Welcome to Culver City, California!

On behalf of the organizing committee for the 2018 meeting of the Society for Decision Making under Deep Uncertainty (DMDU), welcome to Southern California.

The spirit of experimentation has characterized each of our prior meetings. This year, we sought to make our location also our subject. Our Society has always sought to move beyond theory into practice and application; adding this new dimension seems a logical next step. By selecting Culver City as the Society's first 'off-site' annual meeting locale (that is, not in a facility controlled by the hosting institution,) we sought to thread our discussions and deliberations into the ever-changing fabric of Greater Los Angeles – and to make that very change also a subject for our meeting. The complexity of policy problems facing major metropolitan regions globally are all reflected in the issues of today's Southern California. And we will be meeting in a place that has long been associated with the birth of the world's first, modern creative economy. Culver City's motion picture business came only a few years after the very first studio was established in Hollywood. Indeed, this year marks exactly 100 years since Culver Studio's founding – a site still going strong in the same business just a short stroll from our meeting.

The DMDU Society has set itself the task of changing the world by creating the tools for analyzing and then framing policies to solve its 'wicked' problems. Our vision has been one of bringing together people with differing interests, experiences and perceptions but a common desire to move forward together. The program created for this meeting is intended to contribute to that agenda. It also places emphasis on the global nature of this effort by taking advantage of another aspect of the Greater Los Angeles setting, namely as a link to Latin America and the wider Pacific Rim. On behalf of the Society we have reached out to both Central and South America and across the Pacific and are honored to have so many join us here in common effort.

The sessions and discussions that will unfold over the next few days result from the work of many hands, both on the organizing committee and from the selfless contributions from other Society members. I would like to take this opportunity, however, to recognize two people in particular. Thomas A. Small, mayor of Culver City has been tireless in his personal efforts to make this annual meeting take form as we had envisioned. His generosity of spirit and willingness to get things done were indispensable assets that the organizing committee drew upon heavily. My colleague and fellow RAND researcher, Andrea Golay, matched Thomas's enthusiasm and eagerness to engage in the difficult challenges of organization. Without her partnership and unmatched skills, little that you see about you could have been brought to realization.

Steven W. Popper
Chair, Education and Training, DMDU Society
Senior Economist, RAND
Professor of Science and Technology Policy, Pardee RAND Graduate School

2018 Organizing Committee

Steven W. Popper, Chair • RAND Corporation
Andrea Golay • RAND Corporation
Laurna Kaatz • Denver Water, Colorado
Judy Lawrence • Victoria University of Wellington, New Zealand
Robert J. Lempert • RAND Corporation
Sadie McEvoy • Deltares, Netherlands
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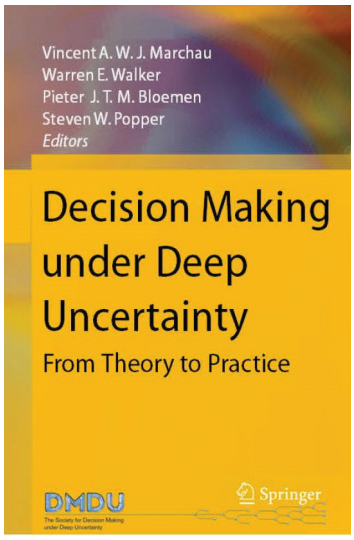
Julie Rozenberg • World Bank
Thomas A. Small • Mayor, Culver City, California



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Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, Steven W. Popper (Eds.)

Decision Making under Deep Uncertainty

From Theory to Practice

- Offers a comprehensive examination of the approaches and tools for designing plans under deep uncertainty and their application
- Identifies barriers and enablers for the use of the various approaches and tools in practice
- Open access book includes realistic examples and practical guidelines to help readers better understand the concepts

This open access book focuses on both the theory and practice associated with the tools and approaches for decisionmaking in the face of deep uncertainty. It explores approaches and tools supporting the design of strategic plans under deep uncertainty, and their testing in the real world, including barriers and enablers for their use in practice. The book broadens traditional approaches and tools to include the analysis of actors and networks related to the problem at hand. It also shows how lessons learned in the application process can be used to improve the approaches and tools used in the design process. The book offers guidance in identifying and applying appropriate approaches and tools to design plans, as well as advice on implementing these plans in the real world. For decisionmakers and practitioners, the book includes realistic examples and practical guidelines that should help them understand what decisionmaking under deep uncertainty is and how it may be of assistance to them.

Decision Making under Deep Uncertainty: From Theory to Practice is divided into four parts. Part I presents five approaches for designing strategic plans under deep uncertainty: Robust Decision Making, Dynamic Adaptive Planning, Dynamic Adaptive Policy Pathways, Info–Gap Decision Theory, and Engineering Options Analysis. Each approach is worked out in terms of its theoretical foundations, methodological steps to follow when using the approach, latest methodological insights, and challenges for improvement. In Part II, applications of each of these approaches are presented. Based on recent case studies, the practical implications of applying each approach are discussed in depth. Part III focuses on using the approaches and tools in real–world contexts, based on insights from real–world cases. Part IV contains conclusions and a synthesis of the lessons that can be drawn for designing, applying, and implementing strategic plans under deep uncertainty, as well as recommendations for future work.

Available Spring 2019!

DMDU Annual Meeting

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DMDU 2018 Annual Meeting

Agenda: Training Day

Tuesday, 13 November 2018

08:00	**Check-in for Registrants [Attendees must pre-register by November 9]**
09:00	**Introduction to DMDU and of the plan for the day** **Interactive exercise on deep uncertainty in practice**
10:30	**Generalized framework for understanding DMDU methods**
11:30	**Lunch [attendees will find many options within 2-3 blocks of venue]**
13:15	**DMDU Ideas Fair: demos of tools, methods and applications**
15:45	**Break**
16:00	**Putting it together: A typology of DMDU methods**
16:30	**Plenary panel and Q&A: DMDU in practice**

Agenda: Day 1

Wednesday, 14 November 2018

08:00 **Registration and Breakfast**

09:00 **Welcome and Introduction (BLUE)**

Survey of the DMDU field and this meeting
Rob Lempert and Jan Kwakkel, DMDU Society; Steven Popper, Chair, Annual Meeting Organizing Committee

I. DMDU Methods in Application

09:15 **Keynote Speaker: Dr. Alejandro Pioré (BLUE)**
Dean, National School of Social Sciences and Government, Monterrey Institute of Technology ("Tec"); former Minister of the Interior, Government of Mexico

09:30 **Plenary: Cities as complex systems faced with deep uncertainty (BLUE)**
Chair: Gerdo Aquino

MEGA-ADAPT: Simulating socio-hydrological and climatic risks in Mexico City through a self-organizing systems approach
Luis A Bojorquez-Tapia, Marco A Janssen, Hallie Eakin, Andrés Baeza, Fidel Serrano-Candela, Paola Gómez-Priego and Yosune Miquelajauregui

DMDU in spatial adaptation: Embracing vagueness to enable emergence of linkage opportunities
Berry Gersonius, Sadie McEvoy, Ellen Kelder and Richard Ashley

Climate resilient management of urban stormwater systems: A pilot study in Pittsburgh
Jordan R. Fischbach, Kyle Siler-Evans, Devin Tierney, Michael T. Wilson, Lauren M. Cook and Linnea Warren May

10:30 **Breakout 1A: DMDU approaches to the issues of megacities (GOLD)**
Chair: Berry Gersonius

Mitigating the increasing risks of urban flooding in central Shanghai: Options and analysis
Tian Zhan, Laixiang Sun, Hengzhi Hu

Chinese policy-making process to promote low carbon technologies: A potential case for applying Dynamic Adaptive Policy Pathways
Huan Zou and Linlan Huang

Nature-based solutions for flooding risk management under climate change and an urban circular economy in creation: The case of Shenzhen New Marine City
Laixiang Sun, Zhan Tian, Junguo Liu, and Dean Ye

Breakout 1B: DMDU-informed urban planning and development (ORANGE)
Chair: Warren Walker

Using DMDU to prepare for energy transition in the Philadelphia region
Oscar Serpell, Cornelia Colijn, Mark Alan Hughes

Land use and transportation planning under deep uncertainty
Kacey Lizon, Robert Lempert, Garett Ballard-Rosa, George Mazur, Debra Knopman, James Symes and Ifeanyi Edochie

Adapting land use and water management plans to a changing climate in Miami-Dade and Broward counties, Florida
David Groves, Debra Knopman, Neil Berg, James Syme, Craig Bond and Robert Lempert

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Breakout 1C: DMDU and infrastructure planning (BLUE)
Chair: Julie Rozenberg

Conflicts in coalitions: A stability analysis of robust multi-city regional water supply portfolios
David Gold, Bernardo Trindade, Patrick Reed and Greg Characklis

Delivering on the Sustainable Development goals through long-term infrastructure planning
Daniel Adshead, Scott Thacker, Lena Fuldauer and Jim Hall

Emerging applications of adaptation pathways for managing and reducing climate change vulnerability in Californian energy utilities
Robert Kay, Judsen Bruzgul, Tommy Hendrickson, Maya Bruguera and Cole Wheeler

Resilience of complex infrastructure systems under deep uncertainty: an analysis of Mexico's fuel transportation and storage infrastructure
Edmundo Molina-Perez, Giovanni Hernandez, Fabian Carranza, Steven Popper and Luis Serra

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12:00 **Lunch and networking activity; Poster session**

13:15 **Breakout 2A: Water resource applications colloquium* [see note on format] (BLUE)**
Chair: Jordan Fischbach

Water resource planning under future climate and socioeconomic uncertainty in the Cauvery River basin in Karnataka, India
Ajay Bhave, Declan Conway, Suraje Dessai and David Stainforth

Multi-objective analysis of funding allocations for non-structural flood risk mitigation in coastal Louisiana
David Johnson, Zach Richardson, Simon Gomez Sierra and Matthew Shisler

Modelling dynamics and adaptation at operational and structural scales for the ex-ante economic evaluation of large dams in Africa
Luciano Raso, Jean-Claude Bader and Bruno Barbier

Malawi's vulnerability to threshold behavior of lake Malawi: informing adaptation decision making under uncertainty
Ajay Bhave, Lauren Bulcock, Suraje Dessai, Graham Jewitt and Declan Conway

Optimized dam portfolios reduce impacts of sediment trapping on the Mekong Delta under deeply uncertain future sediment yields
Rafael Schmitt, Matteo Giuliani, Simone Bizzi, G. Mathias Kondolf and Andrea F. Castelletti

** Colloquium will follow a three-part format: 1) One, brief overview plenary presentation, 10-15 minutes; 2) 30-45-minute breakout poster session during which attendees may discuss work with individual presenters; 3) plenary general discussion based upon the work presented in the posters.*

San Francisco Water: Piloting adaptation pathways for long-term water supply planning
Dana Stuparu, Marjolijn Haasnoot, Willem van Deursen and Alexis Dufour

Uncertainty and evidence-based water policy management in South Africa: the challenge for evaluation
Sandile Ngcamphalala, Olivier Crespo and Johann Louw

Developing a robust water strategy for Monterrey, Mexico: diversification and adaptation for coping with climate, economic and technological uncertainties
Edmundo Molina Perez, David Groves, Steven Popper, Rodrigo Crespo and Aldo Ramirez

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Breakout 2B: DMDU approaches to technology assessment and planning (ORANGE)
Chair: Edmundo Molina Perez

Strategic decision making in the 3D printing industry – a Robust Decision Making (RDM) analysis
Pedro Nascimento de Lima, Maria Isabel Wolf Motta Morandi and Daniel Pacheco Lacerda

Understanding the need for policy action on greenhouse gas removal to address climate change: initial case for Robust Decision Making
Mark Workman, James Maltby and Geoff Darch

Lithium-based transportation system-of-systems: Complexity and uncertainty of socio-environmental impacts
Datu Buyung Agusdinata and Wenjuan Liu

DMDU in a modern risk society: Roles of resilience-based public policy and emerging technologies/AI
Mika Shimizu

Breakout 2C: DMDU Ecosystems planning (GOLD)
Chair: Ashley Hefner

Dealing with deep uncertainty through exploratory modeling: regulating loggerhead sea turtle fishing by catch in Gulf of Ulloa, Mexico
Daniela Pedroza, Luis Bojorquez-Tapia, Germán Ponce-Díaz, Francisco Arreguín and Antonio Diaz-De-Leon

Avoiding fisheries collapse: Can robustness frameworks capture and navigate uncertain harvest trade-offs?
Antonia Hadjimichael, Patrick Reed and Julianne Quinn

Socio-ecological resilience modeling: Policy implications of drought effects in the wildlife management system in Baja California Sur, Mexico
Hilda Zamora-Maldonado, Sophie Avila-Foucat, Víctor Sánchez-Sotomayor and Raymond Lee

Considering uncertainty in multi-objective spatial prioritization for California's agriculture, biodiversity and water resources
Benjamin Bryant, Rodd Kelsey, Adrian Vogl, Stacie Wolny, Scott Butterfield, Abigail Hart

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14:45 **Break**

II. DMDU Methodologies and Tools

15:15 **Keynote Speaker: Dr. John Seely Brown (BLUE)**
Former chief scientist of Xerox Corporation and director of Xerox's Palo Alto Research Center (PARC); Current independent co-chairman of the Deloitte Center for the Edge

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15:30 **The role of monitoring, signposts and triggers in DMDU colloquium (BLUE)**
Chairs: Judy Lawrence and Robert Lempert
This session will include four ten-minute talks on research papers, followed by a panel discussion lead by practitioners.

