Abstracts submitted for the Third Annual Workshop on Decision Making Under Deep Uncertainty

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1. A Robust Strategy For Implementing Lima’s Long-Term Water Resources Master Plan

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ABSTRACT

Inspired by the previous two workshops on Decision Making Under Deep Uncertainty - and particularly the discussions of how methodologies can complement each other - this project draws together principles of several methodologies to help Lima plan for long-term water reliability amid deeply uncertain conditions.

Lima faces major water-related challenges. It is the fifth largest metropolitan area in Latin America and the second largest desert city in the world. A rapidly growing population with approximately one million underserved urban poor, current water shortages, competition for water between sectors, and climate change impacts may leave the region under perpetual water stress. SEDAPAL, Lima’s water utility, has developed an aggressive US $2.5 billion Master Plan to improve water reliability in the coming decades. The Master Plan consists of twelve major infrastructural investments that SEDAPAL proposes to implement between now and 2040. SEDAPAL is also considering two additional projects. These fourteen investments are a mix of reservoirs, water treatment plants, desalination plants, and tunnels to transfer water between watersheds. Together, the investments are designed to meet the 30% increase in water demand that SEDAPAL projects for the coming decades.

Consistent with the state of practice at many water utilities, SEDAPAL developed its Master Plan by projecting future demands based on recent socioeconomic trends and by projecting future water supply based on historical climate conditions. Yet future water supply and demand in Lima may differ markedly from that of the past. These uncertainties raise important questions for decision makers concerned with water reliability in Lima. Is the Master Plan sufficient to ensure reliability in the face of deeply uncertain future climate change and demand? On the other hand, are all proposed projects necessary to achieving reliability? Many projects are challenging to implement—how should considerations of project feasibility shape the city’s investment strategy? Ultimately, how should projects be prioritized? Which should be implemented now, which can be delayed until they are necessary, and what specific indicators would trigger their implementation?

This study draws upon state-of-the-art methods for decision making under deep uncertainty (DMU) to give SEDAPAL and decision makers in Lima answers to these pressing questions. It draws upon several methodologies including Robust Decision Making, Decision Scaling, and Adaptive Pathways, to prioritize the investments in SEDAPAL’s Master Plan. Together these methods help define an investment strategy that is robust, ensuring water reliability across as wide a range of future conditions as possible while also being economically efficient. The strategy is defined in a decision tree that consists of a set of near-term, no-regret investments that SEDAPAL can embark upon now; signposts of specific project feasibility, streamflow, and demand conditions SEDAPAL should monitor in the medium and long term; and sets of deferred projects that SEDAPAL should implement if the signposts are triggered.
This project helps SEDAPAL understand its Master Plan more fully and implement its Master Plan robustly. It also demonstrates how the best principles of different DMU methodologies can be integrated and tailored to yield high-value analyses.

**Keywords:** water resource planning, climate change, multiple methodologies, robust decision making, dynamic adaptive pathways, decision scaling, interactive decision support
2. **Decide To Build And Manage Water Resources Constructions In The Mekong River Delta**

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**ABSTRACT**

Can Tho City is located in the low central of the Mekong Delta. Mekong River water is a valuable resource, but sometimes also the great danger to the livelihoods of local residents.

Every year in the Mekong River Delta have a dry season at the early months and a season of flooding in the last months. In the year there is no water the local people will get low income due to the fishery resources are declining even absent and the next rice crop will not meet requirements for production. In contrast, in the year that there are too much of water. It will cause deep water flooding in the paddy fields and engulf houses, works, it is a disaster. Flood damages buildings, reduces agricultural yields even causes loss of life. Water come to Mekong delta some years are enough, some are very little, and some are very much as a first uncertainty.

Flood water of the Mekong Delta include the following sources: (1) the floodwaters come from upstream Mekong country; (2) Local rainfall water; and (3) tide from east sea. These are water resources which nature play a decisive role in the majority, particularly in the coming years as climate change makes the uncertain and the risks accompanying water resources the more complex. Climate change is an uncertain element to the next.

Mekong Delta at the end of the Mekong River Basin. Hydrological regime of the delta suffer greatly from the activities in the upstream water use. The development activities especially agricultural, urbanization, industrialization and the construction of 20 dams in 5 countries in which the different of qualifications and different institutional form. All will contribute to a complex threats and unpredictable for hydrological regime of the delta. That uncertainty 3rd.

In addition, the risk of distortion due to ground subsidence and no exact forecasts at the local scale makes design calculations works to minimize damage of water resources risks becoming baseless that is the 4th uncertainty.

How to choose and decide the investment works, in order to minimize damage and increase the benefits for the local population against unexpected developments of water resources, on the whole region and for each locality was a problem urgent. Especially the answer must be "no regrets" and high efficiency.

**Keywords:** Delta, Mekong, flood, subsidence, dams
3. **A Philosophical Perspective On Decision Making Under Deep Uncertainty**

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**ABSTRACT**

Conventional risk analysis is based on careful consideration of probabilities, consequences, and alternative actions. In the light of climate change, we often have to make decisions in the absence of such information: We do not know the probabilities of the possible future events that are relevant for the decision, and sometimes we have not even identified these events. It may also be possible that people disagree about the desirability of future events. Together, these uncertainties and ambiguities may influence each other: policy choices are affected by societal and climatological developments and vice versa. In the literature, this is often referred to as deep uncertainty. In order to support policy makers, methods and tools have been developed that are particularly aimed at decision-making under deep uncertainty. These methods and tools often comprise models and other quantitative methods that help strengthen the knowledge base.

The topic of decision making under deep uncertainty has recently attracted the attention from philosophers of risk as well. In this line of research, two focal points can be distinguished. The former takes an argumentative point of view. Methods from philosophical analysis have been proposed for prioritizing among uncertain dangers, for determining how decisions should be framed, for choosing a suitable time frame for a decision and for systematically choosing among different decision options. The second point of view focuses on the ethical implications of policy decisions made under deep uncertainty. Taking into account that decisions taken now affect future generations and recognizing that we live in a pluralistic society in which people may disagree on the principles of distributive justice, there are strong reasons to take those decisions that involve as little irreversible consequences as possible.

In this presentation, I discuss some recent developments in philosophy of risk and show how they may support decision making under deep uncertainty.

**Keywords:** philosophy, ethics, distributive justice, pluralism, argumentative strategy
4. **Robust Portfolio Decision Analysis**

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**ABSTRACT**

In this paper we discuss the problem of “deep uncertainty”. This problem—which is pervasive in climate change—refers to a situation in which there is significant disagreement over probability distributions (McInerney et al, 2012). To date, there have been two differing approaches to decision making under deep uncertainty. The first is to go forward with traditional, rational approaches of decision making under uncertainty (e.g. Baker and Solak 2014, Kelly and Kolstad 1999); but this approach has been criticized for providing solutions that appear too certain or are lacking in “externally consistency” (Gilboa et al 2009). The second approach handles missing or ambiguous information through non-traditional decision rules, for example by applying the machinery of ambiguity aversion (Milner et al 2013) or other worst-case-type analysis. These non-expected utility decision criteria have been criticized, however, as not being internally consistent (Al Najjar and Weinstein 2009).

One concern about both approaches is that they tend to arrive at a single “best” decision. We argue that in cases where there is disagreement, whether over preferences or beliefs, analysts should not provide a single “best” decision. While modelers believe their models are useful, decision makers are well aware that all models are wrong (Box and Draper, 1987). There are always a number of aspects of the real world that cannot be modeled. Therefore, there is good reason to use models to provide insights and a set of good solutions, and then allow decision makers to choose the best. In this paper, we introduce dominance measures that incorporate risk aversion and multiple priors.

We apply this framework to the question of how to allocate funds across a wide variety of energy technologies with varying potential for improvement and differing impacts on the economy and environment. This question is part of a complex phenomenon - one which has been approached through different avenues, including the development of a broad range of different integrated assessment models (IAMs); and studies of expert judgments on the potential for technological change. The IAMs have been useful for developing insights on the relative importance of technologies and the speed of their adoption; nevertheless there are a range of challenges from the viewpoint of decision and policy making, including the large number of assumptions that are required, and the significant uncertainties that they entail. The studies of expert judgments have provided explicit probability distributions over the potential for technological change; however, there are a number of independent and disparate studies, increasing the challenge of trying to incorporate them into the already computationally-complex IAMs.

In this application, we use data derived from three large expert elicitation studies of energy technologies (Baker et al 2015). To model the interactions of the technologies with each other and in the economy, we use two Integrated Assessment Models, GCAM and WITCH. We incorporate deep uncertainty over technological prospects and over climate change damages to derive core, exterior, and marginal investments, and illustrate how this set can provide insights to decision makers on near term actions.

**Keywords:** Robust Portfolio Decision Analysis, Clean Energy RD portfolio, Multiple Priors
5. Adaptation Pathways In Practice: Mapping Options And Trade-Offs For London’s Scarce Water Resources

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ABSTRACT
Adaptation involves sequences of decisions that weigh up climate risks, costs and uncertainties. Analysis of sequential adaptation decision ‘pathways’ helps to demonstrate how climate risk can (or cannot) be managed, whilst retaining the flexibility to respond to future uncertainties. Whilst an adaptive planning paradigm has gained increasing attention, the uptake of such methods has been relatively limited compared to that of the scale of adaptation that is required around the world (Walker et al., 2013).

London’s ability to remain a world-leading city in an increasingly globalised economy is dependent on it being an efficient and low risk place to do business. However, climate risk from flooding, overheating, water scarcity and supply chain exposure is increasing. The Mayor of London has identified anticipatory adaptation as a cost effective strategy to increase the long-term resilience of the city (GLA, 2011). In practice however, the allocation of scarce resources needs to be justified by the benefits of climate risk reduction.

This paper demonstrates how an adaptation pathways approach can be combined with probabilistic risk analysis to make the case for adaptation. We focus on the risks to London’s water supplies, which are being stretched by increasing population.

A range of water supply and demand reduction actions, and the potential limits of those individual actions were identified. Through this process, stakeholders began to define a solution space and identify feasible timescales over which adaptation options could be scaled up. Portfolios of adaptation actions were identified and illustrative adaptation pathways for London’s water supply developed.

We present a quantified assessment of how risk of water shortages varies dynamically for 12 adaptation pathways through time, demonstrating how transient climate projections can be used to extend water resource planning horizons to 2100. The approach considers discreet actions and the timing, rate and scale of implementation of multiple distributed actions as part of dynamic adaptive portfolios. The implications of prioritising flexible actions as a means of achieving robust outcomes are explored through a number of pathways.

The analysis identified a number of pathways capable of maintaining the probability of exceeding a target frequency of water use restrictions below a probability of 0.01 per year, through to 2100 under a medium emissions scenario. Without further adaptation, the probability of water shortage will increase beyond the 0.01 stakeholders considered tolerable. Pathways diagrams demonstrate how a range of dynamic adaptation portfolios may perform, providing an effective stimulus for stakeholders to consider what is a tolerable level of climate risk and how this may change over time. This approach has helped to reconcile multiple decision timescales and demonstrate the value of strategic long-term planning for climate change adaptation to stakeholders by outlining long-term
futures that may influence medium-term decision-making. Adopting a flexible approach to adaptation will be critical to the management of risk under uncertainty. This adaptation pathways approach demonstrates an effective framework for informing such decision processes.

**Keywords:** Adaptation Pathways, Probabilistic Risk Assessment, Transient Scenarios, Decision Making
6. **Tolerable Water-Related Risks? Integrating Multi-Objective Optimization And Stress Testing To Identify Water Management Strategies**

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**ABSTRACT**

It is important to recognize the limitations of conventional risk analytic approaches for dealing with climate change related and inform climate change adaptation decisions. This work presents a two-pronged approach to water management decision-making under uncertainty whereby, instead of trying to simply predict future water availability based on uncertain climate projections, risk analytic tools are coupled with multiobjective search algorithms and ‘stress testing’ methods to explore sensitivity to the unforeseen and identify robustness to unexpected hydrological conditions.

A multi-objective search method is employed to identify alternative water management plans subject to different climate risk tolerability constraints. The method allows water managers to understand the implications of choices around risk tolerability on their investment decisions and the selected plans. The multiobjective search is coupled with novel methods to test the vulnerability of water resource system to unforeseen drought conditions. A large number of plausible synthetic droughts are generated by perturbing the temporal dependence structure of streamflow time series. This allows water managers to stress test their decisions against conditions that go well beyond historical droughts.

The method is applied to the London water resource system (England) to identify adaptation cost and risk reduction trade-offs and to investigate under which drought conditions severe water use restrictions would need to be imposed on water users. Results indicate that the water resource system is vulnerable to drought conditions outside the range of historical events. The vulnerability assessment results were coupled with climate model information to compare alternative water management options with respect to their vulnerability to increasingly long and severe drought conditions.

Traditional robustness assessments hinge upon risk averse preferences whilst our approach allows water managers to gain a more nuanced understanding of the implications that different risk attitudes have on robustness and on the costs of achieving that robustness.

**Keywords:** Tolerable risk, Robustness to drought, Risk-based, Water syooky
7. **Policy Selection Without Mathematical Models**

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**ABSTRACT**

Many real-world planning and decision problems are far too uncertain, too variable, and too complicated to support realistic mathematical models. In this talk we explain the usefulness, in these situations, of qualitative insights from mathematical decision theory. We demonstrate the integration of info-gap robustness in decision problems in which surprise and ignorance are predominant.

Reducing uncertainty is a major focus of planning and decision analysis under severe uncertainty. “Reducing uncertainty” can have two different meanings:

1. Reduce ignorance, ambiguity or potential for surprise in describing relevant situations.
2. Reduce vulnerability to ignorance, ambiguity or surprise. Reduce the impact of uncertainty on the outcome of the decision.

Reducing uncertainty (the first meaning) is very different from reducing the impact of uncertainty (the second meaning). It is not uncertainty per se that is pernicious, but rather the possibility for adverse impact of surprise. Uncertainty about irrelevant situations needn’t be reduced because it isn’t pernicious. More importantly, some policy options are less vulnerable to uncertainty than others. These less vulnerable (equivalently, more robust) options can tolerate more uncertainty. Analysts should identify policy options that are robust to uncertainty.

Reducing the impact of uncertainty requires awareness of policymakers’ goals. This may conflict with policy neutrality of analysts that is characteristic of much expert decision support for client decision makers, for example governmental agencies.

We present practical guidelines for employing adaptable choice-strategies as a proxy for robustness against uncertainty. These guidelines include being prepared for more surprises than we intuitively expect, retaining sufficiently many options to avoid premature closure and conflicts among preferences, and prioritizing outcomes that are steerable, whose consequences are observable, and that do not entail sunk costs, resource depletion, or high transition costs. We illustrate these concepts and guidelines with examples from public health and international security.

**References**


**Keywords:** policy selection, robustness, uncertainty, info-gap
8. Challenges And The State-Of-The-Art For Discovering Tradeoffs & Vulnerabilities In Deep Uncertainty Frameworks

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ABSTRACT

Although exogenous drivers such as climate change, population pressures, system demands, etc. are widely acknowledged and explored in the robust decision making literature, there is a need to better acknowledge and rigorously explore the deep uncertainty associated with eliciting problem definitions. There are nontrivial conceptual as well as computational challenges that should be acknowledged in formalizing our exploration of the structural uncertainties associated with defining complex management problems (e.g., choosing objectives, exploring management decisions, planning horizons, representations of preferences, etc.) as well as the challenges associated with predicting the impacts of actions (e.g., imperfect knowledge of system dynamics, external forcings, or environmental thresholds). There is a growing recognition and interest in using emerging computational tools for discovering the tradeoffs that emerge across complex combinations infrastructure options, adaptive operations, and sign posts. As a field concerned with “deep uncertainties”, it is logically consistent to include a more direct acknowledgement that our choices for dealing with computationally demanding simulations, advanced search algorithms, and sensitivity analysis tools are themselves subject to failures that could adversely bias our understanding of how systems’ vulnerabilities change with proposed actions. Balancing simplicity versus complexity in our computational frameworks is nontrivial given that we are often exploring high impact irreversible decisions. It is not always clear that accepted models even encompass important failure modes. Moreover as they become more complex and computationally demanding the benefits and consequences of simplifications are often untested.

Many of the challenges discussed above have motivated the last decade of my group's research. They shape our ability to operationalize our “many-objective robust decision making” (MORDM) framework for the design and management of complex engineered systems. The MORDM framework has four core components: (1) elicited problem conception and formulation, (2) many-objective search, (3) interactive visual analytics, and (4) negotiated selection of robust alternatives. Problem conception and formulation is the process of abstracting a practical design problem into a mathematical representation. We build on the emerging work in visual analytics to exploit interactive visualization of both the design space and the objective space in multiple heterogeneous linked views that permit exploration and discovery. Many-objective search produces tradeoff solutions from potentially competing problem formulations that can each consider up to ten conflicting objectives based on current computational search capabilities. Negotiated design selection uses interactive visualization, reformulation, and optimization to discover desirable designs for implementation. Each of the activities in the framework is subject to feedback, both within the activity itself and from the other activities in the framework. These feedback processes transition formerly marginalized “constructive learning” activities of reformulating the problem, refining the conceptual model of the problem, and refining the optimization, to represent the most critical and potentially deeply uncertain process for innovating real world systems (i.e., learning how to frame the problems themselves). My presentation will use our recent applications in urban water portfolio planning, multi-sector reservoir planning and satellite constellation design to demonstrate key challenges and recent computational innovations.

Keywords: robust decision making, multiobjective decision support, problem framing uncertainty, scalable decision support, learning
9. Cost-Benefit Analysis For Long-Term Flood Risk Management Strategies. Pros And Cons Of The Method And Options For Improvement

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ABSTRACT
Over the last decade, a number of relative new, 'non-probabilistic' methods for the (economic) evaluation of investment projects to adapt to climate change, have received an increasing amount of attention, both from scientists and practitioners. The methods include amongst others Info-Gap Theory (IGT), Robust Decision Making (RDM) and Iterative Risk Management (IRM). The methods are called 'non-probabilistic', since they are designed to deal with 'deep uncertainty', for example the impacts of future climate change on water systems, for which no or limited probabilistic information exists. Several publications have compared the new methods with traditional evaluation methods, of which the most commonly applied is cost-benefit analysis (CBA). In the comparison, there is a tendency to describe the CBA in a somewhat caricatural way, in which a 'most likely future' is used to evaluate 'now-or-never' investment decisions. Consequently, the CBA method is judged to be ill-equipped to deal with climate change uncertainties as well as with other types of uncertainties.

Over the last decades, however, several methodological developments in the CBA have taken place, which have significantly improved the CBA method to deal with both risk and uncertainty. Those include the use of real-options analysis to evaluate timing and flexibility in the design of measures and strategies, the use of multiple scenarios to evaluate robustness of decisions, Monte Carlo-simulations to provide probability density functions of the efficiency of measures and strategies, the use of switching values to assess the maximum allowable changes of critical yet uncertain variables, the valuation of intangible costs and benefits, the inclusion of risk aversion to value catastrophic losses in another way than simply the product of probabilities and consequences, and hyperbolic discounting in which relative higher weights are assigned to costs and benefits that arise in the far future.

In many countries, the CBA is still the most commonly used evaluation methodology and is often needed to secure government funding, a position the method owns due to its strong and widely acknowledged foundation in economic welfare theory. The CBA framework thus provides solid concepts for aggregating costs and benefits over time (i.e., discounting), to value costs and benefits on bases of consumers' preferences and to aggregate all these. Although those concepts may not always be ideal and are also being criticized, alternative methods have not yet come forth with problem free alternative solutions for the - ultimately necessary - aggregation for decision making. A draw back of the CBA method, however, is that it preferably uses expected (that is, probability weighted) values to assess efficiency of adaptation options. The author discusses pros and cons and how the CBA method can be improved with elements from alternative, non-probabilistic methods, with an application to the CBA for flood risk management decisions.

