

Chapter 4

Showcasing Practitioners' Experiences

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Key Messages

Twelve real-life cases show how policy-makers, decision-makers and researchers have struggled together to deal with uncertainty in adaptation decision-making. Some key features are as follows:

- Most real-life cases conscientiously addressed uncertainties related to the use of scenarios. Few cases dealt with statistical uncertainty and /or recognized ignorance.
- In all cases a combination of multiple methods is applied to address uncertainty. In most of the cases these include expert elicitation, stakeholder involvement and sensitivity analysis.
- The cases all show that conscientiously addressing uncertainty had an effect on the adaptation decision taken and/or changed attitudes to climate change adaptation.
- Most cases show a clear shift in thinking from a deterministic or 'single optimal solution' approach to adaptation towards a flexible, robust and no-regret approach.

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4.1 Introduction

This chapter describes real-life cases showing how policy-makers, decision-makers and researchers have struggled together to deal with uncertainty in adaptation decision-making (Fig. 4.1). We selected these case studies through a world-wide call for practical examples of adaptation decision-making processes and dealing with climate-related uncertainties. Out of the 27 real life stories, that were submitted in a prescribed format, 12 illustrative cases were selected by a group of experts, all of them members of the CIRCLE-2 Joint Initiative on Climate Uncertainties.¹ The key selection criteria were whether the story increased understanding of handling uncertainty in adaptation planning and implementation, and whether the case showed the impact of conscientiously addressing climate uncertainties on the decision taken. Other criteria for selection included: the link to a real adaptation decision-making process, the involvement of different stakeholders, and diversity in scope (geographical, sectorial and scale).

Despite some bias towards Water Management, Infrastructure and Disaster Risk Reduction projects, the cases show a wide range of decision-making processes to address climate change impacts. Only two cases show a clear single-sector focus, while all others report a multi-sector approach involving agriculture, health, biodiversity, energy and finance. All the case study initiatives are publicly funded and present a clear geographical bias towards Europe (10 cases out of 12). This is due to the fact that although we strived for an open submission of case studies and different international networks and websites were used, we mainly approached potential authors via the European network CIRCLE-2, different European research programmes, and national research programmes such as Knowledge for Climate (The Netherlands), Climate Change-Snowll (Austria) and Klimzug (Germany). Five cases describe how uncertainty is addressed at the national scale, two cases at the sub-national scale and five at the local scale (see Table 4.1). Since adaptation is a relatively new field, most of the decision-making processes deal with (policy) plans, while the actual implementation is still some years down the line. Consequently, the uncertainties dealt with in the cases are predominantly related to assessment of climate change impacts and vulnerability. Very few cases explicitly address uncertainties as to the appraisal of adaptation measures or implementation of adaptation.




























The stories are constructed on the basis of interviews with the main decision-maker and the principal scientist involved, together with information on the case study provided in the submission stage. Each description highlights the challenge the decision-maker was facing, the types of climate uncertainties addressed, methods that are used to deal with uncertainties and the final decisions taken. All case studies show how the process of conscientiously addressing climate uncertainties has affected these decisions. Two types of decision making are distinguished
















¹This initiative is a coordinated transnational funding effort, within the scope of CIRCLE-2, aiming at sharing and advancing scientific knowledge and practice on dealing and communicating climate and climate change uncertainties in support of adaptation decision-making. More information on the Initiative is available at: http://www.circle-era.eu/np4/P_UNCERT.html



Fig. 4.1 Real-life cases and their geographic location

Table 4.1 Selected case studies according to their geographical location, sector, scale and type of decision-maker distribution

Case	Country	Sectors and Domains	Scales			Decision maker		
			National	Regional	Local	Private	Public	
Water Supply Management in Portugal (4.2.1)	Portugal							
UK Climate Change Risk Assessment (4.2.2)	United Kingdom	         						
Water Resources Management in England and Wales (4.2.3)	United Kingdom							
Water Supply in Hungary (4.2.4)	Hungary							
Climate Change and Health in The Netherlands (4.2.5)	Netherlands							
Flood Risk in Ireland (4.2.6)	Ireland		   					
Coastal Flooding and Erosion in South West France (4.2.7)	France	 	   					

Québec Hydro-Electric Power (4.2.8)	Canada			 •											• ^a			
Austrian Federal Railways (4.2.9)	Austria			•											•			
Dresden Public Transport (4.2.10)	Germany									•					•			
Hutt River Flood Management (4.2.11)	New Zealand														•			
Communication of Large Numbers of Climate Scenarios in Dutch Climate Adaptation Workshops (4.2.12)	Netherlands			   		 •									•			
Total		7	2	2	1	1	1	2	10	1	4	1	1	1	5	3	0	12

^aState-owned

i.e. strategic and operational. Strategic decisions are fundamental and directional, and over-arching. Operational decisions, on the other hand, primarily affect the day-to-day implementation of strategic decisions. While strategic decisions usually have longer-term implications, operational decisions usually have immediate (less than 1 year) implications.

4.2 Real Life Case Studies

4.2.1 *Water Supply Management in Portugal*



Key Messages

This study examined a variety of uncertainties to determine the vulnerability of a Portuguese water supply company to climate change and developed an adaptation strategy to deal with these vulnerabilities.

Key messages from the project were:

- Decision makers and stakeholders needed to be continuously involved for the success of the project. A high level of trust, generated by time-consuming engagement between the parties was necessary to deal with different views on the topic, and the company's confidential data and internal processes.
- Transferability of know-how on the topic between practitioners and researchers was critical and organisations should be able to share this knowledge.
- Quantifying cumulative uncertainty was achievable and important to support decisions, when clear criteria were agreed from the start and properly communicated.

Background

Empresa Portuguesa das Águas Livres (EPAL) is a Portuguese state-owned water utility company. It supplies about three million people living in 35 municipalities on the north bank of the Tagus River, representing more than a quarter of the Portuguese

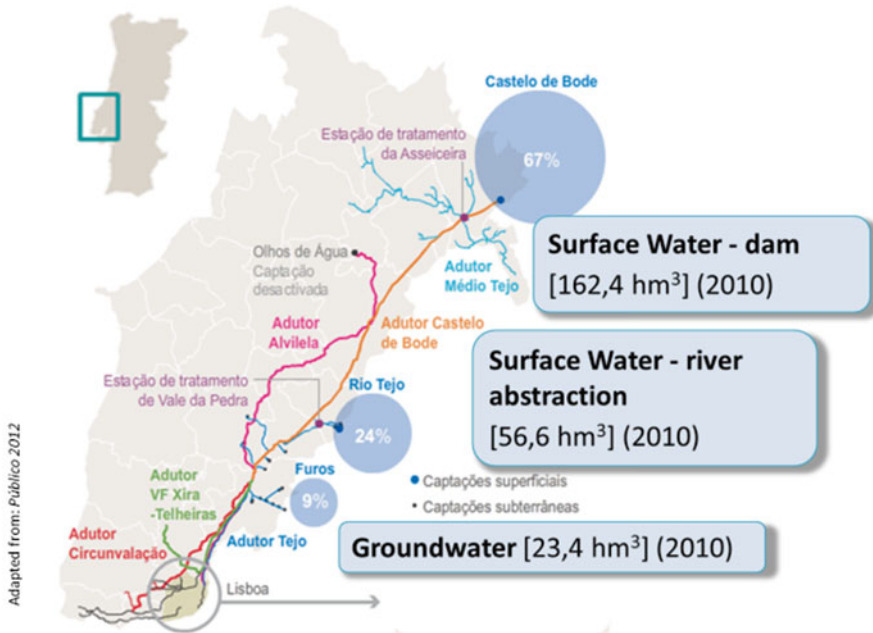


Fig. 4.2 EPAL's geographical system

population. It has three main sources of water: a large reservoir as the prime water source (67 %), the Tagus river (24 %) and groundwater from several boreholes (9 %). Further details are given in Fig. 4.2.

The purpose of the project was to: (i) assess potential climate and demand changes in the geographical area served by the water utility; (ii) identify climate change impacts on the company's water sources; (iii) assess system vulnerabilities, and (iv) identify and appraise a set of potential adaptation options and measures.

The project originated within the company's executive board, because the water sector is seen as one of those potentially most affected by climate change in Portugal. EPAL is conscious of its responsibilities to take climate change into consideration because its main aim is "to supply water, now and in the future, every day, all year round, with the necessary quality and at an acceptable cost". The project began in October 2010 and ran until May 2013.

Coordination of the project was provided by the Faculty of Sciences of the University of Lisbon and involved three other Portuguese universities. From the company's side, there was involvement from EPAL's technical and management staff (one project management committee and one advisory committee) providing company systems data and feedback on the results from the demand scenarios, impact models and other scientific information. Out of 100 of the company's key

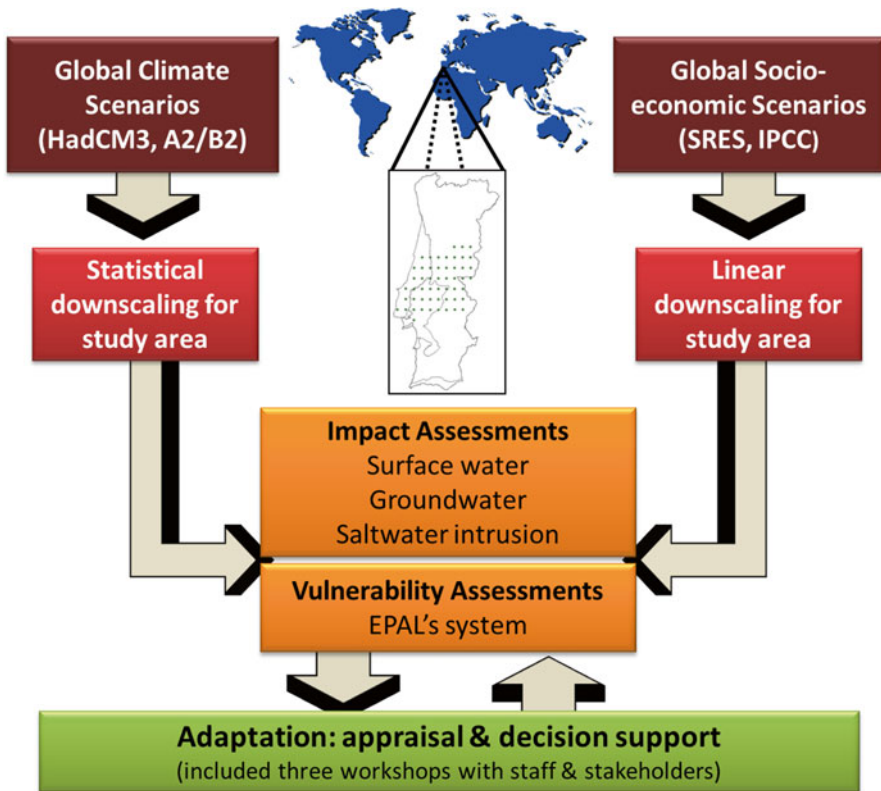


Fig. 4.3 Project general methodology. Top-down and bottom-up approach

external stakeholders (e.g. governmental, regulator, shareholders, clients, NGOs, utilities) about 20 were invited to specific meetings.

Process

The project methodology is shown in Fig. 4.3. Focussing on the development of an adaptation strategy, the project initially reviewed existing global climate and socioeconomic scenarios and downscaled these to suit the company's geographical and time scales. In the past EPAL has considered non-climatic information, such as changes in demographics, and projections on water availability have been incorporated into the project's impact assessments on surface and groundwater resources. In this study scenarios have been utilised. These include climate scenarios (e.g. precipitation) affecting water supply, and socioeconomic scenarios (e.g. demographics) affecting demand. Using these scenarios, impacts



Fig. 4.4 EPAL's Adaptation workshop

on surface water sources, groundwater sources and salt-freshwater interfaces in estuaries were modelled in terms of water quantity and quality. Vulnerability was then assessed by analysing EPAL's capacity to adapt to the potential impacts.

Climate data used

- Interpolated data from European Climate Assessment & Dataset with a grid of 25×25 km
- NCEP reanalysis data for calibration and model validation
- Coupled atmosphere-ocean general circulation model (HadCM3) downscaled using a generalised linear model
- Climate change storylines with quantitative information for socio-economic scenarios A2 and B2 (SRES) to the middle and end of century.

Three workshops were held where the results were presented, discussed and some decisions were validated. These meetings aimed to analyse the main results of the project in terms of potential impacts and adaptation measures, identifying potential synergies, conflicts and trade-offs between different alternatives and different stakeholders (Fig. 4.4).

In the last workshop, each potential impact was labelled with a level of scientific confidence (inversely correlated with uncertainty level) in order to better support the decision. To prioritise the adaptation measures for each potential impact and vulnerability, a gaming-like approach was developed. Participants were divided into smaller groups and had to choose from a set of adaptation measures (in the form of

adaptation cards, previously co-created and characterised together with EPAL staff via a parallel participatory approach that focused on the adaptation objectives) and discuss the final results.

Overall, over 50 of EPAL's staff and about 20 different external stakeholders participated in the workshops. Contact is being maintained with a sample of these institutions to obtain their feedback and further understand their influence on EPAL's adaptation processes. The majority of the adaptation measures, for example the reduction of pollution in aquifers, need the support of external stakeholders, and the feasibility of measures is being discussed with them.

Continuous interaction with the two internal project committees was designed, among other objectives, to help EPAL's staff and stakeholders understand the meaning of uncertainty in the context of climate adaptation decision-making.

Uncertainty Assessment

Within each project phase different levels of uncertainty were acknowledged and considered for each of the project's activities:

Example of handling uncertainty in hydrological impact modelling using a sensitivity analysis

EPAL is concerned that the freshwater-saltwater interface along the Tagus River estuary could reach its abstraction point at Valada (about 32 km upstream) through a potential combination of reduced river discharge, sea level rise and salinity increases. This would either require the implementation of adaptation measures such as nanofiltration, or the abandonment of the facilities. Past assessments place the interface 15 km downstream of EPAL's abstraction point and a numerical simulation model (CE-Qual-W2) was used to evaluate the potential impacts. However, consultation with the company's experts revealed that the complexity around the river-estuary-sea system created extra uncertainty and reduced their confidence in the model results. A sensitivity analysis using additional model runs was undertaken and results supported, with a high level of confidence, that significant salt water intrusion is not to be expected. Thus, the companies' decision was to not advance with specific adaptation measures at this time.

- Selection of scenarios,
- Socioeconomic data downscaling,
- Climate data downscaling,
- Hydrological and hydrogeological impact modelling,
- Vulnerability assessments,
- Adaptation options appraisal.

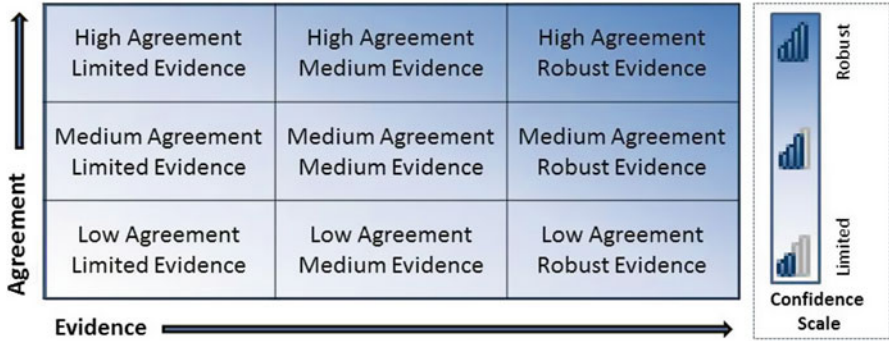


Figure: Confidence integrates models and scenarios Agreement and current and future Evidence. Confidence increases towards the top-right corner as suggested by the increasing strength of shading and it was expressed in three qualifiers: Limited, Medium and Robust (Adapted from "Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties", 2010)

Fig. 4.5 Confidence levels used to communicate uncertainties to decision-makers

Based on current adaptation literature, uncertainties within these activities were dealt with in the following ways:

- Scenario analysis,
- Expert elicitation,
- Sensitivity analysis,
- Stakeholder involvement,
- Extended peer review (review by stakeholders).