Climate-induced tipping points: A typology and application of DMDU toolkit
Kees C.H. van Ginkel and Marjolijn Haasnoot

Designing a monitoring system to get signals for adaptation
Marjolijn Haasnoot, Susan van 'T Klooster, Dirk Eilander, Ferdinand Diermanse and Pieter Bloemen

Identifying Triggers for Metropolitan Water District's Adaptive Integrated Resources Plan
David Groves and Brandon Goshi

Monitoring of dynamic adaptive policies: Design of a monitoring system by scenario discovery
Luciano Raso, Jan Kwakkel and Jos Timmermans

Panel Chair: Robert Lempert
- Judy Lawrence - Climate Change Research Institute, Victoria University of Wellington, New Zealand
- Laurna Kaatz – Denver Water, Denver, CO
- Brandon Goshi– Metropolitan Water District of Southern California, Los Angeles, CA
- Pieter Bloemen - Staff of the Delta Programme Commissioner, Netherlands

17:00 **End of Day 1**

18:00 **Reception hosted by Sony Pictures [enter Culver/Motor gate; see map]**
Keynote Speaker: Hon. Thomas A. Small, Mayor of Culver City

Agenda: Day 2

Thursday, 15 November 2018

08:00 **Registration and Breakfast**

08:30 **Breakout 3A: Explorations of system resiliency (BLUE)**
Chair: Costa Samaras

Accelerated sea-level rise: A game changer for decision making under uncertainty?
Marjolijn Haasnoot, Jaap Kwadijk and Jos van Alphen

NZ coastal adaptation guidance: Interweaving uncertainty through sea level rise scenarios and hazard/risk assessments
Rob Bell, Scott Stephens and Judy Lawrence

Navigating deeply uncertain trade-offs with adaptive climate strategies
Giacomo Marangoni, Jonathan Lamontagne, Julianne Quinn, Patrick Reed, Massimo Tavoni and Klaus Keller

Operationalizing resilience under deep uncertainty: Water supply for Mexico City and the Valley of Mexico
Sarah Freeman, Casey Brown and Diego Rodriguez

Breakout 3B: Using DMDU methods to illuminate economic issues (ORANGE)
Chair: Steven Popper

Assessing the prospects for public revenues from oil in Latin American and Caribbean countries under emerging climate policy
Baltzar Solano-Rodriguez, Steve Pye and Adrien Vogt-Schilb

Harmonizing Discretionary Policy Choice with Fiscal Rule Making: Mexico after Fiscal and Energy Sector Reforms
Eduardo Márquez Peña

How much is needed? Infrastructure investments for sustainable development
Julie Rozenberg, Marianne Fay and Claire Nicolas

Breakout 3C: Innovation in DMDU methods (GOLD)
Chair: Julianne Quinn

Participatory, simulation-driven scenario analysis for long-term decision-making
Laura Schmitt Olabisi, Jing Du and Arika Ligmann-Zielinska

A generalized many-objective optimization approach for scenario discovery
Jan Kwakkel

SPIRE – A decision support system for addressing complex/chaotic environments
Harold Klein

10:00 **Break**

10:15 **Breakout 4A: New tools for DMDU analysis colloquium* [see note on format] (BLUE)**
Chair: Jan Kwakkel

Policy trees and threshold-based adaptation of water resources systems under climate change
Jonathan Herman

WaterPaths: A platform for discovering robust urban water portfolio investment pathways
Bernardo Trindade, Patrick Reed, Harrison Zeff and Gregory Characklis

An interdependent infrastructure systems planning tool to support strategic long-term, national-scale DMDU
Lena Isabel Fuldauer, Scott Thacker, Daniel Adshead and Jim Hall

Travel Model Improvement Program: Exploratory modeling and analysis tool
Martin Milkovits and Sarah Sun

A new free web-based tool to support decision making under uncertainty
Niels Riegels, Oluf Jessen, Silvia Leirao and Henrik Madsen

Breakout 4B: Panel -- The good, the bad, and the wicked: DMDU techniques in practice (GOLD)
Chair: Laurna Kaatz
- Alexis Dufour – San Francisco Public Utility Commission, CA
- Brandon Goshi – Metropolitan Water District of Southern California, Los Angeles, CA
- Laurna Kaatz – Denver Water, Denver, CO
- Sebastian Malter – Philadelphia Water Department, PA

Breakout 4C: Accounting for perspectives and behavior in DMDU (ORANGE)
Chair: James Dewar

Experts' decision-making model under deep uncertainty
Matylda Gerber

Building narratives to characterise uncertainty in regional climate change through expert elicitation
Ajay Bhave, Suraje Dessai, Cathryn Birch, Declan Conway, Luis Garcia-Carreras, John Paul Gosling, Neha Mittal and David Stainforth

Strategic foresight, deep uncertainty, and leadership: A workshop report
Darryl Farber, Mathew Burrows and Martin Pietrucha

11:45 **Lunch and posters**

III. 'Mainstreaming' DMDU Methods & Analyses in Policy Settings

12:45 **DMDU analyses and their relevance to policy decision makers (BLUE)**
Chair: Angela O'Mahony
- Yakov Ben-Haim – Technion - Israel Institute of Technology
- Paul Davis – RAND Corporation
- Steven W. Popper – RAND Corporation

13:45 **Breakout 5A: New approaches to DMDU decision support (GOLD)**
Chair: Marjolijn Haasnoot

Hidden-model processes for adaptive management under climate change uncertainty
Kelly Klima, Milad Memarzadeh and Matteo Pozzi

Applying methods of DMDU to social-behavioral modeling for policy analysis
Paul Davis

The tail wagging the dog: Designing modelling tools to drive better decision processes
Charlotte Brown, Garry McDonald, Erica Seville, Michele Daly, Nicola Smith and Rob Buxton

** Colloquium will follow a three-part format: 1) One, brief overview plenary presentation, 10-15 minutes;*
2) 30-45-minute breakout poster session during which attendees may discuss work with individual presenters;
3) plenary general discussion based upon the work presented in the posters.

Towards incorporating inclusiveness in model-based support for long-term adaptation planning under uncertainty
Bramka Arga Jafino and Jan Kwakkel

Breakout 5B: Panel -- DMDU guidance documents: Turning methods into practice (BLUE)
Chair: Julie Rozenberg
This session will consist of a brief introduction followed by several "speed talks" on how guidance addresses deep uncertainty and what it takes to mainstream these concepts. The audience will then form breakout groups to draft questions for panelists (20 minutes) followed by panel discussion of the questions.

Introduction to the session
Robert Lempert

Sea Level Rise Guidance, New Zealand
Judy Lawrence

Hydropower Sector Climate Resilient Guidelines
Patrick Ray

California Climate Safe Infrastructure Working Group
Juliette Hart

Collaborative Risk Informed Decision Analysis guidelines
John Kucharski

Infrastructure Resilience Committee, American Society of Civil Engineers
Costa Samaras

15:15 **Break**

15:30 **DMDU implementation problem solving session: bring your problems for general discussion§ [see note on format] (BLUE)**
Chair: Judy Lawrence
The session will begin with a brief framing on DMDU implementation with sharing of lessons. It will be followed with the format outlined below.
§ Attendees are invited to place problems in DMDU implementation or stakeholder engagement on a designated board during the course of the meeting. 1) Several will be selected for speed-talks. 2) These will be followed by breakout roundtable discussions for each presented problem. 3) Following the roundtables, gather for plenary reports and discussion.

17:00 **Closing Plenary and DMDU Society Business Meeting (BLUE)**

2018 DMDU Elections, 2019 DMDU Annual Meeting
Rob Lempert and Jan Kwakkel, DMDU Society; Steven Popper, Chair, Annual Meeting Organizing Committee

Posters

Economic evaluation of effectiveness of irrigation development as an adaptation measure to climate change under uncertainty
Daiju Narita, Ichiro Sato, Daikichi Ogawada and Akiko Matsumura

Systems analysis with artificial intelligence based planet gamification
Steven Lisgo

Taking into account deep uncertainty in flood maps: Comparing the US and France
Anna Serra-Llobet, Rémy Tourment and Antonin Montané

Navigating deep uncertainty in water resources management
C. Dionisio Pérez Blanco

Collaborative Risk Informed Decision Analysis (CRIDA) method assessment of hydropower generation in the Magdalena River basin in Colombia
Santiago Gómez Dueñas, Kristin Gilroy, Berry Gersonius and Michael McClain

Can we calibrate and identify agent-based models of flood adaptation?
Vivek Srikrishnan and Klaus Keller

Laying the groundwork: DMDU methodologies for urban planning in the Global South
Supriya Krishnan and Tina Comes

Robust personal decision-making
Maria Teresa Piacesi

Strategic foresight, deep uncertainty, and leadership: A workshop report
Darryl Farber, Mathew Burrows and Martin Pietrucha

Agenda: Optional Field Trips

Friday, 16 November 2018

[Attendees must pre-register by November 9]

We are excited to offer local field trips and tours for Friday, 16 November, the day after the 2-day DMDU annual meeting concludes. The field trip program is in keeping with the main theme of the conference – understanding the complex issues of major urban regions. We will continue to use Culver City, surrounded on most sides by the City of Los Angeles, as a microcosm for the study of different drivers framing developments in the greater Los Angeles basin.

Morning	**Tour I: Culver City Downtown Cultural Corridor** The Culver City Downtown Cultural Corridor tour focuses on the issues and possibilities of an urban core re-inventing itself.
Afternoon	**Tour II: Creative Space: High-Tech, Adaptive Reuse Architecture** The purpose of this tour is to focus on urban and community responses to the possibilities inherent in a growing creative economy.
TBD	**Tour III: Bicycle Tour of Ballona Creek and Wetlands** This self-guided or docent-led tour examines an urban wetland eco-system that has long been the site for conflict between competing needs and interests. They are important breeding grounds for many aquatic and avian species but are considerably reduced in size owing to the pressure of development. The latest round of construction was performed according to a plan that sought to preserve the most essential features for sustaining the local eco-system. You can be the judge of how well this compromise succeeded.

More information on tour details may be found on the DMDU Society web page at (http://www.deepuncertainty.org/annual-meetings/2018-annual-meeting/)

Social Media Policy

In the DMDU Society's tradition of open and honest discussion, we ask you to limit any social media sharing to your own reflections and refrain from attributing statements or quotes to speakers or other attendees.

Abstracts: Day 1

Wednesday, 14 November 2018

I. DMDU Methods in Application

Plenary: Cities as complex systems faced with deep uncertainty
Chair: Gerdo Aquino

MEGA-ADAPT: Simulating socio-hydrological and climatic risks in Mexico City through a self-organizing systems approach
Luis A Bojorquez-Tapia, Marco A Janssen, Hallie Eakin, Andrés Baeza, Fidel Serrano-Candela, Paola Gómez-Priego and Yosune Miquelajauregui

MEGADAPT (MEGAcity-ADAPTation) is a simulation model that addresses the challenging task of eliciting the vulnerability of Mexico City to underlying socio-hydrological and climatic risks. The goal is to make the "soft socio-political infrastructure" (that is, the social and political norms, values, rules, and relationships that undergird the myriad decisions made by public and private actors) visible for enhancing urban risk management

MEGADAPT simulates urban vulnerability from the perspective of self-organizing systems; that is, a process of reflection involving the interplay between the mental model held by an influential actor (the water authority) and the response of the biophysical and social world (the geographic alternatives) to the realization of decisions based on that mental model.

MEGADAPT entails the simulation of both one-way and two-way coupling of socio-ecological systems through exploratory modeling. It is operationalized through geographic information systems-multicriteria decision analysis (GIS-MCDA), multi-objective optimization, and geo-simulation (which consists in merging cellular automata (CA) and agent- based modeling (ABM) into "geographic automata").

Results identify spatial vulnerability patterns, thresholds and trade-offs that shape the built environment and are linked to the socio-political infrastructure. We argue that developing more sustainable pathways of urban development hinges on making this socio-political infrastructure transparent and legible in the tools and approaches available for urban risk management.

DMDU in spatial adaptation: Embracing vagueness to enable emergence of linkage opportunities
Berry Gersonius, Sadie McEvoy, Ellen Kelder and Richard Ashley

The Dutch Delta Programme for 2018 comprised, for the first time since its inception, a Delta Plan on Spatial Adaptation. This plan is drawn up by all government authorities to expedite and intensify the process of spatial adaptation. It calls for commitment among government authorities to incorporate climate change adaptation into spatial planning. As part of this Delta Plan, the Spatial Adaptation Programme encourages such commitment by providing support to, e.g., Living Labs and City Deals. A City Deal acts as a vehicle for mobilizing public and private stakeholders to pool their resources to work together on a specific topic outside of standard operating procedures.