**Keywords:** Cost Benefit Analysis, Flood Risk Management, Uncertainty

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ABSTRACT
Building with Nature (BwN) is an emerging methodology for dealing with coastal erosion by utilizing natural processes and materials. Comparing with traditional hard infrastructures (e.g. dams, seawalls) which are reactive schemes of minimizing and compensating for precarious negative impacts, BwN aims to proactively embrace uncertainties from nature and keeps the flexibility for further adjustment. Therefore, decision making processes of BwN projects require decision makers and stakeholders to obtain a higher level of acknowledgement and acceptance of uncertainties, which is incompatible with customary decision making methods for risk reduction and elimination. Based on existing theories, this research developed a synthetic analytical framework, BwN uncertainty matrix, to disclose uncertainties and different perceptions of uncertainties involved in BwN projects from an actor-based perspective. Four dimensions, including the content, location, level and nature, are used to depict each perceived uncertainty by each actor. Different perceptions of uncertainties are revealed by comparing different dimensions of uncertainties in BwN uncertainty matrices.

Furthermore, the BwN uncertainty matrix was applied for investigating uncertainties in the first large-scale BwN sand nourishment project in Ystad, Sweden. The research results showed that in the Ystad project, uncertainties were across all the natural, technical and societal systems (i.e. content), and different perceptions of uncertainties existed in all the other three dimensions (i.e. location, level and nature). Uncertainties regarding issues in the societal system were addressed more frequently than the issues in the natural and technical systems. The influential uncertainties (e.g. environmental impacts of sand nourishment) were located in the natural and technical systems but strongly affinitive with social issues. Strategies dealing with different perceptions of uncertainties in the Ystad project were analyzed and deconstructed into different strategic scheme, including framing and rational problem solving.

Keywords: Building with Nature, uncertainty analysis, actor-based framework, coastal management

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ABSTRACT

Flood risk is a major source of economic damages and loss of lives worldwide. Many structural and non-structural measures are available to reduce the risk, in particular to people. However, decision makers are challenged with the identification of effective risk management solutions in highly uncertain contexts. For successfully reducing risks, it is, therefore, essential to measure the performance of each risk reduction option in such contexts. In this study, we propose an approach to support decision-making process concerning risk reduction measures for flood risk under uncertainty. For this purpose, we employ statistical and computational tools to construct plausible future scenarios defined through internally consistent combinations of climate and socio-economic drivers, preserving dependencies among the uncertain variables. Furthermore, we utilize data-mining algorithms to describe the weaknesses of a set of proposed risk reduction measures by exploring under which scenarios they may substantially fail to achieve the decision-makers’ targets. The proposed approach is applied to the Eastern part of Dhaka city (Bangladesh), where the impacts of flooding are expected to be severe due to climate, population pressure and urbanization. The results are used to describe the robustness of each proposed option in support of decision-making, considering also possible evolutions over time and adaptation needs. Results are summarized and communicated using decision trees that describe a categorized view of the vulnerabilities of the proposed risk reduction measures, by identifying the states and combinations of key variables that could determine considerable failures.

Keywords: Deep Uncertainty, Robust Decision-making, Scenario Construction, Flood Risk
12. Exploring Lessons Learned From RDM Applications

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ABSTRACT
Robust Decision Making (RDM) and related methods for decisionmaking under conditions of deep uncertainty have now been applied to a wide variety of decisions in a wide variety of institutional contexts. Applications include water supply, flood risk management, energy systems, insurance, and defense planning. Institutional contexts include public sector planning, regulatory planning, engagements with broad stakeholder participation, and engagements focused on a small number of decision makers. In each context, the analyses have often been organized differently, for instance using simulation models with different levels of detail and complexity, and emphasizing different stages of the full “textbook” analyses. This talk will survey these many and diverse applications, situate them in the larger literature on decision support and science-based decisionmaking, and offer lessons learned on applying RDM and related methods in various application areas and institutional contexts.

Keywords: Lessons Learned, Robust Decision Making, Decision Support
13. **Using Minimax Regret Optimization To Search For Multi-Stakeholder Solutions To Deeply Uncertain Flood Hazards**

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**ABSTRACT**

Prescribing long-term urban floodplain management plans under the deep uncertainty of climate change is a challenging endeavor. To address these challenges, we formulate and test with stakeholders a parsimonious multi-stage mixed integer program (MIP) that identifies the optimal time period(s) for implementing publicly and privately financed adaptation measures. Publicly funded measures include reach-scale flood barriers, flood insurance, and buyout programs to encourage property owners in flood-prone areas to retreat from the floodplain. Measures privately funded by property owners consist of property-scale floodproofing options, such as raising building foundations, as well as investments in flood insurance or retreat from flood-prone areas.

The objective function to minimize the sum of flood control and damage costs in all planning stages for different property types during floods of different severities. There are constraints over time for flow mass balances, construction of flood management alternatives and their cumulative implementation, budget allocations, and binary decisions. Damages are adjusted for flood control investments.

In recognition of the deep uncertainty of GCM-derived climate change scenarios, we employ the minimax regret criterion to identify adaptation portfolios robust to different climate change trajectories. As an example, we identify portfolios of publicly and privately funded adaptation measures for a stylized community based on the estuarine community of Exeter, New Hampshire, USA, that are robust to change in flood hazards of both riverine and coastal origin during the 21st century. We explore the sensitivity of recommended portfolios to climate changes, and costs associated with economies of scale and flexible infrastructure design as well as different municipal budget constraints.

We explicitly represent different stakeholder objectives in floodplain management optimization models, which address tradeoffs between public and private spending and the equity of impacts to low-income households. We show the importance of representing these stakeholders in the model by comparing the adaptation measures that these multi-objective optimization models recommend with those suggested by the single social planner formulation. We also consider the integration of decision sequences representative of real-world political hierarchies into the optimization model.

In summary, the MIP rapidly generates adaptation planning recommendations robust to a wide range of climate change that reflect the interests of different stakeholder groups, making it an attractive tool for exploring the possible consequences of adaptation alternatives in stakeholder meetings. In addition, it provides a means of exploring the partitioning of adaptation responsibilities among governments and property owners of different socioeconomic conditions, a task which will be essential for coordinating floodplain management under the deep uncertainty of climate change. We also report upon stakeholder reaction to the tool and possible improvements.

**Keywords:** Urban Flooding under Climate Change, Adaptation, Multiple Stakeholders, Budget Constraints

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ABSTRACT
To successfully limit climate change, today’s greenhouse gas mitigation policies should encourage reductions that continue for decades. History suggests, however, that some policy reforms lead to societal changes that persist over the long-term while others fade away without much long-term effect. Current climate policy literature provides little guidance on how today’s policy choices can successfully shape long-term emission reduction pathways. To address such questions, this paper combines analytic methods for decision making under conditions of deep uncertainty with a new agent-based, game theoretic model designed to compare how near-term choices regarding alternative policy architectures influence long-term emission reduction pathways.

Drawing on Patashnik’s work in political science literature on policy persistence, which identifies the characteristics of policies that persist over time, this simulation for the first time integrates the co-evolution of an industry sector, its technology base, and the shifting political coalitions that influence the future stringency of the government’s emission reduction policies – all as influenced by the initial choice of policy architecture. In particular, we use an evolutionary economics model based on the work of Dosi to which we have added a game theoretic component based on the work of Grossman and Helpman that describes the competition among firms as they attempt to influence future government policy. An exploratory modeling-based analysis, using tools and concepts from Robust Decision Making (RDM), draws policy-relevant conclusions from this model, which represents deeply uncertain phenomena such as the future potential for innovation and the behavior of future governments. The analysis finds that near-term choices regarding the architecture of a carbon pricing policy may affect long-term decarbonization rates significantly. In particular, such rates are higher if program revenues are returned to firms in proportion to their market share thus creating a political constituency for continuing the carbon pricing policy. More generally, the analysis provides a framework for considering how with integrated assessment models near-term policy choices can affect long-term emission transformation pathways.

Overall, this work provides an initial, quantitative, decision analytic evaluation of how near-term choices about greenhouse gas regulatory architectures can affect the long-term co-evolution of technology, market shares, and political coalitions that affect the stringency of greenhouse gas regulation. This talk will present this analysis and its policy relevant results. In addition, the talk will also suggest how analytic methods for decision making under conditions of deep uncertainty can enhance understanding of appropriate policies for sustainability transitions and suggest agendas for future research.

Keywords: Robust Decision Making, Transformation Pathways, Greenhouse Gas Mitigation, Climate Change, Agent-Based Modeling
15. Doggedly Trying To Tame Normative Uncertainty

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ABSTRACT
Most of the traditional (applied) scientific work on deep uncertainty distinguishes between deep uncertainty for analysts and for policy makers, giving most attention to the former (Walker, 2013). Deep uncertainty on the long term for policy makers is less researched (Van Asselt et al., 2010).

This paper analyses how deep uncertainty is dealt with in policy making processes, focusing upon how policy makers and stakeholders use existing policy methods in deeply uncertain policies. In order to do so, we start with developing a framework for deep uncertainty in policy making processes. Deep uncertainty for policy makers does encompass more than the deep uncertainty that is modelled for analysts, as there is a plurality of political or normative perspectives involved in policy making processes. Policy makers face normative uncertainty, also called ambiguity, every day. Hence, it plays a prominent role. Therefore, this paper distinguishes and relates deep cognitive and normative uncertainty in policy making processes.

Over the years, policy analysts have developed several policy methods, in the widest sense of the term (Dunn, 1981), to deal with deep uncertainty such as adaptive planning, scenario discovery, scoping, adaptation tipping points and adaptation pathways, etc. (Hall et al., 2012). However, deep uncertainty is not new, as policy makers have to deal with it since ever. Over time, though, with increasing complexity and all pervading multi-stakeholders participation approaches, this issue has become even more complex. Thus far, research lacks upon how existing methods within policy making processes, such as multi-actor participation, broadening the scope of a project, MCA, etc., are used to handle deep uncertainty, both cognitive and normative.

While the first part of the paper will present a framework to analyse how policy makers and politicians deal with deep uncertainty, the second part of the paper uses this framework in the case of Twente Airport (the Netherlands). For more than a decade, the policy making process around Twente Airport has been captured by deep uncertainty: about what to do with the (former) runway, about employment, about nature, about alternative futures, etc. The policy process shows clear back and forth movements of the reduction and acknowledging of normative uncertainty, and the strategic role of different actors (e.g., the Netherlands’ Commission for Environmental Impact Assessment), deliberately using certain policy methods therein. Without anticipating our conclusions, we seem to observe strong linkages between cognitive and normative uncertainty, and occasionally attempts to substitute normative uncertainty or organize a trade-off between normative and cognitive in the political debate.


Van Asselt, N. Faas, F. van der Molen and S. Veenman (2010), Uit zicht: Toekomstverkennen met beleid, WRR, Den Haag: SDU

**Keywords:** Deep uncertainty, Normative uncertainty, Policy making processes, Policy methods, Twente Airport

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ABSTRACT
New methods and tools have been developed to support sound decision-making under deep uncertainty. Many of those methods emphasize the importance of adaptation in the implementation trajectory of decisions that combine long-term ambitions with short-term actions. Examples in case are Dynamic Adaptive Policy-making and the related Dynamic Adaptive Policy Pathways method. Policy pathways for instance may be used as analytical tool to support planning step-by-step investments in (new) infrastructure systems in response to yet uncertain changes in the system environment. These adaptive policy-making approaches require appropriate monitoring and evaluation arrangements. Decision-makers need to be able to see how implementation trajectories develop and if there is a need to undertake pre-defined adaptive actions, or if a fundamental rethinking of policies is needed, given unexpected new developments or insights.

This need for a well-designed monitoring system is signalled in the literature on decision-making under deep uncertainty, e.g. by Walker et al. (2013). However, the current debate on this aspect of decision-making under uncertainty (DMUU) reasons purely from the logic and requirements that flow from the decision-making process and the ex-ante policy analytic approaches. This logic has some distinctive features, which have important implications for monitoring and evaluation of adaptive policies. For instance, the use of adaptation pathways as a planning technique requires a mental shift towards a focus on pathways, instead of a focus on outcomes, as is common in policy evaluation. Also, monitoring and evaluation should also address uncertainties explicitly. This goes beyond the identification of uncertainties as a disclaimer or confounding factor in observing and explaining the occurrence of policy outcomes and impacts. On the other hand, the experience with current policy evaluations can enrich the debate within the DMUU community. For instance notions such as ‘designed blindness’ and insights on learning evaluations in multi-actor environments have implications for monitoring beyond signposts, triggers and trigger responses.

Meeting the needs of adaptive policy-making methods through a practical evaluation design is clearly a challenge. The Delta Programme in the Netherlands currently faces this challenge and therefore we use this programme as fertile ground for a more fundamental investigation of the implications of adaptive policy arrangements for monitoring and evaluation. In this contribution, we will connect the insights available on decision-making under deep uncertainty, to the main characteristics of existing approaches for evaluation. Literature and empirical evidence on (water) policy evaluations are used to draw out the implications for the implementation of adaptive policy arrangements in the Delta Programme. This results in the proposition of a program of requirements and a set of design principles for evaluation arrangements that support the adaptive implementation and follow-up of decisions made under deep uncertainty.

Reference

**Keywords:** monitoring and evaluation, adaptive policy-making, delta management, the Netherlands
17. Macroeconomic Applications Of DMU Methods And Practices

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ABSTRACT
Recent years have seen advances in tool-building and applications for policy decisionmaking under uncertainty. Yet, most have been carried out in only a relatively small number of policy environments.

Methods are being expanded in fields related to infrastructure, water, climate and others which may be characterized by well-defined system boundaries. These applications occur in areas where DMU methods have demonstrated notable utility for policy decisionmaking. The value of expanding on success is obvious. A less obvious reason for re-visitation of such policy problems or their new application in settings showing great similarity with what has passed before is that researchers themselves develop more class knowledge about and awareness of the nuances of policy in these areas. This works to the benefit of both methodologists and practitioners. But it raises the question of what areas should be targeted next.

Major policy issues of the day do not occur solely in well-defined fields or within relatively easy to characterize open or closed systems. Not a few of these problems stem from macroeconomic concerns. The methods supporting DMU analyses could potentially play a path breaking role in this field by doing what they do best: address problems which have long resisted treatment by more formal methods to provide greater insight into policy choices, the consequences of choosing alternative courses of action and the bases for making short term policy decisions from the perspective of long-term goals.

This paper will be both an intellectual exploration and a presentation of initial examples of treatment of macroeconomic policy questions through DMU tools. It will first characterize this policy environment and describe the challenges which may make application of DMU methods and models a challenge despite the potential benefits of doing so. It will present some of the initial lessons learned from such efforts as well as point in the direction of potential solutions and areas for further methodological and institutional research.

The paper will then showcase three preliminary examples of efforts to apply the Robust Decision Making (RDM) method in three problem areas. The first will be a treatment of the issues related to planning for preservation of the Social Security (social insurance) system in the U.S. The second addresses the problem faced by the managers of sovereign debt who find that traditional rules of thumb for structuring and issuance of a variety of debt instruments no longer provide sufficient assurance of both solvency and the ability to meet several policy goals (which may well conflict) in an environment now perceived as more fraught with uncertainty than had been previously supposed. This study demonstrates the potential value of a robust decisions basis for evaluating choices when future surprise cannot be ruled out. The last provides the most macro view of all: balancing U.S. national debt and choosing among a variety of policy instruments for doing so. Again, preliminary results demonstrate the value of shifting from more traditional frameworks toward ones more formally and systematically cognizant of the trade-offs between uncertainty, policy choice and national goals.

Keywords: dmu, rdm, deep uncertainty, macroeconomics, social insurance, sovereign debt, national debt, strategy, policy
18. Using Causal Models And Exploratory Analysis In Heterogeneous Information Fusion For Detecting Terrorists

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ABSTRACT
We describe basic research that uses a causal, uncertainty-sensitive computational model rooted in qualitative social science to fuse disparate pieces of threat information. It is a cognitive model going beyond rational-actor methods. Having such a model has proven useful when information is uncertain, fragmentary, indirect, soft, conflicting, and even deceptive. Uncertainties are even worse than "deep." Inferences from fusion must then account for uncertainties about the model, the credibility of information, and the fusion methods—i.e. we must consider both structural and parametric uncertainties, including uncertainties about the uncertainties. We use a novel combination of (1) probabilistic and parametric methods, (2) alternative models and model structures, and (3) alternative fusion methods that include nonlinear algebraic combination, variants of Bayesian inference, and a new entropy-maximizing approach. Initial results are encouraging and suggest that such an analytically flexible and model-based approach to fusion can simultaneously enrich thinking, enhance threat detection, and reduce harmful false alarms.

Keywords: Exploratory analysis, Exploratory modeling, Fusion, Uncertainty analysis

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ABSTRACT

Practical methods and tools for supporting decision making under deep uncertainty are developing quickly and will be used ever more broadly given—among other applications—a looming host of climate change adaptation decisions. Philosophers, economists, and other researchers who take a more theoretical perspective on decision theory have so far contributed less to this field than they might have done, one reason being poor understanding across disciplinary boundaries. Many decision theorists who encounter practical methods such as robust decision-making (RDM), decision-scaling, adaptive policy making, and adaptive pathways [3, 2], are inclined by the habits of the discipline to focus on the decision rule—the method of comparing acts and determining which is best. But practical methods often lack a discernible decision rule. RDM, for example, gives no advice about how to balance robustness against cost and other considerations in the final decision. In practice, this is not a problem because decision makers are comfortable taking this final step without additional advice, but to more theoretical researchers it looks like a void right where the decision model should be most explicit. Conversely, the parts of the applied methods where, so to speak, the action is taking place, are not easily mapped onto the usual concerns of more theoretical decision theorists.

In this research, we analyse two approaches to decision support under deep uncertainty: RDM and adaptive pathways, and we characterise the innovative aspects of these methods in terms that help to better locate them within the broader theoretical literature. The first step is recognising that these methods are best characterised as approaches to decision framing rather than decision making (or, similarly, they address the task of the decision modeller rather than the decision maker). The second step is characterising the challenges to decision framing under deep uncertainty that these methods address, and describing their strategies in more general terms. Here we turn to a recent discussion of the types of uncertainty that are bracketed or idealised away within typical ‘small world’ framings of decision problems [1], and we redescribe RDM and adaptive pathways as strategies for managing these uncertainties in the framing of decision problems.

The decision rule is not the only locus for norms of good reasoning; norms of decision framing, while they will necessarily be less formal, are equally important to an overall philosophy of managing deep uncertainty. Greater appreciation that this is what the practical methods offer may help clarify the contributions that these methods make to decision theory, and also help recruit more theoreticians to further develop those methods.