From the beginning, the various scientific teams were asked to qualify the uncertainties in their results. Each potential impact was then communicated and associated with a level of confidence derived from a balance between the level of agreement (with other comparative studies) and the level of evidence (statistic robustness of models; quality of observed data) (Fig. 4.5).

The uncertainties associated with the impact of competition between EPAL and other organisations on water resources were not taken into account in a quantitative way (i.e. via models), but addressed through the involvement of stakeholders and expert elicitation of ‘what if’ issues.

Effect of Uncertainty on Decision-Making

From the start of the project it was clear that not all of EPAL’s staff involved had the same attitude to the climate change topic and level of confidence on the potential results of the vulnerability assessment. This is partly because they come from different areas within the company and so have different perspectives regarding the role of risk and uncertainty in operational and strategic decisions. In practical terms this meant that some EPAL staff members felt that for some decisions, despite uncertainties, there was enough confidence in the results, while for other results there was a need to further reduce those uncertainties. For other EPAL staff members still, uncertainty was deemed to be too large for results to provide sufficient support to decisions.

For example, quantity and quality water issues in the *Castelo de Bode* dam (primary source of water to the system) due to changes in temperature, precipitation and stream flow were modelled using two sets of emissions scenarios (A2 and B2). This provided information to support decisions on the strategic use of the reservoir relative to other available sources in the future. It also inspired the creation of a protocol with EDP (a large electricity company that utilises the same water source) to agree on rules for the use of water in years of scarcity. However, the reservoir is located in an area prone to forest fires that may require adaptation efforts to prevent such wildfires. Despite the efforts of researchers it was not possible to model the physical interactions of such fire events and their consequences on water quality. Significant uncertainties still remain and no decisions on specific adaptation options were made. This contrasted with the work carried out for the Valada abstraction point (see box on ‘dealing with uncertainty’) that accounts for about one quarter of EPAL’s supplied water. In this case the confidence of EPAL’s decision-makers was improved through further analysis to enable them to make decisions on investments in the Water Treatment Plant associated with the abstraction point, such as not to install a nano-filtration system in the near future.

Finally, an adaptation strategy has been prepared, including a diagnosis of EPAL’s current and future climate related vulnerabilities, and a set of prioritized adaptation options. The strategy was designed to accommodate a general no-regret approach but for some decisions the precautionary principle was applied. The strategy is designed to support decisions on which adaptation options or sequences of adaptation measures (pathways) are better able to cope with the current and future vulnerability. The chosen options are expected to be mainstreamed into EPAL’s regular management and strategic planning and can also serve the company in its relationship with external stakeholders. The strategy’s implementation is to be monitored by the company and revised every 5 years.

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4.2.2 UK Climate Change Risk Assessment



Key Messages

The UK Climate Change Risk Assessment (CCRA) was the first-ever comprehensive assessment of the potential risks and opportunities arising as a result of climate change in the UK. The results of the Climate Change Risk Assessment are being used by a variety of government departments in Scotland, Wales and Northern Ireland to facilitate comparisons across sectors, prioritise adaptation actions and improve confidence in decision-making.

Key messages from the CCRA were:

- Despite uncertainties, evidence is now sufficient to identify a range of possible climate change impacts and indicate their relative magnitude to inform adaptation and planning.
- Decision-making needs to consider uncertainties in order to identify robust options.
- Presenting the full spread of results to stakeholders through the use of the “score cards” was a useful way of communicating uncertainty.
- Flexibility needs to be built into adaptation planning to allow for a future climate that may change more slowly, more quickly or in a different way than currently expected.
- The use of “sector champions” appeared to be a useful approach to involve relevant stakeholders in the assessment of risks, including the management of related uncertainties.
- Climate change is only one driver amongst many and should be considered alongside other drivers when assessing future risk.

Background

The UK Climate Change Act 2008 made the UK the first country in the world to have a legally binding, long-term framework to cut carbon emissions and develop adaptation strategies?. As a response to this, the UK government set up the first CCRA, which was reported in 2012 and is scheduled to be updated every 5 years to take into account new data and improved understanding of the issues. This first report outlined some of the most important risks and opportunities presented by climate change across 11 sectors. By analysing existing data, impacts were assessed for three time slices and across three emission scenarios.

The consortium² carrying out the review was supported by leading technical experts in the 11 sectors who acted as “sector champions”. The aim was to build a consistent picture of risk across the UK and allow for some comparison between disparate risks

²HR Wallingford led a consortium consisting of the Met Office, AMEC Environment & Infrastructure UK Ltd, Collingwood Environmental Planning, Alexander Ballard Ltd, Paul Watkiss Associates and Metroeconomica, in order to carry out the review. Sector champions included Cranfield University, CEFAS, Forestry Research, Birmingham University, Acclimatise, the Hutton Institute and the Centre for Ecology and Hydrology.

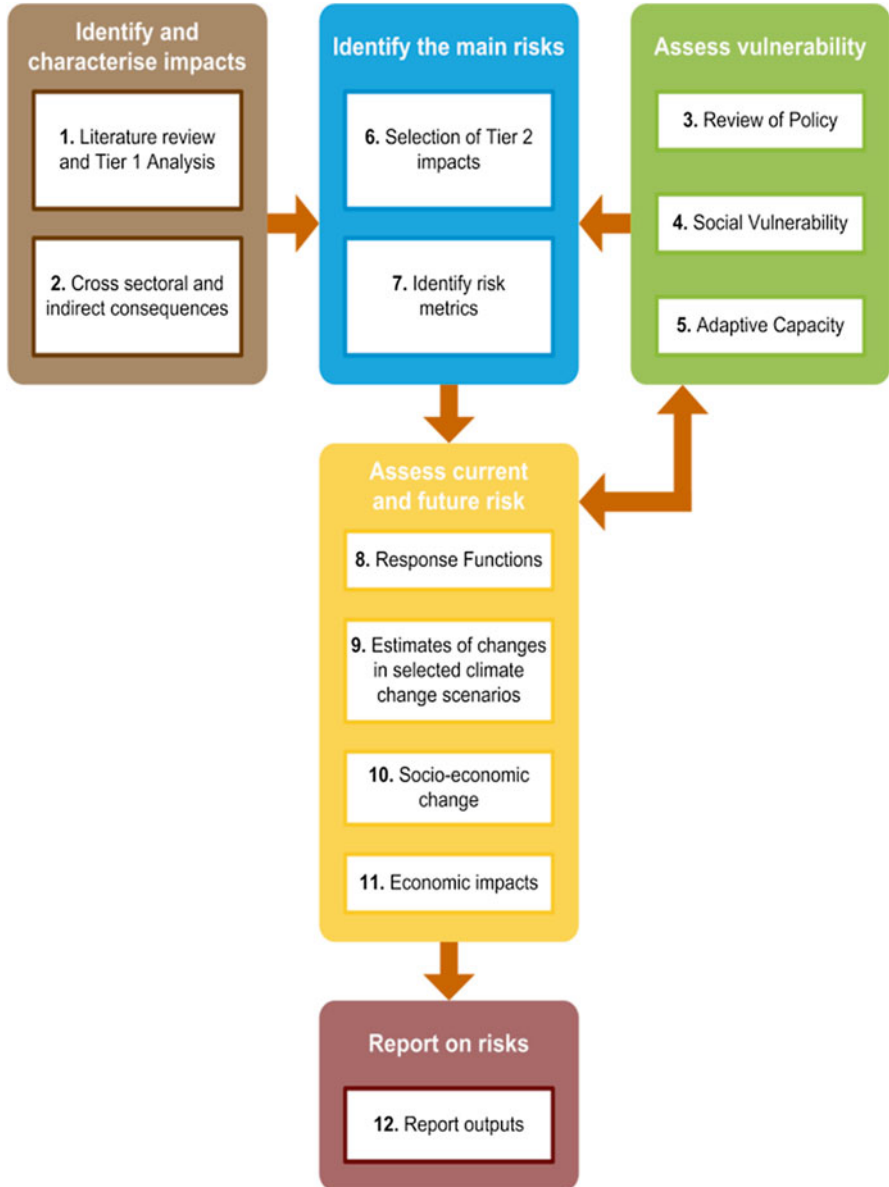


Fig. 4.6 Steps involved in producing the CCRA

and regional/national differences. The UK government was the primary ‘customer’ for the CCRA although the assessment engaged more than 1,800 stakeholders through workshops, online questionnaires and report reviews. These stakeholders came from a wide variety of backgrounds, including non-governmental organisations, leading businesses within sectors, regulatory bodies and government agencies and were involved in identifying and prioritising risks. They also reviewed draft outputs to ensure that the information presented was both understandable and useful.

Process

The steps involved in producing the assessment are described in Fig. 4.6.

Over 700 impacts of climate change were identified (Tier 1) across the 11 sectors under review. These were combined with an assessment of vulnerability across the UK as a whole to identify the main risks. As part of this, a 2nd tier of about 100 impacts was extracted using a simple multi-criteria scoring system based on the magnitude of consequences, likelihood of occurrence and urgency of decision required.

For each impact in the Tier 2 list, one or more risk metric(s) was identified. These provided measures of the consequences of climate change, relative to specific climate variables.

Examples of risk metrics linked to the impact “major drought”

- Reduced summer river flow
- Change in public water supply availability
- Population in areas with future water supply deficits

The next step was to develop response functions, being the relationship between a risk metric (e.g. crop yield) and one or more climate variables (e.g. temperature or precipitation). Response functions were derived in a number of ways:

- Sensitivity analysis of detailed models,
- Historical data to produce a simple statistical relationship,
- Expert elicitation where models or data was not available.

Climate data used

- UKCP09/UKCIP02 projections
- Met Office observed weather and climate
- Hadley Centre HadCM3 (sea ice)
- Low to high emission scenarios
- UKCP09 probability levels

Uncertainties associated with these approaches were taken into consideration as part of the overall confidence scoring for each risk metric. The magnitude of climate risks were then analysed using climate projections for three time slices and three emissions scenarios:

- 2020s (2010–2039) – medium emissions scenario,
- 2050s (2040–2069) – low, medium and high emissions scenario,
- 2080s (2070–2099) – low, medium and high emissions scenario.

It was recognised that many of the risk metrics in the CCRA were influenced by a wide range of drivers other than climate change. For example, risks related to

flooding, water supply and demand, health and energy demand were particularly sensitive to future population and a standard set of population projections were applied to across all sectors.

Uncertainty Assessment

Uncertainties were considered in the following areas:

- **Climate system:** driven by limitations in our ability to model certain aspects of the climate system, as well as intrinsic modelling uncertainty and the nature of the system.
- **Future emissions:** captured within the UKCP09 projections that were used in the CCRA to project the risk moving into the future.
- **Current level of risk faced:** particularly important in relation to extreme events, the estimation of which was also subject to considerable uncertainty.
- **The relationship of the risks to climate variables:** through models, statistical relationships and the use of simple ‘response function’ relationships.
- **Planned or autonomous adaptation and changes in society** (social and economic): assumptions were made on a case by case basis. Population projections were applied but the vast majority of the work in the CCRA took this as a qualitative consideration.
- **Financial consequences** of impacts could only be estimated as part of a monetisation exercise, for example the intrinsic value of elements of the natural environment was not captured.

These uncertainties were handled, amongst others, in the following ways:

- **Emission scenario analysis.** Within each projection a probabilistic range was used, from the 10th percentile to the 90th percentile probability level. Population projections (low, principle and high) were also applied to provide results combining both climate and population changes.
- **Expert elicitation** and **peer-review** were utilised to substantiate whether the assumptions adopted were reasonable.
- **Stakeholder involvement** was utilised to ensure that uncertainties presented in reports were understandable to the reader.

One key method of presenting results to stakeholders, to generate an appreciation of uncertainty, was through the use of “score cards”. The risk metrics considered in this first CCRA varied in character and whilst some were quantified, others had to rely on expert elicitation, or a narrative based on the literature. To allow comparison of these different risks, they were categorised as having either ‘high’, ‘medium’ or ‘low’ magnitude consequences and either a ‘high’, ‘medium’ or ‘low’ confidence. An example for agriculture and forestry is shown in Fig. 4.7. This shows the lower (l), central (c) and upper (u) estimates of magnitude of the consequences (based on the range of emissions scenarios analysed and associated probability levels) for the three time slices considered (i.e. the 2020s, 2050s and 2080s) and the overall level of confidence in these estimates (L – Low, M – Medium or H – High).

Metric code	Potential risks for agriculture and forestry	Confidence	Summary Class								
			2020s			2050s			2080s		
			l	c	u	l	c	u	l	c	u
AG1b	Changes in wheat yield (due to warmer conditions)	M	1	2	2	2	2	3	2	3	3
AG9	Opportunities to grow new crops	H	1	1	1	2	2	2	3	3	3
AG1a	Changes in sugar beet yield (due to warmer conditions)	M	1	1	2	1	2	3	2	3	3
AG10	Changes in grassland productivity	M	1	1	1	1	2	2	1	2	2
FO4b	Increase of potential yield of Sitka spruce in Scotland	M	1	1	1	1	1	1	3	3	3
AG1c	Changes in potato yield (due to combined climate effects and CO ₂)	L	1	1	2	1	1	2	1	1	2
FO1a	Forest extent affected by red band needle blight	M	1	2	3	2	3	3	2	3	3
AG11	Increased soil erosion due to heavy rainfall	L	1	2	2	1	2	3	1	3	3
AG5	Increases in water demand for irrigation of crops	M	1	2	3	1	2	3	2	2	3
AG4	Drier soils (due to warmer and drier summer conditions)	M	1	2	2	1	2	3	1	2	3
AG2a	Flood risk to high quality agricultural land	H	1	1	2	1	2	2	2	3	3
FO4a	Decline in potential yield of beech trees in England	M	1	1	1	2	2	2	3	3	3
BD12	Wildfires due to warmer and drier conditions	M	1	1	2	1	2	3	2	2	3
FL14a	Agricultural land lost due to coastal erosion	H	1	1	1	1	2	2	2	2	3
WA8a	Number of unsustainable water abstractions (agriculture)	M	1	1	2	1	2	2	2	2	2
FO1b	Forest extent affected by green spruce aphid	M	1	1	2	1	2	2	1	2	3
FO2	Loss of forest productivity due to drought	M	1	1	2	1	1	2	1	2	3
AG8b	Dairy livestock deaths due to heat stress	L	1	1	2	1	1	2	1	1	2
AG7b	Reduction in dairy herd fertility due to heat stress	L	1	1	2	1	1	2	1	1	2
AG8a	Increased duration of heat stress in dairy cows	H	1	1	1	1	1	2	1	1	2
AG7a	Reduction in milk production due to heat stress	L	1	1	1	1	1	1	1	1	3
AG3	Risk of crop pests and diseases	L	Too uncertain								

M	Confidence assessment from low to high
3	High consequences (positive)
2	Medium consequences (positive)
1	Low consequences (positive)
1	Low consequences (negative)
2	Medium consequences (negative)
3	High consequences (negative)
~	No data

Fig. 4.7 Score card indicating the consequences and confidence levels of risk metrics under climate change in the agricultural and forestry sector

For example, metric AG1b “Changes in wheat yield (due to warmer conditions)” is projected (with medium confidence) to have low to medium positive consequences by the 2020s and medium to high positive consequences by the 2050s and 2080s. This can be compared with metric AG10 “Changes in grassland productivity”, where it is projected (with medium confidence) to have low positive consequences by the 2020s and low to medium positive consequences by the 2050s and 2080s. Therefore, the score card shows not only shows the scale of the consequences (i.e. low, medium or high), but also the range in uncertainty of the projections (from l – lower, to c – central and u – upper projections) and the speed of onset of consequences (i.e. by the 2020s, 2050s or 2080s). It has been deliberately chosen to use the same colour for both the low positive and low negative consequences. The score card helps the decision-makers to prioritise areas of action by comparing the relative magnitude of risks and indicating how soon action should be taken to mitigate or adapt to that risk.



