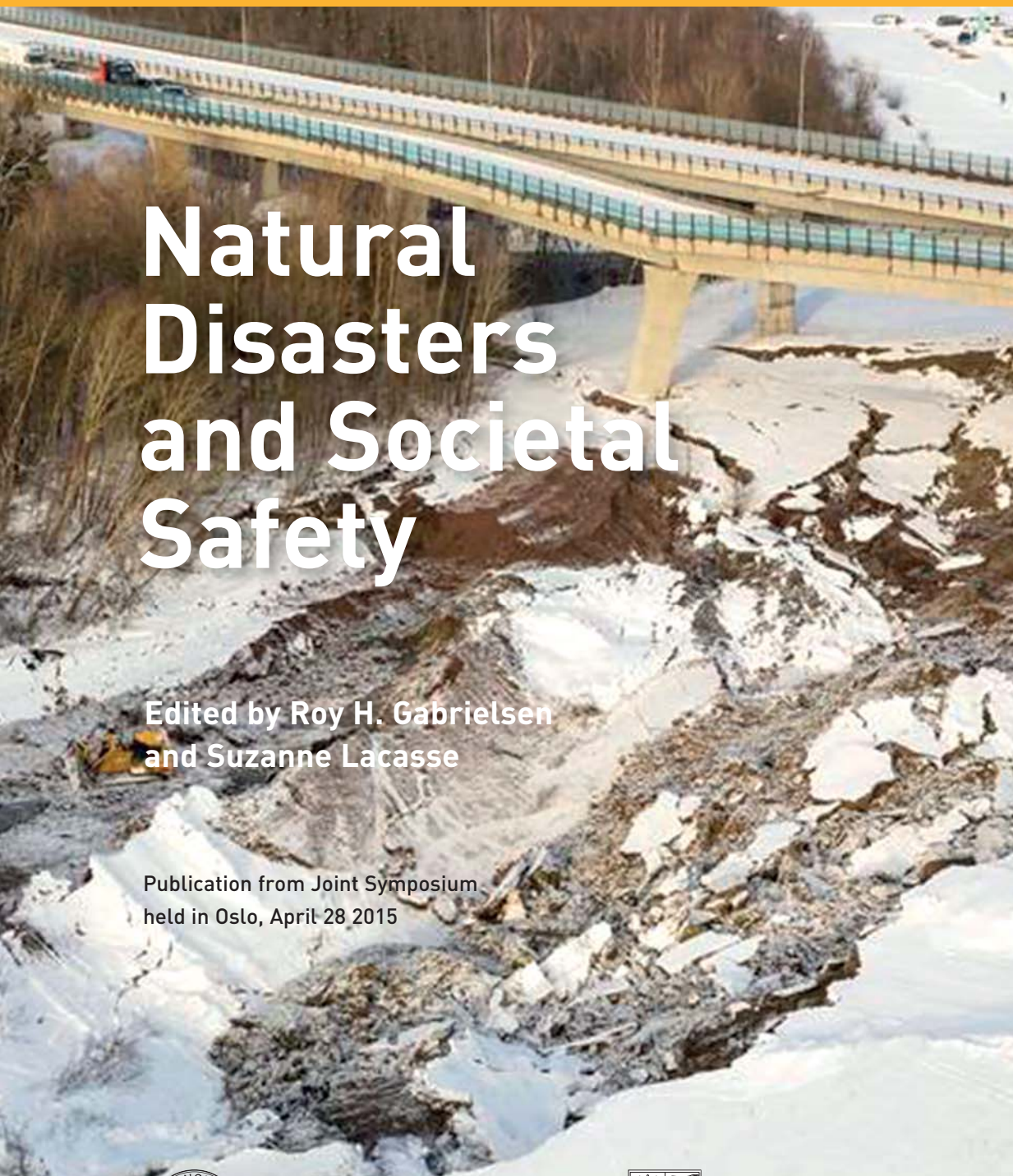

Natural Disasters and Societal Safety

Edited by Roy H. Gabrielsen
and Suzanne Lacasse

Publication from Joint Symposium
held in Oslo, April 28 2015

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Roy H. Gabrielsen and Suzanne Lacasse (eds)

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Preface

King Harald V, DNVA President Kirsti Strøm Bull and Deputy Minister Hans J. Røsjorde as symposium is about to start.

This volume contains the written versions of the lectures presented at the symposium "Natural Disasters and Societal Safety" held on 28 April 2015. The symposium was jointly organised and funded by the Norwegian Academy of Science and Letters (DNVA), the Norwegian Academy of Technological Sciences (NTVA) and The Research Council of Norway (RCN). The programme for the symposium can be found on the next pages.

The organising committee for the symposium consisted of Professors Roy H. Gabrielsen and John Grue from the University of Oslo, Technical Director Suzanne Lacasse from the Norwegian Geotechnical Institute and Divisional Director Fridtjof Unander of the Research Council of Norway.

The contributions of all the authors in this volume are gratefully acknowledged. Mr Adrian Read from the University of Oslo edited all of the texts and translated some of them. Mr Eirik Lislerud from DNVA took care of the practical arrangements, while Mr Lars Thomas Dyrhaug and Ms Ingrid Venås, both from NTVA, helped with the preparation of the final manuscript. These contributions are gratefully acknowledged.

Oslo, January 2016

Roy H. Gabrielsen
Suzanne Lacasse

Programme of Joint Symposium

Natural Disasters and Societal Safety
Oslo, Tuesday 28 April 2015

PROGRAMME

Part 1. Chairs: Director Fridtjof Unander[1] and Professor Roy H. Gabrielsen[2]

16.00-16.10 Opening Address
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16.10-16.30 Natural Hazards and Public Safety
Hans J. Røsjorde, Deputy Minister, The Ministry of Justice and Public Security

16.30-16.55 Natural Hazards in the Norwegian National Risk Analysis
Erik Thomassen, Head of Division, Directorate for Civil Protection and Emergency

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17.20-17.45 Interdepartmental Research Programme on Natural Hazards: Infrastructure, Floods and Slides (NIFS)
Bjørn Kristoffer Dolva, Project Manager, Norwegian Public Roads Administration

Part 2. Chairs: Technical Director Suzanne Lacasse[3] and Professor John Grue[2]

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19.20-19.45 Climate Change Adaptation in Copenhagen
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Sissel Haugdal Jore, Director SEROS Centre, University of Stavanger

20.10-20.30 Discussion
Eivind Hiis Hauge, President NTVA

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[1] *The Research Council of Norway*
[2] *The University of Oslo*
[3] *The Norwegian Geotechnical Institute*

Contents

Natural Hazards: What are they, can they be Predicted, and can they be Prevented?

Roy H. Gabrielsen, Professor, Department of Geosciences, University of Oslo. r.h.gabrielsen@geo.uio.no

Is the Problem of Natural Hazards Serious?

Natural hazards tend to be remote to us living in Norway in a well organised society with an advanced infrastructure, our country being situated on an old and geologically stable craton far from active geological systems like earthquake zones and active volcanoes. There is now, though, an emerging state of unease among the populace of Norway connected to assumed changes in climatic conditions, as illustrated by the impact of a film like "The Wave". The emerging concern of the authorities is also evident (Røsjorde this volume; Thomassen this volume). We still have to set this into an international perspective: according to the Annual Disaster Statistical Review for 2013 published by the Centre for Research on Epidemiology and Disasters (CRED), 96.5 million people worldwide became victims of disasters in 2013, and 21,600 people lost their lives in disasters. These numbers are dwarfed by the average numbers for the period 2003 – 2012, which were 216 million victims and 106,654 deaths, respectively.

Some Characteristics of Natural Hazards

What we call "natural hazards" deals with natural processes of the Earth that have direct, often sudden and violent, impacts on humanity. Although described as "hazards", it is important to realise that they are the effects of natural geological physical (including hydrological, chemical and biological) processes linked to the natural underlying geological dynamics of the Earth. These processes may be associated with the enormous forces working inside our planet that are expressed principally in the context of *plate tectonics* and its secondary processes involving gravitation, temperature contrasts, the atmosphere and the hydrological system, resulting in the modification of the Earth's topography. We can thus subdivide the types of natural hazards into those associated with geological, hydrological and biochemical natural cycles. The hazardous effects of these processes are sometimes exaggerated by human activities like concentration of population and construction and infrastructure.

In our daily and scientific language, we commonly separate between (natural) **hazards** (*sensu stricto*) that characterise the effect of any (potential) natural process

that poses a threat to human life; **disasters** that characterise the (severe) effect of a natural hazard event to society, usually during a limited time span and within a restricted geographical area, whereas **catastrophes** are massive disasters (Keller & Blodgett 2006). In other words, there would be no natural disasters if it were not for humans; without humans these would be only natural events (Nelson 2014).

Risk Analysis

Risk can be seen as an expression for the relationship between humans and geologically induced processes (Nelson 2014). Natural hazards can be monitored, mapped, and sometimes predicted based upon good understanding of natural processes of the Earth supplied with historical data from past events and patterns of events. Such information must be quantified in space, time and with respect to the level of energy involved in the processes. Natural hazards are accordingly amenable to analysis by the use of common methods of risk assessment. The risk analysis of natural hazards describes the likelihood of the occurrence of disastrous effects of natural processes that affect humans, and what the consequences would be.

Natural hazards are phenomena that occur regularly only in restricted time frames and space. The natural risk hazard was significantly different in earlier periods in the brief history of humanity as compared to what they are today, and even more so when geological time spans of millions of years are taken into account. Disastrous geological events tend to cluster in time due to changing natural (and also anthropogenic-related) fluctuations.

For example in Norway and on its continental shelf rock-falls and submarine slides were much more frequent in the first millennia in the aftermath of the last ice age compared to that of the Present (e.g. Ramberg et al. 2008).

Volcanic activity is also commonly cyclic. Vesuvius, the biggest and most dangerous volcano in Europe, experienced periods of particularly high activity in the periods 79-203 (the effects of the major event from 79 AD well documented from Pompeii) and 1661-1794, so that concern for future activity is heavily debated among volcanologists. An eruption of the magnitude well known from repeated events in the near past would of course be disastrous today, taken into account the pattern of habitation in Campania which includes a number of villages, but where a major eruption is also likely severely to affect the major city in the vicinity of Vesuvius, namely Naples (e.g. Scarth 2009).

An illustrative example of the effects of densified habitation are the effects of two separate eruptive events (mud flows) associated with eruptions of the volcano Nevado del Cruise, Columbia in 1845 and 1985, that caused 1,000 and 21,000 casualties respectively, although the first event was the more severe of the two. The disparity was due to the growth in population and settlement structures over a time span of 140 years (Keller & Blodgett 2006).

Some natural scientists even claim that earthquake “storms” have not only influenced, but literally controlled historical events like the termination of some of the ancient Mediterranean cultures approximately 1200 years BC (Nur 2007). The

present effects of global warming may represent another such change in natural conditions, fuelled by anthropogenic activity, which has the effect of accelerating natural processes.

Natural Hazards in Norway

As seen from the ongoing risk assessment of natural hazards in Norway the major risks seem to be associated with the geological and the hydrological cycles (reference this volume). Rockfalls and large landslides, due to their relatively high frequency and some recent events that had disastrous consequences (e.g. Lodalen; Nesdal 1998), these are considered the most likely natural hazards to occur also in the future, and are given much attention (e.g. Blikra, this volume).

As human beings, we are used to Mother Earth providing a solid and stable substratum under our feet, and when this fundamental circumstance fails, like in an earthquake or a great landslide caused by quick clay, it is particularly scary. Due to the relatively high frequency of large landslides and rockfalls, the Norwegian population is to some degree accustomed to such events and are able to relate to them, even though the consequences can be huge (Blikra this volume). Being situated far from active tectonic plate boundaries, we are less accustomed to other geological hazards like earthquakes. Still, such events do occur in the Norwegian mainland and in the Norwegian continental shelf, although both frequency and magnitude are very moderate (Ramberg et al. 2008). Regularly occurring micro-earthquakes do, however, indicate that some larger seismic events may occur in the future (cf. the Oslo earthquake 1904). It would probably be irresponsible entirely to avoid estimating the risk potential and the consequences of such events in the most densely populated regions of Norway, despite their infrequency.

The Acceptance of Natural Hazards

Because natural hazards are associated with the principal forces and processes on our planet, some philosophical/political aspects can sometimes arise when dealing with them. A simple example is the annual problem of flooding: Is it most convenient to solve the problem of flooding by constructing defences that completely prevent water from leaving the river channel but thereby perhaps increasing water levels downstream, or is it better in the long run to find a (sustainable) balance point in the water budget that can be handled locally? This balance point also affects the risk element in warnings: People who are persuaded or even forced to leave their homes may be less willing to do so if the warnings are not correct e.g. in cases where a predicted rock fall or earthquake does not happen (e.g. Blikra this volume). This requires that the political authorities and the populace understand and accept risk assessments, which may sometimes be very challenging (e.g. Nur 2008).

Natural hazards represent a challenge to humanity and we are perhaps approaching a threshold to a period of enhanced risk affiliated with global climate change. As always, the most vulnerable part of the human population are those who

lack resources to cope with the new situation of enhanced risk, and this may cause societal unrest and population migration. Hence, also advanced and rich societies like ours will have to cope with living with both direct and indirect increased risks of natural disasters. Protection against such disasters has three basic elements: First, knowledge about the underlying natural processes of the geology, the atmosphere, the hydrology and the biological systems is paramount. Secondly, a resilient system of warning and plans for adequate actions must exist. And thirdly, a system for detecting, monitoring and analysing natural hazard events demands long-term, reliable and verifiable databases both on national and international scales. This should be an indisputable responsibility of society. In Norway much of this responsibility rests on a few central research institute organisations. Examples are the Institute of Marine Research (IMR), the Norwegian Geotechnical Institute (NGI), the Geological Survey of Norway (NGU), the Norwegian Institute for Nature Research (NINA) and the Norwegian Institute for Water Research (NIVA). The databases and competence of these institutions should be given optimal utilisation by the Norwegian universities and be communicated effectively to the political and administration networks. Indeed, it is the main intention of the present seminar to support such communication. Without it and a long-term and stable capacity in the research institutions, the capacity for natural hazard mitigation will not be available to the future Norwegian society.