References:


**Keywords:** decision framing, small worlds, RDM, adaptive pathways
20. Deep Uncertainty In Landslide Modelling For Urban Risk Reduction In Developing Countries

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ABSTRACT
Landslide risk is increasing for many informal urban communities in developing countries in the humid tropics, in particular for those that are situated on highly weathered residual soils that are already susceptible to rainfall triggered slides. Rapid unplanned urbanisation – altering slope cover, topography, loading, drainage – and changing climate may further exacerbate urban landslide risk in the future. Slope stability assessment can be used to guide decisions about the management of landslide risk, but its usefulness may be restricted by high levels of uncertainty in model predictions. Many of these uncertainties cannot be easily quantified, such as those linked to climate change and future socio-economic conditions. Addressing this deep uncertainty requires the development of robust policies that are expected to perform adequately under a wide range of future conditions and other uncertainties (e.g. of subsurface characteristics). In our study, the Coupled Hydrology And Stability Model (CHASM) has been combined with local knowledge of slope characteristics to diagnose the most important drivers of landslides in informal urban communities in the humid tropics. We assess the impact of deep uncertainty on slope stability predictions in CHASM through a thorough analysis of the feasible input space using structured approaches including CART and regional sensitivity analysis, as well as advanced visualization tools. Our results highlight key uncertainties and thresholds influencing slope failure, and provide valuable information to guide improved landslide hazard management. Our findings highlight the potential of robust decision making to aid decision support for landslide hazard reduction and risk management under conditions of deep uncertainty in developing countries.

Keywords: landslide hazard, deep uncertainty, sensitivity analysis, robustness
21. Deep Uncertainty And Plain Uncertainty: Solving Everyday Problems First For Creating Institutional Capacity In Developing Countries

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ABSTRACT
Climate change is certainly happening, but the effects are different everywhere. To make the right decisions, at the right time, governments need information and analysis. The specific information and analysis for each country is currently not or sparsely available. This concept note describes the support for such creating this capacity in developing countries. Climate change and other major drivers that affect water are not clearcut. There is a need for monitoring and 'thinking capacity' at national level to deal with climate change. Securing a trustworthy, good quality monitoring and policy analysis is essential for governments. But in many countries this trustworthy, good quality monitoring and policy analysis are not (yet) there, and if they are there they are threatened by competing financing needs, misuse of funds and brain-drain.

Climate change is too uncertain in its effects. Countries need a solid set of data and a solid thinking capacity to determine the specifics of their case, and the reactions needed. Experience (ao Benin) learns that national level institutions alone are vulnerable and lack specific capacity and quality. Defining national institutions and their key results 'international pubic goods' allows for more direct support. Institutions could be financed provided they adhere to certain principles, and secure specific quality standards.

The Delta approach as developed in NL is based on handling uncertainty. The approach is based on a dynamic policy analysis where political commitment was secured to take action once specific thresholds have been reached. The approach requires models, policy-analysis capacity and monitoring. The approach could be applied in developing countries, but for this the institutional capacity needs to be secured.

Both tracks come to the same conclusion: climate change adaptation requires national level institutions that provide uninterrupted data and models to follow the water-systems.

It has been easy to find funding for projects aimed at creating institutes. But sustained funding to keep these initiatives afloat is what is needed.

There is an endless series of smaller and bigger studies being done on and about developing countries. Impetus, UN Water info sheets: after 50 years of capacity development, the developing countries are still 'object of study', not partners.

In Benin a national institute, a serious monitoring, an integrated database and a proper modelling of basins are taking place. A serious policy analysis of the major basin (the Oueme) was done. But the national institute lost a major part of its financing after a fraud case in a program that it was depending on.

The situation shows how an essential tool for answering to climate change challenges can easily be compromised by every day life.
In this article it is argued that a more global responsibility is needed and is feasible to secure the monitoring, modelling and policy analysis at national level.

**Keywords:** DEEP UNCERTAINTY, CLIMATE CHANGE, NATIONAL WATER INSTITUTE, LOCAL APPLICATION, INSTITUTIONAL DEVELOPMENT, META DATABASE

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ABSTRACT
In situations where the future is not knowable, traditional analysis and tools evaluate the attractiveness (benefits and costs) of various policy choices under a limited set of futures. These benefits and costs, however, can change dramatically over time as new information and knowledge become available. Thus, making a choice based on these estimates is likely to lead to a flawed policy. In this paper we propose two things: 1) that policymakers focus on broader societal goals, and 2) that they explicitly link the attractiveness of a policy to its performance with regards to reaching these goals. We make this clear with an example below.

For transport policymakers, handling road congestion has been a continuous challenge for the last 50 years. The attractiveness of policy options for reducing road congestion has been traditionally evaluated by estimating their contributions to reducing travel time losses and lowering emissions, relative to the cost of doing so. Thus, a policy option can be attractive even if it delivers small reductions. But there is no explicit link between the attractiveness of a policy option and a high-level policy goal. Also, there is no consideration of, for example, the overall air quality, or the experience with regards to the reason why the trip/travel is being undertaken. Alternatively, consider the issue of road congestion from the goal-oriented perspective we are suggesting. Assume that the explicit goal is to reduce travel time losses by X% and emissions by Y%. Then policies that bring about larger reductions will be more attractive than policies that bring about smaller reductions. But, we can also ask whether reducing road congestion is the right question. A better question to ask may be how we can improve the commuting experience, or the shopping experience? By considering questions such as these, we can considerably broaden the range of options, beyond the range of only transport policy options, to be considered.

Because of deep uncertainty, the evaluation of the options should be done with the participation of the stakeholders. In this paper, we propose that a promising initial policy could be chosen based on consensus among stakeholders that, regardless of their subjective, and uncertain expectations about the future and their preferences, the initial policy will contribute to reducing the problem. The initial policy should include flexibility and adaptivity (so, no lock-ins), enabling adjustments (i.e. changes in the policy) as the future unfolds. The stakeholders need not agree on the rest of the policy; in fact, the differences among them should be made explicit and acknowledged. A monitoring system would be established, and policy changes would be agreed upon, in case of the failure of one or more of the assumptions underlying the initial policy (i.e., if someone else’s guess about the future were the correct one). The policy would, therefore, be adaptive but would be based on Bayesian thinking (in terms of subjective judgments) and public participation, rather than traditional analytic approaches and reflecting the public’s willingness to pay to reach the underlying, long-term goals.

Keywords: policymaking, deep uncertainty, goal oriented
23. Planning For Uncertain Futures In Defence

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ABSTRACT
The UK Ministry of Defence is required, by the practicalities of cost and lead time for research, procurements and changes in force structure, to make long term “strategic” plans which drive current spending. However the future is very uncertain and, in the case of military policy decisions on spending made now, can change the future, as allies and potential opponents change their plans in reaction to those decisions.

In planning for military operations commanders are reminded to consider that “The enemy gets a vote”, meaning that “enemy” decisions will have at least as much impact on plans as the commanders’ own, making any plan in effect a starting point for a complex adaptive system, with intelligent decision makers actively trying to disrupt their opponents plans. For long term strategic planning this complexity is compounded both in terms of the uncertainty in who the opponent might be, what their objectives and capabilities are and the timescale in which those uncertainties have time to grow.

Although planning for complex futures is a problem for many organisations, the additional layers of complexity faced by Defence makes the problem unusually difficult. Dstl has recently worked with academia, through separate collaborations with Lancaster and Southampton Universities, to examine if and how the latest thinking could be applied to the problems of defence planning. This talk will describe the layers of uncertainty which are faced by defence planning and the results of Dstl’s examination of the potential methods for addressing this complexity

Keywords: Defence, Strategic Planning, Complexity, Uncertainty
24. **Hindsight Analysis Identifies Deep Uncertainty In Infrastructure Planning**

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**ABSTRACT**

The planning and design of built infrastructure with large life expectancy requires long-term demand-and capacity projections. These projections are determined by extrapolating properties of the current system over the design horizon. However, once infrastructures have been commissioned it is not very common to compare the outcomes against the original planning assumptions and to reveal the discrepancy between the two. Conducting such a comparison for past design decisions allows us to reveal phenomena that are associated to sources of deep uncertainty.

We analysed the long-term evolution (160 years) of an urban wastewater system and identified the forces that drive the system outside of the region of planning assumptions (Neumann et al., 2015). For both endogenous and exogenous drivers, we assessed the timescales at which they work and the way they interact with one another.

First, the case study illustrates how drivers from various domains, such as economic, medical and engineering, influence the system state and the planning process. Second, we found that the timescales at which drivers change are repeatedly shorter than typical life-times of wastewater infrastructures. In many cases we observed unexpected, fast and abrupt changes in these drivers. We witnessed how spontaneous adaptation takes place: i.e. how the agents become aware of system changes and how they react to them.

Our findings show that the system ontology changes over time. We detected changes in: the set of important drivers, the interactions between drivers, the system boundaries, the objectives and governing paradigms. The realisation that urban wastewater systems behave as complex adaptive system is in stark contrast to the rationale of designing long-lived infrastructure based on projections or scenarios.

Hindsight analysis can be useful in different ways: It can act as a safeguard against overconfidence in design projects, help identifying alternative ways of service provision with higher flexibility or used to test whether decision support tools currently proposed for dealing with deep uncertainty would be able to handle the detected phenomena.

Reference:


**Keywords:** Urban Infrastructure, Wastewater, Planning, Adaptive management, Deep uncertainty, Complexity, Hindsight
25. A Multi-Method Approach To Evaluate The Robustness Of Policies In The Dutch Gas Sector

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ABSTRACT
The long-term development of the Dutch gas sector is faced by deep uncertainty, as many other gas markets over the world. The policy objective in the sector is providing a secure, sustainable, and affordable gas supply. However, not only the inherent conflicts between these objectives but also several deep uncertainties regarding the development of renewable and non-renewable technologies, societal acceptance and institutional aspects impede the achievability of these goals and obscure policy making. To aid decision making, potential policies should be systematically analyzed in terms of their effectiveness to deal with multiple conflicting policy objectives and with deep uncertainties.

Adopting an exploratory modeling approach, such an analysis is conducted in this study, based on a large set of transient scenarios generated by a system dynamics simulation model. A framework has been developed and implemented on this set of scenarios, to address three aspects of decision making with multiple methodological options: To deal with the uncertainty aspect, the robustness of each policy across the uncertainty space is computed, with various expectation-based, regret-based and statistical robustness metrics. To deal with the multiplicity of policy objectives, four different, but simple and transparent, multi-criteria methods are used, such as a lexicographic ordering, or the additive value of robustness values corresponding to each policy objective. Lastly, to deal with the time aspect, such multi-criteria problems are solved statically with metrics which reduce the transient nature of scenarios into a single measure, or dynamically in each year in the scenario horizon (e.g. 50 years).

The results showed a strong method and time-dependence, yet some policies demonstrated considerable robustness against methodological choices, such as the subsidization and communicative stimulation of renewable gas production. Namely, these policies received top ranks with many robustness metrics, multi-criteria methods and for long durations of time. Based on this analysis, none of the methodological options can be argued to be strictly better than the others, since these options reflect preferences and decision making processes of the decision makers, yet the method-dependence implies probable fallacies if the robustness and multiple decision criteria are dealt with single methodological choices.

Further investigation of combining robustness metrics with multi-criteria methods is a potential point of departure for future study. Besides, the changes in the preferred policies identified with dynamic solutions (i.e. in each year) of the multi-criteria problems can be used as a basis for developing adaptive policies.

Keywords: gas sector policies, energy policy, robustness, multi-criteria decision analysis

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ABSTRACT
Road transport networks are vulnerable to many shocks, and in particular to extreme weather events. Floods, for instance, can cause the partial or total disruption of network links, therefore forcing road users to take alternative routes – often longer or in worse conditions than the main road. A malfunctioning road network may lead to high logistics costs, which in turn may limit countries’ competitiveness and productivity and slow economic growth. This study seeks to include resilience to shocks in transport planning, to improve a region’s transport infrastructure and accelerate economic growth.

We propose to help policy-makers answer:

- What is vulnerability to floods of critical links, now and in the future?
- What investment options may improve the reliability of these links – that is, increase their robustness to uncertain future conditions – in a cost effective way?

First, we calculate the criticality of links exposed to floods. We pre-select links with high traffic and we assess their criticality using the technique of interdiction, which calculates change in total cost or accessibility in the network when a link is disrupted or degraded.

We then identify the critical links that are located in flood-prone areas. We consider many possible events: we use historical rainfall as well as different future climate change scenarios, and for each rainfall scenario we look at the links exposed to different return period events. In addition, for climate change scenarios, we consider different GHG concentration scenarios and different Global Circulation Models (which disagree on precipitation changes at the regional scale). We then select, among the most critical links, the ones that are the most exposed to floods. For those links, we calculate expected annual losses, considering the uncertainty on flood duration, on the percentage of traffic that can use the road during floods and on the time and cost of reconstruction.

Finally, we look for the investment options available to improve the reliability of the system, that is to say its high degree of operability under any circumstances. For all links that are found exposed to future flood events among the most critical ones, we look for the investment options available to reduce either their criticality – for instance by increasing redundancy, i.e. building alternative routes – or their vulnerability – for instance by making the road more permeable.

To compare interventions, we calculate the minimum maximum regret brought by each investment (using the net present value of the intervention or an accessibility index) across a large number of scenarios (combining uncertainty on climate change and on the impacts of floods on disruption costs). We eventually exhibit the trade-offs between the different possible interventions and choose the best one using a social utility function that incorporates the decision-makers’ objectives (cost, reliability and others).

Keywords: road networks, robust decision making, floods
27. Long-Term Strategic Planning For A Resilient Metro Colombo: An Economic Case For Wetland Conservation And Management

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ABSTRACT
This is the final iteration of a study that was presented last year.

The Colombo Metropolitan Region (CMR) faces recurrent floods that threaten its long-term economic development. Future flood risk in CMR will keep increasing due to rapid urbanization, economic growth pushing for investments from both the public and private sectors in flood prone areas; changes in land-use (agriculture, transportation, housing development, and other new projects opportunistically located in flood retention areas etc.); combined with new rainfall patterns caused by climate change, bringing more frequent and intense rainfall for longer periods of time.

The Metro Colombo Urban Development Project (MCUDP) is delivering the last set of hard-engineering solutions available to the city to reduce the impact of floods for today’s return period of 30 years. The Colombo urban wetlands have been determined and taken into consideration as a critical component of the city’s flood reduction system, essential to the long-term development and urban resilience of the CMR, as they form natural infrastructure that currently attenuates and stores floodwater across the CMR, reducing impacts on people and assets.

A Robust Decision Making has been undertaken to examine the value of wetlands to the CMR, both in the short-term and long-term, and identify what are the most viable strategies available to increase the city’s flood resilience in an unclear future (in terms of climate change and patterns of urban development). This has involved the use of numerous hydrological and vulnerability scenarios to examine the most robust approaches to future planning and management.

The analysis has determined that if all urban wetlands across the CMR catchment were lost, in some scenarios the CMR economy would have to cope with an annual average flood loss of approximately 1% of Colombo GDP, which is in the order of magnitude of the flood damages experienced in 2010.

Economic analysis of selected wetland benefits including flood protection, carbon sequestration, climate regulation through reduced use of air conditioning near wetland areas and waste water treatment has demonstrated that annually the wetlands are worth between 10 to 12 billion RS to the CMR. This far exceeds, for example, the economic benefits of lakes, which provide a reduced range of benefits only worth between 1 to 2 billion RS annually. In addition, if the potential income from recreation, now being demonstrated at the pilot wetland visitor centres at Beddegana and Thalawathugoda, is included in the analysis, then annual income for the wetland complex could increase to between 16 to 18 billion RS annually.

Finally, a comparison of wetland protection with land-infilling and development shows that this latter option is only beneficial in scenarios in which the Kelani river is low and more than 60% of profits from land development can be shared with all inhabitants in Colombo. Those scenarios are unlikely and even undesirable, because a low Kelani river would bring water supply issues. Conserving the wetlands in Colombo was therefore determined to be the best option according to the decision makers’ criteria.

Keywords: robust decision making, urban floods, wetlands
28. Adaptation Pathways In Practice: Future Challenges

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ABSTRACT

A presentation will be given reflecting on the implementation of adaptation pathways in the UK and NL. It will cover well known examples such as the Thames Estuary 2100 plan and the Dutch Delta Programme as well as developing use in other areas such as water resource planning for London and coastal planning in England.

Common issues and challenges will be highlighted including monitoring of indicators and triggers for changing options in terms of timing or choice of option.

The need for better techniques to link monitoring of indicators to climate change scenarios will also be outlined.

Also we will touch on challenges for the further methodological elaboration of the adaptive approach, including:

- the use of transformational strategies
- the ‘evaporation’ of short term advantages of long term options
- the effectiveness of a diverse set of parallel strategies
- determining tipping points in situations with large natural variability
- maximizing broad commitment in situations of low predictability

The presentation should provide a practitioner’s view of how to develop and implement adaptation pathways as part of long term strategy development and give insight gained from this experience to their future use, monitoring and evaluation.

Keywords: adaptation path ways, climate change, strategy development, methodology, practice, challenges, monitoring and evaluation
29. Discount Rate And The Cost Of Capital

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ABSTRACT
Developing countries and development banks operate under tight capital rationing and this needs to be accounted for in project accounting. Pragmatically, this is often done through the use of higher discount rate, supposed to represent a higher opportunity cost of capital. Here, we show that this practice leads to a suboptimal project portfolio, especially for long-term projects and when future capital rationing is uncertain.

Project evaluation and selection need to account for two components: (1) preferences regarding the value attributed to future costs and benefits; (2) capital rationing. Bringing these two components into one parameter, the discount rate is inappropriate: tighter capital rationing should not affect the balance between short-term and long-term costs and benefits. Instead, we suggest to use two parameters: the discount rate, based on ethical considerations and time preferences, and the shadow price capital, that represents capital rationing.

Introducing these two parameters allows for an appropriate investigation of the uncertainty related to these two inputs into decision-making.

Keywords: discount rate, capital rationing, opportunity cost of capital, decision-making
30. Flexibility In Design: A Procedure For Effective Proactive Planning Of Flood Management Infrastructure Under Uncertainty

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ABSTRACT
Developed countries around the world are facing the emerging challenge of how to systematically and efficiently approach the process of replacing ageing infrastructure assets. These long-term investment decisions in physical assets are increasingly complicated by non-stationarity in natural systems. Increasing the degree of flexibility of infrastructure systems is a method to safeguard the efficacy of current design decisions given future uncertainty.

This paper presents a procedure for effective and proactive planning and design of flood management infrastructure, against uncertain future flooding threats. This procedure provides insights about how long-term replacement planning can be structured in such a way as to identify opportunities to incorporate flexibility within a physical structure, enabling continued satisfactory performance of the system in the future in spite of changes in the external operating environment. We specifically apply the concepts of Real “In” Options to the process of reinvesting in ageing hydraulic structures, evaluating the relative economic value associated with different possible options to build flexibility into a structure.

In response to past criticisms of Real Options, this procedure incorporates a number of distinct methodological features, relative to more standard applications of options. First, acknowledging the deeply uncertain nature of climate uncertainty, distinct scenarios are used to describe uncertainties such as sea level rise and future precipitation. Within these scenarios, probability distributions are used to characterize remaining uncertainties of interest, forming the basis for an analysis of flexibility using Monte Carlo simulation. Second, instead of utilizing relatively arbitrary decision rules to determine when the flexibility built in a structure should be exercised, this procedure incorporates the concept of Adaption Tipping Points as defining the moment when implementation of the built-in option is first warranted. Finally, we explicitly take into account the fact that most hydraulic structures fulfill different functions. This method allows exploration of different options aimed at providing flexibility in the fulfillment of a specific function, and to what extent these individual options interact.

This procedure is demonstrated using the pumping station of IJmuiden on the North Sea Canal in the Netherlands as an example. Here, replacement of IJmuiden with a base case fixed design (a large new pumping station at the location of IJmuiden) is evaluated relative to more flexible designs that embed options, allowing the phased expansion of additional pumping capacity and flood defense capabilities of the structure, as necessary. The different design alternatives are compared based on a number of different economic indicators. Results show that the incorporation of flexibility within the design of hydraulic structures has the potential to improve the lifetime economic performance of the structure, as compared to more traditional, less flexible designs. However, the added value resulting from the incorporation of flexibility is shown to be both function and scenario specific.