Fig. 4.8 The M1 and River Trent valley on 10 November 2000 (Source: Frameworks for delivering regular assessments of the risks and opportunities from climate change: An independent review of the first UK Climate Change Risk Assessment. Final Report, 18 June 2012 Robert L. Wilby)

Effect of Uncertainty on Decision-Making

“There is a risk of being locked into maladaptation”

The reports produced from the CCRA reflected potential risks and opportunities and did not purport to be a prediction of the future consequences of climate change. Despite uncertainties over the magnitude and timing of climate change impacts, the CCRA was able to provide sufficient evidence to identify a range of possible outcomes that can inform adaptation policies and planning.

The results are being used by UK government departments and devolved governments as part of their evidence base to support decision-making on adaptation to climate change in organisations across the country. Decision-makers recognise that they need to consider uncertainties and to allow flexibility in their policies and plans, and they need to report their actions under the “Adaptation Reporting Power” of the Climate Change Act 2008. Decisions range from the simple “low cost, no regret” measures, such as urban greening, through to the adaptation pathway approach, in which flexibility is maintained and adjustments made if conditions or information change. An example of the latter is the Thames Estuary 2100 project being a multi-million pound contract planning for flood risks in London. The CCRA provides a probabilistic climate change framework with differing degrees of confidence over various outcomes to facilitate this decision-making process (Fig. 4.8).

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4.2.3 *Water Resources Management in England and Wales*



Key Messages

“The effects of climate change uncertainties are not as immediate as issues such as changing water demand”

This project stemmed from the desire of the Environment Agency of England and Wales to account for the large uncertainties in climate change projections in planning water requirements of the future.

Key messages from this work were:

- Planning based on just a few storylines was a risk in itself.
- There was a need for water management options that are flexible and robust under a range of possible futures.
- Tools, such as large climate model ensembles in combination with risk based decision-making frameworks, can be used to avoid poor adaptation decisions.

Background

This research project was commissioned by the Environment Agency of England and Wales and initially carried out by the School of Geography and the Environment, Oxford University. Every 5 years, water companies have to indicate how they will guarantee the supply of water over the following 25 years. The Environment Agency wanted to provide guidelines to water companies on how to take into account large

uncertainties in climate change information when preparing the associated 5 year Water Resources plans.

Water companies in England and Wales have considered the impact of climate change in their plans since 1998, but approaches tend to be simple and deterministic, as climate change is one of many factors that companies have to take into account. The Environment Agency wanted to explore how large ensembles of climate information could be used to improve decision-making.

Apart from the Environment Agency, other stakeholders included managers from some of the water companies, climate scientists, and hydrologists. All of these were consulted during the development of the project.

Process

“Tools need to be simple and cheap”

The project concentrated on exploring climate model related uncertainties as represented by the climate data described on the box.

Climate data used

- Perturbed physics ensemble (PPE) – 247 members – based on the HADCM3 model
- An ensemble of opportunity consisting of 21 General Circulation Models (GCMs) available through the CMIP3 database (IPCC 4th Assessment Report)

Both ensembles were run under the SRES A1B emissions scenario.

It was the first project to use such a large range of climate models to study the effects of climate projection uncertainties on the management of a water resources system. The Environment Agency was involved in the design of the project, the selection of hydrological modelling tools and calibration of models, and the choice of adaptation options. Workshops were also organised so that the scientists could understand the information needs of decision-makers in this sector, and determine the sort of information that could be provided.

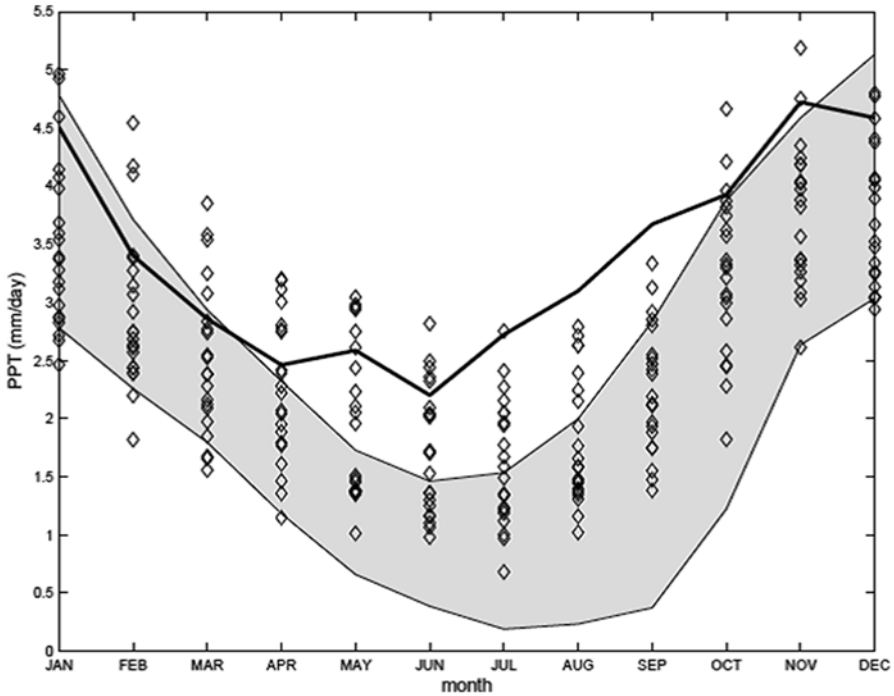


Fig. 4.9 Mean monthly precipitation (mm/day) for 1930–1984. The thick line corresponds to observed monthly means, the grey shadow indicates the range of precipitation simulated by the PPE, and the diamonds indicate the CMIP3 models results

The large ensemble of climate projections was run through a hydrological model and then a water resources model for a catchment in the South West of England, to evaluate the time dependent risk of failure to supply water demand under different adaptation options. The hydrological and water resource models were already in use by water supply companies and regulators. Since time and expense was not required to develop these tools it was hoped that they would encourage the take up of information from large ensembles of climate models.

An example of the exploration of uncertainties in climate projections can be seen in Fig. 4.9 which shows the mean monthly precipitation (mm/day) for the period 1930–1984. The fact that, in this case, uncertainties in the ranges of model physics (PPE) and model structure (CMIP3 models) do not coincide, shows that both ensembles are necessary to better explore the full range of climate model uncertainty.

Uncertainty Assessment

The primary uncertainties analysed by running the large ensemble of climate models through the water resources system model were those due to:

- climate model structure represented by the CMIP3 models,³
- climate model physics represented by the perturbed physics ensemble (PPE).⁴

Other sources of uncertainty such as emission scenario and impact model uncertainty were ignored in this study. It is expected that the uncertainty range might vary when all sources are taken into account.

Within the Environment Agency there was already an awareness of uncertainties in climate change risks. They became particularly interested, however, in the fact that the range of uncertainties explored by the PPE was in general larger than that expected from the CMIP3 ensemble.

Water companies find large ensembles of climate information difficult to use. As a result of this and other projects, guidance was developed in two areas:

- Translation of climate ensembles into a range of river flows being a format that is familiar to water companies. This effectively gave them a set of impact data to use.
- Guidance on how to use the data. This gives them the confidence that using the approach will result in robust decisions.

Water company representatives argued that even though they found the results interesting, they did not have the resources to implement such analysis. They also commented that climate change risks represent only a small part of the total risks they have to face. For instance, in many parts of the UK, the main problem is changes in demand due to population increase. Even though plans have to be made for 25 years into the future, climate change and climate risks may not be the most significant risk drivers. Consequently, water companies preferred the simplified idea of using a maximum of three climate scenarios (low, medium, high) to explore climate change impacts.

³http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php

⁴<http://climateprediction.net/>

Example of handling uncertainty: failure of water supply

This represents the case of a water company required to meet water demand in its catchment region into the twenty-first century at a minimum cost. The top panel of Fig. 4.10 shows a histogram of the percentage change in summer average precipitation of 2050–2079 compared to 1960–1989, for the PPE ensemble.

The bottom panel of Fig. 4.10 shows, for each range of precipitation change on the top panel, the corresponding average number of failures to supply the required demand for the business as usual (BAU) scenario and four different adaptation options. The adaptation options available include increase supply (green and purple lines in bottom panel) and/or reduce demand (red and light blue lines in bottom panel). The blue line represents business as usual. Robust adaptation options are those that, for an acceptable level of risk, reduce the risk of failure across a range of plausible climates. If for instance only five failures are acceptable, only red, light blue and purple adaptation options are robust across the range of plausible futures.

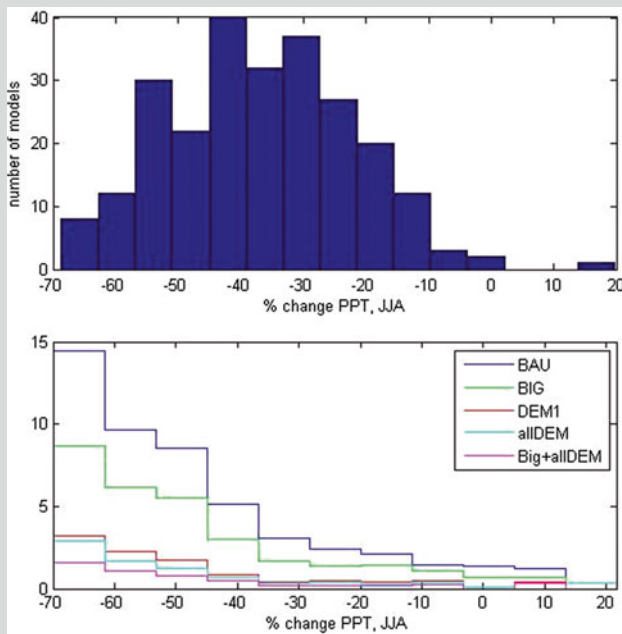


Fig. 4.10 Histogram of the percentage change in summer average precipitation of 2050–2079 compared to 1960–1989, for the PPE ensemble (*top panel*); Average number of failures to supply the required demand for the business as usual (BAU) scenario and four different adaptation options

Effect of Uncertainty on Decision–Making

“Planning based on just a few storylines is a risk in itself”

This exercise showed that using information from a small number of projections could be misleading, either over or underestimating the changes in climate risks. The Environment Agency and water companies accept that planning based on just a few storylines is a risk in itself.

From the water companies’ perspective, there are many existing uncertainties other than climate change which tends to be a long-term issue. Uncertainties due to demand and environmental standards for example are much more relevant on a short-term basis. However, they appreciate the need for the use of many models and are willing to utilise the results as long as it is relatively simple to do so.

From the results produced, the Environment Agency has developed guidance on the use of probabilistic climate change information to explore sensitivity and minimise surprises for the next round of water resources plans. This will be used for the plans due to be drawn up in 2014. It will be interesting to see whether the attitude of the water companies changes after this round of plans.

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Links for more information: Information about the Environment Agency guidelines for managing drought and the balance between water supply and demand can be found at <http://www.environment-agency.gov.uk/business/sectors/32399.aspx>

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4.2.4 Water Supply in Hungary

Country: Hungary

Sector: 

Scale: Regional

Organisation: Public

Decision-type: Operational+Strategic

Key Messages

This project investigated the effects of climate change on drinking water supply in two regions of Hungary in order to support decisions on adaptation.

Key messages from the project were:

- Despite uncertainty in long-term trends of precipitation and the hydrological consequences, decisions were found to be possible.

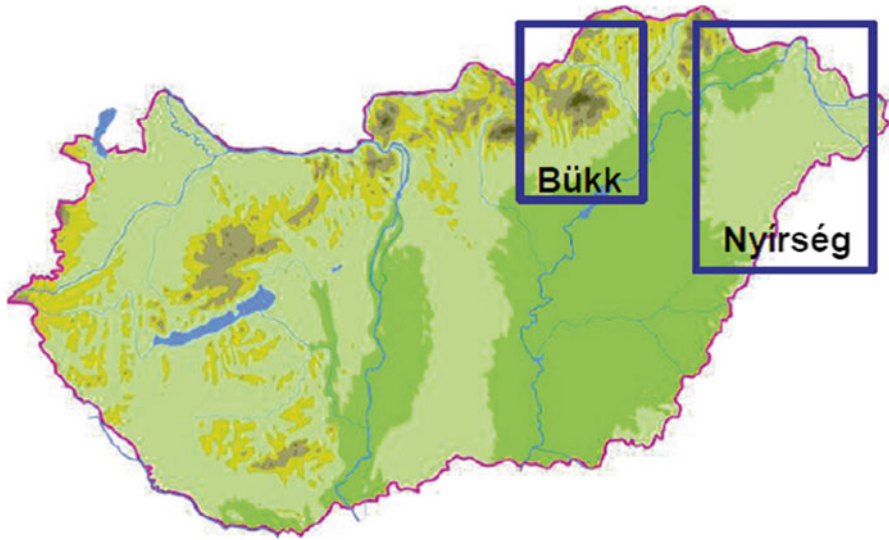


Fig. 4.11 Hungarian test areas

- As a preparation for adaptation planning, all current and future hazards should be estimated and ranked according to likelihood and severity of consequences as in the Water Safety Plan of the World Health Organization.

Background

The Hungarian National Institute for Environment (NeKI) is responsible for the water management policy of Hungary and acted as partner in the Climate Change and Impacts on Water Supply (CC-WaterS) project. The aim was to assess the climate change impacts on the future availability and safety of public water supply. In order to provide information to water managers, it considered the economic losses or benefits related to changes in climate and land use. The project was funded under the South East Europe Transnational Cooperation Programme, comprising 18 partners and was completed in May 2012.