The city of Dordrecht was an early participant in the Spatial Adaptation Programme and a partner of the City Deal on Climate Adaptation. Dordrecht has gained broad experience in applying decision making under deep uncertainty (DMDU) methods in the context of spatial planning. These include: visioning, stress testing, adaptive planning and adaptation mainstreaming. This presentation shares Dordrecht's experiences with these DMDU methods and provides insights into their use and utility in practice. To date the city of Dordrecht has gained both positive and negative experiences with the application of adaptation mainstreaming. The success rate of capitalising upon linkage opportunities will be presented.

Climate resilient management of urban stormwater systems: A pilot study in Pittsburgh
Jordan R. Fischbach, Kyle Siler-Evans, Devin Tierney, Michael T. Wilson, Lauren M. Cook and Linnea Warren May

Pittsburgh, Pennsylvania's metropolitan region currently faces a major challenge in effectively managing its water resources. The region's combined stormwater and wastewater system needs substantial upgrade and reinvestment in order to eliminate untreated sewer overflows and reduce the risk of flooding in low lying areas. The billion-dollar investment decisions currently faced by local decision makers are further complicated by a changing climate, with recent projections suggesting that the northeastern United States is expected to see increased precipitation and more heavy rainfall events. These challenges could also be exacerbated by continued conversion of forested areas to impervious cover for new development.

This study describes an initial evaluation of the region's vulnerability to future climate and land use change. Specifically, the study applies Robust Decision Making (RDM) to evaluate and improve the performance of improved storm and wastewater management strategies across a range of plausible future scenarios.

The study represents an important early application of DMDU methods using a high-resolution, computationally intensive hydraulics and hydrology model in a complex urban context. It provides important insights on how regional storm and wastewater strategies might be improved and made more robust to uncertain future conditions. It also illustrates how DMDU methods can be used to support planning in cities and regions facing challenges from sewer overflows and urban rainfall flooding who have previously not had the capacity to address deep uncertainty.

Breakout 1A: DMDU approaches to the issues of megacities
Chair: Berry Gersonius

Mitigating the increasing risks of urban flooding in central Shanghai: Options and analysis
Tian Zhan, Laixiang Sun, Hengzhi Hu

Shanghai will have to face the adverse impact of extreme rainfall under future climate change, with increasing risk under the current protection standard. However, both historic records and climate models give no firm answer to the question how the climate and precipitation would change due to deep uncertainties. Long-term adaptation planning to manage flood risk is further challenged by uncertainty in socioeconomic factors and contested stakeholder priorities.

In this study, we demonstrate a proof of concept for a combined robust decision making (RDM) and dynamic adaptive policy pathways (DAPP) approach in flood risk management, using Shanghai as a case study. Three uncertain factors, including precipitation, rain island effect and decrease of urban drainage capacity, are selected to build the future extreme precipitation scenarios. Inundation depth and area are simulated; the direct physical loss is calculated based on the depth-damage curve. Increase of public green area, higher standards of urban drainage system, construction of deep tunnel with varying level of capacity, and their combinations, are alternately implemented. The risk reduction performances of all possible levers are examined across different scenarios. The results show that the mid-terms robust plan is the combination of increase of green area, improved drainage system, and the deep tunnel with a runoff absorbing capacity of 30%, which can reduce the future flood risk by up to 98%.

Chinese policy-making process to promote low carbon technologies: A potential case for applying Dynamic Adaptive Policy Pathways
Huan Zou and Linlan Huang

China has been quite actively engaging in reducing its carbon emissions. In 2016, China set the goal to cut its CO2 emissions per unit of GDP by 60-65% from 2005 level by 2030, aiming to increase non-fossil fuel sources in primary energy consumption to about 20% by the same date. To deal with the striking air pollution problem in megacities such as Beijing, Shanghai, China is shifting on renewables, leading the world's investments in renewable sectors, such as wind, solar and marine, guided by its 13th Five-Year Plan.

Innovation is at the heart of the new plan. The core strategy is to lift up research and development in the country, through integrated solutions that can create new growth opportunities while addressing the ecological constraints and increasing costs of growth. In this talk, we will address how Chinese local governments address the ecological and environmental constraints and how they coordinate with local stakeholders.

Based on interviews and focus groups with key experts and stakeholders, we are interested in the application of the dynamic adaptive policy pathways and consider if this approach matches the process of existing decision-making or may help support decision-making under uncertain regional changes in future.

Nature-based solutions for flooding risk management under climate change and an urban circular economy in creation: The case of Shenzhen New Marine City
Laixiang Sun, Zhan Tian, Junguo Liu, and Dean Ye

Shenzhen has risen from a fishing village to the most productive high-tech and financial center in China within 40 years. The rapid urbanization makes resilience to water disasters a critical socioeconomic concern. Shenzhen New Marine City has a strategic agenda to become a national demonstration zone for innovative development of sustainable and energetic economy resilience to future climate change. Future new challenges posed by climate change include the increase in frequency and intensity of rainstorms and storm surge, and sea level rise.

This project aims to provide scientific assistance to this ambitious agenda. Specifically, we propose a system dynamic framework to (1) explore the impacts of population growth, economic development and climate change on urban water resilience; (2) quantify the performance of green and grey infrastructures in reducing flood risk; (3) capture and understand the dynamic interactions between green and grey infrastructures and the urban circular economy and circular resources; (4) explore how local entrepreneurship can help resolve environmental and ecological problems through the exploitation of opportunities, and how their activities facilitate the development of green infrastructure and green businesses; and (5) perform collaborative decision-making of grey and green infrastructures to find robust pathways towards optimal combinations. This project will provide methodological and application support to sustainable pathways of an exemplary urban circular economy in creation.

Breakout 1B: DMDU-informed urban planning and development
Chair: Warren Walker

Using DMDU to prepare for energy transition in the Philadelphia region
Oscar Serpell, Cornelia Colijn and Mark Alan Hughes

Scale matters when it comes to energy planning. At the city scale, additional sources of deep uncertainty come into play. DMDU can help manage these challenges.

Over the last six months, The Kleinman Center for Energy Policy has developed an RDM model that stress-tests eight energy strategies specific to the Greater Philadelphia region to provide local decision makers with robust and efficient energy options designed to adapt to future changes in the policy landscape. These strategies are each assigned two intensities of implementation that generate a total of 1,024 possible policy pathways. These strategies are then stress-tested against six regional uncertainties: the introduction of a carbon price, changes in oil and gas prices, changes in emissions from grid-generated electricity, distributed energy resource innovation, and carbon capture innovation. Measures of a strategy's performance include capital and operating costs to the region, GHG emissions reductions, public health impacts, grid electricity demand, and fuel demand. This research not only provides decision makers in the Greater Philadelphia region with robust policy options, but also offers a framework that can be adopted by other cities facing the challenges of deeply uncertain local energy futures.

Land use and transportation planning under deep uncertainty
Kacey Lizon, Robert Lempert, Garett Ballard-Rosa, George Mazur, Debra Knopman, James Symes and Ifeanyi Edochie

Using Robust Decision Making (RDM) and a simple cohort model calibrated to SACOG's detailed travel-demand model, RAND developed a multi-scenario, multi-objective planning tool that allows the Sacramento Council of Governments (SACOG) to stress test their 2016 RTP/SCS plan over multiple uncertainties. In particular, the analysis examined the factors most important to the agency meeting various combinations of mobility, greenhouse gas, and equity goals. The analysis also evaluated the effectiveness of alternative policy responses.

We find that: 1) there are many pathways for lowering total GHG emissions; 2) when the SB 375 emissions goal is met, total GHG emissions will almost always decrease; and 3) simultaneously achieving all four goals is difficult. Current MPO planning current focused on reducing vehicle miles traveled (VMT). We find that VMT affects many SACOG goals, but in different directions. Total GHG emissions can be reduced through vehicle technology, without affecting VMT, mobility, or equity; reducing VMT to meet SB 375 GHG goal may also reduce mobility and equity; and aggressive policies are needed to overcome these fundamental relationships. This talk will describe the analysis and discuss how these methods can inform SACOG's next round of planning for their 2020 RTP/SCS.

Adapting land use and water management plans to a changing climate in Miami-Dade and Broward counties, Florida
David Groves, Debra Knopman, Neil Berg, James Syme, Craig Bond and Robert Lempert

Florida's Miami-Dade and Broward counties are vulnerable to flooding and intrusion of saltwater into drinking water wells as a consequence of sea level rise (SLR), changes in precipitation, and the distribution of future asset growth across the region. It is uncertain how these drivers will evolve in the future, so it is important to understand the risks, what areas are most at risk and why, and possible ways to mitigate the risks. Looking out to the 2040 time frame, the analysis linked two groundwater flow simulation models developed separately for the two counties with a simple economic model of asset values as a function of groundwater levels and the location of the saltwater-freshwater interface.

Areas of vulnerability were identified, and the results demonstrate that vulnerability to climate change is not constrained to high-value coastal development but also includes inland areas where groundwater is shallow and wetter rainfall patterns could cause flooding. The region's vulnerability to both SLR and increased precipitation is cause for concern, but targeted actions, such as focusing development on higher ground, could reduce further exposure of assets and mitigate effects of saltwater intrusion on drinking water supplies.

Breakout 1C: DMDU and infrastructure planning
Chair: Julie Rozenberg

Conflicts in coalitions: A stability analysis of robust multi-city regional water supply portfolios
David Gold, Bernardo Trindade, Patrick Reed and Greg Characklis
Regional cooperation among urban water utilities can improve the efficiency and robustness of water supply portfolios to deeply uncertain future conditions such as those caused by climate change or population growth. Regionalization does however come at a cost. Regionally coordinated water supply plans may be vulnerable to any emerging instabilities in the regional coalition. If one or more regional actors does not cooperate or follow the suggested robust regional actions, the robustness of the overall regional system as well as its component sub-systems may severely degrade. To date, the DMDU community has largely ignored the cooperative dynamics of implementation for regional systems as a quantified deep uncertainty.

This work focuses on four interconnected water utilities in the Research Triangle region of North Carolina for which robust regional water supply portfolios have previously been designed using multi-objective optimization. This study 1) examines the sensitivity of regional water portfolio performance to operational deviations by individual utilities, 2) compares the impacts of operational deviations to those of exogenous deep uncertainties on portfolio performance and 3) delineates safe operating spaces for each utility within both the decision and uncertainty domains. Results of this analysis are broadly applicable to urban regional water supply portfolio planning globally and provide insights into the nature of robustness in multi-actor water supply systems.

Delivering on the Sustainable Development goals through long-term infrastructure planning
Daniel Adshead, Scott Thacker, Lena Fuldauer and Jim Hall

Through the range of services it provides, infrastructure has the potential to influence all 17 of the Sustainable Development Goals. However, the specific relationship between infrastructure and development outcomes is complex and poorly understood. This research informs decision-making in a national context through the development of a systematic performance assessment linking infrastructure investments and policies to progress toward specific SDG targets. A recent application to the Caribbean island of Curaçao provides a case study for this decision analysis framework. A long-term strategy for meeting infrastructure demand in the energy, water, wastewater, and solid waste sectors was developed, taking into account national priorities shaped by Curaçao's unique geography and characteristics as a small island state, e.g. future threats owing to demographic, economic and climate change uncertainties that may amplify its vulnerability to external economic shocks and climate impacts. Through interviews with in-country stakeholders from government and industry, a cross-sectoral infrastructure assessment was undertaken, aligned with a vision for infrastructure defined by the 2030 SDG Agenda. Key infrastructure interventions were identified for implementation in order to achieve long-term development targets

Emerging applications of adaptation pathways for managing and reducing climate change vulnerability in Californian energy utilities
Robert Kay, Judsen Bruzgul, and Tommy Hendrickson, Maya Bruguera and Cole Wheeler

Californian energy utilities face dynamic challenges in addressing the climate change resilience of assets now and in the future. Utility executives, utility investors and policy makers are addressing the challenge of ensuring service continuity in the face of a changing climate through an emerging suite of vulnerability assessment and resilience building frameworks for adaptation. These frameworks are being applied at both a broad, utility-wide level and for individual assets. Applying Adaptation Pathways provides investment decision-making

flexibility for a variety of infrastructure systems in the face of future uncertainty. Adaptation Pathway analysis and visualization is emerging as one of the tools to support energy utilities to plan investments that enhance climate resilience for mid-century and beyond, in a consistent framework to guide near-term investment choices.

Two projects, focused in the San Diego region and funded by the California Energy Commission (CEC) under California's Fourth Climate Change Assessment, serve as a foundational application of Adaptation Pathways in adapting energy infrastructure to future climate.

The presentation will outline the lessons learned from initial testing of Adaptation Pathways in the two CEC projects completed in partnership with Southern Californian energy utilities within a rapidly evolving Californian climate adaptation policy context. The presentation will also discuss how Adaptation Pathways could be used as a technique to assist multi-actor adaptation planning to coordinate infrastructure system resilience-building with other infrastructure providers, local governments and community-based organizations.

Resilience of complex infrastructure systems under deep uncertainty: An analysis of Mexico's fuel transportation and storage infrastructure
Edmundo Molina-Perez, Giovanni Hernandez, Fabian Carranza, Steven Popper and Luis Serra.

