting of our technical solutions. We had not addressed this issue to any extent in the past. Also, the economic downturn was totally unexpected and hit us by surprise. In recent years also, we have come to recognize the need to protect natural species in river systems, and that building bigger and better dikes and canals is not the only answer. "Room for the River" is a concept we are using today to allow space for the excess river water to disperse over wetlands adjacent to the river. This option is not only cheaper than trying to contain the water in the river channel, but it also provides environmental benefits.

DeLisi: If stakeholders accept a lower level of service, what is the benefit that they will see?

We try to foster a mutual gains approach. This requires lengthy discussions with local people. Also, we need to have really good designers that can combine all elements and look for synergies, local economic benefits, social issues, etc. Local governments took the lead in many of these efforts to determine appropriate solutions.

Drew: How do you deal with stakeholders who don't believe in climate change? South Florida soils are very permeable, so some of the solutions used in the Netherlands won't work. In South Florida, there is no high ground to move to.

Jos: Holland does not have much high ground either. One answer is to create high ground – elevate roads, infrastructure and houses. This option is of course very expensive. Netherlands, like Florida also has permeable areas where dikes and pumps are not effective. These problems ca also can be addressed with, for example, seepage barriers and raising the land elevation, but the solutions are very expensive. In terms of climate change, the government has to make decisions based on what they see is happening. Stakeholders need to be informed of what is happening and hopefully they will understand and support the decisions. Some people live in coastal and low-lying lands where the threats are severe, whereas others live in uplands and are less likely to be impacted. Upland residents will help pay for solutions because they recognize the overall value to our society that we protect the resources.

Unidentified Participant: These forms of "structured" public participation and collaborative computer modeling are good methods. How can local governments gain access to regional modeling or to risk-based modeling? How do they get the data and tell the story?

Jos: "Structured" involvement means providing full potential for legal and informal processes. To be effective, you need to be sure to get a good cross-section of the population – not just elderly white men. People know their regions and need the opportunity to address their concerns. Linking models – regional governance needs to be involved or take the lead to exchange data and assist with providing or obtaining adequate and compatible modeling efforts, resources and personnel.

AFTERNOON SESSION

Cases Studies by Robert Lempert (see presentation link below)

ftp://ftp.sfwmd.gov/pub/jobey/RDM_Workshop_Presentations/RD_workshop_afternoon_090514.pdf

The afternoon session was led by Dr. Lempert who, began with an exercise. He asked three volunteers to form a fictional scientific committee. They were asked to argue about their beliefs on the possibility of a paper cone to fall in three different positions. The scientific committee had to come up with a recommendation on the most likely probability for the cone case; the decision-makers would have to decide on which investment to pursue, based on their recommendation.

This exercise generated a discussion about how decision-makers understand models, and the fact that what matters more for a decision-maker is what is happening in their present situation, rather the long term. The scientific committee was not comfortable proposing with certainty any of the three outcomes, because even though they had a lot of knowledge and could justify any of the outcomes, they viewed all the possibilities as somewhat plausible. Investing in a model that can go in three different direction is very problematic for decision-makers.

Dr. Lempert continued his morning talk with an expansion on the use of deeply uncertain information to help inform decision making. The basic framework that Dr. Lempert proposed integrates the deliberative process with the analytical and implementation ones. He started this presentation by arguing that there are different types of risk; first of all there is a calculated risk and a perceived risk. In conditions of uncertainty the calculated risk is very small in comparison to the perceived one. Not only that, but the perceived risk seldom overlapped with the calculated risk. This is particlarly true in conditions of deep uncertainty. Dr. Lempert's definition of deep uncertainty is that it occurs when the parties to a decision do not know or do not agree on the likelihood of alternative futures or how actions are related to consequences.