Two specific areas located in the north-eastern part of the Hungary were analysed: the mountainous Bükk region, and the plain area of Nyírség (see Fig. 4.11). The Bükk-Mountain region encompasses the highest karstic plateau of Hungary, situated in the Carpathian Mountains. From the group of karstic springs in its South Eastern section, one large city and three villages (about 190,000 people) are supplied by one water company. The lowland area of Nyírség is part of the Great Hungarian Plains and located near the Tisza River. The mean elevation of this region ranges between 150 and 200 m. and about 260,000 people live here, settled in one large city and 60 smaller settlements. The drinking water is obtained from shallow and deep porous aquifers of the alluvial deposit and supplied by one large regional water company (84 % of the

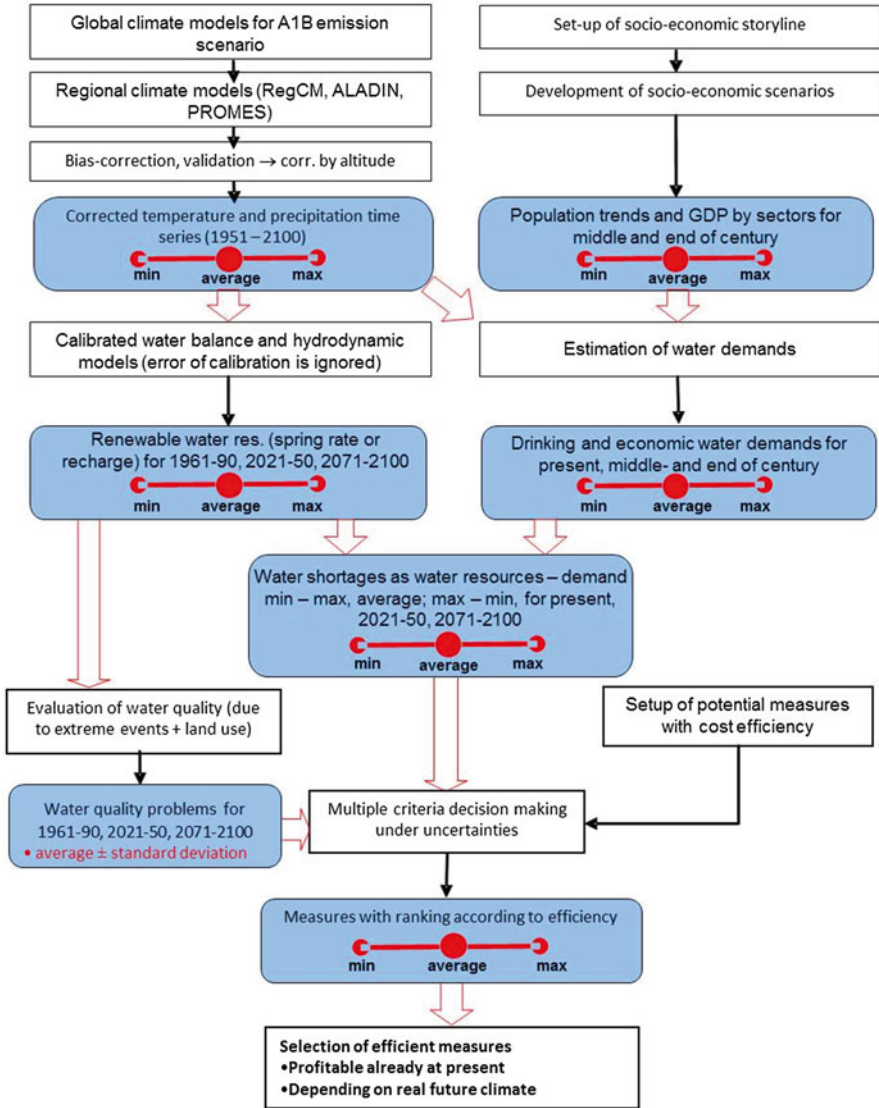


Fig. 4.12 Process of the assessment, including uncertainties (in red colour)

population) and a number of small waterworks. The two large water companies, representative of each region, were involved from an early stage in the study.

The main phases of the project, including the uncertainties involved are summarised in Fig. 4.12. This shows the relationships between different steps such as the establishment of climate datasets, the determination of water resources availability, estimation of water demands, evaluation of problems and selection of efficient measures, and the consideration of uncertainties (in red colour).

The project utilised three regional climate models (RCMs) and the SRES A1B emission scenario, with appropriate corrections (see box). To project the impact of climate change on drinking water availability and quality, the precipitation and temperature time series from the RCMs were used as input for a water balance model, a hydrodynamical model and a crop model. These models also took land use changes due to climate change into account.

Climate data sources

- SRES A1B emission scenario and three RCMs (ALADIN; RegCM and PROMES) were selected for modelling time series of temperature, precipitation and CO₂ concentration up to 2100
- The time series were bias corrected for the two pilot areas using temperature and precipitation data of E-OBS database (1961–90 period).
- Climate data was validated using observations other than those in E-OBS database. In the Bükk region correction according altitude was necessary.

Without a particular link to possible climatic futures, local experts were asked to develop a storyline showing their perceptions of the future for all social and economic aspects such as: market policy, declining and growing sectors, technical development, unemployment, governance structure, role of policy, demography, sustainability and equity. Project managers then used the storyline to develop three scenarios indicating a maximum, minimum and plausible future water demand. Experts and the two water companies were asked to provide feedback on the scenarios.

The changes in the drinking water demand were estimated on the basis of the three socio-economic and regional climate scenarios (maximum, minimum and plausible).

In the last project phase, cost-efficient adaptation measures were selected.

Uncertainty Assessment

All the stakeholders recognised uncertainties, and none of them considered them to be barriers to adaptation. Experience of very heavy precipitation in Bükk (in 2006, 2009 and 2010) and drought in both regions (beginning of 90s, 2000, 2003, and 2007) had convinced them that climate change is an issue which needs to be considered. Water management companies are not worried *whether* climate change will occur but *what* are the possible scenarios and the corresponding efficient measures.

Uncertainties of the following applied models and methods were dealt with:

- Regional Climate Models,
- Hydrological/ hydrodynamical impact models,

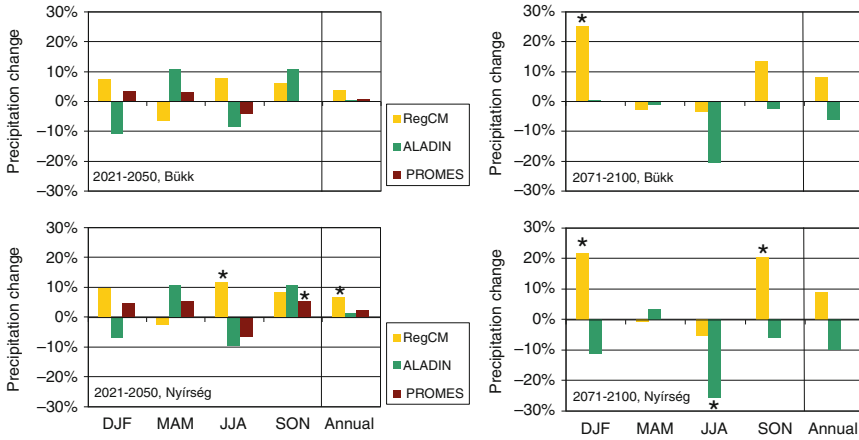


Fig. 4.13 Projected changes in seasonal mean precipitation with the use of three regional climate models, for 2021–2050 and 2071–2100. Significant changes (at 0.05 level) are indicated by asterisks (CC-WaterS, 2010 http://www.neki.gov.hu/uploads/458/Attachments/cc_waters_wp3.pdf)

- Empirical methods for estimating water balance elements (e.g. evapotranspiration),
- Land use change evaluation methods,
- Crop models for evaluation of nutrient balance elements and yields,
- Evaluation methods for socio-economic changes.

A combination of the following methods was used to address uncertainties:

- Expert elicitation,
- Sensitivity analysis of parameters, comparative analysis of formulas,
- Probabilistic multi model ensemble,
- Fuzzy Multiple Criteria Decision Making (see box).

When the project began it was expected that the results given by the three RCMs would be more or less similar but the models presented different climate changes. As can be seen in Fig. 4.13, simulations of the RCMs often do not agree even on whether the projected changes in precipitation is positive or negative. Uncertainty related to predicted seasonal precipitation with different RCMs is larger than the changes compared to the baseline. The uncertainty was more pronounced in precipitation than temperature (not shown), which shows clear and continuous increase in all seasons.

In addition, short heavy rain (causing quality problems in Bükk recently) could not be modelled which poses difficulties in planning adaptation measures against flash flood events.

Evapotranspiration seems to be the most uncertain water balance element since the parameters of the empirical formulas are perhaps not valid under considerably higher temperature. The most realistic formula was selected based on comparative analysis.

In order to draw conclusions on water availability, it was important to determine the uncertainty of climate data in water balance and hydrodynamical modelling, carrying out several simulations with various climate data. As a result, the uncertainty of the available water resources was presented as a range of possible values alongside the average values. It was noted that uncertainties in the parameters of the water balance model and hydrodynamic model were reduced through a detailed calibration procedure.

To analyse future water demand, population birth/death ratio and migration rates were projected, given envisaged economic conditions, social measures, employment and income. The impact of climate change was also considered on the likely increase in water demand for hygienic use and for watering gardens, in proportion to the increase of temperature. In this way, uncertainty in the meteorological prognosis was also incorporated in the estimation of water demand.

In the last step of the process, a Fuzzy Multiple Criteria Decision Making tool was applied to help the water companies take decisions. The best adaptation option can be selected when multiple alternatives exist even under uncertainty, represented by so called fuzzy numbers (see box).

Handling uncertainty – Fuzzy Multiple Criteria Decision Making

Fuzzy sets (representing the minimum, maximum and average values of a parameter) were used to estimate ranking criteria values e.g. cost, acceptance, flexibility and lag time and then to evaluate the composite indicator numbers. Fuzzy Decimaker version 2.0 was used as a Fuzzy Multiple Criteria Decision Making tool that helps the user to select the best solution considering a number of conflicting criteria under uncertainties.

Effect of Uncertainty on Decision-Making

Despite the fact that each of the three regional climate models gave different results, water management companies were prepared to accept the uncertainty and act. They proposed that different adaptation measures should be developed for the future range of scenarios (maximum, minimum and average). Several alternative management measures were formulated: water supply management, water demand management, shortage consequence management, change of allocation of available supply among users, water quality management and combinations of the alternatives. In the mountainous area the water management company has established a new system to monitor heavy rains and flash floods. It also intends to install a new treatment plant which can be used to protect water quality during flash floods. A proper monitoring system to measure climate and hydrological parameters was considered essential for dealing with uncertainty.

In the low lying area the regional company has begun to shut down very small water works and is trying to concentrate on larger water sources, developing a regional pipeline system in order to increase the safety of water quality. They have also made a study of prospective refuges into which they can move their operations which would make the water system less vulnerable to extreme events.

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Links to more information: <http://www.ccwaters.eu>, <http://www.neki.gov.hu/?TeruletKod=0&Tipus=content&ProgramElemID=66&ItemID=458>

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4.2.5 Climate Change and Health in The Netherlands



Key Messages

This case study assessed the degree of uncertainty in various potential health effects of climate change in the Netherlands.

Key lessons learned were that:

- Potential health effects due to climate change were associated with large uncertainties and knowledge gaps.
- Analysing and characterising uncertainty by means of a typology combining a scale of ‘Level of precision’ with ‘Relevance for policy’ was very useful for the selection and prioritisation of robust adaptation policies.
- Recognition of uncertainty of various health effects due to climate change had implications for policy. For example, adaptation policies that focus on enhancing the health system’s capability of dealing with uncertainties were most appropriate for climate related health impacts characterised by recognised ignorance.

Background

Climate change can influence public health in many, often subtle and complex ways. Some of these potential impacts are direct, such as the impact of heat waves on heat-related deaths. Others are more indirect, such as the effect of changing climates on the distribution of vectors such as specific types of mosquitoes, which affect the



Fig. 4.14 A warning of cyanobacteria for swimmers



Fig. 4.15 The oak processionary caterpillar which entered the south of the Netherlands in the 1990s and gradually spread north. A further spread and increase in population size is expected due to climate change

distribution and risk of disease outbreaks (Figs. 4.14 and 4.15). There is a colourful mix of information on the topic, ranging from qualitative discussions on plausible impacts, through lists of knowledge gaps and research needs, to detailed quantitative studies. Projections of health risks of climate change are surrounded by uncertainties, leading to difficulties in determining the policy approach.

The Netherlands Environmental Assessment Agency (PBL), being the Dutch national institute for strategic policy analysis in the field of the environment, nature and spatial planning, has recently produced the assessments “Impacts of climate

change in the Netherlands: 2012” (2012) and “Roadmap to a climate-proof Netherlands” (2009) for the Dutch government. Within these assessments it was important to account for uncertainties in a policy-relevant way and so PBL asked Utrecht University to characterise the uncertainties associated with various health effects, and to provide strategic options on how to deal with them in adaptation policy.

Process

The process carried out by the Utrecht University was as follows:

- A list of 33 potential health impacts of climate change was compiled based on existing Dutch impact assessments and international literature. These impacts were grouped into eight health themes: temperature, allergies, pests, vector-borne diseases, food/water-borne diseases, air quality, flooding/storm and UV effects.
- A questionnaire based on expert elicitation was completed. National and international experts (scientists and practitioners) were asked to indicate the level of precision with which health risks could be estimated given the present state of knowledge.
- Suggestions were made for dealing with uncertainties in climate change adaptation policy strategies.

Categories of health impacts of climate change included

- Temperature
- Allergies
- Pests
- Vector-borne diseases
- Food- and waterborne diseases
- Air quality
- Flooding and storm
- UV-related

The results of the study were used as input to PBL’s impact and adaptation assessment. They were also presented at a World Health Organization (WHO) workshop on policy options for climate change and health.

Uncertainty Assessment

In the first part of the study the participating experts were asked questions to assess the ‘Level of Precision’ with which health risk estimates could be made given the

current state of knowledge. They were also asked to provide full backup for their scores. For example:

- Why is it possible to indicate the direction of change, but not provide a quantitative risk estimate?
- What factors prevent a more precise analysis (e.g. whether data is unavailable, or cause-effect relationships not understood)?
- What factors are available that allows a certain level of precision to be applied (e.g. whether well-established models or detailed data sets are available)?

Example of handling uncertainty: 'Level of Precision' scale

The following 'Level of Precision' scale was used to assess the degree to which health effects of climate change can be quantified:

1. Effective ignorance
2. Ambiguous sign or trend
3. Expected sign or trend
4. Order of magnitude
5. Bounds
6. Full probability density function (i.e. full quantitative risk assessment possible)

The scale provides a range from a qualitative indication i.e. whether it is good or bad for health, a rough estimate of the order of magnitude (i.e. 'hundreds of cases' of disease versus 'thousands of cases'), or a detailed risk-based assessment.

The questions covered the following categories of uncertainties:

- The climate system, e.g. heat wave frequencies and durations.
- The biological systems, e.g. the relationship between climate and insect distributions, and infection biology.
- The human systems, e.g. autonomous adaptation and responses of health systems, effectiveness of hygiene regulations, and disaster response.

The uncertainty typology or the 'Level of Precision' scale used is shown in the box 'Example of handling uncertainty'. The 'Level of Precision' question was relatively broad. Potentially, some participants could have scored health effects based on standard climate projections (e.g. the Dutch KNMI or global IPCC scenarios), while others could have assumed a broader ignorance regarding local climatic changes. Because the reasoning focused almost exclusively on uncertainties in assessing health impacts (i.e. translating a climatic change into its health impacts),

Health effects have:	Low policy-relevance	High policy-relevance
High level of precision health risk assessment	<p>Tailored, prediction-based strategies (e.g. risk approach)</p> <p>Focus: low costs/efforts or co-benefits.</p> <p>Example: providing shelter for homeless people during cold spells.</p>	<p>Tailored, prediction-based strategies (e.g. risk approach)</p> <p>Consider (but critically reflect on) costly and extensive options.</p> <p>Example: financing/subsidizing air-conditioning or other (advanced) cooling systems in buildings.</p>
Low level of precision health risk assessment	<p>Enhance system’s capability of dealing with changes, uncertainties, and surprises (e.g. resilience approach).</p> <p>Focus: low costs/efforts or co-benefits.</p> <p>Example: general improvement in health care including research, and regular impact & adaptation assessments.</p>	<p>Enhance system’s capability of dealing with changes, uncertainties, and surprises (e.g. resilience approach).</p> <p>Consider (but critically reflect on) costly and extensive options, including precautionary options. Assess overinvestment risks and flexibility. Under which circumstances would “robust” measures be advocated and which?</p> <p>Example: changing building materials and increasing urban water and parks to reduce the impact of heat in urban areas.</p>

Fig. 4.16 Appropriate adaptation approaches, considering uncertainty and policy-relevance of health effects (Wardekker et al. 2012)

rather than on climatic uncertainties, the scores were interpreted as ‘given a climate scenario’. The individual scores, the expertise-weighted descriptive statistics, and the reasoning given for each score were assessed.