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Opening Address

Professor Kirsti Strøm Bull, President, Norwegian Academy of Sciences and Letters.
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It is a pleasure to welcome you to this symposium on "Natural Disasters and Societal Safety". The recent disastrous earthquake in Nepal brings a sad reminder of the significance and actuality of natural disasters.

The symposium is organised jointly by the Norwegian Academy of Science and Letters (DNVA), the Norwegian Academy of Technological Sciences (NTVA) and the Research Council of Norway (RCN). The symposium is an arena where academia and research meet with Norway's key decision-makers. The contributions to the symposium reflect the views from sectors concerned with public safety. Our joint symposium arena welcomes diverging and even conflicting opinions.

This is the fifth symposium organised jointly by our academies and the Research Council of Norway, and the third where His Majesty honours us with his presence. We feel privileged that His Majesty King Harald chooses to join our event. We wish to thank His Majesty for his keen interest in our Academies and Norwegian research.

We have experienced dramatic days in the last year: Scary fires in Lærdal and Flatanger in January 2014; extreme weather with flooding in Western Norway, especially in Odda and Flåm in October; avalanches and rockslides blocking our transportation corridors and threatening our homes; polar low atmospheric pressure affecting the Norwegian coast, and the surprising Skjeggestad bridge pillar collapse on E 18 due to a landslide, interrupting all traffic. Fortunately, no lives were lost.

The population of Norway has always experienced natural disasters. The extreme flood Stor-ofsen, or "Large Floating", hit large parts of inland southern Norway in July 1789 and triggered a large number of landslides. The flood is still present in the memories of the families in Gudbrandsdalen and Østerdalen. History was repeated in 1995, with new floods in the same valleys. The 1995 flood was called Lille-ofsen or "Small Floating". Avalanches, rockfalls and rockslides threaten many of our communities. And, not least, rough weather has taken many lives at sea.

How to be prepared and ensure that we are safe from natural threats is not a new topic, but it still proves to be a challenge. Improved weather forecasting has meant a lot. Earlier events have also contributed to develop local assistance and insurance schemes. Preparedness today is mainly based on earlier experience. But nature, and climate change, pose new challenges. The 100-year events seem to occur more often today than before. In the media just last week (Brennpunkt, NRK-TV), it was said: "Nature needs room to dissipate its energy". It may be that nature needs more room than we had first envisaged. The planning of land use in Norway needs

to be adapted to the increasing challenges from nature. Today, every county and community has the responsibility to do hazard, vulnerability and risk assessment. The same "Brennpunkt" TV-programme claimed that many counties do not have the capacity to do such analyses.

The authorities, specialists and researchers you will hear from today come from several different, and relevant, organisations working with natural hazards and risk. They are able to provide the knowledge on how to improve our hazard, vulnerability and risk assessments.

In closing, I wish to thank the symposium organisation committee: Roy H. Gabrielsen, John Grue, Suzanne Lacasse and Fridtjof Unander. I look forward to this symposium on such a timely and interesting theme.

Natural Hazards and Public Safety

Hans J. Røsjorde, Deputy Minister, The Ministry of Justice and Public Security

Our society is exposed to a broad and complex range of risks and threats. This year's Academies joint symposium focuses particularly on threats associated with natural hazards. I will therefore not be addressing threats such as terror and major data hacking in my contribution, although these clearly are of critical concern in a modern society on which we set strong focus in the Ministry of Justice and Public Security (JD).

The Government has the highest level of responsibility, i.e. over and above the responsibility delegated to county and local authorities, for both the risk assessment of potential natural disasters in Norway and for putting mitigation measures in place to deal with such emergencies, should they occur. This includes the political responsibility for the management and planning for potential societal threats. According to our State traditions in Norway, each cabinet minister has the constitutional responsibility for his or her area within the laws and national budget, as determined by the Parliament (Stortinget).

Each cabinet minister retains this constitutional responsibility in a crisis situation, while the Ministry of Justice and Public Security has the overall responsibility for co-ordinating the Government's policy and mitigation and response measures. Accordingly, JD is the lead Ministry in all civil national crises if nothing else has specifically been decided, and carries the main responsibility for the resources for civil public safety and civil rescue operations in Norway.

The Ministry of Justice and Public Security has the following organisations at its disposal for carrying out its responsibility:

The Police Directorate
The Directorate for Societal Safety and Preparedness and the Civil Defence
The Directorate for Emergency Communications
The National Centres for Rescue Operations
The 330 Squadron (Sea King rescue helicopters)

A series of initiatives have recently been launched within these organisations to improve their preparedness for emergency situations.

Long-term plan for research

Public safety and emergency preparedness are characterised by a sequence of activities whereof the following are fundamental requirements: *knowledge, risk*

mitigation, preparedness, crisis handling, restructuring and repair, and learning. The Government's new long-term plan for research and higher education has three key objectives: to strengthen Norway's competitiveness and innovation capabilities, to help solve major societal challenges, and to develop research groups of excellence. All three will contribute to improving the nation's ability to deal with natural hazards.

The Government has decided that public investment in R&D should be one per cent of the national BNP and aims to reach this goal by 2019–2020. The increase in public investment in R&D will be allocated within six long-term prioritised areas, of which the ocean, the climate, and their challenges for societal development, are crucial in the present context. JD has increased its investments in R&D in recent years so that the budget for 2015 is approximately 45 million NOK. It has defined the following strategies for public security and emergency preparedness for the period of 2015–2018 that are of particular interest for public safety:

1) Increase the use of R&D as an active tool to strengthen dedicated activities concerned with the maintenance and preparedness of public security.
2) Actively participate in implementing the long-term plan for research and higher education, where the second aim of utilising research to a greater degree for solving major challenges facing society has the broadest application for natural hazards and disasters.
3) Participate actively and be an active supporter of others in relevant programmes run by the Research Council of Norway.
4) Enhance dialogue with R&D groups and projects to strengthen knowledge-based work for public safety.
5) Activate the use of R&D in the organisations that report to the Ministry.
6) Increase the resources dedicated to R&D and enhance the quality and competence of the nation's research in relevant fields of expertise.

The Ministry of Justice and Public Security has worked more systematically than earlier with its research strategy to identify the competence needed in the sector. This has revealed the Ministry's areas of responsibility that have considerable need for enhanced knowledge and awareness. Lack of knowledge is a hindrance both ways: on the one hand, the administrative environment gets too little information on new research results, while on the other hand, it utilises too scarcely the new knowledge that it does receive.

The Ministry wants to have access to analyses and assessments of risk and vulnerability in the public domain. Imposing security and preparedness regulations can be a costly burden on industry, local councils and other public organisations, so it is vital that it is focused on areas where the risks demand greatest priority. At the same time, it must also be acknowledged that the assessment of the risk will itself inevitably be associated with uncertainties. Decision makers and the population need to live with and understand such uncertainties, and our society needs to be educated to understand and accept the potential risks. Mitigation of present and future risks must be achieved without escalating laws, regulations and measures that damage the economy and jeopardise personal and human rights and the principles of justice. We

therefore need sufficient knowledge about the impacts so that we can make valid assessments of the measures needed to ensure a level of safety that is acceptable to society, and not least to identify the socio-economic benefits that would follow from the improvement in safety and preparedness.

SAMRISK and EU research

The Ministry of Justice and Public Security will, by virtue of its wide segment of responsibility for research and long-term competence-building within natural hazards and public safety, utilise and prioritise participation in dedicated research programmes organised by the Research Council of Norway. Central in this context is the programme "SAMRISK" initiated in 2006 and focusing on public safety and security.

Furthermore, Norway participates, through the Ministry of Justice and Public Security and the Research Council of Norway, in the "Secure Societies" project of the European Union's major research programme "Horizon 2020". The main topics in this programme include resilience, preparedness, handling of crises, the consequences of climate change and co-ordination in critical situations. We are particularly pleased that Norway's social scientist research groups were successful in winning more contracts in this programme than any other nation. It should also be mentioned that the UN held its 3rd World Conference of Catastrophe Prevention in Sendai in Japan March 15–17, with participation from 180 countries and 20 state leaders.

Climate change and extreme weather in Norway

We have good data about climate change, both from international and national sources. In Norway, there is clear evidence that precipitation has increased over recent years. Extreme weather have serious consequences and challenges public safety, e.g. due to floods, avalanches and rockfalls. The storms in western Norway last year demonstrated this clearly when a large number of families experienced that their homes were severely damaged by floodwater. This led to fear and safety concerns for many. We still need to enhance our efforts to mitigate the effects of such catastrophic events. This work can never have high enough priority. With this I mean that the responsibility for mitigation measures and preparedness rests not only on the Ministry and society, but also at an individual level: I can still remember the post-war mentality when the inhabitants of Norway were encouraged to have food supplies stored in case of mishaps or unrest. People did indeed demonstrate their ability and willingness to take on such responsibility. The former minister of the JD, Odd Einar Dørum, was met with laughter and scorn when he encouraged such action after the September 11th 2001 attacks in the US. In my opinion, such reactions were completely misplaced. In our present society, we have had examples of polluted water resources and grocery stores depleted of bottled water within days. A freezer without electric power is useless for storing food. Norwegian house

building trends in the 1970s and 1980s was characterised with the installation of only electric heating. What are those living in such houses supposed to do in winter if there is electric power outage and outside temperatures of -30° C?

Society meets new challenges and increased risks as a consequence of ongoing intensified urbanisation, be it fire, floods or man-made risks associated with criminality or terrorism. This demands new types of risk analysis, plans for public security and safety, mitigation and response plans for potential crises, and robust local communities.

The role of local councils

The system of local borough councils in Norway provides the foundation for national planning and preparedness in matters of public safety. This should ensure that local communities are safe and robustly protected against natural hazards. By law, the councils are obliged to map and prepare for potential unwanted and unforeseen events and evaluate the risk levels they represent. As required by the Civil Protection Act, such preparedness needs to be summarised in a "Risk and Vulnerability Analysis" ("ROS-analyse" in Norwegian).

A survey performed in 2014 displays a positive progression in such analyses compared to a similar investigation in 2012. Most councils are working systematically on natural hazards and public safety. However, there is still some work needed, as some councils have not yet fulfilled the requirements defined in the Civil Protection Act. Every council, irrespective of size, must identify their risks and plan accordingly. One problem in Norway is that many of the smaller councils administer sparsely populated areas, and yet with a high potential for natural hazards.

In this context, the County Governor has a particularly important role, not least as the supervisor of council activities. I would emphasise the importance of building and development plans. We know that homes, houses and larger buildings in many parts of the country are already built on unsafe ground, in locations that hardly would be considered as building sites today. We have seen several recent examples where better planning could have prevented or at least minimised mishaps and disasters. In particular, I am thinking of landslides, mud-flows, rockfalls and floods, e.g. those in Bergen and Namsos.

Another challenge is that Norway has many road and railway tunnels and bridges built through or on problematic ground. We recently experienced the disastrous collapse of a bridge pillar involving a large, relatively new, major bridge construction on one of the busiest highways in southern Norway. This accident fortunately caused no loss of human life, but resulted in very substantial repair costs. There is an urgent need for continued research into soil and rock stability and their consequences for major construction work to avoid accidents and disasters. Several research groups and organisations are focusing on such aspects. This topic will be addressed in more detail in this book.

The Norwegian Directorate for Civil Protection is required to maintain a complete overview of risks and safety issues in Norway and to present an annual

national risk report. It is interesting to note that of the eleven most threatening scenarios in the latest report, five classify as natural hazards. We expect that the national risk analysis will be actively implemented and that it will contribute to the recognition and prevention of such events. The most recent events have been well documented through reports and evaluations. It is of the utmost importance that experience from earlier events is actively utilised for the prevention and mitigation of future risks.

Operational organisations

Society must be well prepared and experienced in responding to hazards and risks when exposed to the impact of powerful natural processes. It is necessary to have carried out response drills, and to have tested equipment, infrastructure, communication and organisation, beforehand. The Ministry of Justice and Public Security has implemented a number of actions to enhance preparedness for coping with natural hazard events.

The Police

On 6th March 2015, the Government presented a proposal for the re-organisation of the police, the Local Police Reform. Several substantial requests are included, one of which is requirements on response time to extraordinary events where the saving of life is at stake. This has already been implemented within today's police structure. The Government aims at a coverage of two police staff per 1000 inhabitants by 2020, which represents a substantial improvement in police capacity. This in turn will influence expectations of the preparedness of the police.

Fire protection and rescue

For more robust and competent units with experience from demanding events, the Government finds that there is a need for fewer but larger units in the fields of fire protection and rescue. The Government's Local Police Reform proposal will therefore, among others, investigate and plan for establishing fire protection and rescue units that will operate within the same boundaries as the future police districts.

Civil Defence

The Civil Defence system provides an important additional capacity in a crisis situation. Although the Civil Defence is perceived by many as an old-fashioned unit designed only to resist a potential military invasion, this is quite wrong. Today's Civil Defence system is a modern and forward-looking resource providing critical capacity in supporting the emergency services, not least in fire protection and rescue operations at all scales. Civil Defence units took part in almost 300 emergencies in 2014. This organisation experiences an escalating demand for its resources, and the Government continues to prioritise financial support of the Civil Defence units. Six priority fields have been selected for the Civil Defence: electric power supply, emergency accommodation such as tents, lighting sources, pumping capacity,

communications, and mobility outside the established road network. The two first county units to be upgraded are Trøndelag (implemented) and Troms (in progress).