Mexico's energy sector is going through unprecedented change: recent legislative reforms have opened, for the first time in 70 years, Mexico's energy market to private and foreign companies, the penetration of renewable energy in the country is growing rapidly and the country relations with the US (i.e. its main energy partner) are at a low historic level. This has resulted in an extremely complex decision environment that exacerbates the traditional challenges associated with developing resilient infrastructure systems in emerging nations, such as rapid growing energy demand and heterogeneous sociodemographic conditions.

We use the Robust Decision Making framework to assist decision makers in the hydrocarbon sector design investments and regulatory alternatives that cement the development of a resilient fuel transportation and storage infrastructure. First, we developed a mathematical model of Mexico's fuel transportation and storage infrastructure, which considers jointly pipe, road and maritime infrastructure. Second, in collaboration with stakeholders we develop a wide range of scenarios that explore trends in renewable energy penetration, fuel theft, regional demand growth and fuel importation shortages. Finally, we use scenario discovery methods to identify the combination of risk conditions that lead to missing stakeholders' goals and to infrastructure vulnerability.

Breakout 2A: Water resource applications colloquium
Chair: Jordan Fischbach

Water resource planning under future climate and socioeconomic uncertainty in the Cauvery River basin in Karnataka, India
Ajay Bhave, Declan Conway, Suraje Dessai and David Stainforth

We develop an iterative multi-method DMUU approach, including scenario generation, co-production with stakeholders and water resources modeling. We apply this approach to explore the robustness of adaptation options and pathways against future climate and socioeconomic uncertainties in the Cauvery River Basin in Karnataka, India. A water resources model is calibrated and validated satisfactorily using observed streamflow. Plausible future changes in Indian Summer Monsoon (ISM) precipitation and water demand are used to drive simulations of water resources from 2021 to 2055. Two stakeholder-identified decision-critical metrics are examined: a basin-wide metric comprising legal instream flow requirements for the downstream state of Tamil Nadu, and a local metric comprising water supply reliability to Bangalore city. In model simulations, the ability to satisfy these performance metrics without adaptation is reduced under almost all scenarios. Implementing adaptation options can partially offset the negative impacts of change. Sequencing of options according to stakeholder priorities into Adaptation Pathways affects metric satisfaction. Early focus on agricultural demand management improves the robustness of pathways but trade-offs emerge between intra-basin and basin-wide water availability. We demonstrate that the fine balance between water availability and demand is vulnerable to future changes and uncertainty. Despite current and long-term planning challenges, stakeholders in developing countries may engage meaningfully in co-production approaches for adaptation decision-making under deep uncertainty.

Multi-objective analysis of funding allocations for non-structural flood risk mitigation in coastal Louisiana
David Johnson, Zach Richardson, Simon Gomez Sierra and Matthew Shisler

Louisiana's Comprehensive Master Plan for a Sustainable Coast is a 50-year plan for reducing flood risk and preventing land loss. As part of the plan, $6 billion is allocated towards nonstructural flood risk reduction measures such as elevating home foundations, floodproofing commercial properties, and buying out high-risk assets through voluntary property acquisitions. The effectiveness of nonstructural risk reduction can vary substantially based on myriad environmental, economic, and other factors.

This presentation will outline a multi-objective robust decision-making analysis of options for allocating funding for nonstructural risk reduction projects. We will i) identify mitigation standards that maximize cost effectiveness within a given set of future environmental and economic conditions, ii) estimate the risk reduction achievable by using such standards under a coastwide budget constraint, iii) analyze how the optimally cost-effective standards vary as a function of environmental, economic, and operational uncertainties, iv) construct recommended strategies for allocating funds that are near-optimal across a wide range of future uncertain scenarios under various budget levels, and v) quantify the difference in projected risk reduction between this new strategy and the current strategy offered in the state's Master Plan.

Modelling dynamics and adaptation at operational and structural scales for the ex-ante economic evaluation of large dams in Africa
Luciano Raso, Jean-Claude Bader and Bruno Barbier

Large dams are strategic assets for the production of electricity and to ensure water security by storing water when it is most abundant and making it available when it is scarcer and hence more precious. Notwithstanding the service they provide, large dams are mega-projects that change, often radically, the hydrological regime of a river, affecting its economic and environmental conditions.

Cost-Benefit Analysis (CBA) is currently the most frequently used framework for the economic evaluations of large dams. Change at different time scales influences the economic appraisal of dams. Presently, however, change and adaptation at both the operational

and the structural level are often not included in the CBA evaluation. Not including change and adaptation, limits the realistic estimation of cost and benefits and the appreciation of resilient solutions that offer satisfactory response for a large set of future, deeply uncertain, scenarios.

In this work, we consider the specific features of large dams in an African context, indicating methods for an economic evaluation that takes into account change and adaptation at both the operational and the structural scales and their interplay. These proposals are applied to the ex-ante evaluation of a system of existing dams in the Senegal River Valley. Results indicate the economic potential of the dams under changing conditions, for both adaptive and non-adaptive reservoir operation strategies.

Malawi's vulnerability to threshold behavior of lake Malawi: Informing adaptation decision making under uncertainty
Ajay Bhave, Lauren Bulcock, Suraje Dessai, Graham Jewitt and Declan Conway

The water, energy and food security of Malawi, a least developed country, depends critically on the Lake Malawi which sustains 98% of Malawi's hydropower, most of its irrigation and sustains biodiversity of a Ramsar wetland. Future irrigation and hydropower plans will increase water demand, and consequently increase future risks. To investigate the risks and evaluate adaptation options under climatic and socio-economic uncertainty, we applied a combined modelling-stakeholder engagement DMUU approach with sectoral stakeholders to identify performance requirements and potential adaptation options for three sectors. We set up a Water Evaluation And Planning (WEAP) model to explore this lake-basin decision context and incorporate sectoral requirements.

The WEAP model satisfactorily reproduces the Lake Malawi levels from 1961-2009, giving reasonable confidence to simulate future changes. We find that the Lake Malawi levels are sensitive to future precipitation and water demand changes. The Lake Malawi outflow occurs above the 471.5 masl. threshold and in some future scenarios there are periods without outflow. Sectoral performance requirements are not met across a large number of potential future conditions, indicating the extent of their sensitivity and vulnerability. Application of some adaptation options does improve individual sector performance requirements, but options demonstrate limited robustness across all three sectors. This suggests that individual options may not sufficiently address future changes; implying residual risk after adaptation.

Optimized dam portfolios reduce impacts of sediment trapping on the Mekong Delta under deeply uncertain future sediment yields
Rafael Schmitt, Matteo Giuliani, Simone Bizzi, G. Mathias Kondolf and Andrea F. Castelletti

Mega deltas, e.g., of the Ganges/Brahmaputra, Irrawaddy, and Mekong, are regional hot-spots for rural and urban socio-economic activity in the Indo-Pacific region. The future of these coupled human-natural systems are strongly linked to the delivery of sediment required to maintain the delta landform against global sea level rise, subsidence and coastal erosion. The direction and magnitude of change in sediment delivery is highly uncertain, depending on global climatic changes, as well as on management decisions regarding land-use and the future development of dams that trap sediment in the basin.

We use a robust approach to a) quantify the impact of hydropower on sediment delivery and b) develop lower-impact dam portfolios under the uncertainty associated with basin-scale sediment yield. The Mekong River basin is used to demonstrate the approach.

To conclude (1) major shifts of the sediment budget of the Mekong Delta are likely even under deeply uncertain future sediment yields and (2) strategic dam sequencing provides a robust option to maximize sediment delivery to the Mekong Delta if hydropower is to be expanded. These findings support energy planning policies, improve predictions of consequent land loss, and inform development of adaptation measures for the Mekong Delta.

San Francisco Water: Piloting adaptation pathways for long-term water supply planning
Dana Stuparu, Marjolijn Haasnoot, Willem van Deursen and Alexis Dufour

The San Francisco Public Utilities Commission (SFPUC) is taking steps to ensure that it is prepared to provide high quality drinking water under different water availability and demand conditions. SFPUC is currently exploring the use of an adaptive pathways planning approach - based on a combination of Decision Scaling and Dynamic Adaptive Policy Pathways (DAPP) - to develop a high level strategy for the long term planning of water resources.

This presentation reports on a pilot study of adaptation pathways for urban water supply and presents lessons on how and with what tools an adaptive plan can be developed for SFPUC and other water utility companies. We followed an iterative and phased fit-for-purpose approach towards pathways analysis and implementation. An example analysis of the vulnerability of the system together with pathways narratives and design was undertaken based on expert judgement and readily available information. A stylized prototype model of the SFPUC water system was used to show how vulnerabilities can be found using simulations. The use of a simple model had multiple advantages: clarity and insights were gained in the functioning and role of different parts of the modelling system to inform planning decisions.

Uncertainty and evidence-based water policy management in South Africa: The challenge for evaluation
Sandile Ngcamphalala, Olivier Crespo and Johann Louw

Equitable and sustainable access to water resources for economic activities remains one of the most contested public management problems in South Africa. Water policy management in South Africa is synonymous with incomplete and uncertain knowledge inputs, changing conceptions about the underlying problems, competing values and perspectives, and rapidly shifting policy targets. In this regard, adaptive water policy management presents great potential for better outcomes for current integrated water resources management (IWRM) efforts in South Africa by enabling improved strategies to handle policy uncertainty.

Evaluation methods or approaches that that are designed to track a linear logic of policy impact, such as theories of change approaches, or logical framework analyses, will have difficulty in exhibiting the necessary responsiveness, especially where policy or programmes change constantly. Consequently, monitoring and evaluation systems are needed that are flexible and tailored to constantly inform policy implementation decisions, especially in pursuit of largely unpredictable, rapidly changing and complex variables. This will assist adaptive policy managers to identify strategies that work, as well as those that

do not work or need to be altered or the introduction of new strategies, with better prospects for success.

Developing a robust water strategy for Monterrey, Mexico: Diversification and adaptation for coping with climate, economic and technological uncertainties
Edmundo Molina Perez, David Groves, Steven Popper, Rodrigo Crespo and Aldo Ramirez

The City of Monterrey in Mexico is rapidly increasing its demand for potable water due to its growing industrial activity and population. It is widely believed that the expansion of the city´s water infrastructure is a key measure needed to support future water demand. However, environmental concerns of different projects and more importantly climate change and water demand uncertainty have increased the complexity of this decision.

This study describes the results of applying the Robust Decision Making method for developing a water master plan for Monterrey which adapts to unfolding climate and demand conditions. Our results show future water demand in the city can be met progressively through a combination of different projects (e.g. efficiency, surface, groundwater and desalination) and policies (i.e. water tariffs). In the short term, small-to-medium scale grey infrastructure that take advantage of different water sources can be used to meet future demand in the face of climate and technological uncertainty. In the medium term, the combination of water efficiency and medium size grey infrastructure projects can help the city meet future demand and save close to 1 billion dollars in infrastructure investments.

Breakout 2B: DMDU approaches to technology assessment and planning
Chair: Edmundo Molina Perez

Strategic decision making in the 3D printing industry – a Robust Decision Making (RDM) analysis
Pedro Nascimento de Lima, Maria Isabel Wolf Motta Morandi and Daniel Pacheco Lacerda

The Additive Manufacturing (AM) industry has seen two-digit growth in the past 27 years and is expected to streamline supply chains, reduce product development time and to enable companies to reshape business models. The future, however, may still hold surprises to the AM industry. While some experts forecast that this industry might be worth 21 billion dollars by 2020, other forecasts point to an economic impact of 550 billion by 2025. Uncertainty in the AM industry manifests not only in diverging industry forecasts, but also in volatility of stock prices, and weak financial results obtained by the leading players. Expiring patents, new product diffusion dynamics and individual strategies adopted by different players are key factors that work together dynamically to shape the future of this unfolding market.

Our study employs the Robust Decision Making (RDM) approach to investigate the robustness of strategies used by industrial-grade AM Systems Manufacturers. In our experiments, aggressive pricing strategies dominate their conservative counterparts and our results do not lend support to Open Source R&D strategies. The candidate strategy employs an aggressive pricing approach, with a closed-source R&D strategy, and presents higher regret when the market size is high, and other players are also aggressive.

Understanding the need for policy action on greenhouse gas removal to address climate change: Initial case for Robust Decision Making
Mark Workman, James Maltby and Geoff Darch

Greenhouse Gas Removal (GGR) Technologies are a suite of technologies which remove CO2 from the atmosphere. These are being considered in climate policy, as it is unlikely that more traditional mitigation efforts alone will be able to keep emissions to within budgets to avoid the worst impacts of climate change. The requirement for GGR technologies to augment mitigation efforts is broadly acknowledged. The concern for some audiences is that the employment of GGR in the modelled scenarios is happening without initiatives to seek a better understanding of GGR in the real world.

Here we make a case for a novel approach to decision making on the use of GGR technologies and development of climate policy using Robust Decision Making (RDM) concepts. It is argued that RDM would help explore and provide a wider set of possible options for GGR use and policies, within a deeply uncertain conceptual area. Whilst present research and policy activity is epistemologically sound - paradoxically it is reinforcing the discourse and policy inaction. By using RDM methods, frameworks and tools wider audiences can be drawn into the debate to unlock the present toxic predicament surrounding the role of a potentially crucial suite of technologies in climate policy and whether they can help in meeting climate goals and at what scale they can be safely achieved.