The second part of the study dealt with:

- The relevance of health effects to adaptation policy (e.g. where there are high health impacts, high societal or political salience, etc.),
- Specific uncertainties not mentioned in the reasons given for the ‘Level of Precision’ scores, and
- Uncertainty-robust adaptation options and strategies.

The relevance of health effects to adaptation policy was assessed by asking participants to select and rank the five effects they considered the most important, interpreting relevance in a broad way, and giving reasons for their choices. This separated the highly relevant from the less relevant effects, and highlighted the different reasons for relevance. For example: current vulnerability to the effect (heat-related mortality); large potential health and societal impacts, difficult to adapt to, and public fright factors (vector-borne diseases); and a large number of people affected and large potential economic impact (hay fever).

The implications of uncertainties for adaptation were discussed using various characteristics of policy options (e.g. costs, flexibility, encroachment, prediction versus capacity-enhancement). The results of this approach are summarised in Fig. 4.16.

Effect of Uncertainty on Decision–Making

“The uncertainty typology can be a very useful assessment tool for the selection and prioritisation of preferred climate adaptation policy in practice.”

The uncertainties assessed had a notable influence on the policy assessments conducted by the PBL for the Dutch government; it affected how they discussed climate change impacts on health and adaptation to these impacts. It became clear that adaptation in the health sector requires a strong focus on enhancing system resilience and on capacity building. The use of uncertainty typologies was also important; they allowed for a systematic and structured analysis of the uncertainties, distilling policy-relevant uncertainty information from the complex mix of imperfect evidence. They have led to the advice that a different policy approach would be needed, for example, for vector-borne diseases than for heat-related deaths. In effect they have made the various potential health impacts and their uncertainties comparable, which in turn have enabled adaptation strategies to be differentiated.

The typologies helped to focus on the most appropriate policy strategies, given the characteristics of both health impacts and policy options:

- For possible climate related health impacts characterised by ignorance, the most appropriate adaptation policies are those that focus on enhancing the capability of the health system and society in general in dealing with possible future changes, uncertainties and surprises e.g. through resilience, flexibility, and adaptive capacity.
- For climate related health effects for which rough risk estimates are available, ‘robust decision-making’ is recommended.
- For climate related health impacts which are less uncertain, tailored and prediction-based approaches are most appropriate.

By providing an interpretative framework for a complex mix of uncertain evidence, a systematic, rather than ad-hoc, formulation of policy advice is created. An example is the central role that uncertainties and uncertainty-proofing policy played in the workshop “Policy options for climate change and health” (PBL & WHO Europe, co-organised by the University of Utrecht, at the WHO office in Bonn, Germany, 11–12 January 2010). The outcome of this case has also been used in a recent follow-up of the PBL outlook studies on climate-proofing in the Netherlands to support the current national Delta Programme (addressing flood risks, fresh water availability, and urban stress). The developed framework for systematically dealing with uncertainties will be used to advocate a second Delta Programme, including a detailed health adaptation policy.

Authors: Arjan Wardekker, Jeroen van der Sluijs

Links to more information:

Wardekker, J.A., A. de Jong, L. van Bree, W.C. Turkenburg, and J.P. van der Sluijs (2012). Health risks of climate change: An assessment of uncertainties and its

implications for adaptation policies. *Environmental Health* 11: 67. <http://www.ehjournal.net/content/11/1/67>

The paper was summarized in the European Commission newsletter Science for Environment Policy: <http://ec.europa.eu/environment/integration/research/newsalert/pdf/317na5.pdf>

WHO and PBL (2010). “Policy options for climate change and health: Report on a joint WHO-PBL technical meeting”. World Health Organization (WHO) Regional Office for Europe, and Netherlands Environmental Assessment Agency (PBL), Bonn/Bilthoven. http://www.pbl.nl/sites/default/files/cms/publicaties/pbl2010-who-pbl-technical-meeting-climate-change-and-health_0.pdf

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4.2.6 Flood Risk in Ireland



Key Messages

The aim of this study was to look at how climate change has been integrated into existing policies for flood protection works and how robust those policies are under a range of climate change scenarios.

Key messages were:

- Reinforcement of the emerging picture that there is uncertainty in projections.
- Consideration of the performance of adaptation options over a wide range of uncertainty to ensure the robustness of the decision.
- The importance of communicating uncertainties in future projections so that decisions can be based on the full range of available information.

Background

In recent years flooding in Ireland has been quite extensive with substantial social impact. This case study looked at how climate change has been integrated into existing policies for flood protection works, and how robust those policies are.

The project was initiated by the Department of Geography at the National University of Ireland Maynooth and funded by the Science Foundation Ireland (SFI). The main beneficiary of the project was the Office of Public Works (OPW),

the national agency responsible for flood risk reduction, whose policies were selected for review. Their policy reports have been influential in past decisions and they are one of the leading national agencies in Ireland that are climate sensitive and trying to accommodate changes.

Most of the work in flood defence in the past has been based on high resolution regional circulation models (RCMs), with a tendency to neglect other uncertainties such as those arising from the use of different general circulation models (GCMs), downscaling techniques, different socio-economic, emissions and land-use/soil sealing scenarios, and impact models. It is critical, for example to include results from a large sample of GCMs to assess the robustness of adaptation schemes. There is also a risk of overconfidence in projections due to the high resolution of RCMs. In adapting to an uncertain future it is important that more effort is made to capture the full range of uncertainties so that decisions are based on as much information as possible.

Process

The first step was to review the policy documents from the OPW. Identified safety margins incorporating climate change allowances were stress-tested using climate projections extracted for the Irish grid cell and pattern scaled to local catchments.

Climate data sources

- IPCC AR4 full range of GCMs (17 in total)
- Three emissions scenarios
- Time horizons 2020s, 2050s and 2080s

Fifty one climate projections were generated from IPCC AR4 data using the entire range of GCMs and three IPCC emissions scenarios. Change factors based on current climate conditions were determined and run through a weather generator to derive catchment scale information. This was then used to force a suite of hydrological models for four case study catchments. The model structure and parameter uncertainty of the hydrological models were accounted for and the sensitivity of safety margins for flood defences was assessed using risk response surfaces.

The OPW was involved in the study through informal meetings and conferences.

Uncertainty Assessment

The primary aim of the project was to test a set of adaptation options on flood risk for their robustness. This was done using sensitivity analysis on the flood defence thresholds incorporated in the policies. Peak flow safety margins of 20 %, for a medium emissions scenario, and 30 %, for a higher scenario were identified for new design flood defences, so sensitivity analysis was used to check how robust those

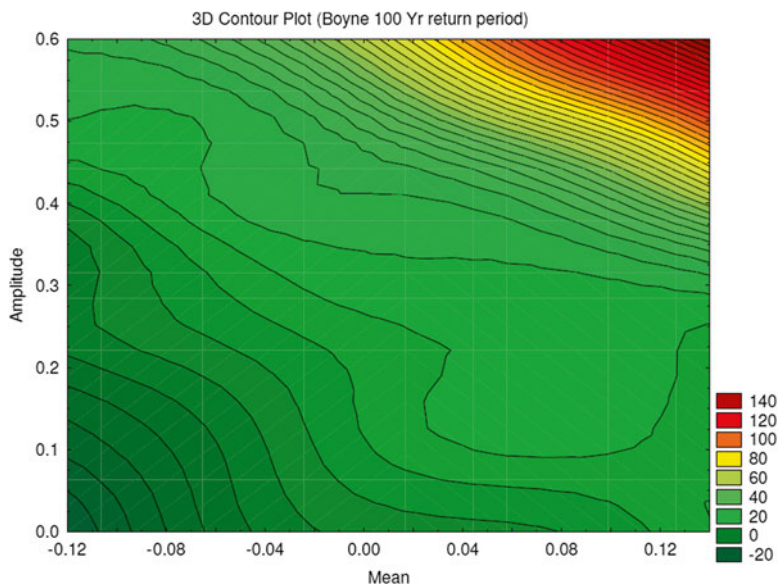


Fig. 4.17 Risk response surface for safety margins of 20 %. Only in case of a combination of relatively high mean precipitation change and high amplitude of precipitation a safety margin of 20 % will not be sufficient for the majority of projected changes in flooding

margins were over as much of the uncertainty range as possible. The research found that the performance of these safety margins differs between catchments. In some instances they were sufficient to cope with the range of scenarios analysed. In others, the safety margins were found to be too conservative for the range of climate projections considered, leaving high residual risk.

The project dealt with the following uncertainties:

- Emission scenarios,
- Global climate models,
- Natural variability,
- Hydrological model – both model structure and parameter uncertainty,
- Potential for future surprises in climatic conditions.

These uncertainties were dealt with in the following ways:

- Sensitivity analyses of which the results are displayed in risk response surfaces
- Risk response surfaces (see Fig. 4.17). These were used to visualise the effectiveness of the policy decision, given certain ranges in temperature and precipitation and the safety margins applied.
- Wild cards

Figure 4.17 displays the results of the sensitivity analysis in a response surface. Future precipitation changes are represented here as the mean and amplitude of the range of precipitation changes. It can be seen that a 20 % safety margin (based on current norms) shown as green area accounts for the majority of projected changes in flooding. However, it is apparent from the yellow and red areas (which exceed the 20 % allowance) that approximately one quarter of all simulations are not catered for by this safety margin. This can be thought of as the amount of residual risk associated with the policy of a 20 % allowance in flood design. The risk response surface was communicated to stakeholders at national meetings and conferences.

Following previous work done by others, particularly in the UK, the expansion of the sensitivity range on both the upper side and lower side to account for new extreme precipitation scenarios was also reviewed.

The project also considered uncertainty in the impacts models, i.e. the simple rainfall runoff models. This was done by looking at different model structures and parameter uncertainty.

Effect of Uncertainty on Decision-Making

“Ensure decisions are robust”

Using 51 different climate scenarios combined with uncertainties in downscaling and hydrological models, meant this was the biggest assessment of uncertainty in hydrological studies so far in Ireland. Previously the OPW has tended to use three scenarios to inform their decisions, but this work has reinforced their growing understanding that uncertainties need to be fully understood in order to take robust decisions. The OPW is moving away from a deterministic approach to adaptation decisions. This revolved around making specific assumptions about the way the climate will change, and designing structural engineering solutions such as building flood defences, perhaps with the capacity to increase their height in the future. They are now approaching decisions with softer techniques to ensure that they are robust under the full range of uncertainties involved.

A good example is Cork City, where a complete structural protection scheme against both fluvial and coastal flooding would have cost in the order of €140 m but would have given a reducing standard of protection over time. This is due to the fact that typical engineering approaches are built to a specific standard. As climate changes, the level of protection offered decreases potentially making the initial outlay of costs unjustified.

The proposed solution is therefore to provide partial defences through the city, with potential amendments to the reservoir operations and some localised protection works upstream of Cork, where land would be deliberately flooded to reduce fluvial flood risk. Barrages are also being considered as suitable alternatives to traditional defences (Fig. 4.18).



Fig. 4.18 Flood problems in Cork (Courtesy: Irish Examiner)

Author: Conor Murphy

Links to more information: Bastola, S., C. Murphy, and J. Sweeney. 2011. The sensitivity of fluvial flood risk in Irish catchments to the range of IPCC AR4 climate change scenarios. *Science of the Total Environment* 409(24): 5403–5415.

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4.2.7 Coastal Flooding and Erosion in South West France

Country: France

Sector: 

Scale: Local

Organisation: Public

Decision-type: Operational

Key Message

This project deals with the increased risk of coastal flooding and erosion through sea-level rise in South West France.

The key message from the project was:

- Using a low/no regret approach serves many functions, such as solving the flood problem, adding value to natural reserves and creating new potential for recreation.
- Add other messages, such as the feasibility of taking meaningful action in the absence of precise predictions of future changes, etc.
- Meaningful coastal investments can be made in the absence of precise predictions of future changes.
- Climate change impacts can be strong drivers to implement projects that strive for both current and future vulnerability.

Background

The lido⁵ between Sète and Marseillan in the Languedoc-Roussillon region of France was threatened by sea level rise and erosion. During the last two decades coastal erosion and flooding have caused increasing traffic disruption on the road between the two towns and the inland biodiversity and heritage was additionally impacted by storm surges. Protection was also needed for economic activities such as vineyards and oyster farming in the Thau pond, as well as the sand beach and the local campsite.

The threat triggered a comprehensive spatial planning project run by the Community of Communes. The project was driven by a desire to counter beach erosion and the climate change dimension wasn't initially considered; it was launched in 2000 with a view to targeting soft protection measures rather than concrete devices. Sea level rise was primarily considered during the implementation phase to ensure that the measures taken would be sustainable in the long term.

Funding was provided by the State, the local authorities (regional and departmental) and the European Union through the European Regional Development Fund (ERDF). An Interreg III project has also been conducted for its demonstrative and innovative purposes.

Process

A study into the feasibility of moving the road, and the sustainable land planning of the lido, started in 2003 and was completed in 2005 with many public consultations. The public consultation is a mandatory process in France, required for significant

⁵Public place for beach recreation, including a pool for swimming or water sports.

spatial planning projects in order to identify natural, social and cultural issues. After completion of the consultations, the development project was finalised and the works started in early 2007.

Climate data used

Ministry of Environment recommendation on sea level rise for long-term planning to be +25 cm by 2050 (DGEC/ONERC 2010).

The current vulnerability to flooding was well known, but data from the Ministry of Environment recommended considering a sea level rise of over 25 cm by 2050. The Community considered the option of leaving the road as it was, but the cost-benefit analysis delivered many benefits of a strategic relocation of the road behind the lido. One of these benefits was the fact that such a move, combined with a regeneration of the sand dunes would “climate-proof” the area against potential flooding for over 50 years. The new road became operational during summer 2010 and the rehabilitation of the sand dunes of the lido continued until 2011 (Figs. 4.19–4.21).



Fig. 4.19 Recurrent erosion impacts on the coastal road



Fig. 4.20 Global overview before the commencement of the project showing the road situated next to the beach



Fig. 4.21 Global overview after completion of the project showing the road moved inland and the restoration of a wider beach and sand dune

Uncertainty Assessment

The two main types of uncertainty were:

- The exact value of sea level rise and its associated extreme wave heights from storm surges.
- Erosion trends under sea level rise.

To cope with the uncertainty surrounding the magnitude of sea level rise, the project decided to combine the relocation of the road with protection of the sand ridge and restoration of the beach width. Expert advice from the technical advising contractor was taken and there was public consultation with stakeholders. The road was moved behind the lido and the sand dunes restored to a height of 4.2 m above sea level. The new road relocated inland has been raised by 1.5 m in order to reduce the risk of permanent road flooding during strong storm surges and to anticipate the new flood risk management scheme; the regional Disaster Risk Management unit has strongly supported the idea of raising the road.

In addition, the restored dunes were populated with plants stored prior to the start of the project and the position of the dunes is now being monitored with cameras along the beach line. Some innovative coastal defense measures are being taken (e.g. sunken geotubes⁶) to attempt to minimise the effects of erosion, and these are also being monitored. This multi-measure approach provided good resilience to the rising sea level and is “low regret” in the sense that the adaptations provide other benefits such as recreational facilities and Natura 2000 sustainability.

Effect of Uncertainty on Decision-Making

“Time is needed to convince a community that changes should be sustainable”

The project did not evolve exclusively from a need to consider climate change, but impacts related to sea-level rise, such as erosion and flooding, were key drivers. The Community of Communes wanted a long-term solution to the problems and found that the best way was to produce defences high enough to deal with all eventualities. This solution was a “low regret” solution as it also provided biodiversity, economic and recreational benefits. Exchanges between the project leader, expert and the regional DRM unit have helped to consider sea level rise in a pragmatic way.