Emergency communication network
Communication is a vital element in protection and rescue operations. A regional/ national Emergency Communication Network is therefore of the utmost importance but represents one of the most difficult and costly steps. The Emergency network will provide a unique tool for the reliable transfer of information between the rescue organisations and civil participants.

New rescue helicopters
The procurement of new rescue helicopters will be of the greatest importance in the coming 30 to 40 years, and will significantly improve our capacity for search-and-rescue operations and for communication infrastructure in large-scale operations. Delivery of the first new helicopters is scheduled for 2017 and the present helicopter fleet will have been completely replaced by the end of 2020.

Emergency warning network
Several reports have identified a major need for improvements in the emergency warning network. To solve this, larger and more robust emergency warning centres will be built. The fire protection and rescue centres and the police operation centres will be co-located with the emergency medical communication (AMK) centres of the health system. One key conclusion in the Gjørv Commission report following the 22th July 2011 tragedy was that the *emergency resources failed to locate each other* and that they needed to be better co-ordinated. The actions heralded above will improve this situation.

The Rescue Service
The Rescue Service is an important element of the emergency system. This system is built on the principle of co-ordination and co-action. It has existed since 1970. This means that all necessary resources connected to rescue and life-saving operations are individually registered, organised, trained and mobilised. The rescue units are organised through co-operation between the public, volunteer and private participants. Norwegian rescue operations have had the characteristics of a Norwegian "*dugnad*", with everyone working together. The two main rescue co-ordination centres, at Sola (near Stavanger) and in Bodø, have co-operated in leading rescue operations, supported by 27 local emergency control centres located in the police districts.

I have here only treated emergency organisations and units that report to the Ministry of Justice and Public Security. It must be emphasised that other ministries and the units reporting to them also contribute to the work on civil preparedness in case of emergencies. Central here are the ministries of Health and Defence.

Summary

Events related to extreme weather and natural hazards can be very serious in Norway. They are already frequent and are likely to increase in both frequency and magnitude. Prevention and protection against such events are dramatic, where both human suffering and costs are concerned. It is therefore important to enhance our knowledge of these events, increase effective communication about them, and strengthen the organisations in society that have to handle the impacts when they occur.

Experiences from events and accidents, as well as drills and exercises beforehand, reveal a need for strengthening co-ordination and the ability for co-action among all types of rescue and support organisations, be they public, volunteer or private. This is a prerequisite for working efficiently for warning, rescuing, and saving lives and material values, should such events occur.

Societal development leads to a mutual dependence between participants of all types becoming more complex. Co-ordination and communication requirements are rapidly escalating. Particularly the impact of climate change illustrate this. The challenge is to reduce societal vulnerability, handle events and accidents and restore the functions in society in the aftermath of accidents and disasters. This is essential to ensure that the basic values and functions of society are protected and to maintain a safe and democratic society. Knowledge and research are important elements in acquiring such resilience.

Natural Hazards in the Norwegian National Risk Analysis

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Introduction

The Norwegian National Risk Analysis was first published in 2011 and has since then been issued annually. This presentation focuses on the 2014 edition with special emphasis on natural hazards and disasters. The Norwegian Directorate for Civil Protection (DSB) conducts the analysis in co-operation with experts representing government agencies, regional and local government and research institutions.

The National Risk Analysis describes serious hazards and threats and presents results from risk analyses that examine a selection of disruptive events that would have disastrous consequences for society.

The National Risk Analysis describes all types of catastrophic events, both natural and man-made, including those which are either deliberate or unintentional. The following are common to all of them:

- The events have consequences affecting several important societal assets.
- They are catastrophic events that require extraordinary efforts from public authorities and cannot be managed through established routines and arrangements.
- The consequences and management of the events transcend sectors and areas of responsibility and demand wide co-operation on a large scale.
- The events that are analysed are "conceivable worst-case scenarios".
- A similar event has actually taken place, but in another location and with other consequences.

The aim of the National Risk Analysis can be summarised as follows:

- Politicians and establishment leaders need an overall risk analysis that does not go into detail as a basis for the prioritisation of resources and overall management.
- Municipalities, counties and sectorial authorities may use the National Risk Analysis to survey what national events they will be affected by and need to prepare for, and as an input for less serious scenarios that they can analyse themselves.

- At the operational level, the scenarios in the National Risk Analysis can be used as input for exercises and emergency planning.

Risk

Risk is always about what can happen in the future and is therefore associated with uncertainty. Uncertainty is associated with whether a specific disruptive event will occur and what the consequences of this event will be. In risk analyses, probability is often used as a measure of how likely it may be that a specific event will occur during a given period of time, given our current knowledge base. The effects of the disruptive event on given societal assets are called consequences. The National Risk Analysis attempts to identify both the observable physical consequences of a disruptive event and the social and psychological impacts that can be so strong that in the worst case they will have a destabilising effect on society. The risk analyses in the National Risk Analysis also include an assessment of the uncertainty related to the analysis results.

In addition to both separate and overall presentations of risk results, the overall risk analysis also includes a description of the areas of risk and the scenarios analysed (the specific course of events), the assumptions they are based upon and the reasoning behind the assessments of the probability, consequences and uncertainty.

Method and process

The method and process are described in a separate guide. Generally, events may have a broad range of possible consequences. Hence, the event that is to be analysed is developed into a scenario – a very specific course of events within the framework of the disruptive event. The specified scenario is to be a worst-case scenario to illustrate the most severe consequences the event can have on the entire range of societal assets. The risk analyses are conducted primarily as a qualitative expert analysis at a working seminar. Relevant knowledge and experience from similar events in Norway and abroad is obtained in advance as preparation.

Quick Clay Slide in a City

In order to show how scenarios are analysed and presented in the National Risk Analysis, we will elaborate on the Quick Clay Slide Scenario presented in the document, localised in the city of Trondheim in Sør-Trøndelag County in Mid-Norway. Trondheim has a population of approximately 185,000 and is the main administrative centre in Trøndelag with a rich cultural heritage including Nidaros Cathedral.

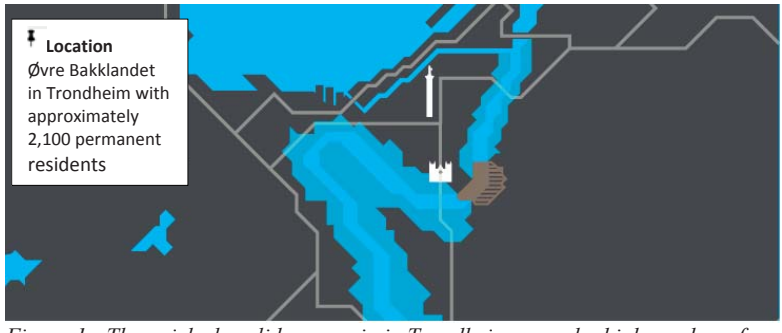

Figure 1: The quick clay slide scenario in Trondheim caused a high number of fatalities and injuries, dammed up the Nidelva River, damaged buildings of high cultural value and caused disruption to critical infrastructure. (Approximate vertical scale=3 km; top blue part is Trondheimsfjord; Nidelva is meandering from bottom to top; Nidaros Cathedral and Olav Tryggvasons statue are shown with white icons).

Quick clays are unique sensitive glacio-marine clays found in Canada, Norway, Russia, Sweden, Finland and the United States. These clays are so unstable that when a mass of quick clay is subjected to sufficient stress, the material behaviour may rapidly be transformed from that of a particulate material to that of a fluid.

Approximately 64,000 people in Norway live in zones where there is a risk of a major quick clay landslide. In addition, there are other buildings, such as schools, day care centres, industry, stores and other central business district buildings within these zones. There are still areas potentially subject to a major quick clay landslide that have not been surveyed.

The worst-case scenario takes place in a known quick clay zone in the highest risk class, where many people live. Øvre Bakklandet in Trondheim with close on two thousand inhabitants is such an area.

Course of events

- Initial landslide one night in October, a 10 x 100 metre slice slides out into the river Nidelva.
- An evacuation is implemented on the following day.
- The main landslide (remainder of the zone) occurs on the following night. The clay runs all the way across the river Nidelva, which is completely dammed up.
- Volume of the slide: approximately 3 million m³ of clay.
- Area of approximately 0.5 km².
- Concurrent event: High rate of water flow in the river Nidelva after heavy precipitation (100–200 m³/s).
- Contributing factors: Construction work or erosion.

Consequential events

- The landslide immediately causes a flood wave upstream and downstream in the river Nidelva, which affects the buildings along the river.
- The clay dams up the tidal river Nidelva, and the water level upstream rises quickly to approximately 12 metres above sea level, which means that all parts of the city beneath this elevation will be flooded. This includes the central business district, and affects approximately 2,100 inhabitants.

Analysis of probability

It was assessed that a landslide in the zone in question could occur every 2,000 to 3,000 years, i.e. a probability of 0.04% per year. The scenario falls thus under the category of low probability. This estimate is based on the following assumptions:

- That one "major" quick clay landslide occurs in Norway every year.
- That 80% of these landslides take place in one of 1,765 mapped quick clay zones.
- The probability of a landslide is assessed as somewhat lower than for an average zone due to the erosion protection measures implemented in the river Nidelva, and good control of construction projects.
- Øvre Bakklandet is one of the surveyed quick clay zones, with the greatest number of inhabitants and potentially the greatest consequences. If we assume that there are 10 areas in the country with a similar risk assessment as Øvre Bakklandet, the probability of a more general landslide scenario of this magnitude will be 10 times as high. This means that a similar landslide could occur every 200 to 300 years, or that there is a 0.4% probability that it will occur in the course of a year.
- The probability of a more general landslide event falls then under the category moderate in the National Risk Analysis.

The uncertainty associated with the rough estimate of the probability is assessed as moderate. The survey of the quick clay and the risk assessment that has been made provide a relatively good base of knowledge. However, the probability of landslides will be highly dependent on the defined frequency of "major landslides", the degree of risk in this zone relative to the average, and on what control exists over construction work in the area.

Assessment of consequences

The consequences of the given scenario are assessed as large. The scenario will primarily threaten the societal assets life and health, nature and the environment, the economy and societal stability. The uncertainty associated with the assessments of the different consequence types varies from low to high.

Life and health

Over 2,000 people live in the surveyed quick clay zone at Øvre Bakklandet. The number of deaths as a result of the landslide is estimated to be approximately 200. A decisive assumption for this estimate is the fact that there is an initial landslide many hours before the main landslide, so that there is time to evacuate the entire area. The landslide will cause 500 injuries and 2,000 people will be ill as a result of the event. Injuries will occur when people in the area are swept away by the landslide, when buildings collapse, etc. Illness after the event will primarily mean a reduced work capacity and quality of life for those who are affected.

The uncertainty associated with the estimates for fatalities and injuries is assessed overall as moderate to low, since the area, population and evacuation are given assumptions. The consequences for life and health are very sensitive to the assumption that there is time for evacuation before the main landslide.

A main landslide occurring without any warning has been the case in several major quick clay landslides. The number of deaths in a scenario without evacuation will be much higher. It is assumed that at least 1,200 people would perish then (around half of those located in the area).

Nature and the environment

Damage to the natural environment will be limited to the actual quick clay slide zone and the adjacent areas that by the displaced clay masses. Landslides and the formation of sludge in the river and fjord are natural processes, and it is assumed that the types of nature that are affected will be restored in the course of ten years. This is a fairly robust brackish water zone.

Several cultural monuments of great national importance such as the Nidaros Cathedral, the Archbishop's Manor and the royal residence Stiftsgården will be lost or significantly weakened. There will also be major damage to other protected buildings in central Trondheim, and to valuable recreation areas.

The uncertainty associated with the estimates is assessed as low, based on experience from other quick clay landslides, flood waves and floods.

Economy

The material losses are estimated to be high, in the magnitude of NOK 30 billion. The landslide, flood wave and flood will destroy bridges, roads, railways, private homes and businesses. An estimated 1,000 households must find a new place to live. There will also be significant financial and commercial losses as a result of the destruction of the premises of an estimated 100 stores and restaurants.

Societal stability

The landslide will entail quite a large degree of social unrest. The quick clay zone has been surveyed, but people expect the authorities not to permit anyone to live in

a location that is very vulnerable to landslides. Therefore no one will be prepared for a landslide in a densely populated area.

A landslide in which the ground suddenly gives way will create fear and a feeling of powerlessness for those who find themselves there. Those who live in other known quick clay zones will also worry and be anxious. A landslide will affect vulnerable groups with mobility problems (the sick and elderly) in particular. Rescue work will be very difficult, because it will depend on helicopter support, and many people will want to come to the landslide area to look for missing persons and belongings.

The local and national authorities' management of the situation will be very demanding with regard to obtaining an overview of the situation, and warning, evacuating and informing the inhabitants. Inadequate information before, during and after the landslide may result in weakened trust in the authorities and people acting individually and in panic. A large area will be evacuated and critical infrastructure such as power, telecommunications, water, roads and railways will be completely destroyed in the release area.