In the case of climate change, five years of research does not make a huge difference in the scientific models. The climate is very unpredictable. Yet, many would argue, climate is not as unpredictable as other systems, such as the transportation system. The RDM process uses an iterative risk management to help manage deep uncertainty. Dr. Lempert stated is that people are much more likely to accept uncertainty if they know what are the options. Cognitive research shows that people are really good at scenario building. On one hand people do not like uncertainty, while at the same time we are used to dealing with it all the time. Scenarios are very common when we deal with climate change. Scenarios are very useful as they deal with the problem of overconfidence. In the cat slide, the cat sees something that seems very familiar, yet – as we can expect, this will turn out very different. In the political process, people use uncertainty to push certain agenda. In the words of Pierre Wack, scenarios can change decision makers' assumptions about how the world works, compelling them to reorganize their mental models of reality. At the same time scenarios can be misunderstood, and can be contested. One of the ways we try to avoid this interpretation and choice problems is by using data analysis to build these scenarios.

In the case of the Metropolitan Water Use District of Southern California, a wholesaler of imported water, RAND did an exercise to understand the vulnerable scenarios for their water management plan (a twenty-five year investment plan – called the IRP). The analysis started with their existent model, which is pretty complex and has a10% buffer to deal with uncertainty. They then used the RDM framework to come up with some vulnerability scenarios. We took their model (called Integrated Resource Plan –IRP), and connected it with the Colorado River decision simulation just to have more climate projections. We run many cases, and then we did a scenario discovery exercise, where we start by indicating which of the scenarios are policy-relevant. We then run statistical algorithms to find clusters with high density of these cases. We further looks for clusters to draw a box around the cluster and in that way we have identified the scenarios that are most relevant to decision-makers.

The results of the analysis, showed in slide 31, present a picture of the climate futures in which their policy would fail to meet its goals. On the x axis, we have the different demand scenarios and on the y axis we have the supply based on climate and yield, where climate is how much precipitation changes, and yield is how much ground water they get compared to their estimates. The black dot shows the scenario in which the IRP meets its goal. If we take both parameters, climate and demand, their baseline plan does not do that well, but if these parameters are taken separatelly, it does. What is important to note is however, that on the demand side, they are being very pro-active and aggressive, therefore they do not expect a great deal of change.

Dr. Lempert continued to explain the difference between robust versus optimal decision-making. Robust decision-making means doing ok over a number of plausible futures – not looking for the best in one single future. Optimal decision-making would be trading some optimum performace, for less sensitvity to broken assumptions. The first one is more appropriate when probablistic

information is not available, while the second one is more appropriate with probabilistic information.

Contining with the HCMC example, Dr. Lempert, talked about an analysis on how the city would perform over a wide range of possible climate futures. On slide 37, risks to the city infrastructure were analyzed in terms of cost. There are a couple of options which are low cost across a wide range of futures. He mentioned that this analysis was conducted on a series of infrastructure objectives.

Slide 39 shows the probability equation, where the expected value is a funcltion of how well that strategy performs over a variety of futures, given that we know the distribution. Some of the most difficult things to do are choosing the strategy to consider, figuring out what futures to focus on, figuring out what performance you would get from this strategy, and then knowing and convincing people that you got it right. Once all of these things are calculating, soving the equation is really straightforward. A final step is doing a stress test over a wide range of estimates, and coming up with a policy which is robust.

Next, Dr. Lempert, expanded on some key points of adaptive strategies. In the California water upply case analysis, once the scenarios were chosen, the challenge was thinking about the potential indicators for demographic and local sypply of water change. These indicators would be used to monitor the demand and possibly get some warning about when the demand would get to the dangerous levels, where the mode indicated that the policy would fail to meet its goals. Some of the demographic indicators chosen were population growth, growth areas, housing trends, employment, while some of the local supplies of water indicators indentified, were water quality, new projects and adjudecations. Once this was done, they created an adaptve plan approach, showed on slide 43.

Therefore, in the RDM framework models are exploratory tools, rather then consolidative tools. Traditionally a model becomes a surogate for the real world – we build a model for an airplae and then we expect the real plane to behave in a certain way, like the model. But models can also be used to map assumptions and link them to consequences, without priviledging one set of assumptions over another. This builds on a series of if statements that cannot reallly be validated. But taking a model which can be tracked, you can monitor to see what you can adjust over time. This is a flexible analytic approach. The model is used to stress against a wide range of futures and think about what can be done to have the best approach.

At the end of the planning process using the RDM approach, we are able to say that even though we might not believe in all the climate models that we generated, we believe in the contingency plan we came up with based on the climate models.