The Community of Communes has been able to propose an amended solution to the local problem. Dunes were previously considered obstacles to the development

⁶The geotubes are sediment-filled sleeves of geotextile fabric and used to build structures such as breakwaters, shoreline protection or island creation.

of tourism and at the beginning of the project some decision-makers just wanted to build dykes to keep the sea at bay. The proposed solution has restored the beach and helped sustain the local economic activity. It also provides the necessary protection from erosion and flooding.

Author: Bertrand Reyssset

Links to more information: http://www.thau-agglo.fr/IMG/pdf/Dossier_Presse_Lido_2011-2-2.pdf, http://www.developpement-durable.gouv.fr/IMG/pdf/ONERC_lettre_2.pdf

Data sources: DGEC/ONERC (2010), *Prise en compte de l'élévation du niveau de la mer en vue de l'estimation des impacts du changement climatique et des mesures d'adaptation possibles*, Synthèse n°2, 6 p. http://www.developpement-durable.gouv.fr/IMG/pdf/synth_niveau_mer.pdf

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4.2.8 Québec Hydro-Electric Power

Key Messages



This case study was designed to determine whether climate change should be taken into consideration when developing a hydro-electric power plant refurbishment strategy.

Key messages from this project were:

- The realisation by the hydropower company that there was no such thing as a single “best (climate change) scenario” and that multiple scenarios should be used to deal with climate change uncertainties.
- Clear communication between the climate scenario developers and the operation management and openness to mutual knowledge transfer were most important in the outcome of the project.



Fig. 4.22 Manic 2 Power House on the Manicouagan River (Source: Hydro-Québec)

Background

“There is no such thing as a single “best” scenario in climate change”

After several decades of operation, a number of dams and hydropower stations of the state owned company, **Hydro-Québec** needed refurbishment (Fig. 4.22). Changes in climate have already and will further affect the flow regimes of the dammed catchments. For example, until now winter precipitation has largely been snow, but this is now changing to include rain which ideally needs to be harnessed.

Hydro-Québec, was the primary stakeholder of this project. Their research division, IREQ (Institut de recherche d’Hydro-Québec), conducts research into energy related fields including the assessment of climate change impacts on the watersheds of their power generation stations. However this time it was the operation management who took the step to request concrete climate change information.

The company wished to update its generating equipment to provide state of the art facilities. As part of this process it wanted to evaluate future hydrological conditions to determine their effect on plans for renovation. If they established that climate change was likely to affect their long-term decisions, they planned to carry out more

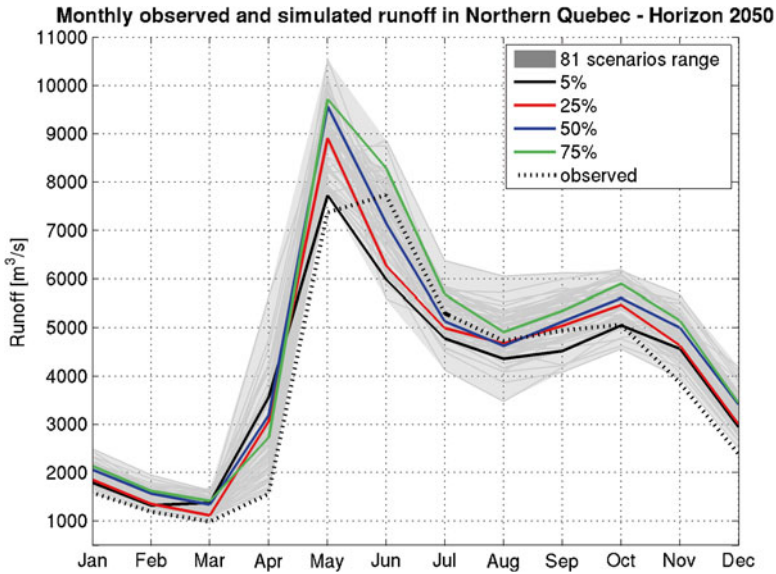


Fig. 4.23 Annual cycle of observed and simulated runoff in a northern Québec watershed. The presently observed runoff is shown as the dashed line. The four selected future scenarios representing the 5th, 25th, 50th and 75th percentile of the range of projected change are shown in colour over the range of all scenarios used. The selection was based on cluster analysis of multiple indicators critical in dam operation and management

in-depth studies of the impacts for specific catchments and sites to be modernised. Their initial approach was to base their study on the “best (climate change) scenario”. However, following involvement in meetings and workshops it eventually became clear to them that climate system and projection uncertainty cannot be considered using a single scenario. A sound approach was then developed to review climate change effects under a broader range of conditions. In the end the economic impact study utilised four different future hydrological scenarios.

Process

Initially, a request was made to the Ouranos Consortium, a private, non-profit making organisation advising in the areas of climate sciences, impacts and adaptation, for the “best climate change scenario” to help the company with their plans for plant refurbishment. This resulted in an investigation into climate simulation data and their hydrological impacts and after many meetings and exchanges about the needs of the stakeholder, four projections, representing the 5th, 25th, 50th and 75th percentiles of the range in uncertainty were asked for by the client and as such provided. This is demonstrated in Fig. 4.23 showing changes in runoff.

The work was shared between the Ouranos Consortium who produced the climate scenarios and IREQ who did the hydrological modelling. Clear communication and

Climate data used

- 81 climate simulations composed from:
 - 73 global climate models from CMIP3 (scale approx. 250×250 km)
 - 8 regional climate models from Ouranos CRCM4 simulations (scale 45×45 km)
- Climate variables used to drive a hydrological model: daily precipitation, minimum and maximum temperatures

openness to mutual knowledge transfer were key to the results. For the production of hydropower, precipitation in combination with temperatures is the key climate vulnerability. The meteorological variables were transformed into stream flow using a hydrological model and the four percentiles described above were selected to cover the uncertainty. The final economic evaluation was done by Hydro-Québec in order for them to decide if there was enough change to affect their investment in infrastructure.

A short description of the study was presented outlining the general impacts of climate change on hydrology in the north of Québec.

Risks for hydropower production under different future hydro-climatic conditions include a loss of efficiency of old installations and possible complications in the management of the available water. For example, a release of excess water in the reservoirs would mean a loss of hydropower production. In refurbishing their installations, Hydro-Québec was trying to cope with these vulnerabilities and risks.

Example of handling uncertainty: Multi-criteria cluster analysis

An ensemble of 81 climate simulations was analysed for 11 watersheds. Daily values for each watershed were bias corrected and used to drive a hydrological model to obtain future stream flow scenarios. They were then filtered in a multi-criteria cluster analysis to represent the 5th, 25th, 50th and 75th percentiles of the range of uncertainty in the hydro-climatological projections. Cost-benefit analyses were then performed using these four different hydrological scenarios. In this manner the range from 5 to 75 % (=70 %) of the uncertainty was effectively addressed.

Uncertainty Assessment

The uncertainties taken into account in this study included:

- GHG emission scenario uncertainty,
- Climate model uncertainty,
- Climate system uncertainty,
- Regionalization uncertainty.

Different possible developments of future societies were accounted for by using three GHG emission scenarios in the climate simulations ensemble. Climate model and climate system uncertainty were addressed by including multiple simulations from 16 different global climate models and one regional climate model. Uncertainty of regionalisation of the scenarios was accounted for by using four different empirical downscaling methods in the production of regional hydrological scenarios.

The methods used to analyse the different types of uncertainties were as follows:

- Project scenario analysis (see box),
- Expert elicitation through consultation with the Atmospheric Sciences department at Université du Québec à Montréal,
- Sensitivity analysis of bias correction methods/empirical downscaling,
- Multi-model ensemble using the maximum number of models possible,
- Stakeholder involvement between parties at Hydro-Quebec and Ouranos.

Example of handling uncertainty: Project scenario analysis

Eleven different watersheds had to be identified and analysed. In some cases watershed boundaries had to be re-examined in order to be correctly modelled and to obtain optimal observational data for the empirical downscaling. These iterations were needed to set up the physical description of the problem. Then, the options of covering uncertainty using different numbers of scenarios were played through to demonstrate that the request of “the best scenario” might be over simplified.

By employing exclusively Hydro Québec’s operational hydrological model, the uncertainty from hydrological model choice could not be considered. This would require a hydrological model ensemble. Likewise, it was beyond the scope of this study to relate the magnitudes of uncertainty from climate change projections to those from cost-benefit analysis. Both issues are important but relatively new fields of research and shall be addressed in subsequent, more detailed assessment.

Effect of Uncertainty on Decision-Making

Uncertainty has had a profound effect on the course of this study, commencing with the realisation that more than one climate change scenario needed to be taken into account.

The four selected scenarios were used as varying assumptions for a cost-benefit analysis to assess the impacts of increased runoff on hydro-power assets. Based on the results of this analysis the stakeholder has decided that the impacts of climate change are of a magnitude that need to be taken into account in the planning of renovations of hydropower facilities. Thus, more in depth studies of climate change

impacts will be conducted and Hydro-Québec will be reviewing its position in more detail to achieve a clear picture of cost-benefit options due to climate change impacts.

Authors: Marco Braun (Ouranos), René Roy (IREQ) and Diane Chaumont (Ouranos)

Links to more information: <http://www.ouranos.ca>, <http://www.hydroquebec.com/en>

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4.2.9 *Austrian Federal Railways*



Key Messages

“Give information to those who need it”

This case study focused on adaptation in railway infrastructure and how uncertainties in future climate need to be properly considered when time-scales of 100 years are involved.

The key messages are:

- Trend analysis is a useful way to handle uncertainties.
- Constant feedback between company staff and experts is necessary throughout the process.
- Messages must be communicated clearly and in a language which matches the stakeholders language, particularly concerning uncertainties.
- Climate change is usually just another uncertain issue amongst others that companies have to handle traditionally.

Background

“Try to be practical”

The **Austrian Federal Railways** (ÖBB – Österreichische Bundesbahnen) runs the national railway system of Austria. It is entirely owned by the Republic of Austria and is divided into several separate businesses that manage the infrastructure and



Fig. 4.24 Winter service ÖBB – West part of Austria in January 2012 (Photos: ÖBB)

operate passenger and freight services. Since 2003 it has also run Austria's largest bus company with its intercity networks (Fig. 4.24).

The ÖBB is a significant organisation, carrying about 450 million passengers a year. It has about 4,800 km of route network and more than 1,000 railway stations. Given the long life-span of up to 100 years in investments in major transport routes, bridges, tunnels etc. the ÖBB recognised the importance of properly considering changes in future climate when making decisions. After all, the company knows only too well that there is little tolerance from passengers towards the late running of trains.

In 2010, the company contracted the Austrian Environment Agency to help identify potential climate change impacts on rail infrastructure and develop recommendations for adaptation. The aim was to investigate as many meteorological variables and climatic changes as possible that might have an impact on the company's infrastructure and security of service. The company wanted to find practical solutions for problems, whilst taking into account the best scientific knowledge available. The ultimate goal was to incorporate the findings in the company's long-term risk strategy.

Process

*“Maintain constant feedback throughout
to achieve a robust outcome”*

The company was not new to the concept of uncertainty, partly because Austria is an alpine country and used to natural hazard management. They had realised uncertainty is not exclusive to climate change and already affects current decisions in natural hazard management.

Senior executives and company experts in the fields of research and innovation, natural hazards and sustainability were assembled into a steering group and included in every step of the project. Such continuous involvement by company staff in the project was seen as critical to its success. Experts from the Institute of Meteorology at the University of Applied Life Science were part of the project team, also participating in the steering group.

The project focused primarily on climate related risks and the company representatives were generally open and very interested in such matters, being aware of the impact that weather related events can have.

The steering group met approximately every 2 months and this close cooperation between experts with vital information was important to the success of the project. Three workshops were also held to involve other members of the company and discuss the following topics:

- Climate change impacts on railway infrastructure – discussing the overview table.
- Vulnerabilities with specific focus on natural hazards – using trend analysis from company data. It was during this discussion that concerns about uncertainties were addressed with one stakeholder declaring “*You can’t tell us what will happen in 2020 in region xxx, so how should we know what to do about this?*” The company’s pragmatic answer to this was to provide clear guidance to staff required to implement decisions.
- Climate change adaptation options – dedicated to presenting possible options for the future and getting feedback from the stakeholders.

Climate data used

Regionalised climate scenario were based on ECHAM5 and HADCM3 models and A1B and B1 IPCC GHG scenarios

The first step was to produce an overview table on observed climate impacts for railway infrastructure and some operational issues. This was based on qualitative information stemming from research projects, grey literature and other information sources, and was used as the first basis for the discussion with company representatives. Past observations and stakeholder knowledge were combined with expert judgements using regional climate data so that important climate related impacts and trends could be identified for the ÖBB. In addition, past trends were extracted from company data to see if there were links between disturbances to operations and meteorological events (see Fig. 4.25).

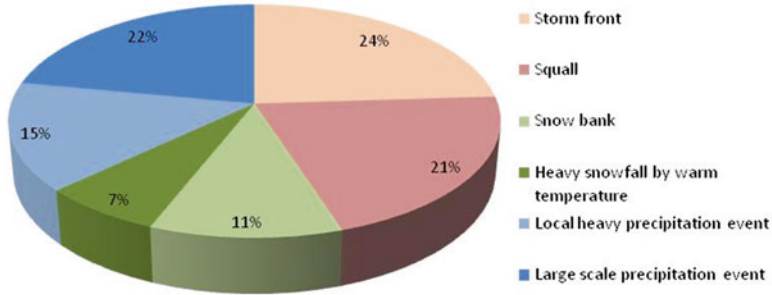


Fig. 4.25 Disturbance cases between 1990 and 2011 clustered by meteorological events (ÖBB data analysed by H. Formayer)

Uncertainty Assessment

It became obvious during the course of the project that dealing with the following uncertainties were key for a good and robust result:

- Uncertainties inherent in climate scenarios (emission scenarios, global models, regional scale issues, problems with consistency of data series). These were dealt with by involving an expert climate meteorologist and working with trend analysis.
- Changes in method of data selection and documentation in the ÖBB internal database on past natural hazards which were used for the trend analysis. Sensitivity analysis was applied to this data.
- No regret/low regret analysis: The Environment Agency collected adaptation options from the literature and highlighted if these options were no-regret or low-regret. The list was discussed with the company's staff to understand if the options would benefit the company and if they could be connected with already existing measures. Considering uncertainties involved, the flexibility of the options was assessed as well.

Handling uncertainty – Trend analysis

More than 1,000 events over the previous 20 years were analysed and compared to parameters such as heavy precipitation, high winds or excessive temperatures responsible for causing disturbances. This formed the basis for the vulnerability assessment and the determination of future trends, although there was some concern over the integrity of this database. Future trends in climate parameters and thus impacts on infrastructure (e.g. rail buckling, infrastructure damage due to floods, storms or heavy snow fall) were then determined based on available regional climate models and expert knowledge.

Other methods of handling uncertainty included:

- Stakeholder involvement

Effect of Uncertainty on Decision–Making

“Implement now to avoid greater costs in the future”

*“Nobody knows what will really happen
so it is safer to act now”*

The project had two very positive outcomes. Firstly, future investment will be climate-proofed; due to the uncertainties in future climate projections, it was decided that planning new infrastructure should not focus on one single “optimal” solution but should be made more robust by taking into account a range of possible climatic changes. Thus, in the case of transport infrastructure, multiple-benefits, no-regret and low-regret adaptation options were recommended.

One example is that of future track drainage. Trend analysis showed that in certain regions future rainfall may become more intense. To cater for this, track drainage will need to be improved. The company reviewed the range of likely outcomes and decided drainage should be improved in some regions to cover all likely eventualities.

Secondly, there was improved sensitivity to climate issues; having experienced the project process, company representatives have built climate change issues into their long-term strategy and developed a sound basis on which to consider such issues in the future.