Uncertainty assessment

INDICATORS OF THE KNOWLEDGE BASE	EXPLANATION
Access to relevant data and experience	There are historic landslide data, landslide databases, quick clay zone surveys and risk assessments, but there is no experience from landslides in urban areas with such major consequences.
Comprehension of the event that is being analysed (how known and researched is the phenomenon)	Known phenomenon in Norway and other countries. Geology and geotechnics are special fields in which research is conducted on quick clay landslides.
Agreement among the experts (who participated in the risk analysis)	No major disagreements among the experts.
Sensitivity of the results. To what extent do changes in the assumptions affect the estimates for probability and consequences?	The number of fatalities and injuries is very dependent on whether it is possible to evacuate all the inhabitants or not, which is dependent in turn on the amount of time that elapses between an initial landslide, if any, and the main landslide. Without the precondition of evacuation, there may be five to six times as many fatalities. The other consequence types are less sensitive than the number of fatalities. The sensitivity of the results is assessed therefore as high.
Overall assessment of uncertainty	The uncertainty associated with the assessments of the probability and consequences is assessed as moderate overall.

Placement of the scenario in the risk matrix

Consequence	VERY HIGH					
	HIGH		X			
	MODERATE					
	LOW					
	VERY LOW					
	Likelihood	VERY LOW	LOW	MODERATE	HIGH	VERY HIGH

The overall uncertainty was “Moderate”.

Other Natural Events Analysed in the National Risk Analysis

Natural catastrophic events are triggered by forces of nature or natural phenomena and not by human activity. Nature itself is the cause of the event, and the consequences can affect people and society in general. The following risk areas and the associated scenarios have been assessed under natural catastrophic events:

Risk Area	**Scenario**
Extreme Weather	Storm in Inner Oslo Fjord Area
	Long-Term Power Rationing Due to Severe Drought
Flooding	Flooding in Eastern Norway
Landslides and Avalanches	Rockslide at Åkneset with an Advance Warning
	(Quick Clay Landslide in a City)
Epidemic Diseases	Pandemic in Norway
Forest Fire	Three Simultaneous Forest Fires
Space Weather	100-Year Solar Storm
Volcanic Activity	Long-Term Volcanic Eruption in Iceland
Earthquake	Earthquake in a City

Storm in Inner Oslo Fjord Area

The Storm Scenario is located to a part of the country not very prone to extreme weather conditions but with a large population and a complex and vulnerable infrastructure.

A storm in this area and with this wind speed will statistically occur once every 50 years. It will often coincide with heavy precipitation, but rarely with a strong storm surge. The scenario described is expected to occur once every 100 years, i.e. there is a 1% probability that it will occur in the course of a year. It is a relatively frequent event among those that are assessed in the National Risk Analysis and falls under the category high probability (once every 10 to 100 years).

The consequences of the given scenario are assessed overall as medium-sized. The scenario will primarily threaten the societal assets life and health and economy. In addition, the scenario will lead to what is defined in the National Risk Aanalysis

as social unrest, as well as some long-term damage to the natural environment. The uncertainty related to the various types of consequences varies from low to high. Overall, the uncertainty associated with the consequence assessment is assessed as moderate compared with the other assessments in the Risk Assessment.

Long-Term Power Rationing Due to Severe Drought

An assessment has been made of the probability of long-term power rationing as a result of a lack of precipitation in an area of Norway with a population of approximately 600,000. This scenario is expected to occur once every 100 to 200 years. In the National Risk Analysis this estimate is at the higher end of the category moderate probability (once in the course of 100 to 1,000 years). The probability of such a rationing situation is assessed therefore as moderate to high. Key contributing factors to the event are two seasons with low precipitation, and severely reduced import opportunities from abroad. A third factor is reduced power generation in Norway, which is described in the scenario as a result of incorrectly estimated reservoir levels. The uncertainty associated with the assessment of the probability of the disruptive event is assessed as moderate in the National Risk Analysis. This is due to several circumstances, including the power system's complexity, unforeseen events, and the relationship between factors such as generation, import, consumption and user-flexibility.

The social consequences of the given scenario are assessed as large. The scenario will primarily threaten the societal assets economy and societal stability. The uncertainty associated with the assessments of the types of consequence varies from moderate to high. Overall, the uncertainty is assessed as moderate compared to the other assessments in the National Risk Analysis.

Flooding in Eastern Norway

The worst-case scenario that has been analysed is extensive flooding due to a very high rate of water flow in the largest rivers in Eastern Norway. Flooding on such a scale is due to concurrent events that are expected to occur every 500 to 1,000 years. In the National Risk Analysis, such major flooding falls under the probability category moderate. The probability estimate is based on prior flooding in Norway and Northern Europe during historic times. Such extensive flooding in Norway requires a rare coincidence of several meteorological conditions. Climate change is expected to result in more precipitation and higher temperatures in the future, and this will mean more frequent and extensive flooding, especially in the autumn and winter. The uncertainty associated with the probability estimate is assessed as moderate.

There are approximately 10,000 people living in the areas that will be affected by the flooding in the scenario. Overall the social consequences are assessed as medium-sized. The scenario will primarily threaten the societal assets life and health and economy. In addition, the scenario will entail major damage to critical infrastructure and result in some social unrest. Overall, the uncertainty associated

with the assessments is considered to be moderate compared with the other assessments in the National Risk Analysis.

Rockslide at Åkneset with an Advance Warning

A disruptive event in the landslide and avalanche risk area is a large rockslide into a fjord, with associated flood waves. Operational preparedness has been established for the target location, Åkneset, such as monitoring and warning of any rockslides and subsequent flood wave. The rock slope over Åkneset is monitored continuously, and movements in the rock mass have been measured since 1986. Norway experienced three large rockslide and flood wave disasters in the 20th century.

A rockslide on this scale in Åkneset is estimated to occur once every 100 to 200 years, i.e. there is a 0.5–1% probability that it will occur in the course of a year. In the National Risk Analysis this estimate is at the higher end of the category moderate probability (once every 100 to 1,000 years). The probability that a rockslide on this scale will occur in Åkneset is assessed therefore as moderate to high. Åkneset is one of several risk zones that are monitored. The probability for the specific scenario is assessed based on historical data and historical frequencies. The uncertainty associated with the assessment of the probability of the disruptive event is assessed as moderate in the National Risk Analysis.

The social consequences of the given scenario are assessed as large. The scenario will primarily threaten the societal assets economy and societal stability. The uncertainty associated with the assessments of the different consequence types varies from low to high. Overall, the uncertainty is assessed as moderate compared with the other assessments in the National Risk Analysis.

Pandemic in Norway

To illustrate how serious the consequences a pandemic in Norway can be, a risk analysis has been conducted on a specific "worst-case scenario". The scenario that is analysed is a somewhat downscaled worst-case scenario from the 2006 National Pandemic Plan.

Pandemics of various degrees of severity arise. Due to better health among the general population and a better healthcare system, the consequences of such diseases are less severe than before. It is assumed that a pandemic as described in the scenario may break out every 50 to 100 years in Norway. A probability of 1–2% per year is high, compared with other events in the National Risk Analysis. The uncertainty associated with the estimate of the probability is attributed primarily to what type of virus in animals is transmitted to humans. The virus types have different properties with regard to the transmission of the disease and its degree of severity. The uncertainty is assessed as moderate.

The consequences of the given scenario are assessed as large overall. The most serious direct consequences of the pandemic are a large number of fatalities and illness in the population. This will result in turn in indirect consequences such as a high rate of absence due to illness in all sectors. Altogether, this will create unrest

and fear in society. The financial losses will also be high because of loss of production and high treatment expenses for hospitals. The consequences of the scenario will be very large for most of the societal assets included in the National Risk Analysis. The uncertainty related to the various consequence types varies from moderate to high. Overall, the uncertainty associated with the consequence assessment is assessed as moderate compared with the other assessments in the National Risk Analysis.

Three Simultaneous Forest Fires

A disruptive event in the forest fire risk area is several simultaneous major fires that get out of control under conditions marked by strong winds and in areas where there has been a long period of drought.

An assessment has been made of the probability of three simultaneous major forest fires that get out of control. This is expected to occur once every 100 years, i.e. there is a 1% probability that it will occur in the course of a year. In the National Risk Analysis, this probability estimate falls under the category of high probability (once every 100 years). The assessment of probability is based on historical data and frequencies, as well as factors of significance to simultaneous occurrence of forest fires, including meteorological data on the frequency of particularly dry years, so-called fire years. This provides a good knowledge base, and the uncertainty associated with the assessment of the probability of the disruptive event is assessed as low.

The scenario will primarily threaten the societal asset nature and the environment. The uncertainty associated with the assessments of the different consequence types varies from low to moderate. Overall the uncertainty is assessed as low compared with the other assessments in the National Risk Analysis.

100-Year Solar Storm

A disruptive event in the “space weather” risk area is a very powerful solar storm. It is assumed that a large solar storm may occur during the course of the sun's 11-year cycle of activity. It is anticipated that electromagnetic radiation, a proton shower and a geomagnetic storm of the strength indicated in the scenario will occur simultaneously once every 100 years, i.e. there is a probability of 1% that it will occur in the course of a year. This probability estimate falls under the category moderate probability (once every 100 to 1,000 years). The assumptions that the solar storm will coincide with an abnormally cold period, as well as the disturbances in the power supply and satellite systems caused by the storm, are not encompassed by the probability assessment. The uncertainties associated with the assessment of the probability of the disruptive event, as well as the cascading events, are assessed as moderate compared with other probability assessments in the National Risk Analysis.

The consequences of the given scenario are assessed as medium-sized compared with other scenarios in the National Risk Analysis. The consequences of

the scenario are primarily cascading effects in the form of disruptions to satellite signals and power outages. The uncertainty associated with the assessments of the consequence types varies from moderate to high. Overall the uncertainty is assessed as moderate compared with the other assessments in the National Risk Analysis.

Long-Term Volcanic Eruption in Iceland

A disruptive event in the "volcanic activity" risk area is a major, long-term eruption in Iceland. In 1783, the Laki fissure system, southwest of the Vatnajokull glacier in Iceland, produced one of the largest lava flow eruptions in historic times. About 15 cubic kilometers of basaltic magma erupted from the 27 km long fissures between May 1783 and May 1785. The scenario in the National Risk Analysis is based on this eruption. During the course of the past 1,000 years, there have been four eruptions of the same type. Two of the eruptions have been on an equivalent scale to the scenario defined. The spread of ash and hazardous gases depends on dominant wind directions, wind speed and precipitation patterns. Because of the size of the eruption, it is assumed that Norway will be affected by the scenario regardless of the wind conditions. Based on the eruption history, it is assumed that the scenario will occur approximately once every 500 years, i.e. there is a 0.2% probability that it will occur in the course of a year. In the National Risk Analysis, this probability estimate falls under the category of moderate probability (once every 100 to 1,000 years). The uncertainty associated with the assessment of the probability of the disruptive event and the cascading events is assessed as moderate.

The consequences of the given scenario are assessed as medium-sized. The scenario will primarily threaten life and health, the economy and societal stability. The uncertainty associated with the assessments of the consequence types varies from moderate to high. Overall the uncertainty is assessed as high compared with the other assessments in the National Risk Analysis.

Earthquake in a City

The event analysed is a major earthquake striking a metropolitan area on the coast of Western Norway. The severe scenario is located to the city of Bergen with approximately 270,000 inhabitants. In the city various building structures, both historical and contemporary, are exposed to strong vibrations. There are also other smaller urban settlements in the greater Bergen area which will be affected by the earthquake.

The Øygarden Fault has been well surveyed due to oil exploration in the area. It runs along the coast from Møre to south of Hardanger Fjord. Clear signs of micro-seismic activity have been observed along this structure. The return period for a large earthquake in the Øygarden Fault can be very roughly estimated from a Gutenberg-Richter distribution of observed earthquakes. For all of Norway south of Trondheim, a study in 1998 calculated a return period of 1,110 years for a quake of a magnitude equal or greater than 6.5. This also included the Oslo Fjord area.

Earthquakes with a magnitude equal or greater than 4.5 are not unusual in Hordaland. The occurrence of larger earthquakes in the coastal waters beyond Western Norway has been known for the past 50 years, but most larger quakes (M5.0 +) have been far from the coast. Estimates for the return period for an earthquake of M 6.5 or greater are therefore encumbered with very high uncertainty. For this specific scenario, the estimated return period is between 5,000 and 10,000 years. In the National Risk Assessment, this corresponds to "low probability". Uncertainty related to the probability estimate is assessed as high.

As a whole, the consequences of the earthquake scenario are assessed to be very large on the scale used in the National Risk Analysis. The scenario entails very high consequences for the societal assets life and health, the economy and societal stability. The consequences for the cultural environment are also assessed to be very high, while the consequences for the natural environment are assessed as being very low. The uncertainty related to the consequence assessments varies from moderate to high. Only the consequences of the main earthquake have been assessed.

Other scenarios in the risk analysis

The National Risk Analysis also includes events caused by accidents and malicious acts.

The matrix below shows the risk areas and scenarios analysed:

Risk Area	**Scenario**
Hazardous substances	Gas Emission from an Industrial Plant
	Fire at an Oil Terminal in a City
Transport accidents	Collision at Sea off the Coast of Western Norway
	Fire in a Tunnel
Nuclear accidents	Nuclear Accident at a Reprocessing Plant
Offshore accidents	Oil and Gas Blowout on a Drilling Rig
Terrorism	Terrorist Attack in a City
Security policy crisis	Strategic Attack
Cyberspace	Cyber Attack on Financial Infrastructure
	Cyber Attack on Electronic Communication Infrastructure

Overall risk analysis

This chapter presents the overall risk picture as it is described in the National Risk analysis of 2014, including scenarios in the categories Major Accidents and Malicious Acts.