Panel Discussion:

The panel discussion was shaped by a series of three questions, as follows:

Question 1. What is your role? Describe some examples of how you are presently dealing with uncertainty. Are you dealing with cases of deep uncertainty?

Shannon Estenos. Director of Everglades Restoration initiatives at the United States Department of Interior. Her job includes supervising the Bureau's activities around Everglades restoration. She is also the executive director of The Everglades Ecosystem Restoration Task Force.

Some level of uncertainty characterizes every decision we make, and a lot of it is deep uncertainty. The plans we are developing will take decades to implement. We are dealing with a changing set of existing conditions that do not meet the assumptions we make when we put the plan together. So, there's a tremendous amount of adaptive decision-making, but a lot of this is not systematic, but rather ad hoc and very political. We change course based on a changed set of political conditions or a changed set of values. We confront the question of what is virtuous to do versus what is cost-effective to do. A gentleman said earlier in the HCMC example, shouldn't you solve the vulnerability problem by solving the poverty problem? While solving poverty would be the most virtuous thing to do, this process does not seem to get us off that hook. In the work that we do, this is the hardest part, making these value-based decisions. And that is the deepest uncertainty, because what is virtuous today, might not be virtuous tomorrow. Also, scientists tend to look at what is most effective and practical, whereas decision makers often look at what is most virtuous relative to long-term social and environmental implications.

Robert Lempert: We are just conducting a project, where we are doing a lot of interviews and what comes up is exactly what you're saying, that scientists think very consequentially, while business people think about what is the most virtuous thing to do for me and my firm, for example.

Virginia Walsh. Chief of hydrology, water and sewer at Miami-Dade County.

My work deals with water and waste infrastructure and master planning, hydrogeology; we're responsible for planning for water supply, wastewater capacity and treatment. Uncertainties include elections, which lead to a whole set of shifts in thinking and organization, political unrest in Latin America, which can have a huge impact on our future demands. We deal with all of these uncertainties, plus the fact that we are at the bottom of the decision-making scale on a regional level. We are highly dependent on the Water Management District and U.S. Army Corps of Engineers' structures and canals, who have their own operational priorities, but which directly affect us. Unless we know what the District is planning on doing with the regional canal system, we have to assume. At the same time we are under very tight time schedules because we

have to comply with the Federal requirements for the Clean Water Act. We basically have to upgrade our entire major infrastructure. The element of uncertainty is very challenging. A lot of the times we have to plan without thinking about the dimension of uncertainty. At the same time we work with the County Compact on climate change because we understand that what we do impacts the whole region.

Hardeep Anan. Public works director for the City of Fort Lauderdale.

I deal with water, wastewater, etc., oversee an in-house design efforts and project management. We have a Division of Sustainability, which includes elements of recycling, waste management etc. In terms of uncertainty, the city is trying first to develop comprehensive master plans rather than just addressing "squeaky wheel" issues. There are public complains that the city is not doing enough.

Jennifer Jurado. Director of Natural Resources Planning and Management in Broward County.

The Environmental Resilience Division is responsible for coordinating countywide water resources management, water supply, water quality, climate initiatives, shorelines, coastal zone, reefs, endangered species, beach nourishment, etc. as well as, 31 municipalities, 25 water utility plants, and various drainage districts. We have robust stakeholder processes, and we are using a variety of planning tools for decision making to address sea level rise, saltwater intrusion, etc.

Eric Carpenter. Director of Public works for Miami Beach.

Sixteen months ago Miami Beach began a neighborhood improvement program. In this process, we discovered that sea level rise was an issue. Our planning efforts had to be tied to mean high tide water levels. It soon became apparent that this was a problem and we needed a higher elevation standard. A new storm-water management solution is needed for the city. All of this planning is occurring with deep uncertainty – we are just making educated guesses about the future. Our programs and processes are designed to work under our best estimates of projected future conditions, but are also flexible, to accommodate changes.

Jeff Kivet. Director of Operations, Engineering and Construction at South Florida Water Management District.