Author: Andrea Prutsch

Links for more information: http://botany.uibk.ac.at/neophyten/download/09_OeBB_Rachoy_KLIWA.pdf, http://www.oebb.at/infrastruktur/_resources/llShowDoc.jsp?nodeId=29841913

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4.2.10 Dresden Public Transport

Country: Germany
Sector: 
Scale: Local
Organisation: Public
Decision-type: Strategic

Key Messages

This project helped refine the current business strategy of a public transport provider in Dresden, Germany to take into account the future effects of climate and demographic change.

Key messages are:

- New tools, such as fuzzy cognitive maps, help clarify uncertainties and identify appropriate strategies within an environment facing a complex mix of challenges.
- Company executives were stimulated to consider the implications of climate change amongst other uncertainties in their decisions.

Background

“An expert partner in the project is crucial”

Public transport is highly sensitive and vulnerable to external impacts which affect the complex relationship between infrastructure, technology, time schedules, and volatile customer behaviour. In a dynamic developing city, the public transport provider needs to deal with changing conditions. Uncertainty in investment funding from the public budget as well as the high dependency on political decisions means that constant planning and refinement of plans is needed.

Climate change primarily impacts this industry through extreme weather events; inherent uncertainties in these have a big influence on both the planning of infrastructure and daily operations of the business. For example, a major flood in 2002 caused roads to be closed and damage to infrastructure which had a long-term impact on the public transport system (Fig. 4.26). Then, in 2003, a heat wave with extreme high temperatures caused discomfort for customers and drivers in buses and trams without air conditioning. In addition, storms, heavy snow fall or ice on the overhead wire can disrupt operation or cause damage through fallen trees etc.

The main goal of the case study was to refine the company's business strategy in the face of future challenges such as climate and demographic change. The company has already taken action to adjust the time schedule of trams and buses in the winter season to handle the possible impacts of continuing snow fall. Economic and technological challenges, such as the increase of energy prices, have also been considered through the introduction of buses with hybrid technology.



Fig. 4.26 Impact of major flood in Dresden in 2002

The project was conducted as part of REGKLAM, an integrated regional climate change adaptation program. It is part of KLIMZUG financed by the German Federal Ministry of Education and Research, involving partners from politics, administration, business and science. The case study itself was run by Technische Universität Dresden (TUD) (under the lead of Chair of Environmental Management and Accounting) and involved the two CEOs of the company along with representatives from company departments such as strategic planning, financial control and human resources. There was considerable understanding within these departments of the negative impacts that climate change is having on the day-to-day running of the transport system through the increase in extreme weather events. The objective was to discuss the final results with the city government to plan for a resilient public transport system.

Process

Figure 4.27 presents the process that was used in the project to develop and use/transfer scenarios in an iterative way. The process began with a kick off meeting in August 2011 to determine the goals. Then, after some desk research, a number of workshops were held, first with experts and then with company representatives, to select key climatic and non-climatic challenges and to analyse the future

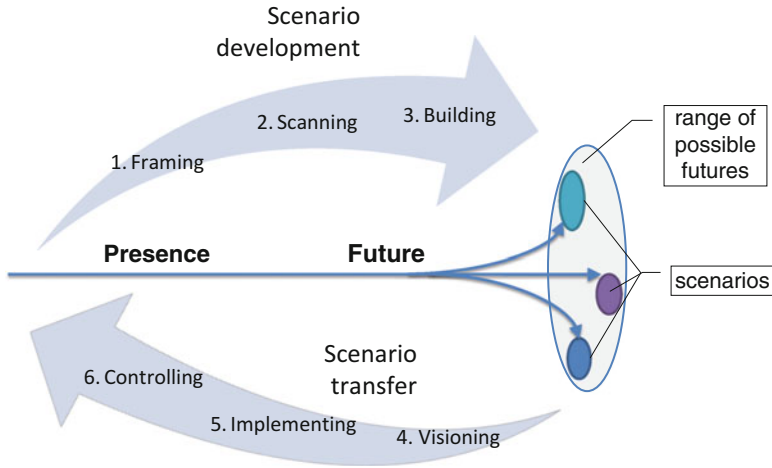


Fig. 4.27 Iterative development of scenarios

development of their associated uncertainties (e.g., climate or demographic change). Accordingly, up to three assumptions for the future development of the key challenges were defined. Various scenarios are developed from this by applying different assumptions to potential pictures of the future. These possible futures will be discussed in workshops with senior executives and options for adaptation identified. The project finished mid 2013.

Climate data sources

- Historic data from the Met Office
- Forecast data using climate models WEREX IV, REMO, CLM and WETTREG (Met Office)
- IPCC emission scenarios

As part of REGKLAM, data was taken from fact sheets developed by the chair of meteorology of TUD. These gave historic data for two time periods up to 2005 for important regional and local climate parameters such as average temperature, average precipitation, dry and hot weather days. They also provided ranges of forecast data for two further time slices up to 2100.

From discussions with company executives however, it became clear that interest was particularly focussed on extreme weather events as these are likely to have the biggest impact on the business. Information was taken from the literature and the whole business environment was scanned. In a first step all potential challenges – 60

in total – were identified and categorised. These were reduced to 19 which particularly affect this public transport sector in order to tackle the problem.

Uncertainty Assessment

Uncertainty in dealing with extreme weather events exists to the extent that no assumptions or prognoses can be made for their future occurrence. The meteorologists in the project developed prognoses for average temperature and precipitation, but they were not able to make such “assumptions” for the occurrence and impact of extreme weather events. The uncertainty related to incomplete knowledge of such events on business challenges was therefore addressed through the use of Fuzzy Cognitive Mapping.

Nineteen climatic and other business challenges were identified in workshops with the stakeholder using Fuzzy Cognitive Maps (Fig. 4.28), with some of the influences described in full below. Possible relationships between the influence factors were identified and assessed according to the strength of the influence. For example it can be seen that extreme weather events such as heavy precipitation, floods, heat waves etc. (EXTWE) have a great influence on the development of information/communication/distribution systems (ICDSY).

Influence factors that have a significant effect or are highly affected by others within the whole system were selected as major key challenges for the next step in the process. Examples included an increase of extreme weather events, changes of customer behaviour, an increase in the development of technologies, and increasing political influence. In this way important relationships between factors affecting a business are identified and the uncertainties are reduced by dealing with these complexities.

The company felt that, through the use of the fuzzy cognitive map, the project provides a clear view on the connections between all factors that influence their business and on the possible effects of their decisions. They feel that it will ease their selections between different options for decision making.

Other methods of handling uncertainty were as follows:

- Scenario analysis (“surprise-free”),
- Expert elicitation,
- Sensitivity analysis,
- Stakeholder involvement,
- Wild cards/surprise scenarios.

Effect of Uncertainty on Decision-Making

*“Time is needed within the process to pause
and reflect”*

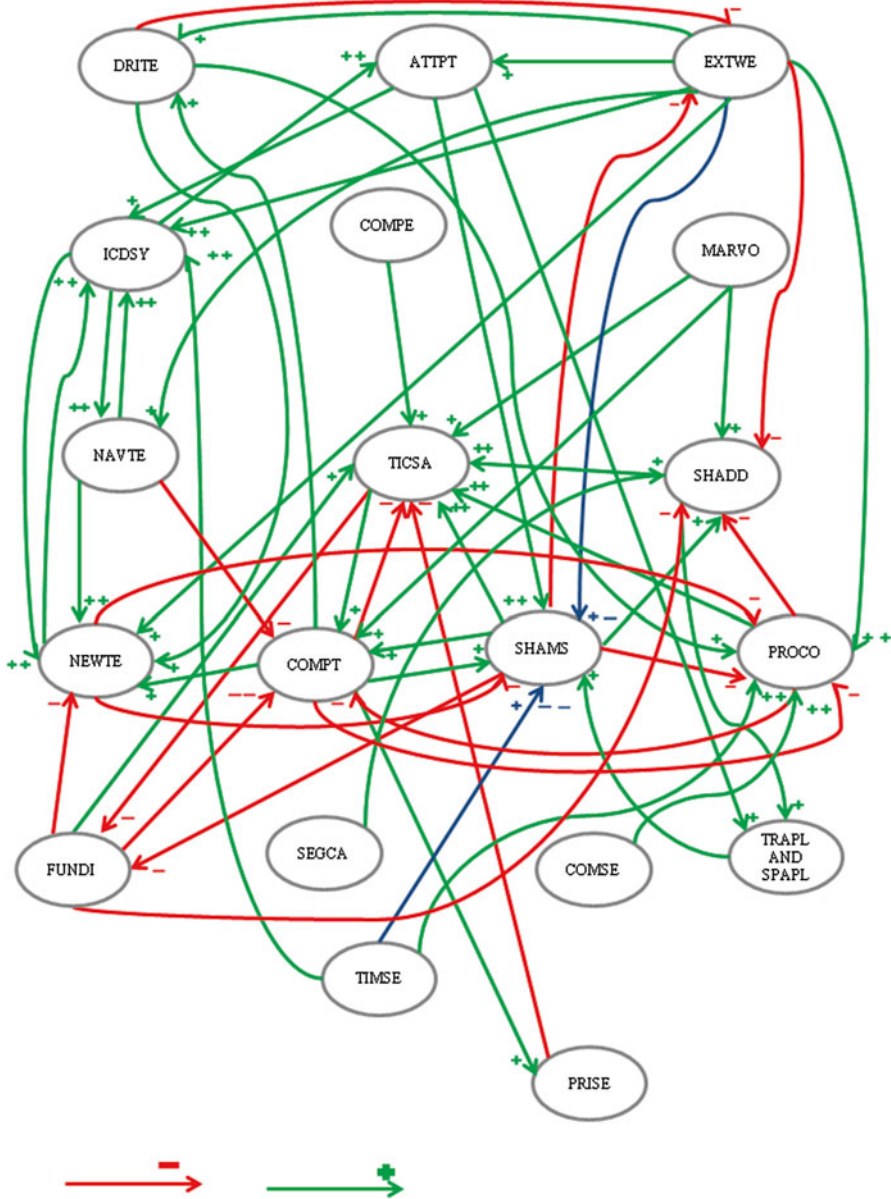


Fig. 4.28 Fuzzy Cognitive Map indicating relationships between influencing factors. *Green arrows* show positive influences and red negative ones. *Blue colour* stands for a relationship that can be both positive and negative. Fuzzy Cognitive Map influences: *EXTWE* Occurrence of extreme weather events, *TICSA* Ticket sales and revenues, *SHADD* Shareholder expectations of deficit development, *NEWTE* New technologies, *COMPT* competition within the public transport community, *SHAMS* share in the modal split, *PROCO* procurement cost, *ICDSY* information, communication, distribution systems, *FUNDI* Funding, *PRISE* Price sensitivity of customers, *TIMSE* Time sensitivity of customers, *COMSE* Comfort sensitivity of customers, *TRAPL* Traffic planning, *SPAPL* spatial planning, *SEGCA* Segregation of duties to the commissioning authority, *NAVTE* Navigation technologies, *MARVO* Market volume, *ATTPT* Attitudes/public transport supporters, *DRITE* Drive technologies or fuels, *COMPE* Compensation

By analysing the whole business environment and identifying the major future challenges, the managers and decision-makers were encouraged to think creatively. This led to a new view on existing strategies and actions and stimulated action to address the associated uncertainties.

The company is very aware that some issues will be strongly influenced by climate and climate change mitigation. For example, diesel engines will disappear in the future, but no-one can yet say what will replace them. Therefore, they need to be involved in the research process. The company culture demands that time is allocated to allow ideas, options and tools to become integrated into general practice. New methods and tools for strategic planning and long-term thinking were introduced and the end result will be an implementation plan for climate change adaptation measures.

Authors: Julian Meyr and Edeltraud Guenther

Links to more information:

For information on the institution leading the case study: http://tu-dresden.de/die_tu_dresden/fakultaeten/fakultaet_wirtschaftswissenschaften/bwl/bu/

For information on the background to the project: www.regklam.de

Contact details: ema@mailbox.tu-dresden.de

4.2.11 *Hutt River Flood Management*



Key Messages

“Better to consider a full range of uncertainties now than to put off action until the future when costs will be higher”

“Uncertainties cannot be dismissed as an area scientists don’t understand”

This project aimed to improve the understanding of flood risks under the uncertainties of a changing climate in a river basin in New Zealand.

Key messages from the project are:

- The traditional tendency to project historical experience forward is a poor strategy in an uncertain climate because the future is unlikely to be like the past.
- Studies of uncertainties can expose the limits of static flood protection and of emergency planning. Understanding this increased practitioners and community consideration of a wider range of options and adaptive management in space and over time.
- Simple models can be used to explore uncertainties at low cost.
- A workshop process helps increase awareness of uncertainties in future flood risk and their planning implications and influence responses.
- Visual depictions are a powerful way to communicate the effects of climate change uncertainties.

Background

The aims of the project were to:

- Find a simple and low cost method of characterising the effect of climate change on flood frequency across a range of possible futures, and
- Demonstrate whether this influenced understanding and responses to changing flood risk.

The traditional way of using best estimates as single numbers or averages mischaracterises the range (uncertainty) and especially damaging extremes, thus entrenching the perception that protection structures offer safety for long-lived settlements and infrastructure. The project highlighted residual risks to settlements above design flood levels which increase with climate change. It was applied to the Hutt River basin, assessing flood frequency and potential damages of increased inundation levels with climate change. The project was run by the New Zealand Climate Change Research Institute at the Victoria University of Wellington, funded by the government Ministry of Science and Innovation. The primary stakeholders were the Greater Wellington Regional Council and Hutt City Council.

Flood risk is enhanced by climate change and there are substantial risks to urban communities which vary according to socio-economic status and ethnicity. Current methods used in flood risk management in New Zealand do not account for the effects of climate change on flood frequency and in particular, do not consider extremes which represent the uncertainties across the range of future changes. Until now, councils have taken a static, inflexible approach to climate risk in their flood management which has had the effect of entrenching and exacerbating this risk. In addition, averages and single scenarios are often used which underestimate extremes. Consequently, design flood levels used for flood risk management can result in inadequate protection for changing climate risk and give rise to a false sense of security to decision-makers and their communities. A more nuanced,

risk-based approach to the effect of changing climate on flood frequency requires consideration of a wide range of alternative scenarios, but this is often constrained by the high cost and complexity of modelling. This project illustrates a simplified approach for evaluating uncertainty in future changes in flood frequencies based on different climate change scenarios, using the Hutt River in New Zealand's lower North Island.

Process

The case study comprised three parts:

- Modelling the effect of climate change on the Hutt River flood frequency and the potential damages from resulting inundation,
- A survey of households on how they responded to flood risk and their views on future climate change induced flood risk,
- A workshop with practitioners across a number of councils in the Wellington region and follow-up interviews with a sample of them.

Climate data sources

- Historical flood data (1972–2008)
- 12 GCMs, statistically downscaled
- Four different emissions scenarios
- An algorithm to infer changes in extreme rainfall based on changes in monthly mean climate

The model used 48 downscaled scenarios to derive changes in monthly average rainfall and temperature in the Hutt river catchment. From these, a simple algorithm determined changes in extreme rainfall which were run through a hydrological model calibrated to the Hutt River.

The results were tested at the workshop to gauge how the participants would respond. Participants included local government practitioners across strategic planning, urban planning, engineering, hazards management scientists, emergency management, and flood management, being those most involved in decision-making on flood risk. The uncertainties were presented visually as a changing risk. This increased the awareness of the participants to a range of possible futures, especially the damage consequences at the extremes, and the need for them to consider a wider range of more flexible responses. They realised that considering the uncertainties more transparently could potentially affect the design and planning assumptions over the life of the flood protection structures. This could thus reduce the risk to the people and assets currently protected. Presenting the dynamic nature of the risk in descriptive and visual form focused the thinking of the participants on the implications and their possible responses.