The "Pandemic in Norway" scenario is assessed as having the highest probability of the analysed scenarios. All six scenarios that are assessed as having the highest probability are natural events. The probability is estimated as low for the malicious acts that have been assessed. "Earthquake in a City" and "Strategic Attack" are assessed as having very large and large consequences, respectively. "Three Simultaneous Forest Fires" and "Tunnel Fire" are assessed as having small

societal consequences. Among the eleven scenarios that are assessed as having the greatest social consequences, five are natural events, four are intentional adverse acts and two fall under the event category major accidents.

The greatest consequences to life and health are found in "Pandemic in Norway", "Nuclear Accident at a Reprocessing Plant" and "Earthquake in a City", all of which entail extreme consequences for life and health. It is the major accidents that cause the greatest damage to natural and cultural assets. The earthquake and quick clay scenarios result in the greatest consequences for the societal asset nature and culture, primarily due to extensive damage to protected cultural artefacts.

All four scenarios for intentional adverse acts are assessed as threatening to societal stability. Malicious acts are carried out to cause damage and injure people and society and to create fear. Societal stability will, however, also be challenged by several of the natural events. This may be attributed to the fact that the scope of the consequences is so great that this in itself will create social and psychological reactions. This may result in frustration, anger and mistrust of the authorities if warning is not possible (earthquake and quick clay landslide), or if the capacity of emergency preparedness is not adequate (flooding scenario).

The "Earthquake in a City" and "Cyber Attack on Electronic Communications Infrastructure" scenarios are assessed as having the greatest costs by far, consisting primarily of production losses and costs for the reconstruction of infrastructure and buildings. The risk matrix shows an indication of probability and consequences for the 20 scenarios analysed. In addition, the three colours indicate varying degrees of uncertainty associated with the analysis results.

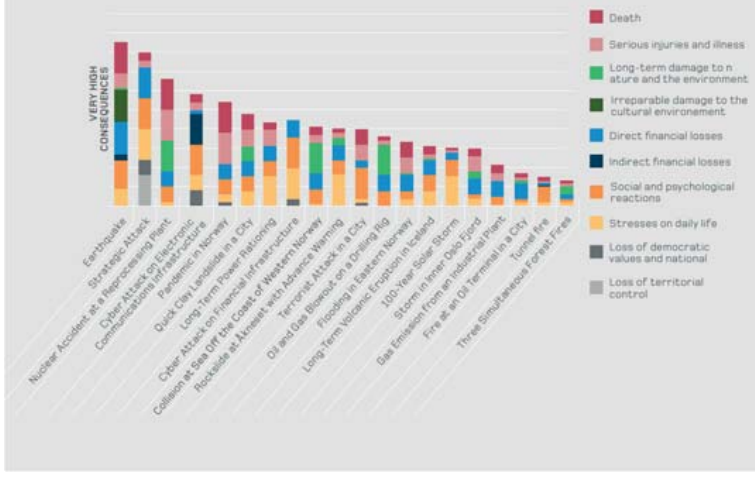

Figure 2: Overall presentation of consequences: The columns illustrate the consequences for each scenario, broken down by eight consequence types.

SCENARIOS PLACED IN A RISK MATRIX	
1	Storm in Inner Oslo Fjord
2	Long-Term Power Rationing
3	Flooding in Eastern Norway
4	Rockslide at Åkneset with Advance Warning
5	Quick Clay Landslide in a City
6	Pandemic in Norway
7	Three Simultaneous Forest Fires
8	100-Year Solar Storm
9	Long-Term Volcanic Eruption in Iceland
10	Earthquake in a City
11	Gas Emission from an Industrial Plant
12	Fire at an Oil Terminal in a City
13	Nuclear Accident at a Reprocessing Plant
14	Oil and Gas Blowout on a Drilling Rig
15	**Collision at Sea Off the Coast of Western** Norway
16	Tunnel fire
17	Terrorist Attack in a City
18	Strategic Attack
19	Cyber Attack on Financial Infrastructure
20	Cyber Attack on Electronic Communications Infrastructure

Figure 3: National Risk Analysis – the composite risk matrix shows assessed risk connected to the serious scenarios that have been analysed.

The scenarios "Pandemic in Norway", "Earthquake in a City", "Nuclear Accident at a Reprocessing Plant", "Long-Term Power Rationing" and "Rockslide at Åkneset with Advance Warning" are the five scenarios assessed as having the highest overall risk. Among the scenarios with the lowest risk, we find "Gas Emission from an Industrial Plant", "Fire at an Oil Terminal in a City", "Tunnel Fire", "Three Simultaneous Forest Fires" and "Strategic Attack". As part of the risk analyses, an assessment is made of the uncertainty associated with both the probability and the consequences. Uncertainty has been presented using three different colours, which indicate the overall uncertainty for both probability and consequence assessments. There is reason to emphasise that all the scenarios that have been analysed are very serious and not very probable. If other, less serious scenarios had been analysed, the probability would have been higher, and the scenarios could have ranked differently in relation to each other in the risk matrix.

When we categorise the scenarios in Natural Events, Major Accidents and Malicious Acts, we see that to a great extent it is the natural events that are assessed as having the highest overall risk. The scenarios that fall under the category of Major Accidents and Malicious Acts are assessed as having a lower probability than natural events, but the consequences of some of these scenarios are deemed to be greater than some of the natural events.

The matrix shows the picture that arises if we compare the risk associated with the various scenarios analysed without attaching importance to whether it is a natural event, major accident or malicious act. The overview can therefore be used as general input for discussions that transcend the areas of responsibility and sectoral boundaries.

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Climate Change Impacts and Adaptation in Norway – Strengthening the Knowledge Base

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Climate change is here today – even in Norway. Just last week we heard news about extreme heat, dangerous rainstorms and huge snowfalls. We expect to see a lot more of this in the years to come.

As you all know, the Intergovernmental Panel on Climate Change (IPCC) published its Fifth Assessment Report (AR5) in 2013 and 2014. The report tells us what the scientific community knows about the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.

Major findings in IPCC AR5

The IPCC AR5 report shows that in recent decades the world has seen significant changes in precipitation patterns, and melting snow and ice have affected both water quantity and quality in several places. Permafrost has thawed. The oceans have become warmer and more acidic, and sea level has risen a total of 19 cm. There are observed changes in extreme weather events since 1950, such as several episodes of extreme temperatures, extreme precipitation and high sea levels. The Fifth Assessment Report is clear; human influence is the dominant cause of the warming observed since 1950.

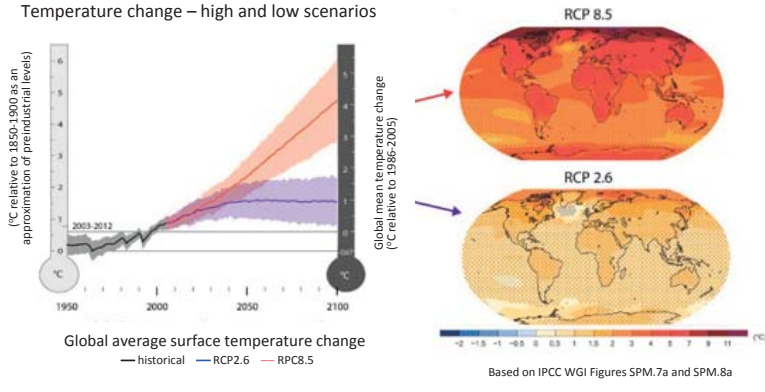
If we continue to emit greenhouse gases at the same rate as today, we risk severe, pervasive and irreversible impacts that will exceed our capacity to adaptation. Climate adaptation and mitigation can reduce the total risk in the short and long term. The two-degree target can be reached by large greenhouse gas emission reductions, it is urgent - and not necessarily so expensive. We must change to green investments and have a slightly lower consumption growth.

Which future do we choose?

We have a choice. The IPCC AR5 shows four emission pathways. The charts below show two of the new Representative Concentration Pathways (RCP) scenarios. The charts are based on IPCC WG1 (2014).

The chart shows the estimated trend in global mean surface temperature (median) at two different emission pathways, compared to 1986–2005. To compare this with the pre-industrial period, we must add 0.61 degrees. The shaded areas show the uncertainty interval. The red line shows an emissions path consistent with a future where no additional policy measures are initiated to reduce greenhouse gas emissions. The blue line shows an emission path that requires ambitious reductions in emissions over time. If we follow this path, we have more than 66 per cent chance of achieving the two-degree target. This will be a far less risky world that the business-as-usual scenario, though nevertheless still a world with serious impacts on human and natural systems due to climate change.

Looking closer at the two emission paths, you see little difference between the two curves in the beginning. It takes a while before the benefits of emission reductions become visible because greenhouse gases have long lifetimes in the atmosphere. We must reduce greenhouse gases, especially CO_2 today, so that we do not find ourselves moving in a completely wrong direction before the end of this century. And, we must also adapt to the changes in climate that we inevitably will experience.

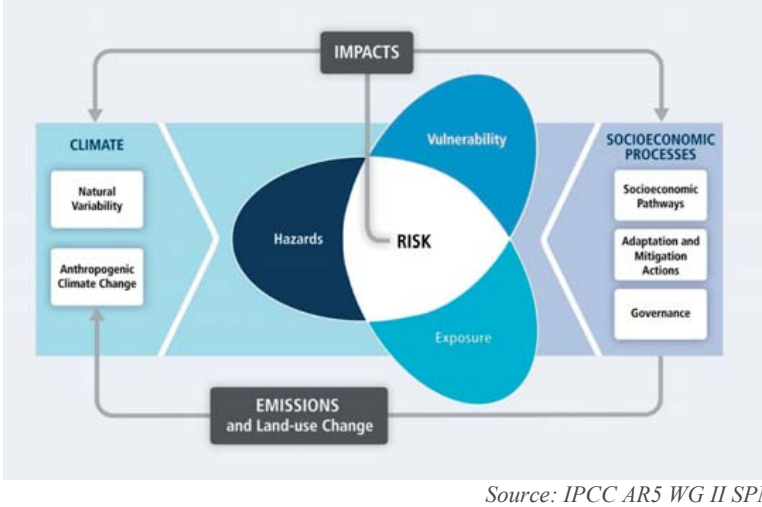


The climate is changing, creating new risks and reinforcing existing ones

The climate is changing, creating new risks and reinforcing existing ones in countries all over the world. There is an increased risk of loss of biodiversity and lack of food and water. We are expecting increased economic losses and deteriorating living conditions – and the poorest are hit hardest. There will be more damage from rain, surface water, floods and rising sea levels. We are expecting deteriorating health and increased mortality. More people can become refugees, indirectly increasing the risk of violent conflict.

The IPCC illustrates climate risk by a tripartite rose

The risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure of humans and natural systems (see figure below). Changes in both the climate system (left) and socio-economic processes including adaptation and mitigation (right) are drivers of hazards, exposure and vulnerability. An example for Norway can be flooding. The flood is then the climate-related hazard that may occur. Whether it entails a risk or not, depends on the exposure and vulnerability of humans and natural systems such as buildings, farmland and infrastructure. Several studies of natural disasters have shown that age, gender, ethnicity, income and wealth have a big impact on the individual's ability to cope with and recover from a crisis situation.



Source: IPCC AR5 WG II SPM

We reduce climate-related hazards by reducing emissions and we reduce our vulnerability and exposure by adapting to climate change.

Climate change in Norway

Norway is fortunate not to be harder hit by climate change. However, Norway will also be affected. This is what we expect to see in Norway towards the year 2100:

- The average annual temperature will increase, rising most in inland areas, northern parts of Norway and Svalbard. We are also expecting more extreme temperatures.

- The number of days with heavy precipitation will increase as the century progresses. On those days, precipitation may be more intense. More frequent episodes of extreme precipitation might lead to increased damage from urban run-off water and greater challenges with urban run-off water management. Urbanisation and more replacement of vegetation by buildings, roads and other hard surfaces enhances this challenge.
- Sea level will rise. However, the magnitude will vary widely along the coast of Norway due to continued land rise from the last Ice Age in Scandinavia. The sea will also become warmer and more acidic. CO_2 dissolves easily in cold water, so acidification will happen more/faster here in the north where the water is colder.

The following pictures show some of the impacts climate change may have in Norway. Some impacts will be of a more acute character and some will be more gradual.

- Picture 1 shows flood damage in Odda.
- Picture 2 illustrates that a warmer climate could affect public health, for example through affecting drinking water quality or increasing in waterborne infections.
- Picture 3. Surface water is already a challenge, but will increase with increased frequency of intense precipitation events.
- Picture 4 illustrates that nature can provide an important defence against climate-related hazards, both for people and society. Meanwhile, nature itself is also vulnerable to climate change and to interventions. The picture shows

meandering rivers, these can mitigate flooding, purify water and prevent erosion, but have become a rare sight in our landscape due to human intervention. The picture shows Sørumsneset nature reserve with Lillestrøm in the background.

- Picture 5. Unstable weather, increased temperature and precipitation could result in greater adverse effects for agriculture caused by existing and new pests such as insects, viruses and fungi. However, a longer growing season can be beneficial for agricultural production. Adapting to climate change is also about taking advantage of potential positive effects of climate change. Rate of forest growth will increase. The treeline will move upward. Overgrowth of cultural landscapes can gain momentum, which can have either positive or negative impact.
- Picture 6 illustrates that rot damage and rising sea levels will threaten buildings and infrastructure, including our cultural heritage.

Climate change adaptation policy: "The Norwegian Story"

In Norway, the national, systematic work on climate change adaptation began in 2007. An inter-ministerial group was mandated to establish information platforms and co-ordinate national adaptation efforts. One important aim was to build capacity for local planners through the county governors' offices. This programme was supported by a secretariat hosted by the Directorate for Civil Protection and Emergency Planning.