In a typical year, we have 3 months of rainfall and nine months of management. Last year we had too much water in the wet season and then one week later we were worried about not having enough water due to drought. The District is constantly making decisions with significant adverse consequences and high levels of uncertainty. In the longer term, we see issues related to the performance of all systems (local and regional) working together. How do we interface with

each of the counties involved? What are their actions and roles vs what the District does? Local actions and changes can make or break regional water management decisions.

Question 2. What information do you wish you had to make decisions? Things I wish I Knew …

Jeff Kivett.

We start with a plan and then it changes over time. How do we deal with the uncertainties of keeping things on track and moving forward? We need plans, but they must be flexible. The plan itself becomes an adaptive document. Not a matter so much of changing goals or directions, but rather changes in the means to reach the end. We typically need to make changes at lower levels of the plan while keeping the upper end intact.

Comment. There is a threshold of actions that may be taken without impacting stakeholders. This may be a risky decision, since even small changes are likely to affect some stakeholders.

Shannon Estenos.

I wish I knew: 1. How is rainfall going to change? A 10% change in rainfall is apparently very significant. 2. Honest knowledge of how the private sector will respond to proposals, e.g. insurance companies. 3. Better integration among government agencies for infrastructure planning.

Lempert Robert.

It might be possible to develop a model to represent likely insurance industry responses. We did some work previously to model insurance responses to terrorist activities.

Shannon Estenos

We are often faced with speculation about what is the best use of a piece of land? Is land best used for flood mitigation vs water treatment vs housing, vs reservoirs, etc. Simple economic models might help.

Virginia Walsh.

I wish I knew what are the economic projections, and what will the water demands be. How do we resolve the need for 50 year planning vs our 6-year planning cycles? Should we attempt to refurbish existing infrastructure and/or move west, as options to protect us from sea level rise? The typical life cycle of a pump station in a neighborhood is 10 years. Water quality is a big concern. Everything you place in the ground either contaminates the drinking water supply, the

Biscayne Bay or the Everglades. Treatment costs are extremely high. What level of risk is acceptable? Who defines it?

Hardeep Anan.

I wish I knew how to streamline regulations, permitting processes, etc. The tools we use today have significant uncertainties. We have to justify our recommendations to decision-makers with the appropriate level of confidence. How do we convert academic studies to address on-the-ground realities? Are there other approaches or methodologies to look at in analyzing and presenting this data?

Jennifer Jurado.

Models are useful but are limited. Models have particular uses and often cannot or should not be applied in other circumstances. The long-term viability of engineering solutions is always a concern. How much time will it buy us? What can we afford? How much can we depend on regional partners to help us deal with those issues? What are the capabilities and commitments among the different players to participate in regional solutions?

Eric Carpenter.

Where is the straw that will break the camel's back? We are making major changes at major costs. Is this viable? Each city is making its own plans and changes to increase structural protections and lower water levels. Does this even make sense? At what point does it become a losing battle?

Question 3: Are there other ways to look at these problems?

Robert Lempert: Here are some additional concepts that may be useful:

Infrastructure integration. Choosing strategies, approaches or solutions that are based on "no regrets", and then analyze what combinations work best over a broad range of future conditions.

Level of Acceptable Risk. This determination comes out of the stakeholder process and is not a single entity decision. Trade-offs must be carefully explained. Generic model plot forms can be customized to look at specific tradeoff components in more detail. Sometimes you can make use of simple models to explore these relationships. This often involves collaboration at different levels and thus leads to institutional issues. Models can help make clear what actions are needed to reduce risks. These exercises can identify players, but you need contracts and commitments to make it work.

Vulnerability Maps. These can be used as a means to represent alternative institutional relationship as a factor that drives the process. Positive and negative loop feedback processes can be represented and the degree to which various options compete against thresholds. How much is acceptable? How do you deal with the threshold?

Participatory Modeling. The decision to use this method is based on the needs and available technology. The outputs can be very complex and hard to explain. A Chinese policy group looked at the outputs from this type of analysis and commented, "this is for young people." Traditional approaches are more *ad hoc*, and often based on expert judgment.

Probabilistic risk/decision analysis. This is the standard water plan approach where you might look at a 25 year planning period, future scenarios, etc. Plans and models change over time as you go forward to implement the plan.