Overall, given the long-lived nature of most engineering structures and the high cost of any upgrade work after initial construction, necessary replacement planning in fact offers a valuable and
relatively infrequent opportunity to reassess the system and incorporate additional flexibility to cope with a multitude of possible futures.

**Keywords:** flood, planning, flexibility, Real Options, climate change
31. A Theoretical Framework For Developing Resilience To Urban Pluvial Flooding

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ABSTRACT
The risk of urban flooding is an issue experienced globally (Field, Barros, Mach, et al., 2014). The likelihood of floods and its associated impacts is increasing due to global trends in urbanisation and climate change. Climate change is driving hydrological non-stationarity (Milly, Betancourt, Falkenmark, et al., 2008), which has lead to the “end of reliability” for water systems such as water supply and flood defence (Brown, 2010). In addition, urbanisation is contributing to increasingly large impermeable areas while the increasing concentration of population leads to higher potential economic losses at risk to events. There is a widely recognised need to adapt to these changing circumstances. However, the complexity of urban flooding systems and large uncertainties in future land use and climate projections lead to a condition of deep uncertainty.

There is much to explore within long-term adaptation planning for urban flood protection, particularly as it can be difficult to implement large-scale changes in such settings. This work will present a theoretical framework for long-term adaptation to urban pluvial flooding risk under deep uncertainty. This would encompass decision-making techniques such as Adaptation Tipping Points (Walker, Haasnoot & Kwakkel, 2013) alongside a toolbox of possible solutions. It is envisaged that this toolbox of solutions would encompass engineering solutions, policy recommendations and financial mechanisms. This is in response to the need for an integrated holistic water management framework as called for by Hallegatte (2009).

The identification of potential Adaptive Tipping Points and potential pathways will be undertaken for a hypothetical case. Adapting to these thresholds would be achieved by utilising different aspects of the toolbox of solutions. The toolbox would identify a wide scope of potential solutions. Engineering solutions would revolve around a real options approach to systems design in order to provide flexibility and adaptability within systems to allow for incremental adaptation (de Neufville & Scholtes, 2011). There is particular interest in utilising green infrastructure as a possible adaption measure against urban pluvial flooding. Policy recommendations would include issues such as regulations on new connections to the sewer systems or limitations on the creation of new impermeable surfaces through the use of Sustainable Urban Drainage Systems. Lastly, financial instruments can also act as a resilience measure against climate change particularly against extremely low frequency events with high consequences, for example the overtopping of flood defences.

These three sets of solutions are to be merged with decision making techniques within a formalised holistic framework. The framework is intended to deliver an urban pluvial flood defense plan that has the ability to be easily adapted to match a wide range of future conditions. This framework will be the basis for further research on applying this framework to a number of case studies across different countries and climates.

Keywords: Deep Uncertainty, Urban Resilience, Urban Flooding
32. Deep And Shallow Uncertainty In Ecosystem Service Assessments: Some Challenges, Some Progress, And Some Help Wanted

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ABSTRACT
Ecosystem services (ES) are the benefits people receive from nature. These include benefits such as water purification and flood protection from forests and wetlands, pollination from bees supported by improved bee habitat, and enhanced well-being from tourism and exposure to nature via recreation. Characterizing these benefits -- and how they change as a result of different decisions -- is an increasingly common endeavor undertaken under the banner of “ecosystem service assessments.” Such assessments are inherently multidisciplinary on both the substantive and methodological fronts, combining fields like ecology, hydrology, economics, and geospatial sciences.

Unfortunately (and perhaps partly because of) this complex multidisciplinary nature, uncertainty in ES assessments has not received the attention it deserves – and it deserves plenty, given both the high-stakes decision-oriented nature of many ES assessments, as well as the presence of manifold uncertainties, both well-characterized and deep. These range from parametric uncertainty in price accounting for studies that involve economic valuation, to handling extreme data scarcity and structural uncertainty in hydrologic processes, as well as incorporating manifestations of global change throughout.

At the Natural Capital Project, a decision-oriented ecosystem services modeling organization, we have slowly but surely been attempting to address these challenges for our own modeling efforts and for those who utilize our open-source software products. This talk will highlight many of the challenges faced in different ES decision contexts, the nature of many uncertainties dealt with, progress to date and remaining challenges. Some challenges are organizational, such as instilling lessons from decision-support modeling practice and philosophy across modeling team members and stakeholders from diverse disciplines. Other are computational, given that spatial decision contexts often rely on extremely large datasets that require intermediate parameterizations before typical “explore the space” deep uncertainty techniques can be applied, or require approximations to otherwise infeasible combinatorial spatial optimization problems. As with other policy analysis efforts, to support the applied nature of ES assessments, these challenges must often be addressed on a relatively short timescale and in manner that is credible and comprehensible to stakeholders.

We illustrate many of these issues by describing uncertainty analysis on a “Water Fund” which is a financial vehicle whereby downstream beneficiaries or external actors pay for conservation oriented interventions upstream in a watershed. Analysis of the economic benefits of a water fund first involves application of an optimization algorithm to identify the location of conservation interventions, then translation of those interventions to hydrologic model parameters and running of a hydrologic model, and finally development and application of varied economic and financial models to quantify the benefit streams resulting from the changes in water yield and sediment retention. As such, water funds provide an ideal platform to convey and seek solutions to the practical challenges of handling deep uncertainty in ES assessments.

Keywords: ecosystem services, spatial optimization, spatial uncertainty, economic valuation, multicriteria assessment
33. **Managing Business Risk Under Uncertainty: Development Planning In The Oil And Gas Industry**

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**ABSTRACT**

The upstream oil and gas industry is distinguished by its dependence on a poorly understood subsurface as the ultimate source of value. All phases of upstream activity: exploration, development, and production, incur significant business risk arising from our incomplete knowledge of the subsurface and of the fluids therein. There are two ways of dealing with this risk: either by trying to reduce it through additional data collection and better characterization of the subsurface, or by better managing it, by better understanding the range of plausible potential subsurface realities that are consistent with a given set of characterization data and the economic implications of this range, by selection actions that optimize return over the range of uncertainty, and by identifying possible responses to unfavorable outcomes. In this contribution we discuss the differences between development and production (or more informally, green-field and brown-field) oriented uses of modeling and simulation, and then focus on development planning applications, which attempt to account for uncertainty early in an asset lifecycle, when both uncertainty and the economic impact of decisions are at their maximum.

**Keywords:** subsurface uncertainty, development planning, modeling and simulation
34. Weshareit: A Nexus Approach To Nile Basin Water Resources Management

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ABSTRACT
The Nile river is the longest river in the world with a basin area of 3,176,543 km². The basin is shared amongst 11 countries, namely Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, South Sudan, Sudan, Tanzania and Uganda. The rising Nile basin population continues to put extreme pressure on the quantity of the Nile water resources. The current population of 437 million is projected to increase by 52% in 2030. The forest area in the basin has shrunk by 18% from 2005 to 2009. A significant number of watersheds and ecosystems have been highly degraded, thereby drastically reducing the water flow from rivers and springs. According to the United Nations Economic Commission for Africa, none of the eleven Nile Basin countries will be able to meet their water needs by 2025, unless major changes are made to address the water security challenge.

The Nile basin water managers lack clear information on how much water will be available at a particular place, date and time, to support their decision-making. Science on such a complex issue as water may never provide such a clear print. One of the biggest challenges for scientists is to acknowledge that there will never be a clear print and focus on supporting decision making amidst deep uncertainty. This requires a new way of thinking, also known as the nexus approach. The nexus approach views water as cross-cutting: water is linked to Energy, Environment, Land, Health and many other sectors.

The purpose of this paper is to assess whether serious gaming can enable learning on the value of a nexus approach. WeShareIt is a computer assisted board game designed to explore the tensions between energy, food and nature within the Nile Basin. The game comprises of five select boards for countries that share the Nile Basin, namely Egypt, Sudan, South Sudan, Ethiopia and the Nile Equatorial Lakes Region. The goal of WeShareIt is to gain as many “happy faces” as possible. The game is played in multiple continuing rounds comprising of a payout round (A) and a water allocation round (B). In round A, crops, wood fuel and hydro-electric energy are harvested, bought and sold. In round B the players can adjust their water allocation strategies with the aim of making their citizens happy.

The paper presents the findings of designing and testing of the game. The paper assesses the contribution of serious gaming in supporting decision making amidst deep uncertainty. The result of playing the game was an instructive group experience and a better understanding of the interplay between food, energy, nature, water and trade.

The paper concludes that serious gaming holds a promise in supporting change of perceptions on water to support decision making in complex basins when the future is very uncertain. Future work will entail the improvement of the game, based on comments received and the application of the game in the Nile Basin.

Keywords: River Basin Management, Uncertainty, Decision Support, Serious Gaming, Tradeoff Analysis, Nexus Approach
35. **Allowances For Evolving Coastal Flood Risk Under Uncertain Local Sea-Level Rise**

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**ABSTRACT**

Sea-level rise (SLR) causes estimates of flood risk made under the assumption of stationary mean sea level to be biased low. However, adjustments to flood return levels made assuming fixed increases of sea level are also inaccurate when applied to sea level that is rising over time at an uncertain rate. To accommodate both the temporal dynamics of SLR and their uncertainty, we develop an Average Annual Design Life Level (AADLL) metric and associated Design Life SLR (DL-SLR) allowances [1,2]. The AADLL is the flood level corresponding to a time-integrated annual expected probability of occurrence (AEP) under uncertainty over the design life of an asset; DL-SLR allowances are the adjustment from 2000 levels that maintain current average risk over the design life. Given non-stationary and uncertain sea-level rise, AADLL flood levels and DL-SLR allowances provide estimates of flood protection heights and offsets for different planning horizons and different levels of confidence in SLR projections in coastal areas. Here we employ probabilistic sea-level rise projections [3] to illustrate the calculation of AADLL flood levels and DL-SLR allowances for a set of long-duration tide gauges along U.S. coastlines.


**Keywords:** coastal impacts, climate change, sea level rise, flooding, adaptation, resilience
36. Policy Experimentation As A Tool To Deal With Deep Uncertainty

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ABSTRACT
Policies are continually being designed for current and future conditions about which policymakers often have incomplete or no information at all (Walker et al, 2001). Conventional forecasting methods such as Monte Carlo simulations and statistical analyses are not adequately equipped to capture ‘deep uncertainty’ (Walker et al 2010, Brugnach et al 2008) as there is little agreement on the choice of models to characterize a system’s variables and their interactions and assign likely probability distributions (McInerney et al 2011). Climate change is a good example of a complex and unstructured policy problem that is characterized by a high degree of uncertainty. Given the likelihood of non-linearity in the future climate, the impacts associated with climate change may be manifested to varying extents (IPCC, 2007). This paper focuses on the role of policy experimentation to deal with climate uncertainty.

Given the uncertainties associated with problems such as climate change, scholars and practitioners emphasize on adaptation efforts to be “flexible and continuous” with a focus on learning and experimentation (IPCC, 2014). Experimentation is important in enabling social learning to overcome system “lock-in” and facilitate restructuring of existing social–technical systems for changes in norms, values, goals, processes and actors. Enhanced experimentation and learning can be instrumental in “keeping pace with the dynamic drivers and expressions of risk” (O’Brien et al, 2012). Pilots form a common and important form of policy experimentation and involve the “phased introduction of major government policies or programmes, allowing them to be tested, evaluated and adjusted before being rolled out nationally” (Cabinet Office, 2003).

Using cases of policy pilots in India aimed at adaptation in climate-sensitive sectors such as agriculture and water (for example those focusing on weather-based insurance, crop productivity enhancement, technology innovation and climate services) this paper will firstly, identify how the level of uncertainty projected in the agriculture and water sectors affects and is affected by the design and scaling-up of specific pilots designed to operate under this uncertainty. A Qualitative Comparative Analysis (QCA) approach is used to compare these pilots for adaptation to projected impacts of climate change on water and agriculture.

The second part of the paper will identify challenges to design of proportionate adaptation policy responses under uncertainty, which can also be aided by experimentation. Adaptation literature has largely focused on policies and programmes for “accommodating change” rather than processes for “consciously creating alternatives” (O’Brien et al, 2012). Questions of how much and how best to adapt have given rise to issues of ‘optimality’, ‘proportionality’ and ‘appropriateness’. Studies that test for optimality of adaptation options are only relevant for pre-determined scenarios that do not cover the broad spectrum of uncertainty (Klein, 2003). Determining ‘proportionate adaptation’ or ‘how much adaptation is enough’ to match the scale of change in the climate and associated impacts under deep uncertainty is an ongoing challenge (Hall et al, 2012). The QCA will thus also aim at developing a typology of the policy experiments and their outcomes based on the level of uncertainty they are designed to deal with.

Keywords: Uncertainty, Climate change adaptation, Experimentation, Proportionality, Pilots, Agriculture and water
37. Decisive Moments In Adaptation Planning : Experiences And Challenges

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ABSTRACT
Adaptive delta management has emerged in response to concerns over long-term, uncertain climate and other changes. Key elements of the approach are: to explicitly take future uncertainties into account, to identify decisive moments for (future) decision-making, to develop adaptation pathways over time, to include and value flexibility, and to avoid ‘lock-in’.

This presentation reflects on seven contributions to a recent special issue of the Journal of Water and Climate Change. Focus is on the use and elaboration of future decisive moments as parts of adaptation pathways, and on adaptive deltamangement in general. We summarise main points from the papers, put these in a broader perspective and conclude with lessons learned as well as challenges remaining.

First, the ‘adaptation tipping point’ concept (ATP - “points where the magnitude of change is such that the current strategy will no longer be able to meet its objectives”) borrows its terminology from ecological system behaviour. Applied to adaptation decision making however, tipping points always contain a normative component, and non-desired situations are not necessarily irreversible nor fundamentally different. This is why some authors prefer the term adaptation turning point.

A variety of criteria are proposed defining critical performance of the ‘managed system’ ranging from relatively well-defined physical thresholds, to more complex socio-economic parameters like risk levels and social acceptance. Some papers define multiple levels of critical performance.

Moreover, next to physical drivers, a set of co-drivers may determine the conditions that necessitate adaptation. Also, a variety of adaptation actions is possible. Next to taking (physical) measures, objectives may be altered, for example by allowing for lower performance levels. In addition to the projected violation of performance levels, opportunities originating in other domains can be a trigger for taking action.

Another complication is that trends in decision variables with a high natural variability (such as peak flows) may be hard to detect. Moreover, appropriate timing of decisions also depends on the time required for implementation of a policy change, i.e., the decision to adapt may need to be made well ahead of the time when the threshold is reached.

As a result, the ex-ante assessment of the time frame until when the performance of the current policy will be satisfactory, is found to be difficult if not problematic.

We conclude with recommendations: First, there is a need to design monitoring and evaluation schemes that can handle (a) adaptation criteria that are difficult to monitor or evaluate unequivocally; (b) the presence of multiple drivers of change, and (c) situations in which change is gradual. Second, the approach should be extended to include developments in adjacent fields in order to be able to benefit from opportunities for synergy. Third, the governance dimension requires further attention, regarding both the feasibility of implementation of future adaptation decisions, and
the monitoring, evaluation and learning over time. Fourth, there is a need for more clarity and consistency in the use of terminology. Fifth, there is a need for designing simple visualisations to support effective communication of the results of analysis.

**Keywords:** Adaptive delta management, Adaptation pathways, Adaptation Tipping points, Adaptation Turning points, Governance of adaptation
38. Water Resource Planning Under Uncertainty In The Cauvery River Basin In Karnataka

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ABSTRACT
Uncertain regional climate change impacts and rapid socio-economic changes make long-term planning of water resources particularly problematic in developing countries. Although highly relevant, application of Robust Decision Making (RDM) approaches in developing countries has been limited. From a methodological perspective, RDM studies often involve either a computationally intensive quantitative analysis or a qualitative stakeholder judgement based analysis. A comparative assessment of the relative merits of each approach would enhance understanding of their roles and applicability. Recognizing these research needs, the Centre for Climate Change Economics and Policy (CCCEP) is conducting a study on decision making in water resources management under uncertain future conditions in India, in which a key aim is to compare simple and complex RDM approaches. The chosen study area is the Cauvery River Basin in Karnataka (area: ~35960 sq.km), which has a unique combination of underlying vulnerabilities including: observed climatic changes, high groundwater extraction, rapidly expanding cities, irrigation expansion and water resource conflict. Applying RDM approaches in such a context requires careful thought and this paper presents preliminary results from initial stakeholder engagement and a formal stakeholder workshop conducted in Bangalore. Stakeholders including academics, water managers, planners, agriculturists and non-governmental organizations, discussed key functions of the river and outlined a detailed water resources model for key elements of the system. The workshop process also allowed the elicitation of current and future vulnerabilities along with short and long-term water management options for managing envisaged future drivers and stressors. Key aspects of this complex water resources management problem which were revealed included: increased pumping from the river and excessive groundwater extraction in Bangalore, constraints imposed by the water sharing agreement with riparian states and agricultural expansion in upstream areas. Ongoing work involves further stakeholder engagement to discuss results from the quantitative approach and their implications for sustainable water resources management in the CRB-K.

Keywords: robust decision making approaches, stakeholder workshop, developing country context

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ABSTRACT
To make sound and robust climate change adaptation decisions, decision makers need not only relevant information about risks and uncertainty, but also need to utilise information in their decisions. Many discourses from a local to national planning have addressed climate change uncertainty, mainly because of its potential harmful and hard to predict impacts. But, in the context of adaptation, and in forestry in particularly, knowledge is missing how the available information from impact models affects or not decision-making process under deep or inherent uncertainty. Therefore, we a) developed new adaptive forestry management pathways maps including climate change impacts and intrinsic uncertainty, and b) investigated how decision makers, in our case forest planners, comprehend and respond to climate change uncertainty and ambiguity in their decisions. Essentially, their response to uncertainty will influence whether or not planners will be keen to apply adaptation measures.

To combine climate change impacts and intrinsic uncertainty, we incorporated assessed ecosystem services into a map of adaptive forestry management pathways for Scotland. This new pathways map build upon the dynamic adaptive policy pathways method developed by (Haasnoot, Kwakkel, Walker, & ter Maat, 2013) with more detailed spatial and temporal assessment of management actions using detailed climate change information. We used the novel probabilistic climate change projections for the UK (UKCP09) to estimate the drought risk for ecosystem services provided by British forests, which provide the key criteria to specify expiry dates. The UKCP09 provides subjective probabilities about the future climate - quantifying different associated uncertainties. The results for combined quantified ecosystem services into a map of adaptive forestry management pathways shows, when and where a specific forest management action reaches its environmental limits. We found, for example, the need to adapt Sitka spruce and its management now in the lowlands if the limiting threshold value was set to 10% reduction of ecosystem services from the baseline (Petr, Boerboom, Ray, & van der Veen, 2015a).

To evaluate the usability of the forestry management pathways maps in practice with assessing ambiguity – representing uncertainty, we conducted three workshops with forest planners in Scotland (Petr, Boerboom, Ray, & van der Veen, 2015b). We provided to planners information in the form of adaptive forestry management pathways maps for their district. We investigated changes in planners’ decisions about forestry actions representing species choice and forest tourism, and their expiry dates - representing environmental constraints to provision of ecosystem services. Presented climate change information modified planners’ understandings and frames about forestry actions and related expiry dates. Comparing ambiguity about different forest management actions, our results show diverse responses caused by new climate change information. Ambiguity understanding resulted in postponing or bringing forward several forest actions, and also in making it harder for planners to decide. Overall, planners’ ambiguity was found to be dependent on planners’ diverse
frames and difficulty to evaluate multiple ecosystem services. These findings imply that due to ambiguity forest planners might find it hard to choose relevant climate change adaptation measures.