Lithium-based transportation system-of-systems: Complexity and uncertainty of socio-environmental impacts
Datu Buyung Agusdinata and Wenjuan Liu

Aimed to reduce emissions, emerging technologies such as electric-drive vehicles (EDVs) rely on lithium-ion batteries (LIBs) for high-density energy storage. In the past 10 years, the production of LIBs has increased in capacity almost eightfold. Expected increased demand of LIBs will put pressure on the supply of lithium minerals. This happens particularly in the "Lithium Triangle region" bordering Argentina, Bolivia, and Chile that contains more than 75% of world known reserves of lithium.

For LIBs to be fully sustainable, it is imperative to consider its externalities along the extraction, production, use, and end of life phase. Tackling this complex issue requires a broader system perspective with a framing of impacts across geographical boundaries. This work focuses on defining and specifying the socio-environmental impacts of lithium mining activities within a lithium-based transportation system-of-systems (SoS).

The study analyzes uncertainties associated with socio-environmental impacts of lithium mineral extraction. It considers both parametric, structural, and actors' value uncertainties. The uncertainties stem from various sources (a) natural system including weather, ecosystem, and hydrology, (b) human system including mining decisions, well-being impacts, and (c) policy system including national mining policy and water rights legislation.

The developed conceptual system-of-system framework and inventory of key uncertainties enables a quantitative model to develop scenarios and policy assessment.

DMDU in a modern risk society: Roles of resilience-based public policy and emerging technologies/AI
Mika Shimizu

While a modern risk society poses a challenge of deep uncertainty for decision makers in public policy, technology advancements are another characteristic of a modern risk society which may positively or negatively impact lives, social functions, and coexistence with natural environments. The presentation demonstrates that the benefits of emerging technologies to humans, society and nature depends on how they are utilized and incorporated in the policy formation process, and this relationship is critically linked with resilience-based public policy. Specifically by highlighting Artificial Intelligence (AI), the presentation articulates what is resilience-based public policy, what are roles of resilience-based public policy in relations with emerging technologies, and how AI can be connected or disconnected with resilience-based public policy with the focus on AI's impact on human and social environment.

Breakout 2C: DMDU Ecosystems planning
Chair: Ashley Hefner

Dealing with deep uncertainty through exploratory modeling: Regulating loggerhead sea turtle fishing by catch in Gulf of Ulloa, Mexico
Daniela Pedroza, Luis Bojorquez-Tapia, Germán Ponce-Díaz, Francisco Arreguín and Antonio Diaz-De-Leon

Tackling highly political and contested problems like the bycatch of loggerhead sea turtles in Gulf of Ulloa requires a transdisciplinary inquiry approach supported by an exploratory modeling rationale. This approach was applied to address the challenging task of devising regulations for curtailing bycatch under a context of deep uncertainty. We combined ecological threshold analysis and area oriented multiple use framework to evaluate a wide range of plausible scenarios consistent with the available data.

Results identified the bycatch level that indicated a potential critical transition regime of the loggerhead population to a low resilience, and an alternating multiple use management scheme. Results constituted the backbone of regulations aimed to set a bycatch cap and a refuge area for the loggerhead population in the region. We argue, that coping with the challenges posed by deep uncertainty in policymaking, demands the use of exploratory modeling to enhance the ethical and epistemological dimensions of transdisciplinary inquiry. In this case, exploratory modeling was effective for dealing with the lack of agreement on the issues, contradictory evidence, and adversarial attitudes that amplified the effects of fragmentary and divergent ways of understanding alternative policies. Results underscore the role of exploratory modeling for achieving sustainable governance.

Avoiding fisheries collapse: Can robustness frameworks capture and navigate uncertain harvest trade-offs?
Antonia Hadjimichael, Patrick Reed and Julianne Quinn

Managing ecosystems poses a significant decision-analysis challenge, as these systems are often governed by highly nonlinear dynamics and threshold responses. The growing risks to our global fisheries present an example where the tradeoffs between economic and environmental objectives pose a deeply uncertain problem framing challenge. Management strategies need to be established to maximize fish harvest without endangering the species, or worse, causing collapse. The framing of such complex systems' decisions, in terms of which parts of the system are included or excluded in the analysis, can yield severe and surprising outcomes.

In this study, we explore the effects of different problem and management strategy formulations on system performance and the robustness of different formulations under a wide range of states of the world. Our results show that classical assumptions for a simple instance of the highly nonlinear fisheries management problem can yield severe instabilities of perceived tradeoffs, and their ability to inform stakeholder preferences is questionable. Small changes in deeply uncertain factors can fundamentally alter system dynamics, risks of collapse, and the validity of the candidate harvesting strategies. Insights from this study highlight the importance of ensuring models capture deep uncertainties in fundamental system dynamics as well as a breadth of economic and ecological criteria when seeking to discover if robust management options even exist.

Socio-ecological resilience modeling: Policy implications of drought effects in the wildlife management system in Baja California Sur, Mexico
Hilda Zamora-Maldonado, Sophie Avila-Foucat, Víctor Sánchez-Sotomayor and Raymond Lee

Extensive wildlife management is a strategy to maintain the habitat and the basis of the ecosystem and their services. It requires the joint consideration of human and ecological dimensions. This research describes a framework inspired on the socio-ecological systems (SES) resilience concept. We describe the bighorn sheep (Ovis canadensis) management system in a model that addresses the links between ecological and socio-economic subsystems. We validate and formalize this model by conducting semi-structured interviews in a community in Baja California Sur, Mexico, literature review and consultations with experts in the field of recreational hunting and wildlife management. In order to explore implications of SES resilient behavior under a stressor, we conduct experiments to assess the impact of drought patterns and potential policy responses.

Our results indicate that rainfall variation with respect to the historical record has the potential to disrupt both the specie and the household income and the lack of adaptive capacity in a policy may affect the dynamics of the whole SES. We identify thresholds and explore adaptive changes to the environmental policy in order to generate positive trends in both subsystems. We argue that updating the current policy, such that it can adapt to unfolding drought conditions, can increase the resilience of this SES. Our framework could potentially be applied to different species and socio-economic contexts.

Considering uncertainty in multi-objective spatial prioritization for California's agriculture, biodiversity and water resources
Benjamin Bryant, Rodd Kelsey, Adrian Vogl, Stacie Wolny, Scott Butterfield, Abigail Hart

Multi-objective spatial prioritization for various ecosystem services remains an emerging field where existing insights from different sub-disciplines are being drawn on to improve the state of practice, e.g. connecting conservation and landscape planning literatures, and linearizing complex habitat contiguity requirements to facilitate game changing improvements in optimization. While there is some progress on improving uptake of uncertainty assessment in ecosystem

services modeling itself, holistic consideration of uncertainty in spatial prioritization generally remains lacking, especially with multiple management actions available in individual spatial planning units.

This talk describes a novel spatial prioritization effort in California's San Joaquin Valley, where we examine opportunities to enhance habitat for desert species and water-dependent refuges amid a rapidly changing water policy environment for agricultural water. Using the integer linear program formulation of Marxan with Zones (prioritizr), as well as outputs from a Positive Mathematical Programming economic model (SWAP-RTS), we consider multiple sources of scenario uncertainties, as well as parametric and value uncertainties. While we do not optimize for robustness, we thoroughly assess sensitivity of portfolios to many alternate assumptions, and explore the feasibility of implementing a robustness-oriented policy-search.

II. DMDU Methodologies and Tools

The role of monitoring, signposts and triggers in DMDU colloquium
Chairs: Judy Lawrence and Robert Lempert

Climate-induced tipping points: A typology and application of DMDU toolkit
Kees C.H. van Ginkel and Marjolijn Haasnoot

We distinguish four types of tipping points related to climate change: 1) climate tipping points of large elements of the climate system, 2) ecological tipping points indicating critical transitions which can be induced by climate change, 3) climate-induced socio-economic tipping points indicating fundamental changes in socio-economic systems and 4) policy tipping points representing fundamental changes in policies in response to climate change to continue to achieve objectives under changing conditions.

A well-known application of DMDU tools to explore tipping point behavior is the lake problem, wherein the occurrence of an ecological tipping point (type 2) is to be avoided to maximize economic benefits from polluting industry of a neighboring town. This problem has been explored with 'multi-objective optimization' and 'direct policy search' to identify robust control strategies. Another method is 'adaptive policy pathways' to support water management, for example in the United Kingdom and the Netherlands. Here, adaptation tipping points (type 4) indicate thresholds of unacceptable performance of adaptation measures. The occurrence of climate tipping points (type 1) can be studied by exploring the RCP/SSP space using exploratory modelling. Finally, we present a list of potential climate-induced socio-economic tipping points (type 3) from the EU Horizon-2020 COACCH project and discuss how these examples can be studied with tools from the DMDU toolkit, to support urban planning.

Designing a monitoring system to get signals for adaptation
Marjolijn Haasnoot, Susan van 'T Klooster, Dirk Eilander, Ferdinand Diermanse and Pieter Bloemen

Adaptive plans aim to anticipate uncertain future changes by combining low-regret short-term actions with long-term options to adapt, if necessary. Monitoring and timely detection of relevant changes is crucial to ensure successful and timely implementation and reassessment. However, little guidance exists on how to design a signal monitoring system to support adaptive planning. What are good signposts to monitor and how to wisely analyse them to get timely and reliable signals for adaptation? Here, we present a framework for designing a monitoring plan for adaptive decision making under uncertainty. We use the following criteria to evaluate signposts and their critical (signal) values: measurability, timeliness, reliability and convincingness. We illustrate the approach based on the signal monitoring system of the adaptive plan from the Delta Programme in the Netherlands. We show how trend analysis can be used to evaluate signposts by highlighting trade-offs between accuracy and timeliness for different futures.

Identifying Triggers for Metropolitan Water District's Adaptive Integrated Resources Plan
David Groves and Brandon Goshi

The Metropolitan Water District of Southern California prepares an Integrated Resources Plan (IRP) every 5 years, in which it projects future water demand and identifies how existing supplies and new resources can meet that demand. The latest IRP expects to meet demand through 2035 through a combination of existing local and imported supplies, additional conservation, newly developed local resources, Colorado River supplies and storage management, and a large state investment in the infrastructure that delivers supplies to Southern California through the San Francisco Bay-Delta (California Water Fix). This talk will describe how Robust Decision Making (RDM) is being used to (1) identify the uncertain future conditions in which the IRP would not achieve sufficient reliability and (2) define an approach for monitoring over time climate and demographic conditions to provide the necessary lead time to make new investments if conditions warrant them. While we will demonstrate this approach to the design of a robust, adaptation program in the water sector, the method is easily generalizable to other contexts and RDM applications.

Monitoring of dynamic adaptive policies: Design of a monitoring system by scenario discovery
Luciano Raso, Jan Kwakkel and Jos Timmermans

In this work we present an innovative method for the design of monitoring systems for dynamic adaptive policies. The method simultaneously applies Scenario Discovery to the design of an adaptive policy and its complementary monitoring system. In scenario discovery, a simulation model is used to explore the response of a system for a large set of uncertain conditions. Appropriate machine learning algorithms are then used to identify those conditions that are highly predictive of policy failure. This information is then used to design a robust policy. The method proposed in this paper uses a similar approach but includes the observational uncertainty of the uncertain

variables, i.e. the possible mismatch between the real value of these variables and the value estimated from their observation in the real world. Including observational uncertainty of signposts enables the characterization of how signpost estimates obtained from system observations are predictive of policy failure and, ultimately, the selection of the most informative combinations of signposts and triggers.

We demonstrate this novel method on a water management problem regarding the Ijsselmeer region, in the Netherlands. Results show the effectiveness of the technique in handling the system complexity, and how an adaptive monitoring system, which enlarges the number of signposts only when necessary, is a means to increase parsimony while guaranteeing robustness of the monitoring system.

Abstracts: Day 2

Thursday, 15 November 2018

Breakout 3A: Explorations of system resiliency
Chair: Costa Samaras

Accelerated sea-level rise: A game changer for decision making under uncertainty?

Marjolijn Haasnoot, Jaap Kwadijk and Jos van Alphen

Uncertain future sea-level rise complicates decision making on adaptation. Although scientists agree upon the rising trend, there is large uncertainty about the future rate. Recent observations and model projections indicate that a faster acceleration of sea-level rise from the second half of this century onwards is possible and could result in a rise of 2 to 3 meters in 2100, and eventually 5 to 8 meter in 2200. Such new scenarios have serious consequences for the required planning and timing of investments in protective infrastructure and land-use, and ultimately the future liveability of low-lying coasts and deltas, such as the Netherlands.

A first assessment has been made to clarify the potential impact of this accelerated sea-level rise for the adaptive strategies for the Netherlands, with regard to coastal and river flood protection and fresh water supply. We present here the results of this first assessment that details potential impacts on these systems and related time frames. The results show that adaptive planning for sea-level rise requires scenarios that describe not only the extent of change, but also the rate of change and should go beyond 2100. Signposts for early warning signals based solely on local sea-level measurements may be insufficient for timely adaptation.