In 2009, the report "Climate in Norway, projections of atmosphere climate, ocean climate and hydrological conditions up to 2100" – in short "Climate in Norway 2100" (2014) – was prepared. This report was followed by an Official Norwegian Report on Norway's climate change vulnerability and adaptive needs in 2010. The White Paper on climate change adaptation was published in 2013 and adopted by Parliament in 2014 ["Climate in Norway 2100" (2015)].

As a part of the Norwegian climate change adaptation story, I will mention the "Cities of the Future" programme. This was a collaborative effort between the Government and the 13 largest cities in Norway to reduce greenhouse gas emissions and adapt to a changing climate. The programme ran from 2008 to the end of 2014, and emphasis was on networking to share lessons learned and practical experience with adaptation.

White Paper on Climate adaptation – main messages

I would particularly like to highlight some messages from the White Paper:

- All sectors and levels of government have responsibility to reduce the impact of current and future climate change in their own areas/sectors.

- The local character of climate change makes adaptation at the municipality level particularly important. Land-use planning, water and sewage management, natural resource management etc. are key areas where local authorities need to work on climate adaptation.
- Co-ordinated efforts at the national, regional and local levels are important.
- We still need to strengthen the knowledge base and update the report "Climate in Norway 2100", thus downscaling the IPCC AR5 global scenarios into Norwegian data for precipitation, temperature, sea level etc.

The Norwegian Climate Change Service (NCCS) is doing important work with "Climate in Norway 2100" as we speak. NCCS, consisting of the Norwegian Meteorological Institute, Norwegian Water Resources and Energy Directorate and Uni Research, will provide climate data for use by municipalities and others. "Climate in Norway 2100" was published September 22, 2015.

We also need new analyses and studies that are relevant for climate change adaptation work (for all sector areas).

Strengthening the knowledge base

Research on climate change adaptation needs to be enhanced In line with the messages from the White Paper.

Valuable research was carried out in the large-scale research programme NORKLIMA and more is now being done in the ongoing programme KLIMAFORSK. I want to focus on some areas where the knowledge base should be further strengthened – some of these are addressed (partially) in KLIMAFORSK, and some are not.

Research on the climate system is necessary, *inter alia*, to understand how much the climate will change and what kind of changes are anticipated, in order to make predictions for Norway and downscaling these, and to develop systems for climate forecasts. Research on climate change impacts on nature and society is important for identifying key areas where adaptation is necessary. The research on the climate system and climate impacts form the basis for research and knowledge on strategies for adapting to climate change and how these can be implemented in an effective and equitable manner.

Climate System research

We know quite a lot about the climate system and the Norwegian research community is also particularly strong internationally. But there are still a number of challenges. I would like to highlight research on:

- *Sea ice extent* has implications for developments in the Arctic. *Snow accumulation* is important for avalanches. *Permafrost melting* has significance for traditional industries and infrastructure.

- Further development of *regional and local long-term climate projections.*
- *Predictability of the climate system*, including methods for climate forecasts, i.e. prediction on shorter term than today.
- *Carbon cycle and land use change*. For instance, forest management and development of land impact on the carbon cycle and hydrology, which again are important for climate change adaptation.

Climate Impact research

While we know relatively much about the climate system, we know a little less about the impacts of climate change on nature and society. What are the impacts on infrastructure, business and living conditions, impacts on the physical and chemical changes and impacts on ecosystems? How can we for instance protect ecosystems and their ecosystem services such as carbon sequestration, flood and erosion protection, in the best possible way?

Climate Adaptation research

We know less about climate change adaptation. The evaluation of the NORKLIMA-programme (March 2014) stated that climate change impacts on society, and how to strengthen adaptability, are relatively new research areas. NORKLIMA has contributed significantly to increasing our knowledge in these fields, particularly through interdisciplinary research. An evaluation report from 2012 of Norwegian climate research states that the Norwegian social science climate research is of high quality and international visibility. For climate change adaptation, we need more knowledge on:

- Identification of particularly vulnerable areas, population groups, industries and resources and adaptation needs and opportunities related to climate change, in Norway and globally. Need for information, local involvement and access to expertise to deal with vulnerability, including knowledge of local conditions. The importance of social inequality.
- The effects of strategies to safeguard biodiversity in a changing climate.
- Comparison of different strategies for adaptation to climate change and their effects; barriers, constraints, measures and comparison of experiences from different social sectors, industries and countries.
- Climate services for climate adaptation, such as accessible and user-friendly translations of climate data and information.
- Economic consequences of climate change, including cost-benefit analysis of adaptation measures, the consequences of failing to act, and how to utilise the positive effects of climate change.
- Management of risks and uncertainties.

- Ethical and legal responsibilities and rights related to climate adaptation. One international example is whether industrialised countries can be held liable for emissions in the past that now causes damage. Poor countries are most vulnerable to climate change. They are more exposed to the negative effects of climate change, and have fewer resources to cope with the consequences. Another example is whether society at large (national or regional authorities) has a responsibility to protect its citizens against climate-related hazards. Individuals or regions may not have the ability themselves.
- Meta-analysis on how our management model works and how to deal with new challenges related to climate change. Knowledge about solutions for co-ordination between and within various administrative levels, including sector areas and municipalities.

And - we are frequently experiencing floods and landslides. More knowledge is required on how to reduce the risk and consequences of increased floods and landslides.

We must see greenhouse gas emissions reduction and climate adaptation in context. Moreover, we must not forget the gradual changes. I am thinking about the sea level which slowly but surely is rising, humidity and higher temperatures that cause more decay damage, and impacts on biodiversity and agriculture.

Global challenges

Developing countries and vulnerable people and communities will be harder hit by climate change than is the case for the population in Norway. Hence, stressing the importance of international and regional co-operation and development aid. We need more knowledge about the consequences of climate change for developing countries, adaptation options and relevant measures.

In Europe, research is now also directed towards the so-called “indirect effects”: Climate change outside the country in question might impact on that country. Such indirect impacts might in some cases pose a greater risk than those within national borders. Some areas for indirect effects:

- Food safety: the world’s and Norway's population are increasing, hence increasing the demand for food. This will be challenging for food production internationally. And for us – Norway imports much of its food from other countries. In Norway, a prolonged growing season might result in larger yields, if we safeguard our soil resources and adapt our agriculture to a changing climate.
- Wars, conflicts and refugees: many studies find that climate change is an additional stress factor contributing to the increased mobility of people.

- Financial impacts: Norway has a small, open economy. We need knowledge of how our trade relations and investments abroad will be affected by climate change.

How to meet complex demands for knowledge

So, how do we meet these complex demands for knowledge and ensure relevance? I think it is important with a holistic and integrated approach.

Interdisciplinary co-operation is important. While climate system research is traditionally natural science-based, research on climate adaptation requires a collaboration and interaction within (interdisciplinarity) and between natural science, social sciences and the humanities (radical interdisciplinarity). Over half of the projects in the KLIMAFORSK programme now have some interdisciplinarity and slightly more than a quarter have radical interdisciplinarity. However, radical interdisciplinarity is challenging, both internationally and nationally, as there is little tradition for this and the academic structures are not well organised to accommodate it.

Co-ordination is necessary. Much climate research takes place in sector programmes like energy, transport, petroleum and bio-industries (ENERGIX, CLIMIT, Transport programme etc.), and other environmental research programmes (Environment 2015, Oceans and Coastal Areas, Polar programme). KLIMAFORSK collaborates extensively with other programmes, but until now mostly with environment research programmes and not so much with sectoral programmes.

International co-operation is important for improving the quality of research and is a high priority in Norwegian research. EU co-operation is particularly important, with programmes and initiatives such as NordForsk, JPI Climate, Belmont Forum and Horizon 2020.

Involvement of end-users, both business and government, is important for ensuring relevance through their experience and for contributing to learning.

Which future do we choose?

I started by showing you two emission paths and two different globes. Unfortunately, it is towards this red planet we are heading with the current emissions. This planet will, in that case, change dramatically and we know very little about how we can adapt or if that is even possible. So I will just conclude by highlighting the message from the IPCC once again:

- We know much about how to get to a low-emission society and limit global warming to 2-degrees.
- It will be demanding to reach this yellow globe.
- We must not forget that this yellow planet will also give us great challenges that we must adapt to.

- Efforts to reach the yellow globe, mitigating climate change, and adapting to climate change must go in parallel.

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Interdepartmental Research Programme on Natural Hazards: Infrastructure, Floods and Slides (NIFS)

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Background

Natural hazards – Infrastructure for Floods and Slides (NIFS) is a multi-disciplinary project based on White Paper No. 15 to "Stortinget" (2011–2012) entitled "How to live with the risks – about floods and slides" (Norwegian Parliament 2012), and the subsequent parliamentary debate.

The Norwegian National Rail Administration (NNRA), the Norwegian Water Resources and Energy Directorate (NVE) and the Norwegian Public Roads Administration (NPRA) have been working in partnership over a number of years

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across several areas. Together they have developed the accumulated knowledge this has produced into a major, targeted, R&D initiative. The project has a wide remit ranging from the strategic to the operative sphere in connection with natural hazards. The project period was set to 2012–2015, and NOK 42 mill. as well as considerable internal resources have been allocated to the task, which is organised in seven different work packages. Collaboration between agencies, government and academic communities, internally and externally, has been central for achieving our goals.

Significant importance has been attached to reaching joint solutions and fostering collaboration between government agencies, as well as with other resources in Norwegian society within these areas. The latter include research and education organisations, trade and industry, and other public institutions. The project outcome is published on an ongoing basis on our joint website www.naturfare.no. Relevant research outcome is implemented in accordance with the resolutions of our three organisations. The NIFS project is relatively large and wide-ranging, and there are great expectations for the results, both internally and externally.

The programme was ambitiously designed to successfully accommodate close co-operation with the Geological Survey of Norway (NGU), the Norwegian Meteorological Institute (MET), the Norwegian Mapping Authority, Norwegian universities and university colleges, research institutions, the county administrations and the county governors and local authorities, as well as external experts and on-going/planned research projects.

Natural hazards such as avalanches and landslides (soils, quick clay, rock falls and rockslides) and floods with erosion expose infrastructure like roads, railways and buildings to risk. The agencies face major common challenges, and a good working partnership will be cost effective and help build competence within the organisations. Community safety and emergency work are interdisciplinary. Co-operation is sought out, both in enterprises with responsibility for safety and emergency preparedness, and in the demand for research that will create new knowledge in these fields.

We must adapt and live with natural hazards, but the challenges are increasing due to increasing development and climate change. The Government wishes to improve the community's ability to reduce flood and landslide impact by targeted efforts to keep these risks at an acceptable level. Safety for citizens, a high focus on prevention, and a preparedness to handle all events, are our main goals.

Framework

Prior to the start of the NIFS programme, considerable research efforts had already been made and the results have been published in several reports on the need for climate adaptation, e.g.

- In November 2010, the publication of NOU 2010:10 "Adapting to a Changing Climate"[1] was published. This Official Norwegian Report was followed up by a White Paper concerning "Climate adaptation"[2] submitted to Parliament by the Ministry of the Environment in the autumn of 2013.
- In the autumn of 2010 the Norwegian Water Resources and Energy Directorate presented its "Strategy for Climate Adaptation" as a basis for further work within the sector (NVE, 2010).
- In 2011 the Norwegian National Roads Administration completed its four-year R&D project entitled "Climate and Transport", to which the Norwegian National Rail Administration, the Norwegian Water Resources and Energy Directorate and the Norwegian Meteorological Institute were the main contributing partners. The objective was to improve procedures and regulations for planning, construction and operation of roads and railway lines in the climate we have at present, and as the climate changes. Significant attention was addressed to natural hazards under this project (NPRA, 2013).
- In the spring of 2011 a report on climate adaptation was written for the National Transport Plan 2014–2023. This report provides guidelines for the transport services and Avinor's climate adaptation initiatives.
- The National Transport Plan (NTP) 2014–2023 was published in February 2012 and provides a set of measures concerning natural hazards. The Norwegian Parliament debated the NTP in the spring of 2013.
- In the spring of 2012 the Ministry of Petroleum and Energy submitted a White Paper to the Norwegian Parliament, entitled "How to live with the risks – about floods and slides". This report also has been debated in the Norwegian Parliament.

Close connection between the weather and natural hazards has led each work package and each activity to take into account climate and climate change. By strengthening the competence of each agency in providing protection against natural hazards, we have new capabilities to develop more robust infrastructure. This allows us to reduce the risk of damage caused by natural hazards, to improve traffic flow and to protect our infrastructure.

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[1] NOU 2010: 10 Adapting to a changing climate: Norway's vulnerability and the need to adapt to the impacts of climate change. Recommendation by a committee appointed by Royal Decree. 5 December 2008. Submitted to the Ministry of the Environment on 15 November 2010. https://www.regjeringen.no/nb/dokumenter/nou-2010-10-2/id668985/

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It is important to provide a closer link between specialists within different agencies in order that experience is shared and even better use made of the competence available within each department. This builds on the co-operative relationship we established through the "Climate and Transport" project.

NVE, NNRA and NPRA – working in partnership with MET – are committed to an ongoing joint project on avalanche and landslide forecasting, the project owner being NVE. The partners are working on a number of ongoing projects associated with stability and incidents in relation to landslides involving quick clay. This partnership will continue under an operational "national avalanche and landslide forecasting service" which was proposed in the 2013 budget as one of NVE's initiatives for the period 2013–16.

It is possible to limit the risk of damage from natural disasters by taking the hazards into account during the planning stage. Plans and designs must accommodate any prognoses for climate change that may lead to changes in the probability of landslides and floods. This may involve the siting of new infrastructure such as roads/railways and buildings away from areas prone to landslides, on safe ground, and on higher ground than where flooding may be expected. This means, among other things, that greater importance must be attributed to the planning, building and maintenance of drains and culverts. The requirements imposed by the future climate must be seen in connection with the life of the structure. For existing infrastructure, there will be a need for increased resource allocations for maintenance and for condition surveys, as well as further development and strengthening of climate contingencies.