**Keywords:** uncertainty, forestry, climate change adaptation, forest planning, ambiguity, framing
40. Adaptive Planning For The Flexible Expansion Of London’s Water Supply System

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ABSTRACT
Changing societal needs and increasing value placed on ecosystem services require water resource systems to react and flexibly adapt to such dynamic conditions. In addition, these systems must meet the multi-sector demands of a range of stakeholders whose objectives often conflict. Understanding these conflicts necessitates exploration of many alternative plans to identify possible compromise solutions and important system trade-offs. The uncertainties associated with future conditions such as climate change, population growth, and changing preferences pose further challenges for the decision making process. Planners therefore seek portfolios of supply and demand management schemes represented as dynamic trajectories over time, which are able to be adapted to the changing environment whilst considering many system goals and plausible futures. Yet such plans are difficult to identify due to the large number of alternative plans from which to choose, the uncertainty of future conditions, and the computational complexity of such problems. Given these complexities, fixed schedules of possible interventions may provide inefficient portfolios as they are not able to adapt as time progresses and uncertainties become known. Instead of scheduling the timing of possible interventions, rules to guide the implementation of options as the future unfolds may result in more flexible strategies where a decision is made based on observations on how the future is actually unfolding. We investigate how this dynamic adaptive policy pathways approach can be applied and communicated to stakeholders within the UK’s water supply planning context. In our study, we optimize London’s future water supply system investments and their adaptation over time using many-objective scenario optimization. In this optimization, we use an efficient water resource system simulator. To analyse the results, we use visual analytics for exploring key system trade-offs. We show how the visual analysis of solutions can aid decision making by investigating the implied performance trade-offs and how the individual schemes and their trajectories present in the Pareto approximate portfolios may affect the system’s behaviour. Decision makers are given the opportunity to decide on the balance between the many system goals a posteriori, as well as take only necessary immediate actions leaving the system open to further adaptation when needed. By doing so, planners can identify plausible pathways that their strategy may follow once future conditions become known instead of a single fixed long-term plan.

Keywords: Multi-objective optimization, Planning under uncertainty, Adaptive planning

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41. Expressing Uncertainty In System Models As A Level Of Understanding

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ABSTRACT
Various methods are used to express the uncertainty associated with scientific measurements, descriptions, explanations and predictions. But these often contain hidden assumptions about the structure of the problem being addressed that can be missed or not appreciated by the reader. For example, expressions of uncertainty around predictions need to take into account the accuracy of the system model that has been used to make those predictions, as well as uncertainty in the data fed into that system model. Describing the uncertainty due to inaccuracy in a system model is far more complex than the simple methods used to express uncertainty in data, or to aggregate the effects of uncertainties in multiple data items through an unchanging model using sensitivity analysis. As a result, uncertainty due to inaccuracy of the system model is not easily calculated or communicated, and its effects can easily be ignored by the researcher and the reader.

This paper proposes replacing the metric of “uncertainty” in a system model with a more positive metric of “understanding” and explores options for a simple framework to achieve this. In this way, a researcher would demonstrate the extent to which they understand a system, leaving the reader to make up their own mind about how certain to be in their conclusions. A metric of “understanding” would also allow us to track the progress of science as we develop understanding over time, and to set reasonable targets for understanding, dependent upon the nature of a problem. Although there is a logical contradiction in assessing either the “uncertainty” or “understanding” of a system model (neither can be accurately measured without perfect knowledge of the system), it might be possible to estimate, evaluate and improve metrics of understanding through feedback as we gather new knowledge through discovering “known unknowns” or hitherto “unknown unknowns”.

Keywords: Uncertainty, Understanding, Metrics, Framework, System Model, OR, Simulation, Operational Research
42. Implementation Of Adaptive Delta Management Through An Opportunistic Approach

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ABSTRACT
Based on experiences from the application of adaptive delta management (ADM) on the Island of Dordrecht in the Netherlands, this presentation focuses on how an opportunistic approach can contribute to putting adaptive policies in practice.

ADM is a strategic planning approach in which long term developments are taken into account in the assessment of short term decisions. The approach has been developed in the Dutch Delta Programme to develop adaptive policies for flood risk management and water security with a planning horizon until 2100. Ideally, these policies would lead to optimised investments in terms of avoiding expenditures that appear in hindsight to be too much, too little and/or too late.

ADM incorporates two routes to achieve its goal. The first route involves a systems approach that takes into account various spatial scales and values flexibility with regard to the timing of implementation. This also enables switching between strategies through adaptation pathways. The second route involves an opportunistic approach to achieve adaptation at a relatively low cost by inter-linking various investment agendas and looking for opportunities for mainstreaming adaptation with planned investments (e.g. road reconstruction, urban (re-)development, ecosystem restoration).

ADM was used in the Delta Programme to develop a flood risk management strategy for the Island of Dordrecht. This strategy is based on the principle of multi-layered safety and contains: 1) protection against flooding, 2) prevention of damage and casualties in case of flooding, and 3) preparedness for emergency response and recovery after future flooding. The regional authorities in Dordrecht have identified several ongoing infrastructure and ecosystem restoration projects that could provide an opportunity for realising adaptation measures cost-effectively.

For example, the ecosystem restoration project “Nieuwe Dordtse Biesbosch”, south of the urbanised area of the Island of Dordrecht, provides an opportunity to divert the flood water away from the urbanised area in case of a dike breach in the east. In addition, the planned reconstruction of the N3, which is a regional road that connects the Island of Dordrecht with other dike rings in the North and West, could possibly be used to realise an elevated access route to enhance emergency response and recovery after a flood.

In-depth studies of the technical, financial, legal and organisational feasibility of both opportunities are currently underway as part of a national pilot study on multi-layered safety. Preliminary findings for the Nieuwe Dordtse Biesbosch show that the opportunistic approach may pose new constraints to the land-use of the island, because diverting the flood water would change the distribution of risks on the island. As a result, additional measures may become necessary, such as spatial zoning. In addition, the example of the reconstruction of the N3 illustrates that adaptation pathways may be temporarily closed off and diverted if an opportunity is not taken, since this road is the only sensible elevated access route to other dike rings. Instead, vertical evacuation and self-sufficiency might be needed to establish the multi-layered safety strategy for the Island of Dordrecht.

Keywords: Adaptive Delta Management, Flood Risk, Multi-layered safety, Opportunities
43. Evaluating Climate And Other Future Risks To The Hydropower Investment Of The Upper Arun Dam, Nepal

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ABSTRACT
Hydropower is potentially vulnerable to climate change, particularly in South Asia, where complex glacier- and mountain-influenced hydrology, high sediment loads, and high reliance on hydropower as a dependable source of electric energy present important challenges.

Uncertainty in future climate projections remains, and downscaling efforts do not reduce this uncertainty. As a result, it is unwise for the World Bank Group to plan and design future infrastructure based on projections of unknown credibility or solely on the use of historic records (so-called "stationarity" approaches). Moreover, other future conditions are deeply uncertain and may impact the success of the project. For one, the energy prices may vary greatly if an agreement to export energy to India during the monsoon season were sealed. Or else, the lifetime of the plant depends on good sediment management and the absence of natural disasters. These uncertainties should not however stall the decision making process.

We applied a conceptual framework for climate risk assessment and risk management, the “Decision Tree” developed by the World Bank Water Sector, to the hydropower planning in Nepal. We applied the Decision Tree to the proposed Upper Arun Hydropower Project (UAHP), incorporating both climate and non-climate uncertainties when assessing the infrastructure project in a participatory process with the Nepalese energy sectors and policy analysts. We investigated five possible hydropower capacities.

The results indicate that the net economic benefits of each of the designs were robust to plausible climate changes. The larger the design, the more the net present value was affected by climate uncertainties. Among non-climatic factors, the price of electricity and construction costs emerged as key risk factors. Smaller hydropower capacities appear quite robust to all uncertainties.

These risks and their plausibility or acceptability need to be considered by decision makers and they themselves need to make the final choice. For the first time, the Government of Nepal was presented these risks and opportunities in an analytically robust and transparent fashion. The policy-makers themselves will in the end decide whether the presented risks are sufficiently acceptable to justify the investment. This is precisely the advantage of DMU approaches, like those implemented in this analysis via the Decision Tree: the decision is back in the policy-makers hands, and risks and opportunities are presented in as a transparent way as possible. These types of analysis can help them make informed choices, even when they cannot have confidence about what the future will bring.

Keywords: Climate risks, socio-economic uncertainties, hydropower, Nepal
44. A Decision Making Under Uncertainty Approach To Identifying Efficient And Robust Hydropower Investment Portfolios In The Koshi Basin, Nepal

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ABSTRACT
Nepal is currently developing a national hydropower strategy where efficient use of capital and natural resources to meet electricity generation goals is a government priority. Multiple factors related to the supply and demand of both energy and water can affect the returns on hydropower investments. Uncertainty surrounds future changes in many of these factors, so a four-phase decision-making under uncertainty approach is designed and applied as a proof-of-concept at basin level as a step towards a national analysis. Its aim is to help identify portfolios of hydropower assets that could provide an acceptable mix of benefits under a wide range of plausible futures, identifying key vulnerabilities to socio-economic uncertainties to help mitigate their impacts.

The approach is applied to the Koshi Basin, considering combinations of five proposed hydropower dams in addition to the basin’s five existing dams. One of the proposed dams has five generating capacity options leading to 95 possible combinations of dams. Two of the proposed dams are storage-type for which operating rules affect the balance between the benefits provided. The range of operating rules available for the storage dams increases the possible combinations of dams and operations to many billions. A multi-criteria search algorithm is used to filter these efficiently to identify the best ones, as defined by a number of performance metrics evaluated by a simulation model.

The analysis identifies robust portfolios of investments (those that are efficient over a range of plausible futures) considering firm, dry season, and total annual electricity generation as well as environmental flow, urban and agricultural water supply and flood alleviation criteria (for storage schemes). Scenario discovery is then applied to promising portfolios to identify combinations of socio-economic factors, which could lead to unfavourable returns on investment.

Non-climate uncertainties of construction cost and electricity price are shown to be the key risk factors for the achievement of expected gains from hydropower investments. Operating storage dams to balance electricity generation with other objectives could also limit revenue generation.

This Koshi Basin analysis is preliminary, but identifies a number of the best hydropower investment portfolios, which might be implemented, according to decision maker preferences for robustness and trade-offs between diverse water-dependent benefits.

Keywords: hydropower, robust portfolios, climate and non climate uncertainties, koshi basin
45. Adaptation Pathways From The Perspective Of Real Options Analysis

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ABSTRACT
Developing strategies for climate change adaptation is complicated by multiple sources of uncertainty, regime shifts, path-dependency, and long time frames. In this context, it is important to understand the value of preserving flexibility in order to learn and adapt to changing circumstances. We show how adaptation pathways can be characterized as sequences of alternative regimes delineated by decision thresholds. The nature of these thresholds is determined by the sources of uncertainty and the degree of reversibility between regimes. We build on recent developments in the application of real options analysis to managing uncertainty under climate change to investigate the value of flexibility and information within adaptation pathways. This provides an approach for understanding optimal decision pathways in terms of expected future returns and the option value of future regimes. In particular, we show how the resilience of adaptation pathways can be understood in relation to key decision thresholds and how this approach can be used to help identify practical strategies for preserving flexibility and managing uncertainty.

Keywords: real options, climate adaptation, adaptation pathways
46. Designing Signposts And Triggers As Adaptation Signals In The Dynamic Adaptive Policy Pathways Approach

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ABSTRACT
It is increasingly being recognized that adaptation to climate change is a dynamic process over time instead of a static single moment decision. Only by adapting over time can one account for the various deep uncertainties encountered in planning climate adaptation. The Dynamic Adaptation Policy Pathways (DAPP) approach aims to support policymakers and analysts with this process through the development of an adaptive plan. Adaptation pathways form the basis for such a plan. The first part of designing an adaptive plan is the evaluation of adaptation pathways under an ensemble of possible futures, which enables policy analysts to recognize potential ‘locked-in’ situations and to assess the flexibility and robustness of decisions.

Monitoring is second part of the process. Signposts are identified and monitored to assess the need for action when pre-specified threshold values (triggers) are reached. This generates both early warning signals and adaptation signals. Early warning signals give a first signal to start thinking that actions may need to be taken, while an adaptation signal is a much clearer signal that an adaptation tipping point, meaning unacceptable performance of a system, is approaching, and that the next action(s) of an adaptation pathway may need to be implemented. The signals should thus trigger thinking about actions; not only the next action of a pathway, but also corrective actions to stay on track and preparatory actions to prepare for adaptation or to keep planned options open.

In this paper, we present a framework for designing and using signposts and triggers in the DAPP approach. The framework has been developed in cooperation with the Dutch Delta Programme and will be applied to two adaptation pathway maps developed for decision making on fresh water supply, which are contained in the Delta Plan presented in 2014. We give criteria for identifying good signposts and triggers and present an example of the use of transient scenarios to identify triggers for climate adaptation. From a policy perspective it seems logical to select triggers that are related to norm values, objectives, or acceptability values, as these are the values the policies are evaluated upon. However, these are often too extreme to detect (systematic) trends. Our results show that other trigger indicators — not necessarily policy related — can be used instead as signals for change.

Keywords: monitoring, early warning signal, adaptation pathways, deep uncertainty
47. Dealing With Risks and Uncertainties In Urban Masterplanning and Implementation. The Case Of Beira, Mozambique

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ABSTRACT

Beira, with a population of more than 500,000, is the second largest city in the country and is located in the estuary of the Pungue river.

The city is facing numerous challenges. According to recent studies, Beira is seriously threatened by climate change. The city is just a few metres above average sea level and a clear adaptation strategy is required to provide enduring protection against water related problems such as floods, coastal erosion and salt water intrusion.

Spatial developments also need to be addressed. The expansion of the coal transport and export activities of the port of Beira is required to utilize the great economic potential.

The currently poor living conditions of a large part of its inhabitants, mainly due to poor basic infrastructure and service coverage, need to be improved.

To respond to the various challenges it was decided to create an integrated vision for the city through the so called Masterplan Beira 2035. The overall goal of the Masterplan Beira 2035 is to make a significant contribution to a safe, prosperous and beautiful Beira. To realize this overall goal, Beira essentially faces three challenges:

- To utilize the great economic potential of the city and its hinterland, mainly due to its strategic location at the Indian Ocean and at the end of an important transport corridor and the presence of a sea port;
- To improve the currently poor living conditions of a large part of its inhabitants, mainly due to poor basic infrastructure and service coverage;
- To adapt to climate change and sustainably coexist with its natural environment. Beira is located in a delta and large parts of the built up areas are prone to flooding and are threatened by sea level rise and are prone to flooding.

An integrated and planned approach to meet these challenges has been prepared. The planning process was based on socio-economic growth and climate change scenarios to deal with the uncertainties. In addition, a clear implementation and financing strategy was added. A list of implementation projects was identified for which financing is procured based on business cases and financing proposals. These project proposals will be submitted to public and private financing partners. The increasing dependency on private investment capital provides an additional challenge since private parties are generally risk avoiding. Several uncertainties and risk play an important role in the decision making process of the private investors. Uncertainties regarding political commitment, implementation capacity, technical risks and financial economic aspects require special care when preparing these PPP business cases.

Keywords: masterplanning, Climate change, socio-economic growth
Flood Risk Management Under Deep Uncertainties Regarding The Coastal Development Strategy In Jakarta

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ABSTRACT
Jakarta is facing serious problems related to land subsidence and corresponding flood risks from upstream water as well as from sea water.

To address the sinking of Jakarta, the National Government and DKI completed the National Capital Integrated Coastal Development (NCICD) master plan in November 2014. The NCICD strategy consists of a broad set of measures including strengthening and raising the existing sea wall and in the long term the creation of an outer sea wall defense in the form of the Great Garuda. NCICD has been accepted as the direction to address the coastal emergency by development of the coastal zone of Jakarta. In December 9, 2014 the special parliament committee confirmed the strengthening of the current seawall (NCICD phase A), which should be ready within 3 years, but also requested the further evaluation of NCICD phase B and C that consists of building a giant sea wall. This complex project, apart from the huge investments it will require contains numerous risks and uncertainties for which scenario analysis is being ongoing. The presentation will expand on the ongoing activities to deal with these risks and uncertainties and what methods are used.

Keywords: land subsidence, flood risk management, scenarios
49. Assessing The Sustainable Use Of Aquifer Thermal Energy Storage (ATES) Under Uncertainty

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ABSTRACT
Aquifer Thermal Energy Storage (ATES) can provide major reductions in energy use within the built environment, by storing thermal energy in aquifers for the heating and cooling of buildings. In the Netherlands, the use of ATES in large residential, commercial and institutional buildings has rapidly grown over the last two decades, and the number of operational systems is expected to further increase tenfold by 2025. ATES systems are thus likely to become the largest user of groundwater in the country by 2020, as defined by total pumped volume. Given this rapid evolution and the sensitivity of aquifer resources, the sustainable use of ATES requires the consideration of multiple environmental, technical and social criteria; although these systems do not result in a net extraction or injection of groundwater, they create thermal disturbances which must be monitored and managed. As such, planning approaches for urban ATES systems must find a balance between stimulating the adoption of the technology to maximize collective energy savings, and preserving the long-term thermal storage potential of the subsurface. From this perspective, current permitting policies in the Netherlands follow the precautionary principle and aim to avoid thermal interactions between neighbouring systems. However, these policies do not fully account for the uncertainties which are inherent to ATES adoption and operation. For instance, variable weather conditions and building occupancy patterns make it difficult to accurately predict energy demand and maintain the thermal balance of ATES systems; this creates an incentive for developers to apply for oversized permits, artificially creating a scarcity of space for new systems. Furthermore, the adoption of new systems is subject to a range of socio-technical uncertainties, while the thermal performance of systems is dependent on local geohydrological conditions – which are difficult to assess and monitor.

In order to identify potential pathways towards improved governance policies which acknowledge these uncertainties, this work first introduces a framework to assess the sustainable use of subsurface resources for thermal storage. This framework is then applied to explore the specific trade-offs between collective energy savings, subsurface use, and ATES system performance. These trade-offs are studied using a hybrid simulation environment which couples an agent-based model of ATES adoption and planning with a geohydrological model of the subsurface, with both models representing typical operating conditions for ATES systems in urban areas. This hybrid environment is used to investigate suitable options for the spatial planning of ATES systems under a robust optimization approach. The Borg multi-objective evolutionary optimization algorithm is thus applied to identify ATES well layout parameters which perform well in relation to the criteria set by the assessment framework, under a range of socio-technical and geohydrological uncertainties. Techniques for scenario discovery are then used to identify the combinations of uncertainties which may create system vulnerabilities under these layout parameters.

Keywords: Aquifer Thermal Energy Storage, social-ecological systems, robust optimization, scenario discovery

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ABSTRACT
Planning and design of urban drainage infrastructure has to deal with uncertainties in urban development and climate change. As investments in upgrading of existing and development of new drainage systems have long time horizons and existing underground systems are very expensive to change, engineers and decision-makers increasingly look at flexible solutions to compliment traditional, inflexible drainage designs. New paradigms and approaches such as Water Sensitive Urban Design and Sustainable Urban Drainage Design focus on temporary water storage resulting in lower peak discharge and hence reducing pressure on the traditional drainage system. These approaches can provide additional benefits beyond drainage, such as improved urban quality, positive impact on Urban Heat Island and storage of water for dry seasons.