NZ coastal adaptation guidance: Interweaving uncertainty through sea level rise scenarios and hazard/risk assessments

Rob Bell, Scott Stephens and Judy Lawrence

New Zealand's national guidance on planning and decision-making, related to coastal hazard risks and climate change adaptation has been extensively updated (released December 2017).
The presentation will focus on two key components of the new coastal guidance: i) Incorporating possible coastal futures represented by 4 sea-level rise (SLR) scenarios; ii) Methods for hazard and risk assessments (including compound hazards) that are commensurate with the level of uncertainty and scale of development.

Several principles were developed and applied to selection of SLR scenarios. These four SLR scenarios are intended to test adaptation plans, through application of the dynamic adaptive pathways planning (DAPP) approach and to better resolve local/regional triggers for unacceptable hazard risks (adaptation thresholds). The DAPP process also requires risk and uncertainty considerations to be transparent in the hazard and risk scenarios used in such planning. A framework was developed for uncertainty identification and management within coastal hazard assessments, which recognizes different types of decision and identifies the types of uncertainty that must be accounted for, such as statistical, scenario and deep uncertainty types. We show how coastal-inundation hazards and risk can be mapped and presented in a way that clearly separates sources of uncertainty (such as the widening spread of future SLR) so that they are transparent within a DAPP process.

Navigating deeply uncertain trade-offs with adaptive climate strategies

Giacomo Marangoni, Jonathan Lamontagne, Julianne Quinn, Patrick Reed, Massimo Tavoni and Klaus Keller

Anthropogenic carbon dioxide (CO2) emissions drive sizeable societal risks. International agreements call for a strong reduction in CO2 emissions to manage these risks. However, identifying a sound strategy poses nontrivial challenges. Multiple preferences and deep uncertainties in the future climate-economy dynamics makes consensus among climate policy makers far from trivial. Integrated Assessment Models (IAMs), used to identify optimal strategies, often sacrifice complexity for computational tractability. They either optimize a single objective, or rely on strategies that cope poorly with evolving uncertainties.

Here we derive strategies that capture dynamic and deeply uncertain trade-offs using a well-known global Integrated Assessment Model (IAM). These strategies adapt abatement intensity to observed temperatures, and optimize action as climate uncertainty unfolds and warming realizes. We find a positive environmental and economic value of adapting abatement to observed warming. We then evaluate these strategies against alternative climate ensembles and damage functions, and find improved robustness to deep or ignored uncertainties with respect to a non-adaptive approach. We believe that adaptive strategies have the potential to provide greater support and consensus among climate decision makers in their difficult task of balancing different preferences and hedging against deep uncertainties.

Operationalizing resilience under deep uncertainty: Water supply for Mexico City and the Valley of Mexico
Sarah Freeman, Casey Brown and Diego Rodriguez

Evaluating the performance of water supply investments in terms of their performance amid known and unknown stresses is an emerging theme in urban water resources infrastructure planning. This study presents the implementation of resilience as a direct performance goal in the design an investment portfolio to improve water supply service in Mexico City Metropolitan Area (MCMA) and the surrounding Valley of Mexico. There are few places in the world where the water management challenges associated with urbanization are as fully visible as in MCMA. The MCMA has a population of approximately 22 million people of which only 82% have daily water provision. Local water agencies project this figure to decrease drastically in the next decade. Additionally, the MCMA faces major planning challenges due to factors such as demographic changes, seismic risk, infrastructure degradation and climate change not only in the city itself, but also in the Valley of Mexico from where approximately 44% of their water is sourced (i.e. the Lerma and Cutzamala Systems). New performance-based metrics of resilience are introduced within a multi-objective optimization framework which represent both sensitivity to trends and recovery from shocks for social, economic and environmental objectives. This presentation represents the results of a three-year process of stakeholder consultation and modeling of the integrated MCMA-Valley of Mexico water supply system.

Breakout 3B: Using DMDU methods to illuminate economic issues
Chair: Steven Popper

Assessing the prospects for public revenues from oil in Latin American and Caribbean countries under emerging climate policy
Baltzar Solano-Rodriguez, Steve Pye and Adrien Vogt-Schilb

Many countries in Latin American and the Caribbean (LAC) have large oil production sectors or future prospects for generating revenues from oil resources. However, producers in the region face large uncertainties relating to future global demand for oil, particularly if demand growth slows as sectors such as transport move to low carbon alternatives.

In this study, we explore the prospects for oil production in LAC countries across a wide range of global demand scenarios, and the potential public revenues raised from oil taxation and royalties To do so, we use BUEGO (Bottom-Up Economic and Geological Oil field production model) to determine the choice of oil field development and production across a global database of 7000 fields, based on projected oil demand. The prospects for LAC producers to compete for this demand will depend on project economics under the outturn oil price. A key influencing variable is the fiscal regime of a specific country, determining the competitiveness of field investments and the tax take for Government. This research uses robust decision-making principles to investigate the impact of different fiscal regimes on the economics of different fields in LAC countries, and implications for the revenue generation out to 2035.

Harmonizing Discretionary Policy Choice with Fiscal Rule Making: Mexico after Fiscal and Energy Sector Reforms
Eduardo Márquez Peña

It is widely recognized that under the hypothesis of rational expectations, economic agents' intertemporal decisions over consumption and investment are affected by the discretionary use of fiscal policy (Kydland and Prescott, 1977). Consequently, it is not surprising that modern macroeconomics is seeking to develop a "coherent framework for the design of economic policy that takes into consideration three relevant aspects: (i) a model to predict how people will behave under alternative policies, (ii) an economic criterion to rank the outcomes of alternative policies, and (iii) a description of how policies will be set in the future" (Chari and Kehoe, 2006).

This study utilizes, for the first time, the Dynamic General Equilibrium (DGE) modeling formalism within the framework of The Robust Decision Making (RDM) approach to develop a new and innovative technique for characterizing the deep uncertainty conditions of the discretionary use of fiscal instruments and translate the results into effective robust alternatives that can set the "rules of the game" for improving economic activity and reducing income inequality across Mexican families.

How much is needed? Infrastructure investments for sustainable development
Julie Rozenberg, Marianne Fay and Claire Nicolas

The infrastructure gap is large in developing countries, and the solution, many argue, is to spend more. But the story is not so simple. This report aims to shift the investment needs debate away from a simple focus on spending more towards spending better on the right objectives using relevant metrics. It does so by offering a careful and systematic approach to estimating the funding needs (capital and operations and maintenance) to close the service gap in water and sanitation, transportation, electricity, irrigation, and flood protection. One of the main innovations of our work relative to other investment needs estimates is that we explore thousands of scenarios to identify the most important cost drivers of future infrastructure investments and to expose the implications of different policy choices. One conclusion is that decarbonization goals are not a major driver of cost. Instead, spending efficiency is key and depends on the quality of the policies accompanying the investment. With the right policies, infrastructure investment paths compatible with the goals of the Paris Agreement can be cheaper than more polluting alternatives. Many methodological lessons are also drawn from this exercise which coordinated eight parallel assessments with fourteen models and thousands of scenarios run.

Breakout 3C: Innovation in DMDU methods
Chair: Julianne Quinn

Participatory, simulation-driven scenario analysis for long-term decision-making
Laura Schmitt Olabisi, Jing Du and Arika Ligmann-Zielinska

Long term policy making for complex societal and environmental problems is more than multivariate optimization. Due to the deep uncertainty embedded in these problems, it can be extremely difficult, if not impossible, to forecast the long term outcomes of a policy.

As a result, decision makers often turn to scenario analysis (including participatory scenario analysis) to consider how policies will perform under different plausible future scenarios. Most scenario analysis methods, however, construct and evaluate only a handful of narrative scenarios, as scenario development requires a substantial effort. Small sets of scenarios may neglect many important factors, potentially leaving decision-makers vulnerable to surprise. In addition, most scenario analysis methods are driven by a single goal, either to reduce system risks or to optimize outcomes. A method that balances different goals is needed.

We propose to develop a simulation-based hierarchical scenario analysis method to examine a substantially large number of future scenarios about the studied problem regardless of likelihood. More specifically, this proposed method will identify balanced policies acceptable for varying goals, characterize the vulnerabilities of proposed policies, and evaluate trade-offs among them over the long term. The proposed method will be tested with a case study about agricultural production in West Africa under climate change.

A generalized many-objective optimization approach for scenario discovery
Jan Kwakkel

Scenario discovery is a model-based approach for scenario development that aims at finding one or more subspaces within the uncertainty space associated with a model that are decision relevant. Scenario discovery involves solving a three-objective optimization problem: maximize coverage, density, and interpretability. The dominant algorithm for scenario discovery, the Patient Rule Induction Method (PRIM), however, is a lenient single objective optimization approach. PRIM maximizes density, while coverage and the number of restricted dimensions, a proxy for interpretability, are calculated afterwards. Adopting a single objective optimization algorithm for a many objective optimization problem implies that the full trade-off space is not identified.

In this paper, we introduce a many-objective optimization approach for scenario discovery. We compare this with an improved usage of PRIM for identifying the multidimensional trade-offs amongst coverage, density, and interpretability. We find that the many objective optimization approach produces results that dominate those of the improved version of PRIM on all three objectives. Qualitatively, however, both approaches identify essentially the same subspace. The prime benefits of the many objective optimization approach are its potential in bringing additional scenario relevant concerns such as consistency into the scenario discovery framework, as well as its ability to avoid overfitting. It also paves the way for future work on using more sophisticated metaheuristic optimization approaches for scenario discovery.

SPIRE – A decision support system for addressing complex/chaotic environments
Harold Klein

A decision support system (DSS) called SPIRE (Systematic Process for Identifying Relevant Environments) has been developed and applied that is responsive to the needs of a decision maker confronting a complex and/or chaotic situation. In these complex situations, the ordinary assumptions and/or givens of decision making problems invariably studied do not exist. In sum, all the necessary inputs to the application of an analytically-based decision making protocol are absent.

These are the key questions that need to be addressed well before any "decision making" can take place: Which decisions need to be made in the first place? In what sequence should these decisions be addressed or acted upon? Which actors/activities/organization units need to take action? Which actors/organization units/decisions/tasks need to be coordinated? How should prospective complex environments be represented so as to stimulate/trigger appropriate actions? What changes are necessary to the current organization structure? Where are the most appropriate environmental intervention points? How can organization actions alter the prospective environment?

The information organization of SPIRE output is analogous to neuronal group architecture. The SPIRE protocol itself have attributes of a complex adaptive system: self-organization, emergence, plasticity and connectivity. SPIRE process output architecture is in that of small world networks. SPIRE diagrams provide the decision maker with the necessary cognitive frames for rationally addressing the complex situation at hand that immediately provide the answers to the above critical questions. The results of an actual large-scale SPIRE application will be presented.

Breakout 4A: New tools for DMDU analysis colloquium
Chair: Jan Kwakkel

Policy trees and threshold-based adaptation of water resources systems under climate change
Jonathan Herman

Water resources systems face irreducible uncertainty in supply and demand, requiring policy alternatives capable of responding to changing conditions on multiple timescales. Recent studies have developed adaptive policies based on tipping points or "signposts", which are threshold values of observed variables that signal a change in policy. One such approach, policy tree optimization, is a recently developed conceptual framework and computational algorithm to search the space of indicators and their threshold values in a binary tree structure that is easily interpretable for decision makers.

This presentation describes the opportunities and challenges in the design and implementation of policy trees to inform climate adaptation strategies. First, we consider the design of short-term (i.e., daily to monthly) control rules to adapt to a range of plausible future climates. Second, we consider the design of policy trees to inform long-term (i.e., decadal scale) infrastructure adaptation decisions. We use illustrative case studies in the western United States to identify planning thresholds in GCM-based streamflow ensembles that suggest a long-term decrease in average annual water availability. These thresholds are tested by computing the frequency of incorrectly identifying or failing to identify a vulnerable scenario (false positives and false negatives, respectively), which highlights the tradeoff between frequently triggering unnecessary action, or failing to identify potential vulnerabilities until later in the century.

WaterPaths: A platform for discovering robust urban water portfolio investment pathways
Bernardo Trindade, Patrick Reed, Harrison Zeff and Gregory Characklis

Financial risk, access to capital, and regional competition for limited water sources represent dominant concerns in the US and global water supply sector. This work introduces the WaterPaths framework:

a generalizable, cloud-compatible, open-source exploratory modeling framework designed to inform long-term regional investments in water infrastructure while simultaneously aiding regions to improve their short-term weekly operational decisions. Uniquely, WaterPaths has the capability to identify the challenges and demonstrate the benefits of regionally coordinated planning and management for groups of water utilities sharing water resources. Another distinguishable benefit of WaterPaths' use of the computationally efficient ROF-based rules, is that it scales well with the number of actors. Lastly, as a platform for decision making under deep uncertainty, WaterPaths accounts for uncertainties not only related to hydrological or climate extremes, but also to key urban systems factors such as demand growth, effectiveness of water-use restrictions, construction costs, and financing uncertainties.

The WaterPaths platform is introduced here through a case study where four major water utilities in the Research Triangle, NC, improve their weekly operations and individual, as well as joint infrastructure investments subject to 45-sources of deep uncertainty to attain higher supply and financial performances.