Analyses that take account of climate change may form the basis for deliberations concerning the timing and scope of improvement initiatives. As part of this work, the project employs risk and vulnerability assessment (RVA) to pinpoint any vulnerable points. It is important to sustain the investment in landslide and avalanche protection. There is a need to review the agencies' avalanche and landslide protection plans to assess whether reprioritisation is required to take into account the impact of climate change. A good cost-benefit tool must be developed to ensure optimal use of allocated resources. Investment in permanent slope protection devices will reduce the cost of comprehensive inspections in the longer term.

Because large parts of our infrastructure are exposed to natural hazards, emergency preparedness constitutes a special area of focus. Resources must be allocated for the further development of proactive systematic contingencies. Furthermore, emergency preparedness plans must be drawn up for all types of avalanches and landslides, as well as forecasting systems that present and make use of good weather prognoses. This includes the development of climate models (especially short-term precipitation, wind and storm frequency predictions) and the presentation of outcomes for practical use. The forecasting systems require a network of measurement stations, and close liaison capability between agencies. The project partners must review and revise their regulations, standards and procedures associated with natural hazards and draw up joint handbooks and guidelines so that

procedures will operate smoothly between their different areas of responsibility, reducing the risk of harm and destruction.

Objectives and Outcomes

The overall objective is a safer society with more robust infrastructure, safe buildings, safe transport and good forecasting systems for landslides, avalanches and floods. The programme's main objective is to build good partnership platforms by co-ordinating the activities of the agencies in order to reduce vulnerability and prevent accidents and injuries caused by these natural hazards. In order to achieve this objective, the agencies have equipped themselves with relevant tools to acquire the knowledge necessary to raise awareness and adjust their contingencies for situations that involve unacceptable levels of risk. Also, co-ordination and partnership in connection with databases, hazard mapping, forecasting systems and R&D ensure more efficient use of public funds.

The programme must take into account current and future climate challenges. Climate change introduces increased vulnerability for society as a whole, as a consequence of increased risk of floods, avalanches and landslides.

Impact targets are used to describe the future situation the project should seek to attain. We wish to reach them by:

- Improving the level of safety for the population by providing infrastructure that is better designed to withstand the impacts of natural hazards, at their present level and in the future.
- Systematic contingencies to ensure better preparedness for when natural disasters happen.
- Better co-operation between agencies in disaster situations.
- Optimal use of financial and professional resources to solve shared challenges associated with natural hazards.
- Raised levels of safety and robustness, and improved traffic reliability.

Specific outcome targets and results are listed under the various work packages. Descriptions with more detail are being written in separate reports for each work package and activity. Outcome targets were defined in NIFS-NVE Report 57, 2013.

The organisational structure of the Government Agency Programme and its work packages is shown in Figure 1. The figure shows that there is an extensive need for co-ordinating data and information across the agencies and the work packages (WPs). Similarly, all the work packages interface in some way with various other projects that have been completed, are ongoing or are being planned. It is and has been important for the project to clarify and meet the need for co-ordination and interaction.

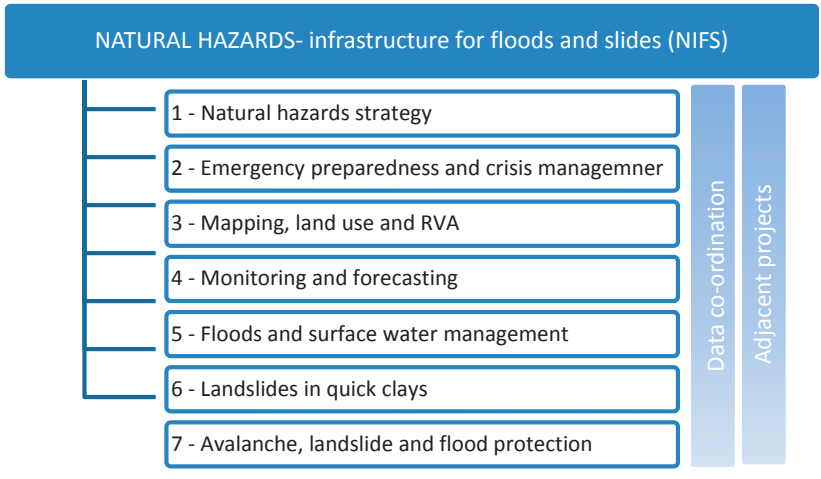

Figure 1. The NIFS project organisation model (2012–2015).

WP1 Natural Hazards Strategy

At the beginning of the NIFS-programme, it was necessary to identify the framework for handling natural hazards within each agency, identify shared challenges with respect to floods, avalanches and landslides, understand in a better way how the responsibilities are divided and where interaction can be improved. In addition, NIFS wanted to assess the impact of the decisions in the White Paper Meld. St. 15 on management – within each agency as well as generally.

An assessment of the regulatory documents (those including commitments with respect to policy, approved strategies etc.) gave the NIFS programme more insight into possibilities for better co-ordination. Additional case studies of three infrastructure projects provided instructive examples of the beneficial effects of establishing collaboration lines, both at project level and at start-up of an infrastructure project. The findings from this work helped us decide on further priorities within this work package in NIFS.

There is a need to harmonise the definitions of technical terms commonly used in the field of natural hazards. NIFS is working on terms in the field of mapping, landslide and avalanche types and materials, protection measures and preparedness. Our goal is to produce an easily accessible common list of term definitions, e.g. connected to the alert system portal www.varsom.no.

Another important harmonisation lies in the contact between forestry and management of natural hazards. Forest management has impacts on the surrounding terrain in several ways: cutting of forest on slopes, negative effect of lack of drainage on forest roads, effect of deep wheel tracks on surface water flow during heavy rain, etc. Regulations need to be better harmonised to achieve sufficient safety of infrastructure. NIFS has initiated dialogue with state authorities for forestry. Potentials lie in increasing knowledge about the effects of forest management on surrounding terrain and infrastructure, wider risk assessment (from all involved agencies) prior to interventions in the terrain, and monitoring of conditions in existing forest properties.

How natural hazard and risk is communicated to residents in areas prone to flood or landslide is an important and often neglected part of natural hazard management. For example, when evaluating the risk level, or the level of remaining risk after protection measures have been put in place, the residents' perception of the risk must be taken into consideration. We are looking for ways of achieving better public participation.

Starting early is a general rule. Schools need to do their part of the work by educating young people to recognise impacts of natural hazards and to learn how society can protect itself.

The White Paper Meld. St. 15 in 2012 recognises the importance of obtaining a good overview of the "whole picture" and of interdependencies in areas with especially high risks from natural hazards. Complex management plans can be developed through co-ordinated planning where NVE, municipalities and county authorities (Fylkeskommune, Fylkesmann) are involved.

The White Paper states also that NVE and other relevant authorities shall develop a "National strategy for natural hazards". The aim is to achieve better co-ordination and collaboration between all parties involved, and within priority areas of collaboration. NVE is responsible for defining the work scope and for implementing and monitoring the strategy. The other participants are the Directorate for Civil Protection and Emergency Planning (DSB), the Police Directorate (PD), MET, and educational and research institutions, in addition to municipalities and county authorities. Dissemination, training, and in-house information within the three agencies (NVE, NNRA and NPRA) are also important tasks in order to raise the level of competence and knowledge about the work of other agencies in areas where there is interaction.

The NIFS programme makes concrete proposals for this strategy, including measures for co-ordinated management, communication, common datasets, and common tools such as web portals and risk assessment tools.

WP 2 – Emergency Preparedness and Crisis Management

Being prepared for natural hazard emergencies and able to manage the crises which inevitably accompany them are major concerns for all the agencies involved. The different aspects of crisis management will have a bearing on a number of subordinate activities in other work packages. The WP 2 team has chosen to

concentrate on general aspects rather than details, in order to establish guidelines that will facilitate interaction between agencies.

Under each activity, the focus is on describing "best practice" and opportunities for effective interaction. Our approach has been to focus on collaboration - both internally and externally, through joint exercises and joint approaches to other participants, shared experience and recommendations.

NIFS have defined a set of main activities, each with a subset of action points. WP 2 has thus followed a wide-ranging remit, looking at many aspects of dealing with different types of natural hazard events: existing documents and guidelines, experience of transnational co-operation, available data, descriptions of the current situation, challenges and opportunities**.**

Role appreciation and the clarification of responsibilities within the three agencies, together with crisis definitions and clarification of terminology, are vital interfaces both between agencies and with external agencies. Planning for emergencies also has many elements, such as clarifying the type of event (including climate challenges), understanding strategic, tactical and operational levels, defining emergency preparedness levels, designing contingencies, contingency planning, guard duty rostering, forecasting (internally and externally), tools, checklists, action cards. RVA (risk and vulnerability assessment) as a tool for cross-agency quality assurance has also been discussed. Regarding crisis management, our evaluation has covered definitions of crisis, normalisation, evaluation and lessons learnt. Drills and training across agencies and externally are essential.

Information flow and control is the cornerstone for succeeding with a joint effort under critical conditions. WP 2 has stressed this, recommending that the strategic team in each organisation appreciates just how vital it is, along with the importance of co-operation when it comes to important messages to the public.

Report 64-2014 considers the three agencies' contingency plans and how they are co-ordinated with each other and in relation to others involved. The focus is on the overarching strategic level, especially in terms of communication between agencies and across to other participants. The basis for assessments is approved plans, evaluation reports, and oral sources in and outside the affected organisations.

In Report 76–2014, entitled "Crisis Support Tool CIM® – Management system for emergency preparedness and security" from a seminar in Trondheim arranged by WP 2 in April 2014, CIM is described and evaluated based on experience from agencies that are using it already. Recommendations are made for its introduction in NNRA and NVE, and for further work in NPRA.

WP 3 – Mapping, Data Co-ordination and RVA

Key challenges connected to mapping floods, avalanches and landslides have been identified and addressed. The different agencies have approached this task in different ways. It has been useful to collate an overview of the various current mapping projects within each of the agencies, as this has enabled us to meet the

need for mapping in a more cost-effective way. This requires closer co-operation between agencies to ensure that specific tasks are appropriately co-ordinated. The methodology required for mapping floods, avalanches and landslides is being assessed. Specific outcomes are presented through seminars and research reports. This spring WP 3 arranged seminars in Oslo on "Mapping avalanches in steep terrain" and on "Notification of natural hazards – Now and in the future". Our latest reports are focused on the use of InSAR technology for monitoring natural hazards and the use of vegetation to reduce the run-out from snow avalanches. Database co-ordination is seen as imperative for maintaining an overview of work undertaken on floods, avalanches and landslides in Norway. This co-ordination drive includes work to achieve uniform formats, standardisation, visualisation etc., as well as gaining the necessary access to established data within the project by means of downloadable solutions, Geo-network and shared web portals for NVE, NPRA and NNRA.

This work package is expanding our existing shared web portal www.skrednett.no, with the objective of collating and presenting proactive information and data about the mapping of flood, avalanche and landslide risks, hazard reports, protective measures, ground surveys etc. conducted by both public and private sectors, to make it easy for users to find joined-up information.

Use of risk and vulnerability assessment (RVA) plans related to land use is essential to solve our challenges dealing with natural hazards. There is a need for improvement in conducting RVA within and between agencies in order to ensure that the impact of potential floods, avalanches and landslides is sufficiently investigated and documented at the planning stage. WP 3 has proposed a number of improvements to planning guidelines and procedures (for construction projects etc.) within the NPRA/NNRA. The NIFS project is delivering a report/guidance about RVA analyses for our agencies in the context of the work of the DSB.

Lessons learned from flood and landslide events are fundamental for handling future events in the best way. Teamwork and co-ordination are required with respect to management plans for flood, avalanche and landslide events. This includes guidelines and procedures for recording data as well as data quality requirements and assurance. The work package has also highlighted the need to establish and improve our routines for transferring data between agencies. Common guidelines and a co-ordinated programme to establish our activities (scope, content and quality) will give us adequate and uniform recording of flood, avalanche and landslide events. This information is useful in various tasks within the agencies and will be available for helping solve the needs in other parts of society, such as providing better maps and knowledge of the danger areas and improved alert services. These tasks will be addressed in our final report.

WP 4 – Monitoring and Forecasting

Our intention is to develop, test and evaluate methodology for the monitoring and forecasting of avalanche and landslide hazards. This includes the following activities:

- Monitoring weather parameters by supporting ongoing programmes for building new weather stations located for avalanche and landslide forecasting.
- Improve detection of instability and mass movements for areas that are already identified as unstable.
- Monitoring incidents in real time.

So far, a variety of methods for new applications within the field of natural hazards have been tested, such as RADAR, LiDAR, photogrammetry, infrasound, snow glide shoes, snow thermistors, weather stations, accelerometers and different uses of RPAS (Remotely Piloted Air System) techniques. We have contributed to the development of new data services and applications as well as sharing and publishing data. This has increased the knowledge base within the agencies, provided a basis for future tools, improved the preparedness systems and made it possible to introduce more use of active avalanche control.

WP 4 also looks into avalanche and landslide forecasting in connection with the research, development and implementation of an operative avalanche forecasting service. These activities involve an ongoing PhD study on wet snow processes by Christopher D'Amboise. He is based at NVE and University of Oslo.

NIFS has been involved in the development of the web portal www.varsom.no that has become the information platform for the public service for warning of flood, landslide and avalanche hazards.