A question is, however, how to plan and design an optimal drainage system, taking into account a multitude of complex, inter-related and imperfectly understood processes: what combination of traditional and new approaches will provide the best protection against flooding against reasonable costs? Particularly for development of new towns and neighbourhoods, where no traditional system exists, this question is difficult to answer as long-term climate predictions vary considerably and urban development can follow many different scenarios. In addition, engineers are often unsure about the performance of the new approaches, while government decision-makers may have questions about implementation and management of this type of solutions.

Although no definite answer can be provided without knowing how the future will unfold, decision-making under deep uncertainty in this case can be supported by recently developed methods and tools. Dynamic Adaptive Policy Pathways is a step-wise approach that provides insights in sequencing of actions over time through adaptation pathways. To provide insights in the costs and benefits of actions over time, and calculate a value for flexibility in the system, we propose to complement the approach with real options analysis. Adaptation pathways can be reconfigured into decision trees, which allow a real options approach that capitalises on uncertainty and flexibility. For real options analysis to work, several questions will need to be addressed though, such quantification of uncertainty, costs and benefits, and timing of decision moments.

The approach is illustrated by two cases. Firstly for the planning of a drainage system for Tuy Hoa city, a medium-sized city in Vietnam. The proposed planning approaches will be analysed and compared to a dynamic adaptive planning. We find that a dynamic adaptive planning approach should result in better designs, though higher upfront costs may be an implementation hurdle for a city in a developing country. In the second case we look at megacity Bangkok. The Thai government is putting in place a new flood prevention response by upstream ecosystem restoration for water retention and technical solutions such as a ‘wall-defence structure’ protecting key installations in the city. Given such policy initiatives and projections of increasing flood risks in the future, we analyse how dynamic adaptive planning with real options can be used to develop adaptive options for better flood risk management.
Keywords: Dynamic Adaptive Pathways, Real Options Analysis, Water Sensitive Design, Urban Drainage Systems
51. Adjustable Robust Optimization For Sustainable Water Policy Pathways

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ABSTRACT
A few years ago, a new concept for deriving sustainable water policies has been proposed and elaborated. This concept is proposed in [1], and elaborated and applied to concrete cases in many more papers in the last few years. In this talk we describe how the recently developed techniques from Robust Optimization, and in particular Adjustable Robust Optimization, can be used to calculate optimal adaptation paths for sustainable water policies.

The field of Robust Optimization was founded in the late 90s by the three founding fathers Aharon Ben-Tal, Arkadi Nemirovsky and Laurent El-Ghaoui. The difference with the more classical Stochastic Programming approach is that in principal there is no need to specify a distribution function for the uncertain parameters. Instead of a distribution function, a so-called uncertainty set is specified. This set contains the values for the uncertain parameters to which the decision maker wants to safeguard the final solution. Another advantage of Robust Optimization is that, contrary to Stochastic Optimization, the optimization problems remain computationally tractable. For Stochastic Optimization already small-sized problems become computationally intractable.

In 2004 an essential extension of Robust Optimization was proposed: Adjustable Robust Optimization. This approach allows for so-called wait-and-see variables; the value of these variables can be determined when (a part of) the values of the uncertain parameters are known. The final optimization problem that is solved contains variables for the here-and-now decisions, and variables that are in fact functions of the uncertain parameters for the wait-and-see decisions.

We apply the framework of Adjustable Robust Optimization to obtain sustainable water policy pathways. First, the uncertain parameters and the corresponding uncertainty sets have to be identified. Second, we have to specify the ‘learning process’: what do we learn with respect to the uncertain parameters at several points of time? Third, the possible actions at each point of time have to be specified. Fourth, a final Adjustable Robust Optimization problem is set up and solved. The solution not only specifies the here-and-now solution but also the dynamic adaptation paths and signals to adapt. We also discuss important notions of Pareto optimality and how to find alternative optimal adaptation paths.

The theory is illustrated by a toy problem and a more realistic problem in which optimal sets of measures have to be found such that the dikes satisfy the safety standards for the coming decades, and the total discounted costs of taking the measures are minimal. One of the uncertain parameters in this problem is the sea level rise.


Keywords: Sustainable Water Policy, Adaptation paths, Uncertainty, Adjustable Robust Optimization
52. Making Long-Term Investments In The Sacramento-San Joaquin Delta Amid Deep Uncertainty

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ABSTRACT
The Sacramento-San Joaquin Delta in the State of California is the largest estuary in the Western United States. It is home to a unique ecosystem and culture and plays a critical role in providing water for 23 million Californians. Levees in the Delta are of statewide importance to help protect people, property, natural resources, and numerous infrastructure systems. Catastrophic levee failure would cause devastating flooding and disruption of the assets that the levees currently protect. Levee maintenance and improvement over the past 30 years has helped maintain the levees. However, the State does not have a long-term strategy to guide future investments of its limited funding in the face of deeply uncertain climate change, development, and flood risk.

This talk will report on a multi-year effort to support the Delta Stewardship Council in developing a Delta Levee Investment Strategy (Strategy) to prioritize State investments in levees in the (Delta), reduce risks to people, property and State interests. For this project, we developed an objective, science based planning framework and a Planning Tool to estimate a broad range of risks without and with additional investment and highlight key tradeoffs among portfolios of investments. The framework and tool are currently being used to support deliberations over a suitable strategy to guide millions of dollars of State investment in the coming years.

Keywords: deep uncertainty, delta, levees, long-term strategy
53. Teaching DMU To Practitioners

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ABSTRACT
The techniques of decision making under uncertainty (DMU) began as a guerilla campaign by analysts dissatisfied with the tools available to perform policy analysis when deep uncertainty prevailed. The field moved from vision, to development of tools, to esoteric practice to the current state of widening acceptance. However, the performance of DMU support in policy settings usually requires the services of external, highly trained analysts who will perform the required steps in service of planning staffs and the policy makers whom they serve.

Is the field now capable of its next stage involving transfer of knowledge and capabilities so planners in public agencies may now perform the necessary DMU analyses themselves? This talk will present insights from two recent experiments in doing so. It will then draw conclusions based upon the direct experience gained from these efforts to suggest possible paths forward, challenges and opportunities.

The first experiment consisted of a workshop under the auspices of the NGO START.org held at the Shanghai Climate Center. Twenty selected participants from five Asian countries received four days of workshop instruction in the methods associated with Robust Decision Making (RDM). Each prepared preliminary exercises and during the course of the workshop worked on assignments accompanying instruction. They also worked in stages through a specific policy problem related to uncertainty over climate in rapidly developing urban areas. Following the workshop, four participants received fellowships to spend four weeks in residence at RAND for further work on their planning problem.

The second experiment was conducted under the auspices of the Transportation Research Board of the U.S. National Research Council. The goal was to develop a protocol and set of tools that would permit individual transportation agencies of varying capacities (the U.S. possesses 52 state departments of transportation and more than 350 metropolitan planning organizations) to make better decisions regarding technology adoption despite the profound uncertainties involved. The Systematic Technology Reconnaissance, Evaluation and Adoption Methodology (STREAM) was designed to provide local agencies with the means to better evaluate technological alternatives in terms relevant to agency missions, integrate such findings into ongoing decision processes and operate with a more sophisticated understanding of the influence of the various uncertainties involved.

The presentation will briefly outline the main points of both experiments, present findings and draw conclusions for similar efforts to train practitioners directly in DMU techniques.

Keywords: Training, Planning, Capability transfer, Skill building
54. Infrastructure System-Of-Systems Modelling And Decision Analysis For The Uk’s National Infrastructure

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ABSTRACT
National infrastructure provides essential services to a modern economy: energy, transport, digital communications, water supply, flood protection, and waste water / solid waste collection, treatment and disposal. The OECD estimates that globally US$53 trillion of infrastructure investment will be needed by 2030. The UK’s National Infrastructure Plan set out over £460 billion of investment in the next decade, but is not yet known what effect that investment will have on the quality and reliability of national infrastructure services, the size of the economy, the resilience of society or its impacts upon the environment. Such a gap in knowledge exists because of the sheer complexity of infrastructure networks and their interactions with people and the environment. That means that there is too much guesswork, and too many untested assumptions in the planning, appraisal and design of infrastructure, from European energy networks to local drainage systems.

The UK Infrastructure Transitions Research Consortium (ITRC) is a consortium of seven UK universities, led by the University of Oxford, which has developed unique capability in infrastructure systems analysis, modelling and decision making. The ITRC has developed and demonstrated the world’s first family of national infrastructure system models (NISMOD) for analysis and long-term planning of interdependent infrastructure systems. The research is already being used by utility companies, engineering consultants and many parts of the UK government, to analyse risks and inform billions of pounds worth of better infrastructure decisions. Infrastructure UK in the UK Treasury is now using NISMOD to analyse the National Infrastructure Plan.

This paper will describe the system-of-systems analysis that NISMOD is based upon and demonstrate how it is being used to analyse alternative long term infrastructure strategies for the UK. Four headline strategies are considered:

Minimum Intervention (MI) – with limited new investment.

Capacity Expansion (CE) – focussing on expanding the capacity of the infrastructure system.

Systems Efficiency (SE) – focuses on deploying the full range of technological and policy interventions to optimise the performance and efficiency of the current system targeting both supply and demand.

Systems Restructuring (SR) – focuses on fundamentally restructuring and redesigning the current mode of infrastructure service provision, deploying a combination of targeted centralisation and decentralisation approaches.

These strategies are analysed in the context of a range of uncertain factors (population, economic growth, energy prices, climate change) and appraised with respect to multiple performance metrics. The paper will demonstrate the sensitivity of these national infrastructure strategies to the effects of deep uncertainty and will identify robust strategies.

Keywords: Infrastructure systems, Scenario analysis, Decision analysis
55. Improving Scenario Discovery With Iterative Behavior Space Sampling

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ABSTRACT
In this proposed workshop contribution and paper, we present a new output-oriented sampling approach that, in combination with classification, clustering, and scenario discovery techniques, allows for generating the largest variety of behaviors simulation models could generate. The primary focus is to direct the sampling process in such a way that the widest variety of dynamics of interest is generated.

Sampling is the numerical practice of selecting, following specific experimental design principles, input values from distributions or sets to generate experiments, which can be used as inputs for simulation models to generate large varieties of simulation runs. There already exist a multitude of sampling methods; systematic full factorial methods, random Monte Carlo methods, and lean Latin Hypercube methods. These sampling methods focus on the design of input values in order to assemble a picture of output behavior.

The trouble with above mentioned sampling methods, is that there is no guarantee of revealing the full behavioral spectrum a simulation model could generate in sufficient density, when applied to highly non-linear simulation models, to identify regions in the input space that generate particular types of behavior. Although input-oriented random sampling may coincidentally reveal all behaviors, in case of non-linear models, it may take some amount of processing time to identify the most interesting regions in a sufficiently dense way for them to be identified by PRIM-like scenario discovery techniques.

Adaptive sampling approaches use information obtained during the sampling process (i.e., the ‘outcomes’ of previous samples) to determine where to sample next. The concept of adaptive sampling is not new; Bucher (1988) and Bishop et al. (2001) use adaptive sampling in weather forecasting and construction safety. In this paper, we present and demonstrate an adaptive multi-stage Behavior Space (BS) sampling approach that, starting from a burn-in sample generated with a Latin Hypercube sampler, in each resampling iteration draws a minimum spanning tree on a two-dimensional representation of the output space to determine the n largest gaps to be filled, each with m Latin-Hypercube samples. This adaptive output-oriented sampling approach extends traditional sampling with iterative gap searches in the behavioral space based on well-chosen two-dimensional representations of the behavior space. The current version of the BS sampler is especially useful for generating and representing the full behavioral spectrum of simulation models, for identifying input spaces responsible for particular types of behaviors, and for identifying and selecting representative exemplars, especially if intricate non-linear behaviors are generated within interior subspaces.

In this paper, we present and illustrate the current version of the BS sampler. The BS sampler has been tested on a large variety of (non-linear) models. We demonstrate how the BS sampler, in combination with classification, clustering, and scenario discovery techniques, enables one to sample for the widest variety of dynamics of interest, identify the associated regions of the input space and for each of these regions, identify and select an exemplar.

Keywords: Uncertainty Analysis, Exploratory Modelling and Analysis, Behavior Space Sampling, Dynamic complexity, Roughness, Classification, Time Series Clustering
56. Flood Protection: Option Flexibility And Its Value

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ABSTRACT
Changing risk profiles over long time periods are a challenge for assessing the economics of infrastructure projects like flood protection schemes. Several techniques such as robust decision making and real options analysis are useful for analysing such challenges. However, these are not yet well embedded in decision practice generally and New Zealand is no exception. We present a study based on the Hutt river, one of the largest flood scheme in New Zealand, that applies real options analysis to Dynamic Adaptive Pathways developed for retaining existing flood design levels (1:440 ARI or 2800 cumecs) over the next 100 years. We looked at the value of pursuing flood protection options that are flexible, rather than adopting a single solution that cannot be adapted to deal with changing and unpredictable external conditions – namely climate change and its effect on peak river flows.

The results show that a flexible investment strategy that enables a change of course in the future is more likely to deliver a lower cost outcome than pursuing a single option, unless the probability of a climate change induced increase in flood frequency and its associated economic loss is almost certain. The effects of changing the benefit metric from avoiding expected loss, to Value for Money based on a Multi-Criteria Analysis, are also presented. Following feedback from the decision makers, a subset of investment options and flexible pathways were subjected to further analysis which confirmed the value of flexibility. In particular under most scenarios examined, it was better to invest in a lower cost option initially and defer investment in a higher cost option until policy triggers indicate that the lower cost option is no longer adequate to meet the agreed design standard. The results held true regardless of whether the outcome was based on Multi-Criteria Analysis or on minimising the expected total cost (cost of flood protection investment plus the residual risk of property loss in the event of a flood) of each option.

Keywords: real options, dynamic adaptive pathways, climate change, flood risk management
57. Practice Problem And Dynamic Adaptive Approach Taken: Hutt City CBD Flood Protection Scheme, New Zealand

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ABSTRACT
The community in the Hutt valley, New Zealand are protected by one of the largest flood control schemes in New Zealand. The floodplain is also the most densely populated floodplain in New Zealand, including significant road, rail and water infrastructure essential for the region. The community have decided on a level of protection (1:440 ARI) that should be maintained for at least 100 years. Climate change will reduce that level of protection as flood frequency and magnitude increase. The Greater Wellington Regional Council, responsible for flood risk management along with the two city councils who manage land use and developments protected by the flood scheme, have a challenge to maintain protection levels when there are affordability limits. The new information on climate change has suggested that the desired standard of flood protection cannot be provided within the existing river corridor and that additional land, currently occupied by building development, may be required for flood mitigation structures.

This paper outlines how knowledge of the effects of climate change on flood frequency and magnitude has influenced how we have approached the completion of the flood scheme adjacent to the Hutt CBD. We adopted the Dynamic Adaptive Policy Pathways (DAPP) approach in a real-life decision setting to assess options and do costings for the scheme completion. The problem, context and decision process are presented using the DAPP. The issues that arose during the process, how the DAPP was used for long term management of a dynamic river system, provides a case example for feedback from workshop participants.

Keywords: climate change, flood protection, dynamic adaptive policy pathways
58. Deep Uncertainty, Non-Stationarity, Scenarios, Robustness And Adaptation: How Do They Fit Together In Environmental Modelling?

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ABSTRACT
The advent of climate change and the recognition that environmental systems are operating in non-stationary environments has increased the importance of considering deep uncertainty in the analysis of environmental systems and associated methods of decision support. Within the broader concept of deep uncertainty, we focus on non-stationary systems for which there are multiple plausible futures, the relative likelihoods of which are unknown. Future system behaviour is affected by processes for which data have not been or cannot be observed. This notably occurs as a result of dynamics of a system. Interactions between system components over time lead to transitions in system behaviour. For example, decisions may adapt over time due to their interaction with the environment, often introducing path-dependencies. As a result, it is difficult to represent and estimate deep uncertainty using traditional methods of uncertainty analysis, which are geared towards stationary systems where probability distributions associated with uncertainties can generally be estimated with the aid of existing data. Consequently, a number of different approaches to dealing with the temporal aspect of deep uncertainty have emerged, including the use of scenarios for exploring plausible system states and the consideration of robustness as a means to aid decision-making. However, given the relative immaturity of this field and the fact that methods for dealing with deep uncertainty span a number of disciplinary areas, there has been some inconsistencies surrounding terminology, methods of analysis and approaches to decision-support in relation to non-stationarity and deep uncertainty. In order to go some way towards addressing this problem, the purpose of this paper is to unpack the meaning of some of the concepts used in dealing with the aspects of deep uncertainty related to temporal dynamics and non-stationarity, including scenarios, robustness and adaptation, and to provide some guidance on their application in order to assist with understanding and consistency in this important field of research. In particular, treatment of non-stationarity within different definitions of deep uncertainty is discussed, as well as different methods for dealing with non-stationarity and deep uncertainty in the analysis of environmental systems. In addition, the factors influencing the selection of different approaches to addressing deep uncertainty in decision-making contexts are explored, specifically in the context of environmental modelling.

Keywords: non-stationarity, robustness, adaptivity, terminology, modelling
Learning From Facilitated Scenario Development

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ABSTRACT
Scenario planning helps organizations to scan their environment and assess the importance and uncertainty of developments in its surroundings. This approach rests firmly on the assumption that the future is inherently uncertain and therefore preparation for multiple plausible futures is required. Scenarios are among the most frequently used strategy tools and a wide variety of approaches to scenario planning is available. Surprisingly little is known about its effectiveness. A limited number of success stories describe how scenarios were used to prepare for future developments and get ahead of the competition. Pierre Wack’s analysis of oil prices helped Royal Dutch Shell managers to anticipate an increase in oil prices. When the oil crisis became a reality, Shell reacted faster than other oil companies. In stark contrast, the unsuccessful case by Hodgkinson and Wright describes managers who refuse to accept scenarios and their implications for strategy. The wide variety in reported outcomes leads some authors to conclude that scenario planning does not consistently meets its expectations, and that success seems to depend at least as much on the consultants involved as on the exact approach used.

Recognizing that most scenario evaluation studies are single case reports, and a systematic review of scenario projects and their impact is missing, Van der Heijden proposes a theoretical basis for scenario effectiveness. He groups scenario studies along a process axis, separating one-off from ongoing interventions and an outcome axis, which distinguishes projects aimed at opening-up from those trying to achieve closure. He then describes each of the resulting four combinations and finds that some of these are more likely to be successful than others. A one-off intervention, for instance, is unlikely to generate insights fundamental enough to change the accepted way of thinking in an organization, which means that one-off projects attempting to achieve closure (an action plan) are likely to fail.

In this study we bring together a set of scenario planning projects planned and implemented by the Methodology Department of the Nijmegen School of Management. We group project according to the framework proposed by Van der Heijden. Our study is one of the few reviews of scenario planning projects and presents a direct test of Van der Heijden’s theoretical assumptions. Results indicate several possible clarifications and extensions of his framework.

Keywords: scenario planning, review, evaluation, learning
60. Adaptation Pathways For Enhancing Urban Resilience To Extreme Rainfall Events

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ABSTRACT
Extreme rainfall events are becoming more frequent due to climate change. Urban stormwater systems are generally not designed to cope with such events, but only to comply with national design standards. The use of design standards makes it possible to identify threshold values that the system should meet, and (subsequently) to devise possible adaptation actions that will maintain the required performance. A well-recognized method for the exploration and sequencing of actions is Adaptation Pathways, which uses the concept of Adaptation Tipping Points for defining the moments when actions are likely to be needed.