An interdependent infrastructure systems planning tool to support strategic long-term, national-scale DMDU
Lena Isabel Fuldauer, Scott Thacker, Daniel Adshead and Jim Hall

The Infrastructure Transitions Research Consortium (ITRC) has developed a first-of-its-kind National Infrastructure Systems Model for International contexts (NISMOD-Int). This step-wise process facilitates a systematic evaluation of national infrastructure needs and how those needs can be met into the future under uncertainty.

We will provide a demonstration of the user-friendly NISMOD-Int. tool, applied to the Caribbean Small Island Developing State of Curacao, developed and deployed in partnership with the United Nations Office for Project Services (UNOPS) and the Curacao Ministry of Traffic, Transportation and Urban Planning. The application will showcase: 1) how the tool was used to develop Curacao's first cross-sectoral, long-term infrastructure plan – considering energy, transportation, water, wastewater and solid waste and 2) the methodological process, which integrates many concepts central to 'Decision Making under Deep Uncertainty' (DMDU). In addition, we will highlight how data confidence and uncertainties are made transparent throughout the processes and how decision-makers can input updated data and configure their own strategies in order to visualise decision trade-offs. By exploring the consequences and robustness of key decisions under uncertainty, such as national infrastructure policy choices and investments, before implementing the choices is demonstrates the application which is highly relevant to the DMDU community.

Travel Model Improvement Program: Exploratory modeling and analysis tool
Jeffrey Newman, Martin Milkovits and Sarah Sun

Emerging autonomous and connected vehicle technology, new mobility services, and changing travel behavior will potentially have significant impacts on future surface transportation operations and travel demand. This presents both opportunities and challenges for state and regional agencies; the primary challenge being to understand the scope of impacts and interactions and the implications on traditional planning strategies. The potential impacts due to changing travel behavior and emerging technologies call for a more comprehensive and exploratory approach to planning future mobility.

In this presentation, we will describe the application of the Travel Model Improvement Program - Exploratory Modeling and Analysis Tool (TMIP-EMAT) in an exploratory manner with results from the proof-of-concept. As part of the application, a range of uncertainty was initially defined across the potential vehicle technology impacts and socio-economic development of the region. TMIP-EMAT was then used to design a set of experiments using a Latin Hypercube sampling method and develop a combined linear regression and Gaussian Process Regression meta-model to estimate a given set of performance measures or outputs from the full model. We will also demonstrate and request feedback on a proposed exploratory analysis approach illustrated with results from a Monte Carlo simulation against the estimated meta-models.

A new free web-based tool to support decision making under uncertainty
Niels Riegels, Oluf Jessen, Silvia Leirao and Henrik Madsen

In collaboration with the United Nations Environment Programme, DHI have developed a free, web-based tool to support elements of the Robust Decision Making (RDM) workflow. The tool facilitates analysis of ensemble simulation results through the use of summary indicators and plotting tools. The workflow supports evaluation and comparison of alternatives according a robustness metric, as well as vulnerability analysis steps to identify assumptions associated with unacceptable performance.

The tool is simple to use and requires only a .csv table of ensemble results as input. The formatting requirements for the .csv table are not restrictive and enable considerable flexibility for comparing planning alternatives, uncertainty types, and output indicators. The tool facilitates stakeholder involvement in the RDM workflow through tools for viewing sensitivity of results to different threshold values for output indicators. Plotting tools are equipped with functionality for efficient visual comparison of alternatives and uncertainty ensembles.

A vulnerability analysis workflow helps users of the tool identify combinations of uncertain factors that may cause alternatives to fail. The vulnerability workflow is also equipped with plotting tools that facilitate efficient comparison of the impacts of different uncertain factors.

The RDM tool is freely available on the web and can be accessed at http://www.flooddroughtmonitor.com/RobustDecisionMakingTool.

Breakout 4C: Accounting for perspectives and behavior in DMDU
Chair: James Dewar

Experts' decision-making model under deep uncertainty
Matylda Gerber

Decision making process of three groups of experts was analyzed: police criminal intelligence analysts, GP doctors and Executive Search Consultant from UK, Belgium and Poland (n=20). All with over 10 years of domain relevant experience and with outstanding decision-making abilities that allowed them to become experts in their domains.

Based on 46 analyzed decision making situations, a decision making model was created that focuses on a path experts follow in situations

under deep uncertainty. The model is based on different approaches to intuition and on the concept of meta-reasoning. It indicates that experts use an emotional impulse as a signpost for choosing direction for data collection and analysis. The emotional impulse (Feeling of Rightness/Feeling or Error) informs that there are implicit structures that fit to the given decision-making situation. The model indicates also how an initial hunch transforms into explicitly defined solution that arrives in form insight.

The author proposes that intuition should be defined as a mechanism that processes and structures implicitly acquired experience and delivers to consciousness it's manifestations in form of feelings, appraisals, assumptions, or suppositions. Intuition should not be treated as something special but as an indispensable component of the whole field of consciousness. However, the regulatory importance of intuition rises under conditions of ambiguity, uncertainty and complexity of the environment.

Building narratives to characterise uncertainty in regional climate change through expert elicitation
Ajay Bhave, Suraje Dessai, Cathryn Birch, Declan Conway, Luis Garcia-Carreras, John Paul Gosling, Neha Mittal and David Stainforth

Knowledge about regional and local climate change can inform climate risk assessments and adaptation decisions. However, estimates of future rainfall change at the regional and local level are deeply uncertain for many parts of the world. A novel methodology was developed that uses climate processes and expert elicitation to build narratives of future regional rainfall change. The narratives qualitatively describe physically plausible evolutions of future regional climate substantiated by climate processes.

This method is applied to the Indian Summer Monsoon, focusing on the Cauvery River Basin in Karnataka, Southern India. Six climate narratives are constructed as a function of two drivers prioritised by the experts: moisture availability over the Arabian Sea and strength of the low-level westerly flow. The narratives describe how future rainfall could change until the 2050s and which climate processes and anthropogenic factors could influence this evolution. Analysis using observed (Global Precipitation Climatology Centre) and re-analysis (ERA20 and Interim) data shows the experts' judgement on key drivers fits well with empirical relationships. The study shows that through expert elicitation, process-based narratives enable climate scientists to characterise and communicate elements of deep uncertainty in future rainfall change.

Strategic Foresight, Deep Uncertainty, and Leadership: A Workshop Report
Darryl Farber, Mathew Burrows and Martin Pietrucha

This presentation reports on a workshop held in partnership between the Atlantic Council, a global Washington, DC-based think tank, and Penn State University on strategic foresight, deep uncertainty, and leadership. The overarching theme was shaping the future of the human-technology systems frontier. The workshop was a professional educational initiative that brought together strategy and policy practitioners with academics in engineering systems. The objective was to introduce early and mid-career professionals to the ideas and methods of strategic foresight and deep uncertainty through a combination of panel discussions with global experts and through a scenario planning exploratory systems modeling exercise. Security, emerging technologies, and sociotechnical systems innovation and resilience was a leitmotif. The presentation will describe the intellectual architecture of the workshop, the lessons learned from this unique think tank-academic partnership, and the next steps for creating a professional forum for developing strategic foresight and deep uncertainty expertise, the sine qua non for 21st century leadership.

III. 'Mainstreaming' DMDU Methods & Analyses in Policy Settings

Breakout 5A: New approaches to DMDU decision support
Chair: Marjolijn Haasnoot

Hidden-model processes for adaptive management under climate change uncertainty
Kelly Klima, Milad Memarzadeh and Matteo Pozzi

Predictions of climate change can significantly affect the optimization of measures reducing the long-term risk for assets exposed to extreme events. Although a single climate model can be represented by a Markov stochastic process and directly integrated into the sequential decision-making procedure, optimization under epistemic uncertainty about the model is computationally more challenging. Decision makers have to define not only a set of models with corresponding probabilities, but also whether and how they will learn more about the likelihood of these models during the asset-management process. Different assumed learning rates about the climate can suggest opposite behaviors.

This talk proposes a set of optimization procedures based on the Markov decision process (MDP) framework to support decision making depending on the assumed learning rate, thus trading off the need for a prompt response with that for reducing uncertainty before deciding. Specifically, it outlines how approaches based on the MDP and hidden-mode MDPs, dynamic programming, and point-based value iteration can be used, depending on the assumptions on future learning. The talk describes the complexity of these procedures, discusses their performance in different settings, and applies them to flood risk mitigation.

Applying methods of DMDU to social-behavioral modeling for policy analysis
Paul Davis

Social-behavioral modeling is nowhere near living up to its potential for benefiting society. Some reasons have roots in current social-science research itself, which emphasizes a multitude of discrete hypotheses, statistical testing, and separate paths for adherents to the diverse theories. Modern researchers with massive data study which

of the miscellaneous "theories" best" match data. Why? When each of the "theories" is explicitly myopic and focused on only one explanation of behavior, why should we care which happens to fit some empirical data best? Instead, we need comprehensive causal theories that coherently combine features from previously separate theories.

DMDU methods are well suited to a new generation of research linking causal theory, empirical data, and computationally generated data. The deep uncertainties involve, e.g., the very structure of models, including the mechanisms necessary to generate emergent behavior in the real world, which include new narratives and movements emerging and others dying off. Sometimes, these appear as the equivalent of societal "phase changes." A next level of sophistication would be to assess the robustness of models with respect to assumptions and conditions. Exploiting data could benefit from computational "scenario discovery," and other DMDU methods.

The tail wagging the dog: Designing modelling tools to drive better decision processes
Charlotte Brown, Garry McDonald, Erica Seville, Michele Daly, Nicola Smith and Rob Buxton

MERIT is an integrated spatial decision support system that enables a high-resolution, dynamic assessment, across space and through time, of the economic consequences of infrastructure failure. Central to MERIT is a multi-sectoral, multi-regional and fully dynamic economic model, formulated as a System Dynamics model using finite difference equations. This innovative approach allows us to simulate, and better understand, how economic shocks, and our response to them, progress over time. Despite its sophistication, MERIT is often called upon simply to validate decisions. There is an opportunity to better integrate increasingly complex and dynamic modelling tools, like MERIT, to help shape decision processes.

We explore the current capability and ready potential of MERIT to become a tool that shifts how decisions are made; including, uncertainty exploration (aleatoric and epistemic uncertainty evaluation and multiple-futures scenario modelling), multi-capital reporting, equity measures, co-benefit and adaptive pathway opportunity evaluation, and system driver identification that hone the decision-maker in on key leverage points in the system. In addition, we emphasise the need to make tools more accessible, intuitive, and user-friendly; and to improve how we communicate the best way to use these tools. Better design and use of modelling tools in decision-processes will result in more robust, holistic, and future-proof decision-making for our communities.

Towards incorporating inclusiveness in model-based support for long-term adaptation planning under uncertainty
Bramka Arga Jafino and Jan Kwakkel

Model-based decision support tools have often been used in long-term adaptation planning to evaluate the performance and the robustness of alternative adaptation plans under deep uncertainty. However, the evaluation of adaptation plans in such models to date often take a system-level perspective, where the costs and benefits of a plan are aggregated across actors and across time. In reality, a plan that is optimal from a system perspective may be suboptimal, or even harmful, to some actors.

In order to account for inclusiveness, we use two concepts from the social justice theory: intra-generational justice (fair distribution of impacts across different actors) and intergenerational justice (fair distribution of impacts across different future generations). With respect to the model-based decision support approach, there are two requirements that follow the incorporation of inclusiveness. First, we have to redefine the output indicators variables that will be observed from the model and hence reformulate the model structure. Second, we have to modify the evaluation framework with which we analyse the model outputs to allow for the assessment of the degree of inclusiveness of a candidate plan.

Posters

Economic evaluation of effectiveness of irrigation development as an adaptation measure to climate change under uncertainty
Daiju Narita, Ichiro Sato, Daikichi Ogawada and Akiko Matsuura

As climate change adaptation is becoming a recognized issue, the needs are growing in terms of evaluation methodologies of adaptation-related public investments that could reflect the uncertainties of climate change. As an application of the Robust Decision Making (RDM) approach, we conduct a case study of a Kenyan irrigation development project to evaluate the effectiveness of the project on climate change adaptation under uncertainties of climate change and socioeconomic factors through a combination of model simulations. The simulation results show that despite uncertainties of precipitation trends, high temperatures resulted from climate change have a tendency to reduce farmers' income due to loss of crop yields, and that irrigation development will mitigate that income loss, i.e., it will likely be effective as a means for climate change adaptation. Using these simulation outputs, we attempt a systematic assessment of uncertainties and robustness, including a PRIM (Patient Rule Induction Method) analysis.

Systems analysis with artificial intelligence based planet gamification
Steven Lisgo

For sustainability, finite planetary resources are both the problem and a constraint on the solution, which implies that any strategic plan be executed with maximum efficiency. Unfortunately, the optimal deployment of resource over the next century requires a good model for the future, which is lacking.

In an effort to address this issue, it is proposed that a comprehensive planet simulator be developed and packaged in a user-friendly game interface. Human and A.I players take control of the population and advance to the year 2100, looking for scenarios with positive outcomes. State-of-the-art environment, resource, agriculture, and climate models will be integrated. A massively multiplayer cooperative game mode allows for participation on regional scales.