Hardeep Anan

What if we don't have a model? How do we determine if we need one?

Lempert Robert

I am not sure what to advise. Models can be really useful, but are not always required. You may want to cost share with others or get outside funding. Regional planning level models provide some general features, but local utilities need more detailed models. Developing scenarios is the most important first step. We may need to go to detailed models for design. Planning level models give a general idea of resources and costs. Detailed models provide better estimates. Use of local models often requires changing stochastic to deterministic models. Managers often experience "sticker shock" moving from planning level analyses to design estimates. What level of uncertainty can policy makers be comfortable with? We often fail to engage the public in this process.

Comment. With regard to the issue of future sea level rise in South Florida, how do we make this accessible to residents? We run the risk that people (business, economy, real estate, insurance industry) will panic if they hear the truth.

Lempert Robert: the public needs to understand how infrastructure works. There are things that can be done to address these issues. Visual tools help show what goes on underground.

Shannon Estenos.

Epcot, for example, has excellent displays that communicate complex issues to the public.

Lempert Robert.

Information about risks also needs to include information about what can be done about it. Don't present problems without also providing solutions.

Jennifer Jurado.

We have a pilot project on how to communicate this issue. We've considered options of taking staff recommendations or decisions to the county or engaging the county in developing solutions. People need to understand the consequences, and that future impacts will occur due to sea level rise and storm surge plus tide and rainfall. All of these factors contribute to flooding and water management problems. We have a "Fast Forward" longer-term visioning process and a "Press Play" 5-year plan. Among the general population, belief in sea level rise follows the 80/20 rule.

Jeff Kivett.

Less than 100 years ago, people couldn't live in South Florida. The challenge for us is not to repeat the kinds of damage we have done in the last 50 years that got us to where we are today. Future planning needs to be more cautious with respect to the environment. Better designs and implementation are needed to protect resources. The answer is NOT more pumps, structures and canals.

Comments:

We need to use the right model for the right purpose. An older model that is well understood may be better than a new model with more features that is less understood. We also need to ask ourselves, what is a reasonable time frame to look at? Look as far as the consequences of your actions will extend. How do we make uncertainty easier to understand?

Going Forward:

Virginia Walsh.

Collaborative efforts are needed. Regional flood studies need to be brought together

Shannon Estenos.

We need to know more and have more of these kinds of workshops. We need better analysis and tools. The exercise of examining increases and decreases (±10%) in future rainfall should be repeated, but it needs to incorporate possible future changes in operations, water supply deliveries, water shortage management, possible additional storage facilities, etc. to help understand causal relationships and potential remedial actions. It is very important to break down infrastructure management silos between agencies. For example, highway construction often occurs on its own schedule without adequately considering impacts on other facilities.

Once roads are in place, they have major effects on all other infrastructure, especially water management.

Jeff Kivett.

Collaboration is needed. SFWMD needs to interact better with stakeholders. We need to conduct more planning-level exercises.

Hardeep Anan.

Need to work better with stakeholders. New engineering design standards need to be developed to consider effects of sea level rise. Likewise, the development of engineering solutions should examine many more options and will likely require more lands, more storage, etc. The procurement process is outdated. We need to expand our RFQs to include analyses and streamline the requisition process.

Jennifer Jurado.

Regional work with the Climate Compact has accelerated efforts and interest in these issues, especially in terms of policy and planning. However, more collaboration is needed, particularly at technical levels, notably in terms of modeling, etc. The District should become a source of funding for local efforts, also to provide resources to help integrate local efforts and models with District models. In addition, better interaction and coordination is needed with state agencies to develop robust tools and integrated communication.

Eric Carpenter.

Need to spend more effort over an extended period of time rather than wait until the issue becomes a crisis and then try to get it done all at once. Not only is this a better use of funds, but people will become interested and encouraged to participate if they see things happening on the ground.

Lempert Robert.

A big issue in dealing with uncertainty is kowing how to transform people's behavior? Scenarios provide a means to help people to think about doing incremental steps over time. They help define paths to get to our visions and the right steps that need to be taken to get there.

Closing

The discussion ended at 3: 45.