The use of Adaptation Pathways has previously been demonstrated for design rainfall events and river discharge events; however no studies have applied this method for extreme rainfall events. The application for this context requires to tailor the Adaptation Pathways method, (among other) because the definition of threshold values is not as straightforward as for design standards. In the Netherlands, the legal requirement for the management of extreme rainfall events is defined by ‘good housekeeping’. The term ‘good housekeeping’ gives design freedom to decision makers and aims to promote design solutions according to the specific needs of the urban stormwater system. Moreover, it enables the combination of multiple adaptation actions, in reaction to the different mainstreaming opportunities provided by the interaction with other urban systems, like road networks, blue-green networks or recreational areas.

Three different stormwater management districts in Dordrecht were analysed using a 1D2D model (SOBEK Urban) for the simulation of design and extreme rainfall events. Firstly, the available capacity of the sewer system was assessed for the design rainfall (20 mm/2h, T=2 years). The results showed that few nodes are surcharged and threshold values for the general performance of the systems are not exceeded. Secondly, two synthetic extreme rainfall events (60 mm/2h, T=358 years and 100 mm/2h, T=1288 years) were modelled. The model results showed that flood water started flowing on streets, affecting buildings, critical infrastructure objects and main roads. As such, adaptation actions might be needed to keep the urban stormwater system delivering its objective.

The definition of objectives is done considering the severity of impacts and the frequency of the events, and zoning for possible actions is performed accordingly. Different adaptation actions like changing street profiles, implementing water plazas and changing surface types have been proposed, and their efficiency was assessed with the stormwater model. Next steps will be to define Adaptation Pathways that take account of the various mainstreaming opportunities, together with the quick-wins that they represent (in terms of impact reduction). Mainstreaming opportunities in Dordrecht arise from the maintenance and renewal works that the municipality has planned for these neighbourhoods. It is expected that this type of adaptation action will not represent substantial extra cost for the municipality, because of the timing together with ongoing works.

Keywords: Extreme rainfall events, Adaptation pathways, Resilience
61. Calibrating Decisions: Using Economic Instruments In Sequential Decision Adaptation Pathways

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ABSTRACT
Decisions about investments in large long-lived infrastructure — balancing interests across multiple stakeholders and generations — have always been difficult. These decisions are often defined through technical bodies of knowledge such as engineering and science, but most decision makers often use economic tools to decide between alternative pathways. The gaps between these definitions of uncertainty, knowledge, and decision raises profound challenges in a period of climate change, especially about long-lived investments. Ideally, investment decisions should be economically viable and environmentally sustainable over long timescales, robust to a number of credible risk scenarios, and flexible enough to adapt to changing conditions, preferably at least cost to society. Water infrastructure investment decisions typically have long-lived footprints, affecting communities, economies, and ecosystems for decades or even centuries. In some case, the infrastructure's legacy can actually outlive the infrastructure itself, as the economic system reorganizes itself around the infrastructure's presence. Water infrastructure has the power to transform "difficult hydrologies" and insecure economies into water-secure environments with growth-oriented economies, reducing climate variability and increasing the economic stability of a region. Here, we show how sequential decision adaptation pathways for water infrastructure investments -- defined largely for technical decision makers -- can be married to existing economic tools to enable policy and strategic decision makers to make more effective, robust, and sustainable choices.

Keywords: freshwater, infrastructure, investments, climate adaptation, economics, adaptation pathways
62. Dealing With Deep Uncertainty In Long-Term Infrastructure Planning In The Netherlands

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ABSTRACT
Long-term infrastructure planning must deal with all of elements of deep uncertainty, since it involves large investments with a long lifetime, and societal impacts that are often irreversible. Moreover, new infrastructure often triggers (uncertain) societal responses. In the Netherlands, long-term infrastructure planning is based on a national, high-level vision for infrastructure and spatial development (including ambitions for accessibility, livability, safety, and economic competitiveness in 2040). This vision is implemented through the Long-Range Program for Infrastructure, Spatial Development and Transport (‘MIRT’). The MIRT involves an annual programming and budgeting system of roadway, railway, and waterway projects, as well as spatial projects of national importance (e.g. housing and industry). The MIRT programming process includes four stages: (1) problem analysis (2) generating alternatives and choosing a preferred solution, (3) planning (for implementation of the preferred solution), and (4) realization. Uncertainties can be identified for each MIRT stage, as well as across stages.

The problem analysis begins by identifying the potential gap between future transport demand and supply in order to specify the problem. This analysis is based on applying scenarios that have previously been shown to be incomplete. For example, they do not include exogenous developments such as the speed of implementation of automated vehicle driving, the possible implementation of road pricing, a decrease in population in some parts of the Netherlands, etc. These developments are at least plausible and will, if they happen, have serious consequences for future transport demand and/or supply. The choice of a preferred solution is based on a cost-benefit analysis of promising alternatives, which scarcely addresses uncertainties related to the future impacts of alternatives or monetization of impacts. With respect to the planning and realization stages, practice shows that (unforeseen) cost overruns and delays often occur. It is, therefore, difficult, if not impossible, to realize the long-term objectives behind the MIRT due to deep uncertainty, including technological uncertainty associated with the preferred solution, and uncertain behavior of the actors involved.

In essence, the MIRT policymaking process assumes that the future is known to a certain extent, an assumption that is increasingly being violated. This weakness has been recognized by policymakers, and ways are being studied to incorporate uncertainty into the process. We suggest the use of a flexible or adaptive policy framework that enables policymakers to take some actions right away (basic policy) and prepare future actions that allow for adaptations of the basic policy over time as experience and knowledge about the real world functioning of the transport system is gathered. It includes the specification of options that might be implemented in the future, in case critical events occur. In this presentation we propose a MIRT process that exemplifies the adaptive policymaking principles. Institutionalization of such a process would require changes in some existing executive, legislative, and judicial systems, since they are generally based on developing, implementing, and enforcing static, robust policies. But these may not be insurmountable barriers if the benefits are large enough.

Keywords: Deep Uncertainty, Adaptive Policymaking, Infrastructure Planning
63. Using Robust Decision Making To Support Seasonal Water Management In The Chao Phraya River Basin, Thailand

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ABSTRACT
A robust decision making application is demonstrated that supports seasonal water management in the Chao Phraya River basin in Thailand. The approach uses ensemble simulation and data mining tools to identify uncertain factors that may lead to unacceptable performance. The approach has the potential to support decision making through evaluation of decision performance under uncertain future conditions that may not be possible to characterize in terms of probabilities.

The Chao Phraya River basin supports significant dry season irrigation, particularly for growing rice, and the management of reservoir storage to support dry season irrigation has emerged as a challenge. Dry season irrigation in Thailand is managed through a mixture of non-binding recommendations about the maximum extent of rice cultivation, along with incentives to grow less water-intensive crops. Recommendations are made at the beginning of each dry season based on reservoir storage.

The extent of rice cultivation during the dry season frequently exceeds recommendations, and management authorities lack authority to prevent river withdrawals for irrigation. In practice, this means that authorities have to provide enough water to irrigate the actual planted area because of downstream municipal water supply requirements and water quality constraints. This results in dry season reservoir withdrawals that exceed planned withdrawals, reducing carryover storage to hedge against insufficient wet season runoff, which varies considerably from year to year.

The dry season planning problem in Thailand can therefore be framed in terms of decisions, objectives, constraints, and uncertainties. Decisions include recommendations about the maximum extent of rice cultivation and types of incentives given for growing less water-intensive crops. Objectives are to maximize benefits to farmers, minimize the risk of inadequate reservoir storage at the start of the following dry season, and minimize the amount spent on incentives. Constraints include downstream municipal water demands and water quality requirements. Uncertainties affecting the decision include the actual extent of rice cultivation, dry season precipitation and reservoir inflow, and precipitation and reservoir inflow in the following wet season.

A robust decision making approach is used to provide analytical support to this decision making process. The approach is based on a river basin simulation model and a crop water demand model. The crop water demand model estimates irrigation water demands, and the river basin simulation model estimates reservoir drawdown required to meet demands given forecasts of precipitation, evaporation, and runoff. An ensemble of uncertain model inputs is generated by randomly sampling from hydrological data and crop areas observed in the historical record. The input ensemble is used to generate an ensemble of results and indicator values for each of the decision objectives: farmer benefits, end-of-wet-season reservoir storage, and the cost of incentives. Threshold values are defined for each of the objectives to identify ensemble members for which objective values are unacceptable. The PRIM data mining algorithm is then used to identify input values associated with unacceptable model outcomes. The approach will be tested with stakeholders and decision makers to assess whether it is useful for evaluating and refining decisions given uncertain future conditions.
Keywords: Robust decision making, Seasonal planning, Irrigation, Uncertainty
64. Exploring Adaptation Tipping Points For Flood Risk Management In Europe

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ABSTRACT
It is assumed that policy changes in flood risk management could be triggered by different causes: for instance a significant increase in the frequency of occurrence of extreme events or an increase of the expected annual damage resulting from ongoing monitoring and research. Within the FP7 BASE project, we systematically explore different thresholds (adaptation tipping points) that could indicate a need for adapting flood risk management practices. We assess adaptation options for risk management of river flood risk at a European scale, by applying a framework for analysing tipping points. A European scale flood risk model is employed to calculate annual expected damage across river basins in Europe. The model simulates both a reference period (1960-1999) as well as two climate change scenarios (RCP4.5 and 8.5) for the periods 2010-2049 and 2060-2099. We take into accounts best estimates of current flood protection levels across Europe. Model results for the reference period have been evaluated using information from local studies. The results show how tipping points, under different climate scenarios, will lead to an earlier or later need for adaptation across countries in Europe. Tipping points are defined by measured by annual expected flood damages as percentage of national GDP. Also, European scale pathways are developed for flood risk management. We assess the performance of the associated adaptation options, aimed at risk reduction. This resulted in a map with early adaptors and identification of promising options for adaptation, as well identification of the period during which these measures will help to reduce flood risk to acceptable levels, and associated uncertainties. We show the variations in timing of these tipping points using a range of different climate models, as well as two RCP scenarios.

Keywords: Adaptation, Flooding, Tipping point, Europe, Impact, Climate change
65. From Theory To Practice; A Timeline Of Interventions By A Change Agent With The Developers Of The Dynamic Adaptive Policy Pathways

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ABSTRACT
Decision making under conditions of uncertainty and dynamic change pose challenges for decision makers and flood risk managers. Making decisions about the effects of climate change on flood frequency, magnitude and timing, is an example. The challenges arise from a combination of uncertainties in climate impacts, their dynamic behaviour over time, and the established institutional frameworks and practices adopted by the decision actors; frameworks and practices which are designed to create certainty for those relying on the decisions. We discuss how a theoretical approach for managing uncertainty and dynamic change (Dynamic Adaptive Policy Pathways, DAPP) has been ‘socialised’ within a local council using the Sustainable Delta Game as the catalyst. The result is a better understanding of a) the implications of uncertainty and change occurring in flood risk, b) adaptation as a sequence of decisions over time that can path-dependent, and b) the role that institutional frameworks and practices play in blinding actors to these impacts resulting in inadequate assessment of uncertainty and dynamic climate change.

The historic timeline of interventions taken with the Greater Wellington Regional Council in New Zealand has enabled the council to implement the DAPP approach through the development of an adaptive plan with flexible options. Moreover, it has enabled a transition to occur in decision practice from a static plan to a dynamic plan. The actions taken included; a workshop using visualisation of changing risk emphasising the effect of moving means on the tail of rainfall distributions; a report recording the workshop findings that presented the concept behind the DAPP; workshops to discuss the effect of climate change on flood frequency; discussion of how taking a mean or a number expressed as a probability gives a false sense of security where uncertainties are rife and dynamic change exists; contact from the developers of the DAPP in Netherlands and subsequent training and use of the Sustainable Delta simulation Game to “socialise” the actors in decision making under conditions of uncertainty; developing Dynamic Adaptive Policy Pathways for flood risk management options and identifying potential tipping points for policy options; presenting and using the Game with the politically elected local government decision makers; introducing an economist to the DAPP which lead to a real options analysis being included in the project assessment; review of the project assessments for implementation of the DAPP. The role of change agents, both external to the project and within the council, facilitated the transition over a 3 year period based. This has led to further development of the DAPP with its Dutch creators, to interface with the Game and be used to generate pathways, options prioritisation and for developing dynamic adaptive plans in real-world decision contexts.

Keywords: Uncertainty, Dynamic change, Climate change, Adaptive pathways
66. Evaluating The Resilience And Robustness Paradigms For Water Resource Systems Adaptation

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ABSTRACT
Resilience, as a component in fresh water supply systems evaluation, currently lacks clear definition and classification as an operational paradigm. Multiple methods exist for assessing Integrated Water Resource Management (IWRM) systems under deep uncertainty, however the output results from adaptation investigations can be highly dependent on the assessment metrics employed. Resilience as a potential primary metric for measuring the performance of a water resource system is an axiom increasing in popularity in current literature. In this research we explore the various potential calculations of resilience in terms of likelihood, duration, magnitude and overall system risk to isolate the potential impacts on adaptation strategy performance levels when varying this governing metric across uncertain future scenarios. The metrics are applied to a real world water supply adaptation case study and tested on a dynamic monthly time-step supply and demand model. Potential forms of calculating overall system robustness to uncertainty are also examined under the selected resilience metrics, isolating the effect of utilising a local and global robustness methodology, i.e. via the application of Info-Gap decision theory and Robust Optimisation respectively.

Keywords: water resources planning, decision making methods, resilience, robustness, climate change uncertainty, Robust Optimisation, Info-Gap decision theory
The Deeply Uncertain Local Sea Level Response To Anthropogenic Climate Change

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ABSTRACT
Sea-level rise threatens many coastal areas around the world. The integrated assessment of potential adaptation, mitigation, and geoengineering strategies critically hinges on projections that carefully resolve the upper tails of the uncertain local sea-level response. The major components that shape sea-level change respond in very different ways to climate change with respect to time-scale and potential threshold behavior. Besides, they show very different regional patterns of local response, mainly as a result of mass loss induced changes in gravity field. Therefore, most (not all) local sea-level projections rely on methods that explicitly assess the contributions of thermosteric expansion, the Antarctic Ice Sheet, the Greenland Ice Sheet, and the combined effect of glaciers and small ice caps.

The exact behavior of these different components is, however, characterized by deep uncertainties. Projected uncertainty ranges strongly depend on (necessary) pragmatic choices and assumptions on, for example, the applied climate scenarios, the level of modeling detail, which processes to include and how to parameterize them, and on the error structure of observational data. The relative likelihood of different assumptions is hard to assess. Hence, uncertainties of local sea-level response are hard to summarize in a single cumulative distribution function.

In this study, we aim to identify the major drivers of the deep uncertainties that characterize local sea level projections. First, we simply compare recently projected ranges and assess to what extent they might lead to different decisions. By interchanging assumptions from different assessments we try to isolate the major drivers. Finally, we explore the possibility to develop a simple model framework allows for easily including and excluding assumptions. Ultimately, this framework can be used to reproduce earlier assessments and to analyze and discuss what other sources of uncertainty might be important.

Keywords: deep uncertainty, local sea level projections, assumptions, simple modeling
68. Assessment Of The Application Of Decision Tools For Policy-Making Under Uncertainty In The Water Sector

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ABSTRACT
Over the last 15 years, greater attention has been paid to uncertainty in policy-making both in the academic literature and among practitioners in the water sector and a number of methods and computational techniques have been proposed to address the different types of uncertainty. At the level of uncertainty about values, for example, methods such as Monte Carlo simulation have become well established. Real options analysis, meanwhile, is widely used in corporations when taking capital investment decisions and has been applied in policy-making regarding climate change in the Dutch Delta (van Rhee 2011) and water resource planning in the UK, among other examples. At the deepest level of uncertainty, the adaptive policies and policy-making (Walker et al 2001) and adaptation pathways approaches (Haasnoot et al 2012) offer guidance to policy-makers.

These approaches need not be taken as alternatives – indeed, they may be better seen as complements. Most policy decisions are complex and have multiple dimensions: some variables in the decision have low uncertainty and can be analysed in terms of probabilities, while other variables may have high uncertainty requiring adaptive approaches. Hence, combined approaches could cover a spectrum of uncertainty in a policy decision.

The proliferation of models and techniques calls for a systematic assessment of their differences, strengths, weaknesses and scope for application. This paper aims to provide that assessment through a systematic literature review and Qualitative Comparative Analysis (QCA) of the application of tools for decision-making under uncertainty in the water sector. It identifies factors related to the successful application of the tools as well as barriers to successful application. The tools examined include: real options analysis, adaptation pathways, dynamic adaptive policy-making, and adaptation frameworks.

Through a literature search, we identify papers concerned with the practical application of these tools to the water sector, covering water resource development, water supply, flood management and wastewater management. For each paper, we identify:

- The policy objective and the type of uncertainty being addressed;
- The tool used;
- Whether the tool was used in isolation or jointly with other tools;
- Capacity of the decision-makers involved to use the tool;
- Limitations in the way the tool was applied;
- Indicators of the suitability of the tool to address that type of uncertainty.

We use QCA to identify sets of factors associated with the successful application of each tool. We consider whether these factors are similar across tools and the implications for combined application of the tools. We discuss the limitations of the tools both in theory and practice and deliver recommendations on how the tools may be adapted and refined in the future in order to make them more useful, and consider which other changes are needed in the policy process to allow for the full integration of these tools into the decision-making process.
Keywords: Water sector, Uncertainty, Decision-making tools, QCA
69. **Decision Tree Framework And Dynamic Adaptive Policy Pathways – How Can They Complement Each Other In Managing Uncertainty In Hydropower Projects?**

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**ABSTRACT**

Hydropower projects require huge investments while at the same time these investments are particularly sensitive to changes in climate and socio-economic conditions. For many hydropower projects in developing countries international financing is sought for. After a down period of involvement in hydropower projects the World Bank is considering again to finance such projects. To test the robustness of their investments in hydropower they have developed the “Decision Tree” approach, a conceptual framework for climate risk assessment and risk management. This approach has been tested on several dams in Nepal and proved to be very useful to support the decision to build or not to build, the current action. What is missing in this approach is the considering future options and adaptivity. In the Netherlands the Dynamic Adaptive Policy Pathways (DAPP) approach has been developed. Combining the Decision Tree approach and DAPP will bring in the decision making process the timing of (adaptive) actions and the consideration of path-dependency. In this contribution we will present the concept of the combined approach and apply that on two hydropower projects.

**Keywords:** uncertainty, hydropower, climate change, robust decision making
70. Bangladesh Delta Plan 2100: A Holistic, Adaptive And Long Term Strategic Plan

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ABSTRACT
Bangladesh aims at becoming a developed country by 2041. To achieve this goal, the country must balance its available resources as well as plan against uncertainty related to rapid urbanization, population growth, industrialization, land subsidence and environmental degradation as well as climate change related pressures such as sea level rise, more frequent drought and floods. It is imperative to have a long term plan for the sustainable development of the country.

Long term planning, has to deal with (climate and socio-economic) uncertainties and the lack of confidence in resource management. We look to science to develop a range of possible futures or scenarios to analyse what these uncertainties can mean in terms of climate change, water resources availability, food security, population change and economic growth.

The Bangladesh Delta Plan is the Government’s response to this need for ‘planning for uncertainties’, and the urgent need for sustainable and integrated development of the country. The plan aims to be a holistic, adaptive and long term (50 to 100 years) strategic plan for land and water management in support of a sustainable living environment. It provides a vision, scenarios and adaptive strategies with interventions for the long term and investment options for the short and medium term. The Government’s draft Delta Vision is defined as: “Ensure long term water and food security, economic growth and environmental sustainability while effectively coping with natural disasters, climate change and other delta issues through robust, adaptive and integrated strategies, and equitable water governance.”