Completed games are collected and analysed for trends, with the results used to guide real world decisions. At a minimum, partici-

pation from academia, government institutions, and the video game community are needed. The overall exercise can serve as a popular culture awareness and education tool, and as a focal point for model development and systems analysis. Lead partners and the required computing resources will be discussed.

Taking into account deep uncertainty in flood maps: Comparing the US and France
Anna Serra-Llobet, Rémy Tourment and Antonin Montané

Hazard and risk maps are powerful tools for decision-making. The way these maps are created can have tremendous implications in the territory since they can create different future scenarios of exposure and vulnerability to risk. In this study we compare different flood hazard and risk maps in the USA (the "Flood Insurance Rate Maps", the "Levee Safety Risk Analysis") and France ("Plan de Prévention de Risque d'Inondation" and the "Etudes de Dangers") to document how they deal with deep uncertainty inevitably associated with extreme events.

A key finding is that the regulatory maps under the US National Flood Insurance Program do not regulate areas behind accredited levees, despite their exposure to residual risk of overtopping or failure from floods larger than the 100-year return-period design flood, exposing large populations to involuntary flood risk. These profound uncertainties of flood risk exposure are exacerbated by changing climate, land-use changes, and urbanization in flood-prone lands, who increase hazard and exposure, respectively. The French Plans de Prévention de Risque d'Inondation consider levees invisible in the flood models, thereby acknowledging risk behind these structures. In the Mediterranean region of France, these maps include a layer showing extent of extreme events (aléa résidual), areas prone to flash flood.

Navigating deep uncertainty in water resources management
C. Dionisio Pérez Blanco

Water crises are the global greatest societal threat. The conjunction of increasing anthropic and environmental pressures on water resources calls for reforming water management through Transformational Adaptation Policies (TAP).

This paper develops a hierarchy and set of layers of feedback protocols that leverages on the conceptual models already available in the socioeconomic and hydrologic research to represent the interrelations in human-water systems, enable system functionalities potentially not achievable by isolated modules, and develop an ensemble experiment that describes the range of possible system(s) outcomes, samples uncertainty through the model spread, clarifies tradeoffs associated with each proposed policy option, and suggests a set of policy options that perform reasonably well compared to available alternatives across a range of future states. In this context, modules are specialized, self-contained mathematical models, which process information and generate outputs. Modules are interconnected through layers of feedback protocols, which are defined as rules designed to manage interrelationships between systems' modules. Following a protocol-based structure it is possible to switch or replace modules according to the specificities of the location (e.g. to include river basin authorities' specifically-developed hydrologic models). All this enables the provision of a replicable and flexible framework that supplies transparent, simple and easy-to-understand inputs to experts' discussions. Methods are illustrated with an application to the Segura River Basin in Spain.

Collaborative Risk Informed Decision Analysis (CRIDA) method assessment of hydropower generation in the Magdalena River basin in Colombia
Santiago Gómez Dueñas, Kristin Gilroy, Berry Gersonius and Michael McClain

Engineers and decision makers face significant uncertainties in water resources management and planning as a result of climate change. While the availability of climate data is increasing, guidance for interpreting these data and communicating the uncertainty for decision making is lacking. This case study aims to address this need.

The study demonstrates the use of climate data in decision making by applying the Collaborative Risk Informed Decision Analysis (CRIDA) method to the hydropower sector in the Magdalena River Basin of Colombia. CRIDA focuses on tailoring a traditional planning process to the problem at hand to avoid over- or under-investing in both the planning process and the final plan. Through a process referred to as the Level of Concern Analysis, the analyst assessed the climate risk and uncertainty involved in the problem at hand. CRIDA then provides guidance corresponding to this assessment.

While the CRIDA method itself is a novel approach, few real-world applications exist. This study provides greater depth to the vulnerability assessment than currently exists in the CRIDA guidance manual. In addition, the application to the Magdalena River Basin builds on the existing method by incorporating climate variability/change and sediment retention to hydropower production.

Can we calibrate and identify agent-based models of flood adaptation?
Vivek Srikrishnan and Klaus Keller

Agent-based models are useful for simulating emergent features of complex systems. However, this complexity can complicate model calibration and identification. Here we use a positive control experiment to assess whether a very basic agent-based model can be calibrated using statistical methods. First, we calibrate a simple model for household migration under flood risk, including the effect of using varying numbers of agents and data-record lengths. Second, in perfect model experiments, we quantify the degree to which we can successfully identify the underlying data-generating process, using two competing flood-risk migration models (one with emergent spatial features, the other without). Finally, we assess how hindcasts might be used to validate the calibrated models.

Strategic foresight, deep uncertainty, and leadership: A workshop report
Darryl Farber, Mathew Burrows and Martin Pietrucha

This presentation reports on a workshop held in partnership between the Atlantic Council, a global Washington, DC-based think tank, and Penn State University on strategic foresight, deep uncertainty, and leadership. The overarching theme was shaping the future of the human-technology systems frontier. The workshop was a professional educational initiative that brought together strategy and policy practitioners with academics in engineering systems. The objective was to introduce early and mid-career professionals to the ideas and methods of strategic foresight and deep uncertainty through a combination of panel discussions with global experts and through a scenario planning exploratory systems modeling exercise. Security, emerging technologies, and sociotechnical systems innovation and resilience was a leitmotif. The presentation will describe the intellectual architecture of the workshop, the lessons learned from this unique think

tank-academic partnership, and the next steps for creating a professional forum for developing strategic foresight and deep uncertainty expertise, the sine qua non for 21st century leadership.

Laying the groundwork: DMDU methodologies for urban planning in the Global South
Supriya Krishnan and Tina Comes

The transfer of scientific methods for decision making from the Western world to the Global South has led to a methodological myopia. Currently, the application of methods for Decision Making Under Deep uncertainty (DMDU) in developing contexts see restrictions as the method is largely underpinned by availability and granularity of data. In the domain of long term urban planning in rapidly urbanizing regions, this necessity for accurate data coupled with a systematic planning framework is prohibiting meaningful analysis and application of DMDU methods. This is because traditional linear planning practices follow shorter time frames and cannot afford the resources for complex simulations.

This study will present an overview of the challenges in deploying DMDU methods in urbanizing regions in the Global South with a focus on India. In order to understand spatial transactions in the built environment, this study draws from successful applications of DMDU methods for prominent cases such as the Colorado River Basin, Ho Chi Minh City, Louisiana Coast master plan, Rhine Delta and Australia to understand their institutional frameworks, input variables, objectives, timelines and incentives set out to utilize DMDU methods. Using the learnings, it reflects back on how the method must expand its vocabulary and the bargain in considering model based decision support for the Global South at all.

Robust personal decision-making
Maria Teresa Piacesi

This work applied principles of decision under deep uncertainty theory to an ordinary personal decision, analyzing the approach suitability and differences in the outcome when emphasis is placed on each of the four ways to deal with deep uncertainty: resilience, resistance, static robustness and adaptive robustness. It has been observed that a simplified model can be used in personal decisions such as the plans for retirement.

DMDU 2018 Annual Meeting
Attendees

Daniel Adshead, University of Oxford
Buyung Agusdinata, Arizona State University
Francis Andem, University of Uyo
Gerdo Aquino, SWA Group
Bramka Arga Jafino, Delft University of Technology
Wyatt Arnold, California Department of Water Resources
Garett Ballard-Rosa, Sacramento Area Council of Governments
Emem Bassey Inyang, University of Uyo
David Behar, San Francisco Public Utilities Commission
Robert Bell, National Institute of Water and Atmospheric Research
Yakov Ben-Haim, Technion - Israel Institute of Technology
Ajay Bhave, University of Leeds
Pieter Bloemen, Staff Delta Programme Commissioner
Luis Bojorquez-Tapia, El Laboratorio Nacional de Ciencias de la Sostenibilidad
Tom Brandeberry, Rural Community Development Corportation
Charlotte Brown, Resilient Organisations
John Seely Brown, Deloitte Center for the Edge
Benjamin Bryant, NatCap/Water in the West
Mary Butler, University of Minnesota
Anastasia Buyalskaya, California Institute of Technology
Fabian Carranza, Instituto Tecnológico de Monterrey
Andrea Castelletti, Polytechnic University of Milan
Cornelia Colijn, University of Pennsylvania
Paul Davis, RAND Corporation
George DeMartino, University of Denver
James Dewar, RAND Corporation
Alexis Dufour, San Francisco Public Utilities Commission
Darryl Farber, Pennsylvania State University
Jordan Fischbach, RAND Corporation
Nathan Foged, Brown and Caldwell
Sarah Freeman, University of Massachusetts
Momo Fukushima, Japan International Cooperation Agency
Lena Fuldauer, Oxford University
Nathan Geldner, Purdue University
Matylda Gerber, Warsaw School of Economics
Berry Gersonius, IHE Delft Institute for Water Education
Ben Geske, Delta Stewardship Council
Andrea Golay, RAND Corporation
David Gold, Cornell University
Brandon Goshi, Metropolitan Water District of Southern California
Henry Graumlich, Calleguas Municipal Water District
David Groves, RAND Corporation
Marjolijn Haasnoot, Deltares
Antonia Hadjimichael, Cornell University
Juliette Hart, US Geological Survey
Rory Heard, UK Defence Science and Technology Laboratory
Ashley Hefner, City of Culver City
Jonathan Herman, University of California Davis
Giovanni Hernandez, Instituto Tecnológico de Monterrey
Julio Herrera Estrada, Stanford University
Arlene Hopkins
Linlan Huang, SOAS University of London
Mark Hughes, University of Pennsylvania
Sunday Ibuot, Akwa Ibom State Goverment
David Johnson, Purdue University
Laurna Kaatz, Denver Water
Robert Kay, ICF
Klaus Keller, Pennsylvania State University
Tim Kellett, San Bernardino Valley Municipal Water District
Steven Kimbrough, University of Pennsylvania
Harold Klein, Temple University
Kelly Klima, RAND Corporation
G Mathias Kondolf, University of California Berkeley
Weilong Kong, Pardee RAND Graduate School
Supriya Krishnan, National Institute of Public Finance and Policy
John Kucharski, US Corps of Engineers
Jan Kwakkel, Delft University of Technology
Steven Lavine, Thomas Mann House Los Angeles
Judy Lawrence, NZ Climate Change Research Institute
Robert Lempert, RAND Corporation
Cris Liban, Los Angeles County Metropolitan Transportation Authority
Pedro Lima, Unisinos
Steven Lisgo, ITER Organization
Kacey Lizon, Sacramento Area Council of Governments
Stephen Maack, REAP Change Consultants
Sebastian Malter, Philadelphia Water Department
Giacomo Marangoni, Polytechnic University of Milan
Eduardo Marquez, National Laboratory for Public Policy, Mexico
Stephanie Martin, The Aerospace Corporation
Juan Matute, UCLA Institute of Transportation Studies
Tim McDonald, Pardee RAND Graduate School
Sergio Miranda-da-Cruz, MdC Institute of Advanced Studies
Edmundo Molina, Instituto Tecnológico de Monterrey
Sarah Moody, The Aerospace Corporation
Daiju Narita, University of Tokyo
Jeff Newman, California Department of Transportation
Jeffrey Newman, Cambridge Systematics, Inc.
Sandile Ngcamphalala, University of Cape Town

Claire Nicolas, World Bank
Robert O'Connor, National Science Foundation
Daikichi Ogawada, Nippon Koei Co., Ltd.
Angela O'Mahony, RAND Corporation
Karishma Patel, Pardee RAND Graduate School
Ann Pendleton-Jullian, RAND Corporation
C. Dionisio Pérez Blanco, Universidad de Salamanca
Alejandro Pioré, Instituto Tecnológico de Monterrey
Steven Popper, RAND Corporation
Julianne Quinn, University of Virginia
AHM Rahman, Bangladesh NGOs Network for Radio and Communication
Pavitra Rammohan, Deep Root
Luciano Raso, Delft University of Technology
Patrick Ray, University of Cincinnati
Patrick Reed, Cornell University
David Rheinheimer, University of Massachusetts Amherst
Niels Riegels, DHI
Caleb Robinson, Georgia Institute of Technology
Darren Rockett, Ministry of Defence
Evan Rosenberg, Los Angeles County Metropolitan Transportation Authority
Julie Rozenberg, World Bank
Jessica Ruvinsky, Bellwether Collaboratory
Costa Samaras, Carnegie Mellon University
Ichiro Sato, World Resources Institute
Rafael Schmitt, Stanford University
Laura Schmitt Olabisi, Michigan State University
Andrew Schwarz, Delta Stewardship Council
Oscar Serpell, University of Pennsylvania
Anna Serra-Llobet, University of California Berkeley
Amanda Sheffield, National Oceanic and Atmospheric Administration
Mika Shimizu, Kyoto University
Thomas Small, City of Culver City
Rebecca Smith, US Bureau of Reclamation
Baltazar Solano-Rodriguez, University College London
Vivek Srikrishnan, Pennsylvania State University
Dana Stuparu, Deltares
Laixiang Sun, SOAS University of London
James Syme, RAND Corporation
Maria Teresa Piacesi, Inst.de Fomento e Coordenação Industrial
Zhan Tian, Southern University of Science and Technology
Bernardo Trindade, Cornell University
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Lily Zhao, University of California Santa Barbara
Huan Zou, SOAS University of London