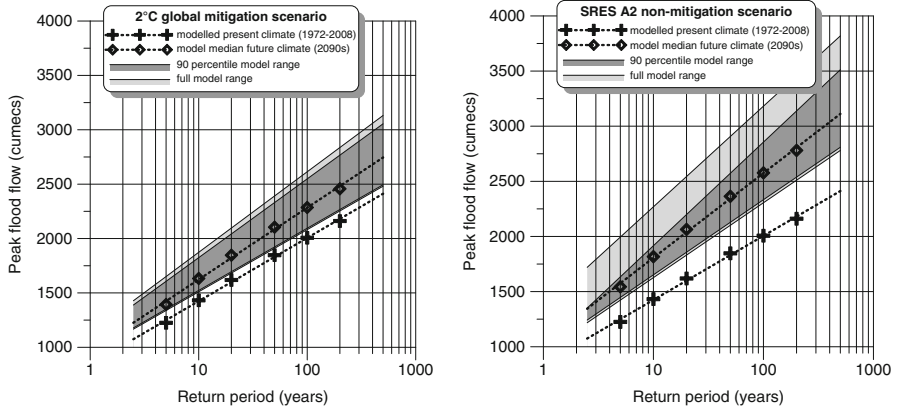


Fig. 4.29 Changes in exceedence probabilities under different emission scenarios. The *black dots* and *solid line* show estimated exceedence probabilities for a range of design flood volumes. The *dotted line* shows the flood volumes for alternative emissions scenarios in 2090 (*left*: 2 °C stabilisation; *right*: A2 SRES emissions) for a range of climate models. The *light grey* band shows the full model range, whereas the *dark grey* band shows the 10–90 percentile model range. A return period of 100 years in the *left hand graph* becomes 30 years and for the *right hand graph* becomes 20 years

The risk context of the visual presentation also resonated with elected councillors. A time and functional element to discussions was introduced, whereby the participants could identify activities with different lifetimes and conceive that changes could be staged over different timeframes to address the changing risk. This was effectively a discussion of adaptive management.

Uncertainty Assessment

The prime uncertainty addressed in this study was the effect of climate change on flood frequency, especially at the extremes. A quick and relatively low-cost methodology to explore the implications of alternative climate change scenarios for flood frequency was presented and applied in a stakeholder workshop setting. Exceedence probabilities, as shown in Fig. 4.29, appeared to increase under all scenarios but with considerable differences between alternative emissions scenarios and climate models. Understanding the full model range and how it changes in frequency emphasises the importance of low probability high impact events for planning and design of responses.

The approach used to assess the potential changes in flood frequency through to the 2090s comprised three steps:

- Statistically downscaled 12 GCMs and four emissions scenarios were used to produce 48 alternative climates (i.e. changes in *monthly average* rainfall and temperature) over the twenty-first century for the Hutt River catchment

- A simple procedure (algorithm) was used to estimate changes in *extreme rainfall* for the catchment
- Hourly rainfall data was run (both historical and adjusted for future climate changes in both means and extremes) through a hydrological model to derive flood frequencies under historical and 48 alternative future climates.

Stakeholder consideration of uncertainty

Flood frequency information affected by climate change was presented visually to participants from councils in the Wellington region. This resulted in participants questioning their reliance on flood warnings, emergency management and levees. The information focused attention on a wider range of complementary response options including protection, accommodation, spatial planning and retreat and the timing of different decisions.

The analysis represents a key advance on those earlier studies in that it quantifies uncertainties in the projected changes depending on emissions and climate models. This supports a more risk-based assessment of impacts and response options and avoids a premature collapse of a range of futures into single estimates, or reliance on simple scaling of current flood volumes that may not account for non-linearities and thresholds in catchment hydrology.

The following methods were used in combination for analysing uncertainty:

- Scenario analysis,
- Sensitivity analysis,
- Probabilistic multi-model ensemble,
- Stakeholder involvement.

Effect of Uncertainty on Decision-Making

“Studies such as these can increase a community’s acceptance of a wider range of appropriate options”

This project has catalysed a shift in thinking from static safety and path dependency, to thinking about how to build flexibility into decision-making. For example, a realisation that the bottom of the Hutt catchment could face risks from increased runoff and rainfall, sea level rise, and storm surges, has led to a sharper focus on managed retreat as an option for one low-lying area. The Greater Wellington Regional Council, responsible for the Hutt river management, is including the findings of this study in a review of their flood risk management plan. They have also used the results to discuss a wider range of response options with the local council in the area of the Hutt valley.



Fig. 4.30 Flooding of the Hutt river

Modelling a range of possible futures and showing how a changing climate could affect flood frequency has enabled stakeholders to see the value of the approach developed for their consideration of future risk. Within the community there is an expectation of continuous structural protection. Examination of uncertainty however, exposed the limits of static protection and enabled practitioners to more seriously consider complementary measures that could address changes in climate impacts. These limits may include the costs of raising higher levees and of higher residual damage, as extreme events increase in frequency and intensity and design levels are exceeded. The need for continuous consideration of changing climate risk was also highlighted.

Feedback received from the local government organisations was very positive. They felt it gave them a framework to think about changing climate risk, allowing them to quickly scan responses and discuss them with the elected councillors and local urban councils to consider the implications for a range of options, their costs and timing to enable uncertainties to be a catalyst for decision-making for the future (Fig. 4.30).

Author: Judy Lawrence

Links to more information:

Reports from the research programme can be found here: <http://www.victoria.ac.nz/sgees/research-centres/ccri/ccri-publications>

The Ministry for the Environment Guidance on the effect of CC on flood flows and which includes the methodology that we used to generate the effect for the Hutt Valley can be found here: <http://www.mfe.govt.nz/publications/climate/climate-change-effects-on-flood-flow/tools-estimating-effects-climate-change.pdf>

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4.2.12 *Communication of Large Numbers of Climate Scenarios in Dutch Climate Adaptation Workshops*



Key Messages

This study used workshops to discuss climate change impacts on spatial planning. Climate uncertainties were addressed by means of scenario analysis and different ways of visualising scenario outcomes were tested.

Key learning experiences are:

- The method of presentation of climate change scenario information is key to the understanding of decision-makers.
- Interactive forms of visualising scenario outcomes allow stakeholders to handle the data themselves and so to better understand the impact.
- Policy-makers have a tendency to focus on the ‘middle of the road’ scenario, whilst scientists focus on extremes, highlighting the inadequacy of a single scenario map.
- There is a high risk of using a single map as decision makers tend to see this as a prediction rather than a projection.
- The challenge of uncertainty combined with high costs of extreme adaptive measures triggers creative minds to look for innovative alternative solutions.

Background

“Everyone needs to be engaged”

“We need to be prepared for change”

In order to stimulate climate adaptation at municipal level, the Province of Gelderland initiated Climate Workshops in close collaboration with the Alterra Research Institute of the Wageningen University and Research Centre. In the municipal environment, planning choices are made between issues such as housing, transport, water systems and safety, agriculture, recreation and the natural environment. There is a general understanding of climate change and its uncertainties within

the population of the Netherlands. However, the workshops set up in this project aimed to enhance local understanding of the issues in order to start the process of developing climate-proof policies and plans.

Alterra was joined by an independent architectural expert and the Wageningen University to facilitate the workshops. The municipalities also played an important role, providing indispensable information on local characteristics of the area, and designing the 'climate resilient' spatial plans. Disciplines represented at the workshops ranged from (waste) water management, to green space and urban planning and infrastructure, dealing with spatial planning and urban design.

Even though the workshops did not specifically focus on uncertainty, dealing with uncertainty was unavoidable.

Process

“Spread knowledge widely throughout the organization”

An initial workshop was held over 3 days in September 2010 to discuss and create plans to climate-proof specific regions (Fig. 4.31). At this meeting the idea of organising further workshops aimed at individual municipalities was generated. It was felt by the researchers and stakeholders present that if you do not spread climate change related knowledge to everyone in an organisation, then it is wasted. Four of these workshops took place a year later in 2011 with further workshops organised in 2012 and planned for 2013. They bring together many influential individuals round a table to discuss what climate change means for their town. They are usually policy- and decision-makers involved in spatial planning, but aldermen, i.e. senior political representatives of the municipality, have been invited as the ultimate challenge is to engage such politicians.

The workshop process can be roughly divided into the following steps:

- Analysis of the potential **climate change impacts** on a municipal level.
- Assessment of the potential **consequences** of these changes for municipal (spatial) plans.
- **Design sessions to adjust plans** to make them more resilient to a changing climate.
- **Review** of the workshop process, making improvements as necessary and discussion of the process of generating climate-proof spatial plans.

Rather than focussing on changing existing plans the workshops aimed to give the participants a feeling for climate change and adaptation. Actual case studies, relating to water conservation, water nuisance from heavy precipitation, urban heat islands and the robustness and connection of natural areas were used to illustrate the position. Participants attempted to answer the question “how could this plan have been designed to be able to deal with projected climatic changes?” Initially



Fig. 4.31 Workshop in progress

information was presented in a PowerPoint format but as the workshops progressed, various visualisation techniques were developed.

All climate information used during the workshops originated from the Climate Adaptation Atlas (CAA). The adaptation atlas is an ever growing web-portal in which many climate impacts relevant for the Netherlands have been visualised in geospatial maps. It contains maps of projected changes in precipitation, temperature, water nuisance, water safety, droughts, urban-heat-islands and the consequences of these changes for agriculture and nature. It forms a solid foundation of knowledge for the development of adaptation strategies.

Four KNMI scenarios

- W: warm (+2 °C)
- W+: warm + changed air circulation
- G: moderate (+1 °C)
- G+: moderate + changed air circulation

Within the CAA climate uncertainties are addressed by means of scenario analysis, based on the four climate scenarios of the Dutch meteorological office KNMI over four different time steps (2020, 2030, 2050 and 2100). It was important to consider an even number of scenarios to avoid the temptation to focus on a mid-range or average scenario. Precipitation, temperature, water nuisance, water safety, droughts, urban-heat-islands and the consequences of these changes for agriculture, for example in the production of maize, and nature are visualised using the resulting 16 maps (or 17 including the current situation).

Uncertainty Assessment

“Interactive tools allow decision-makers to manipulate the numbers themselves”

The difficulty in presenting such a large number of maps encouraged researchers to seek innovative ways of presenting a broad range of scenario outcomes. How well the information was perceived was subsequently reviewed in detail and the following three different visualisation techniques were experimented with:

- Static visualisation – all maps presented on one page,
- Animated visualisation – an animated presentation displaying a succession of the maps – either over time or across scenarios,
- Interactive visualisation – combination of all maps into one tool, providing a menu to allow a switching between the stacks of images.

Of the three methods presented, the interactive tool, as shown in Fig. 4.32, resulted in the quickest solving of the tasks, giving it the highest score for efficiency. The participants were unanimous in feeling that the interactive tool was the most intuitive. They also liked the ability to continuously compare the different scenarios and time steps with the current scenario.

At the start of the workshops most participants had a good basic knowledge of climate change and its consequences for The Netherlands. However, the extremes and possible range of outcomes were often much greater than expected, and seeing impacts visualised specifically for a municipality was often an eye-opener for them. Practice has shown that single maps are often preferred by decision-makers and are used as predictions rather than being used to explore a range of plausible futures. Also, while policy makers might have a tendency to focus on one of the ‘middle of the road’ scenario outcomes, scientists often focus on the extremes.

As the design sessions got underway the confrontation with a large range of possible climatic changes and high potential costs of extreme adaptation measures,

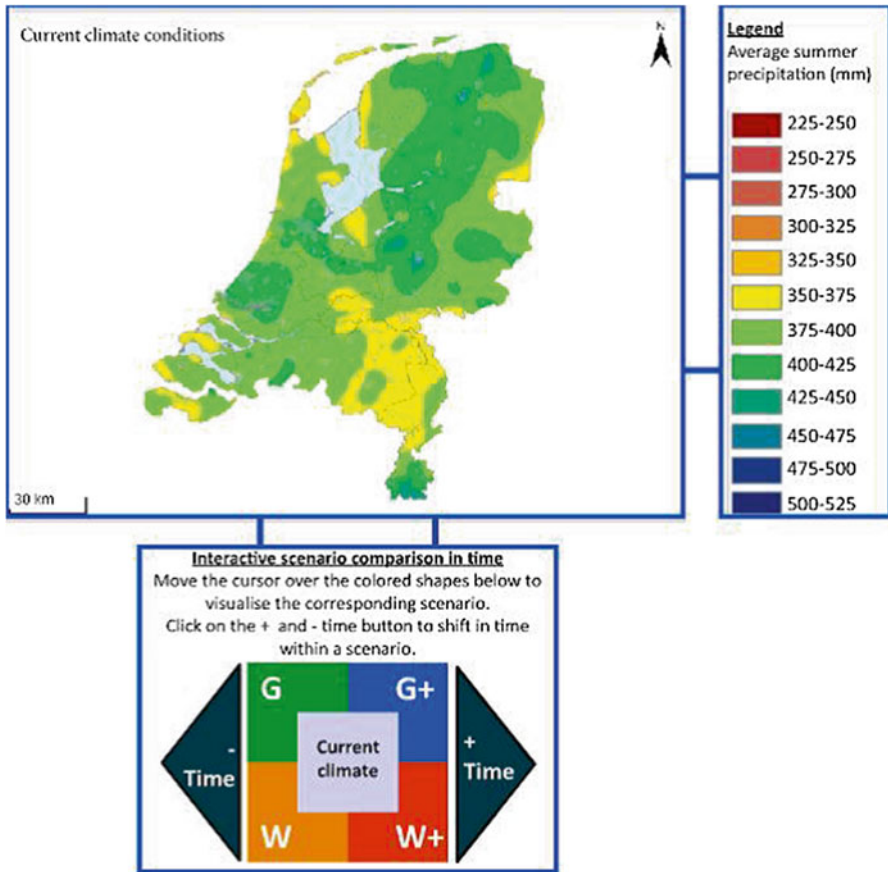


Fig. 4.32 A static representation of the interactive visualisation tool

triggered creative minds to look for innovative, robust measures and to mainstream adaptation measures into other policies. Some examples of this included green roofs as water buffers and insulation, and extra green space in residential areas to increase living comfort.

Effect of Uncertainty on Decision-Making

“Decision-makers need to realise they are not 100 % sure how climate will change”

The project was primarily designed to communicate the problems of climate change and one of the most significant outcomes was that the project improved the way

scenario maps are presented. This is critical to ensure decision-makers fully appreciate the implications of uncertainty in the climate data. Three methods of static visualisation, animated visualisation and interactive visualisation were experimented with. First testing shows that most participants prefer the interactive visualisation as it is the easiest way to handle different information and because of its ability to see patterns in time.

The initial central question of the workshops was 'how can we adapt to climate change?' In the course of the workshops and partly due to the use of a range of scenario outcomes the focus gradually turned towards 'what measures can we take that would allow us to deal with the entire range of possible outcomes?' In one workshop an alderman was looking at houses built in a low, flood-prone part of the region and asked "how could we have been so stupid?" This prompted a rethink of the latest proposal to build on even lower ground, and a realisation of the need to be prepared for change, whatever it might be.

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Links for more information:

A general description of the workshops organised at regional level can be found at the website of the national climate programmes of the Netherlands: <http://www.klimaatonderzoeknederland.nl/projecten/archief-projecten-nieuws/10657914/Klimaatateliers-COM37>.

A report of the Climate Atelier Gelderland on a regional scale can be found at the web portal of the Climate Adaptation Atlas: <http://klimaateffectatlas.wur.nl>.

The Climate Adaptation Atlas is part of the newly founded foundation Climate Adaptation Services: <http://www.climateadaptationservices.com/uk/home>

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