In addition to traditional assessment methods such as MCA, the adaptive pathway approach, including the use of multiple scenarios, is used to analyse alternative strategies and measures in time deal with multiple futures and to avoid lock-in situations. Developing alternative pathways also supports the preparation of future decisions. Another core principle of the plan is integrated assessment of the strategies on water system and socio-economic policy indicators. Results of the Delta Plan are visualised through the Climate Atlas; an interactive touchtable in which the results of the 19 thematic baseline studies are combined, visualised and used as input for integrated strategy development. Strategies are developed for freshwater and flood risk management, as well as for the main river system and the coastal region. In addition to these long term cross-sectoral strategies, in-depth analysis – informed by developing adaptive pathways – is carried out in Hot Spot areas. In these areas, investment needs and opportunities are defined and detailed as Show Case for the Delta Plan.

Whereas making use of adaptive pathways and integrated assessment is a logical way of dealing with uncertainties, they also introduce a level of complexity into planning and decision-making. Existing planning practice is focussed on sector-based needs and resources and structured into 5-year plans. To ensure sustainable implementation and move beyond the planning stage; a strong linkage with the existing planning and implementation cycle is therefore key.

Keywords: adaptive pathways, long term strategic plan, Delta Plan 2100
71. Advances In National Scale Long Term Investment Planning For Flood Risk Management In The UK

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ABSTRACT
‘Decisions taken today will have a profound impact on the size of flood risks that future generations will need to manage. They will also strongly influence the options available for managing those risks’ (Foresight Future Flood Study)

Flood and coastal erosion risk management has always faced the challenge of decision-making in the face of multiple uncertainties relating to the climate, the economy and society. In response recent years have seen a significant focus on investment planning under conditions of future uncertainty in the private sector (e.g. Water Utilities); in Government agencies (e.g. Environment Agency) and in academic communities. Some of these methods are finding their way into investment planning processes (such as the Agency’s Long Term Investment Strategy, LTIS, and Thames Water investment planning processes).

The first part of the paper outlines the progressive development of the national flood risk assessment in the UK (since original development of the RASP methods, Hall et al, 2003). The paper explores the underlying methods and the various associated developments that have repeatedly been used to assess flood risk in England and Wales. The second paper focus on how these approaches have been used alongside long term investment decision analysis (taking account of severe uncertainties in climate, population and asset deterioration) to help determine the national investment need as part of the LTIS. In particular recent advances in the methods underlying the LTIS 2014 studies, and the role it plays in shaping the flood risk management agenda at a national scale, is explored. Throughout the paper, the tension between scientific rigour and practical application is discussed together with the key insights and lessons from the UK experience.

Keywords: long term, investment planning, national scale, flood risk
72. Is Unlocking Long Term Investment A Wicked Problem Of Deep Uncertainty?

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ABSTRACT
Avoiding “policy-based evidence” on the one hand and “uncertainty paralysis” on the other in the search for new and better options for dealing with messy and puzzling situations characterised by deep uncertainty cannot simply rest on better policy briefings and is enabled instead through creating a space for interactive and immersive learning.

We illustrate this proposition with reference to the OECD Ministerial Council Meeting 2015 which engaged in a scenario based policy discussions as a way to exchange knowledge and forge common ground on the challenges of unlocking investment for sustainable growth and jobs.

Our learning from this process centres on the importance of prototyping high-level structured dialogues across diverse policy communities. This prototyping is key to opening up a space for discussion of latent futures – which are already in the here-and-now but left tacit, suppressed or denied by the “official future” of the dominant policy narrative. Deep uncertainty creates anxiety in the expert (including senior policy makers). Combined with institutional incentives for stepping up in crisis, rather than avoiding missed opportunity, this anxiety is expressed of in terms of the fear that conflict will lead to chaos rather than inform effective action.

Addressing the weak culture of foresight in policy, which often confuses scenario planning with conditional projections called “baseline scenarios”, requires attention to a combination of cognitive, behavioural and institutional barriers in diplomatic and policy analysis communities. It involves a fundamental shift from “predict and control” and “zero sum” strategies, to “design rationality” and balancing competitive tactics and collaborative strategies. Rather than the predictability of decision outcomes, the emphasis shifts to the quality of judgment in terms of the quality of strategic conversation which is enabled by the social and intellectual processes of scenario planning that contribute to the framing, reframing and re-perception the present messy and puzzling situation.

Keywords:
73. **Prospective strategy: balancing Anticipation and Agility**

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**ABSTRACT**

An important strategic function of government is to adequately anticipate future developments – even though they are inherently uncertain and unforeseeable (Fuertth, 2009; Slaughter and Inayatullah, 2005; Lempert et al, 2003; Newman and Howlett 2014; Schwartz, 1996; Van Asselt, Mesman and Van ‘t Klooster, 2007). As complexity grows and systems become more integrated, the necessity of prospective strategizing grows, while it at the same becomes harder as developments are less linear and less continuous. In order to prepare for what may be coming, organizations attempt to look beyond the present status quo and to expect non-linear and discontinuous events and developments (Brown, Rappert and Webster, 2000; Swanson et al, 2009, 2010; Walker et al, 2010; Inayatullah, 2006; Moynihan 2009; Riedy, 2009; Van der Steen, Van Twist, Van der Vlist and Demkes, 2011; Van der Steen, 2014; Howlett & Ramesh 2014; ).

*Strategy formulation* is not merely a matter of formulating the right goals and the route towards achieving them; it is also about formulating *timely* answers to emerging problems. Strategizing is not only about doing the right things and doing them right, but also about doing it at the right time. Therefore, strategizing involves a prospective element, where strategists take into account not only what is already there but for what may be coming (Van Twist, Peeters and Van der Steen, 2007). Minor developments can become major disruptions, as major drivers start out small and fundamental change often grows from small seeds. Also, trends and developments that are defining variables for the organization in the present may be marginal in the near future. Just as seemingly insignificant cracks in structures have the potential to break down the entire building.

Time and time again the evaluations of disasters and crises show that, on second glance, there were many early indicators and signals for the unexpected and unanticipated events. In hindsight, we can often see what we had missed prospectively. Complexity theory calls this the *retrospective coherence* of complex systems: in hindsight, when we know what to look for, there is plenty to see and there are recognizable patterns that lead to what took us by surprise. For instance, the report by the US Senate ‘9/11 Commission’ shows an abundance of ‘clear’ signals of the upcoming ‘unprecedented’ attacks. That seems to indicate incompetence of security services to connect the dots between signals; they did not miss one clue, but an entire array.

Evident as patterns may seem in hindsight, their coherence is essentially retrospective; we ‘recognize’ them because we know the outcome. For organizations, the challenge is to turn retrospective coherence around and develop capacity to recognize *prospective coherence*. That also implies the ability to look beyond continuity and ‘foresee’ discontinuity even under conditions of ‘deep uncertainty’ (Walker et al, 2010) and for ‘wicked issues’ (Rittel & Webber, 1973). Therefore, it is important to understand how early warnings can be collected, interpreted and used for strategy in a productive and systematic way. How can the ‘right’ signals be distilled from the infinite tangle of possible developments? How can early warnings be interpreted when they are often ambiguous and open for different interpretations? And how early warnings be linked to and used in the current strategy while they often diverge from what we currently know and base our strategy on? That involves the capacities of *anticipation* and *agility*; systematic attempts to foresee and ‘know’ what may be ahead, but also the capacity to deal with inevitable surprises, unexpected developments, and
emerging issues. Amidst complexity and deep uncertainty, prospective strategy is a matter of balancing anticipation and agility.

This paper describes the practical attempts of an organization to develop the prospective capacity to recognize early warnings and weak signals that will or may define the future of the organization. We first conceptualize the different ways for organisations to look at early warnings and weak signals and describe the inherent dilemmas of that activity. After that, we turn to our empirical case study by describing the design of the Early Warning (EW) system of ‘Rijkswaterstaat’, the Dutch government department of Public Works and Water Management. Furthermore, we describe how the organization further professionalized and streamlined this methodology over the years in an attempt to increase the impact on strategic decision-making. We conclude with a discussion about the findings on how early warnings can be used for prospective strategizing, and what the balancing of anticipation and agility means for designing policy-systems that can deal with deep uncertainty.

Keywords:
74. Planning, Programming and Budgeting of Infrastructure and Spatial Development in Uncertain Times: Experiences with Adaptive Planning in the Netherlands

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ABSTRACT

As water safety and transport infrastructure are seen as crucial national interests, an extensive set of instruments has been developed for the planning, programming and budgeting in the Netherlands. National policies are primarily implemented through projects. Accordingly, the Dutch Ministry of Infrastructure & Environment prepares annually the Long-range Programme for Infrastructure, Spatial Development and Transport (‘MIRT’); a programming and budgeting system that regulates the budgets and is updated every year. This MIRT process involves a rather extensive staged process of developing plans, analysis, stakeholder involvement, review and decision-making resulting in projects that might be implemented. The basic idea behind MIRT seems to be a rather technical-rational planning concept, in which there is one dominant actor and a strong focus on good project management (controlling scope, time and budgets), on managing risks and on juridical acceptability.

However, in current planning we are confronted with (deep) uncertainties of climate change, ageing infrastructures, a shift from new infrastructure development toward replacing existing infrastructure, societal and spatial transformation processes, financial-economic dynamics and critical stakeholders, which are all challenging this rather technical-rational planning concept. Important issues in practice are: the protracted planning process, dependency on national funding, cost and time overruns, limited public support, detailed modelling and calculations, vulnerability of decisions for negative court decisions and limitations in flexibility during all stages of the planning process. These complexities call for a more adaptive planning, programming and budgeting approach.

This has been acknowledged by national government, which is currently renewing the MIRT framework focussing on 1) a broad scope focusing on challenges instead of solutions (projects), 2) a tailor-made approach and 3) cooperation between multi-stakeholders (co-creation). Also more adaptive planning approaches are developed relating to modelling, using scenarios, new ways of financing, programmatic approaches and innovative concepts for cooperation between public and private parties. A shift is sought from a sectoral, project-oriented planning towards more task-/goal-oriented planning in which the various challenges in a region and the network are central (‘opgave-gericht werken’). In addition, in recent practice experiences have been gained with more adaptive planning such as in the ‘Room for the River’-programme and the ‘RRAAM’-project (integrated regional development Amsterdam-Almere).

This paper aims to discuss the challenges and approaches in current Dutch infrastructure and spatial planning for dealing with deep uncertainties. Although this paper focuses on Dutch planning, we believe that the discussion is also relevant for an international audience as many of the issues are applicable in other (western) societies. To this end, the paper describes first the current MIRT framework and planning process in the Netherlands. Subsequently, current dilemmas and challenges of dealing with deep uncertainty in planning practice are discussed. Next a discussion follows on the new avenues that are explored to deal with these challenges and recent practical experiences gained with more adaptive planning. Finally some conclusions are drawn and promising avenues and issues for future exploration are discussed.
75. Dealing with the uncertainty of severe weather and assisting emergency managers to make better decisions

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ABSTRACT
Australia has experienced a decade of intense tropical cyclones, monsoon lows, severe thunderstorms and extreme riverine and flash floods with the state of Queensland the most significantly affected. The total damages for weather related disasters in Queensland alone is estimated at over $15 billion dollars starting with over $500 million dollars from Tropical Cyclone Larry in 2005/06 and peaking in 2011/12 with over 7 billion in damages from Tropical Cyclone Yasi and the extreme floods in the Queensland capital city of Brisbane.

The Bureau of Meteorology is Australia’s national weather, climate and water agency. Its expertise and services assist Australians in dealing with the harsh realities of their natural environment, including drought, floods, fires, storms, tsunami and tropical cyclones. The Bureau is an organisation that makes risk based decisions on uncertain forecasts every day and especially during extreme events. Events evolve rapidly and our key role is to present and communicate uncertain information is such a way that leads to quality risk-based decision making by emergency managers and the community.

The focus will be on the deep uncertainty involved in predicting the movement, intensity and wind and storm surge impacts of tropical cyclones and the complexities of predicting intense rainfall and floods. The weather forecasters have access to eight different Numerical Weather Prediction (NWP) models providing forecasts of the cyclone movement and all have equal likelihood. The flood forecasting service operates at a local scale and predicts flood levels at specific points along a river but relies on rainfall forecasts from the same NWP models and the uncertainty in time, space and intensity are considerable. The Bureau is developing ensemble based rainfall forecasting systems that try to quantify the uncertainty but how this is then used by forecasters and disaster managers.

This presentation will cover how we communicate uncertainty in our operational products, briefings, liaison and education programs focusing on Topical Cyclones and Floods and using a case study of events that occurred during the summer of 2014/2015 including Tropical Cyclones Marcia and Nathan.

Tropical Cyclone Marcia had ingredients that challenged the warning system with extremely rapid development, rainfall impact that occurred well away from the system centre and it struck much further south than other systems of this strength had previously done.

Tropical cyclone Nathan developed the month after TC Marcia and provided an opportunity to better describe the uncertainty within routine products and media broadcasts.

The presentation will explore these differences, bringing decision making into the frame of the emergency managers and the community taking action on the ground.
ABSTRACT
Over the past three years, the World Bank Sustainable Development group and Climate Change group have been tailoring and applying a number of decision-making under uncertainty tools to manage deep uncertainties and disagreement in long-term infrastructure projects. In Lima, Peru, we integrated and adapted several methodologies to help the water utility, SEDAPAL, build their Master Plan. In Nepal, we supported the government in the hydropower sector planning, evaluating basin level planning and an individual project design, and following the “Decision Tree” developed by the World Bank Water Sector. In Colombo, Sri Lanka, we applied Robust Decision Making to help the city develop and build consensus around a Colombo Wetland Management Plan. In Peru again, we worked with the Ministry of Trade and Competitiveness and the Ministry of Transport to identify the critical segments of the Peruvian road network and their exposure to floods and storm surges. We then used DMU techniques to prioritize interventions now and in the next decades.

These projects were conducted in close collaboration with the client countries, achieved their full buy-in, and eventually modified the decision makers’ initial plans. SEDAPAL, for instance, received the green light for the implementation of the revised Master Plan of water supply investments, while the government of Sri Lanka decided to freeze development on the urban wetlands and is developing pilot projects to manage and fully integrate wetlands in the life of the city. In Nepal, DMU methods are now being used to prioritize projects to be financed by the IFC. Overall, more and more project leaders within the World Bank are now willing to apply these techniques.

These successes however did not come without challenges. First, access to good data and lack of appropriate models is often a challenge in our client countries. As a result, significant time and budget have to be spent on both data collection and model development. When sufficient resources were not available, we treated most parameters of the analysis as uncertain, but this complicates the decision making process as decision makers struggle not find confidence in the results when they are determined by too many uncertainties. Nevertheless, the analyses still raise interest as a proof of concept for future projects.

Second, support in monitoring and implementation of the projects is not ensured after the decision making process. Resources are available to assist clients to make decisions but may not be available to help them through the (political, often) implementation process. In Sri Lanka for instance, although the Ministry of Urban Planning has decided to freeze the development on the wetlands, this decision may be reversed in the next few years when the Minister changes and priorities change. A way to mitigate this issue is to build capacity in the client countries, in government agencies and universities in particular.

Finally, the scaling up of DMU methods within the World Bank is challenged by limited internal resources, either technical, to carry the analysis in house, or financial, to contract external consultants. Even with sufficient resources, the number of DMU experts is still contained compared to the projects that would need analytical support. Therefore, training is again paramount. As a start, we are building a community of practice within the World Bank that we hope we can link with the community of this workshop.

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76. Challenges and Progress in Implementing DMU methods in World Bank Projects
The impacts of climate change on poverty in 2030, and the potential from rapid, inclusive and climate-proof development

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ABSTRACT
The impacts of climate change on poverty depend on the magnitude of climate change, but also on demographic and socio-economic trends. This analysis creates hundreds of baseline scenarios for future economic development in the absence of climate change and in each of the 92 countries of the I2D2 database. It combines household surveys and micro-simulation techniques in a framework inspired from robust decision-making techniques, in which all uncertain parameters are varied systematically to the full range of possible outcomes. Then, the conditions under which extreme poverty can be eradicated by 2030 are identified. The drivers of success are different across countries: for instance, demography dominates in many poorer countries, while redistribution only matters in middle-income countries. Out of these scenarios, two representative scenarios are selected. One is optimistic regarding poverty and is labelled “prosperity”; the other one is pessimistic and labelled “poverty”.

Results from multiple sector-scale analyses of climate change impacts are introduced in the two scenarios, looking at agriculture, health, and natural disasters. The analysis is partial, disregards possibly important impacts, and results remain highly uncertain. It also looks only at 2030, a timescale for which climate change remain moderate compared with expected long-term changes. Conclusions are twofold.

First, by 2030 climate change can have a large impact on poverty, with between 3 and 122 million more people in poverty, but climate change remains a secondary driver of poverty trends within this time horizon. Climate change impacts do not only affect the poorest: in 2030, the bottom 40 percent lose more than 4 percent of income in many countries. The regional hotspots are Sub-Saharan Africa and – to a lesser extent – India and the rest of South Asia. The most important channel through which climate change increases poverty is through agricultural income and food prices.

Second, by 2030 and in the absence of surprises on climate impacts, inclusive climate-proof development can prevent most of (but not all) the impacts on poverty. In a scenario with rapid, inclusive and climate-proof development, climate change impact on poverty is between 3 and 16 million, vs. between 35 and 122 million if development is delayed and less inclusive. Development appears to reduce the impact of climate change on poverty much more than it reduces aggregated losses expressed in percentage of GDP.
78. Lessons and challenges from early applications of Dynamic Adaptive Policy Pathways

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Decisions on adaptation and other investments are taken over time, often in response to changing conditions and events that illuminate current or future problems and opportunities. Exploring staged decision making through adaptation pathways is receiving increased attention both in science and practice. Under deep uncertainty, the exploration of pathways under various changing conditions helps in identifying both actions that should be taken in the short term and long-term options that can be taken if needed. One approach, for which several applications already exist, is Dynamic Adaptive Policy Pathways (DAPP). A key element of DAPP is a vulnerability assessment to assess the conditions under which a policy starts to perform unacceptably (an ‘adaptation tipping point’), which is then used to explore various adaptation pathways (sequences of actions after an adaptation tipping point). Pathway maps enable policy analysts, decision makers, and stakeholders to recognize potential ‘locked-in’ situations and assess the flexibility, robustness, and efficacy of decision alternatives. ‘Signposts’ and ‘triggers’ can then be specified to get early warning signals for the implementation of the next actions in an adaptation pathway. Most of the applications of DAPP have been in deltas, coastal cities, and floodplains, often within the context of climate change adaptation.

In this talk, we will describe the DAPP approach, discuss different methods and techniques that have been employed in applications of DAPP, and close with lessons learned and key challenges that require further attention. From early applications of the DAPP approach, different ways of identifying adaptation tipping points emerged, including (a) sensitivity analysis and expert judgment, (b) semi-static assessment, and (c) transient scenarios. Given an overview of tipping points, pathways can be specified. This has been done a) by exploring (combinations of) actions after these points, b) through narratives, and simulation gaming, and c) computationally through the use of multi-objective robust optimization and agent based modelling. Early DAPP applications showed that the evaluation of alternative pathways has received little attention and appears not straightforward, as assumptions about the project time horizon, discount rate, and assessment of costs of switching between pathways are crucial for the results. Moreover, the way in which a monitoring plan is to be designed in light of an adaptation pathway has received little attention so far. Early applications show that, although from a policy perspective it makes sense to select triggers that come from norms, values, and objectives, it might be better to use signposts that occur earlier in the impact chain as signals for changes.