Some benefits from the project are the establishment of new forms of collaboration, new weather stations, advanced instrumentation, new data services and notification procedures, increased competence and opening up the market for innovative providers.

The work package has produced 19 publications so far. Future deliveries will comprise reports about the use of statistics in local warning procedures, a review of monitoring of glide avalanches, LiDAR for stability analysis, and also some general overviews of the entire project portfolio regarding monitoring and warning.

WP 5 – Floods and Surface Water Management

This work package examines what constitute the greatest current and future challenges with respect to robust infrastructure and natural hazards. In recent years, water-related problems such as flooding in small catchments, surface runoff and water-related landslides have been the cause of most of the damage from natural hazards. These challenges will increase in frequency in the future and also may become even more extensive as climate change continues.

A high level of uncertainty associated with the available data and calculation tools, with respect to the design as well as the contingency/forecasting criteria (threshold values), is giving rise to further challenges.

Many problems, particularly those concerning system operation and maintenance, are related to financial constraints. Consequently, WP 5 draws

attention to the fact that being proactive is actually profitable. This is achieved by clearly demonstrating the cost benefits of implementing good surface runoff solutions for new-builds, introducing good routines for operation and maintenance, and introducing a host of measures with respect to existing drainage systems.

Our main objective is to reduce personal injuries and infrastructure damage caused by flooding and surface runoff. Working in partnership with respect to construction and operation, and co-operating to improve the guidelines and tools involved with hydrological case work within our agencies and the local municipalities, aims to achieve this. Two joint guidelines will be delivered during the project period. One is for calculating localised flooding, the other for managing floods and surface runoff in connection with operation of water courses, as well as reporting the financial benefit of proactive interventions based on comparison with the costs incurred with various natural hazard events.

The corresponding agencies and society at large should have increased focus on mapping flood and landslide risk, in connection with streams and surface water, caused by human intervention in the natural drainage system. There is a need to improve mapping data – and therefore this work package recommends an increased effort on laser scanning covering the entire country. This must be used to improve and develop flood maps (both at regional and local scale) regarding all natural hazards. This includes mapping all drainage systems within the actual area. All necessary GIS-information – including historical maps – should be available through a web portal. Society needs to join forces on common initiatives to achieve agreements on operation, maintenance and accountability for each and all landowners within catchments. The Government needs a unified system for mapping and reporting weather-related incidents/injuries, and NIFS also has made some proposals to different authorities outside our agencies to help solve this challenge. Socio-economic analyses and calculations should be done for all weather events which involve injuries. This would be a great help for our agencies in the planning process with respect to budgeting and the need to get the priorities right.

Key input on water, based on our experience, highlights the need for:

- Additional monitoring stations for meteorological and hydrological short-term data (e.g. hourly values of precipitation and water flow).
- More expertise in all agencies regarding drainage challenges, with greater competence and control of planning, development and renovation in connection with both operation and maintenance.
- More robust measures – both construction and renovation after flood events.
- More co-operation in sensitive catchments to reduce the risk of incidents due to the impacts of climate change and increased human impacts on drainage systems.

The work package has already published research reports and initiated an extensive collaboration in Gudbrandsdalen (Lågen area) between our agencies and local

municipalities and landowners. It is also reporting on natural hazards connected to recent events that occurred at the following five sites: Notodden (2011), Røros-banen (2011), Hallingdal (2011), Burud (2012) and Dovrebanen/Gudbrandsdalen (2011/2012/2013). Several MSc studies are involved, based on fieldwork and laboratory testing at NTNU in Trondheim. In 2015, WP 5 will also be publishing a technical handbook on drainage of infrastructure that will be useful for design, construction and maintenance.

WP 6 – Slope Stability and Landslide-related Challenges in Quick Clay

In the quick clay deposits of Norway, slope failures and consequent landslides are particularly destructive. This is due to the possibility of small landslides initiating retro- or progressive slides, which may involve massive soil movements in the order of millions of cubic metres. Quick clays in Norway, when provoked by man-made or natural causes, have led to a number of landslide disasters throughout our history. Two of the most well known in modern times happened in Verdal (1893) and Rissa (1979). They led to 116 and 1 causality, respectively, as well as huge material destruction. In the last 40 years there have been approximately one or two slides per decade with a volume exceeding 500,000 m^3.

Another well-known quick clay landslide recently caused irreparable damage to one of the two large bridges that carry the E18 highway at Skjeggestad in Vestfold County in the south-eastern part of Norway. The landslide took place on 2nd of February 2015, and led to huge traffic challenges for about 5 months. The damaged bridge had to be demolished, and construction of a replacement will probably be completed by midsummer 2016. A man-made mass movement triggered the landslide. Luckily there were no casualties. Simple socio-economic analyses and calculations indicate additional traffic costs amounted to more than NOK 450 mill. for the period February – June 2015.

There are currently a number of guidelines and standards in use with respect to construction and developments in quick clay areas. One of the main objectives of this work package is to clarify and facilitate the development of current regulations and procedures. Whether relating to the surveying and delineation of geographical areas, interpretation of laboratory and field data, or development of new calculation tools, our work will provide a foundation for better and more uniform practice in quick clay areas, based on similar safety policies, independent of the location and the identity of the developer.

WP 6's main objectives are to prevent landslides by means of regulations, development of methods for ground reinforcement and better calculation and design tools. The work package contributes to our basic understanding of quick clay material properties in general, and especially for assessments of potential landslide distribution and run-out distance.

More than 40 technical reports covering a broad range of topics have been published by WP 6, which also has supported the initiation of several Masters, PhD and Post Doc studies, as well as articles and presentations at national and international conferences. Some key outcomes from this work package are:

- A national database for soil surveys, NADAG (http://geo.ngu.no/kart/nadag/).This is a collaborative project between NIFS agencies and NGU.
- Common definitions and delineations between local and overall stability integrated into different agencies' guidelines are essential.
- Whether relating to the surveying or delineation of geographical areas, the interpretation of ground surveys, or calculations and reports, the database will provide a foundation for uniform practice in quick clay areas if they are based on similar safety policies, independent of the location and the identity of the developer.
- Web-based solutions developed to provide access to updated information at all times for consultants, developers and authorities concerning ground conditions and quick clay zones, including reports and risk assessments.
- Updated shoreline landslide information made available to all developers, surveyors and central and local authorities.
- Common interpretive models for detecting quick clays, based on surveying methods applied in our site investigations.
- Robust numerical tools, based on how calculation models are intended to handle and accommodate the strain softening in quick clay and other high-sensitivity clays.
- Safety policies and regulations are co-ordinated with respect to ground stabilisation and local safety measures in areas with quick clay or other high-sensitivity clays.
- Further development of an empirical and numerical model for the calculation of the retrogression and run-out distance of landslides.
- Further development of stabilising quick clay with salt if traditional work methods may cause reduced stability during the construction phase and in areas where topographical modification is impossible or undesirable.

WP 7 – Avalanche, Landslide and Flood Protection

Every year vast sums of money are spent on flood defences and landslide/avalanche protection of roads, railways and watercourses. New structures and initiatives must be optimally based on the knowledge available. It has been necessary to review all descriptions found in regulations, manuals, guidelines and checklists to see if they still are adequate.

To ensure a sound basis for carrying out the task, we needed to review safety measures that have already been implemented, in order to see how the planning and building processes were conducted and why the structures worked as planned, or not, as the case may be. Based on the acceptable level of risk defined by the

agencies, there is a need to standardise their acceptance criteria for landslide and flood events.

Our main objectives have been to look at slide processes and protective measures (why things go wrong), guidelines/handbooks/checklists (how to prevent things from going wrong) and flood, avalanche and landslide acceptance (when it is okay that things go wrong).

Our experiences gained during inspection of protective measures carried out against natural hazards are typically: Inadequate erosion control of waterways and embankments, under-dimensioned hydraulic capacity for bridges spanning high discharge watercourses, short planning process → lack of feasibility studies, lack of a plan for operation and maintenance, and lastly lack of co-ordination between authorities.

Studies of models for avalanches and debris flows have aimed to find the model(s) most applicable to Norwegian conditions for making the correct choice of location for road or railway line, and correctly dimensioned protective measures.

The field manual is made for professionals from our agencies and advisors, who follow up flood and landslide events in the field when imminent danger from actual events threatens. The manual gives instructions for general tasks such as communication and responsibility, as well as professional tasks like equipment deployment, collecting data, risk evaluation and protective measures.

WP 7 observes the need for this to compensate for the lack of co-ordination between the agencies i.e., to provide support in decision making in emergency situations, to collect and share expertise from experienced professionals, collaboration – co-ordinated scientific assessments, particularly at inter-departmental level and in major events, and to share useful experiences gained from exercises with other agencies abroad.

One of our goals has been to take advantage of the use of new technology. The NIFS project team took an interest in the use of UAVs (Unmanned Aerial Vehicles) in the context of natural hazards. Our state of the art report on UAVs – Report 87/2014 "Mapping the status and potential for drone-based technology" – led us to arrange an open conference in Trondheim 13th January 2015 to meet stakeholders, e.g. entrepreneurs, government authorities and researchers.

When the quick clay slide occurred at Skjeggestad Bridge on 2nd February 2015, there was an obvious need to see and map the extent of the landslide and the condition of both bridges. This was done using a drone. Through this work package, the involved agencies have gained actual knowledge of what may be applicable technology and equipment available in a short time, both nationally and in this case locally. Our experience is that this technology could be very useful in relation to both crisis management and decision-making in connection with avalanches and other natural hazards. Key words in this respect will be that technology helps us to work: faster, better, safer and cheaper.

Outreach

The NIFS programme communicates its work transparently through different channels in all three agencies. We use our common web page www.naturfare.no as the main channel to reach the public with full transparency and free of charge.

Our results – so far – have been published in more than 100 different reports, and a further 20 will be delivered within the project period. Most of these reports are in Norwegian. 2 PhD studies are ongoing, and more than 30 MSc studies will be carried out in collaboration with different NIFS project teams. Our summary report is in progress, and it will specify what has been done and present our recommendations (Annex A).

We will conduct our final conference on 12th April 2016 in Oslo. NIFS results will be presented and discussed with representatives of academia, research institutes and local/national authorities.

Acknowledgements

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NVE (2010) "Strategy for climate adaptation" as a basis for further work within the sector.

NPRA (2013) "Climate and Transport 2007-2011", NPRA Report No. 210. www.vegvesen.no.

Annex A List of NIFS reports

(All reports can be found on www.naturfare.no)

No.	Title	Editor/Author	ISBN/ ISSN	Status or Reference
2012 -33	Naturfareprosjektet (DP 6) Kvikkleire. En nasjonal satsing på sikkerhet i kvikkleire-områder	Editor: Vikas Thakur (SVV); Lecturers: Frode Oset, Arnfinn Emdal, Claes Alén, Maj Gøril G. Bæverfjord, Einar Lyche, Hans Petter Jostad, Inger-Lise Solberg, Vikas Thakur, Tonje E Helle	978-82-410-0821-4 1501-2832	NVE: Oct. 2012
2012 -34	Naturfareprosjektet (DP 6) Kvikkleire. Datarapport for kvikk-leireskred ved Esp i Byneset i januar 2012	Author: Vikas Thakur (SVV)	978-82-410-0822-1	NVE: Oct. 2012
2012 -35	Naturfareprosjektet (DP 4) Overvåking og varsling. Erfaringer fra studietur til Ministry of Transportation (British Columbia) og Canadian Avalanche Centre	Author: Tore Humstad, Eivind S. Juvik and Gunne Håland (SVV)		NVE: Oct. 2012
2012 -40	Programplan 2012-2015 for etatsprogrammet "Naturfare – infrastruktur, flom og skred (NIFS)"	Editors: Bjørn Kristoffer Dolva and Marie Haakensen; Authors: Ragnhild Wahl *et al*.	978-82-410-0828-3 1501-2832	NVE: Nov. 2012
2012 -46	Naturfareprosjektet (DP 6) Kvikkleire. Detektering av kvikkleire fra ulike sonderings-metoder	Authors: Rolf Sandven, Arne Vik & Sigbjørn Rønning (Multiconsult), and Erik Tørum, Stein Christensen & Anders Gylland (SINTEF)	978-82-410-0834-4	Multi-consult: 4155592012 :11:20 NVE: Nov. 2012
2012 -73	Naturfareprosjektet (DP 6) Kvikkleire. Probabilistisk analyse av grunnundersøkelser i sensitive leirområder	Authors: Maj Gøril Bæverfjord & Erik Tørum (SINTEF), and Rolf Sandven & Arne Vik (Multiconsult)	978-82-410-0861-0	SINTEF: SBF2012 A0310, 2012:11:30
2012 -74	Naturfareprosjektet (DP 6) Kvikkleire. Prosentvis forbedring av materialfaktor i sprø-bruddmaterialer	Authors: Vikas Thakur & Frode Oset (SVV), Erik Tørum (SINTEF) and Håvard Narjord (Multiconsult)	978-82-410-0862-7	SINTEF: Notat 3C0970-2 rev. 2 av 2012:11:30

No.	Title	Editor/Author	ISBN/ ISSN	Status or Reference
2012 -75	Naturfareprosjektet (DP 6) Kvikkleire. Bruk av anisotropiforhold i stabilitetsberegninger i sprøbruddmaterialer	Authors: Odd Arne Fauskerud, Corneliu Athanasiu & Cristian Rekdal Havnegjerde (Multiconsult), and Erik Tørum, Stein Olav Christensen & Anders Gylland (SINTEF)	978-82-410-0863-4	Multi-consult: 415559-RIG-RAP-002 av 2012:11:30
2012 -78	Naturfareprosjektet (DP 5) Flom og vann på avveie. Ekstrem kort-tidsnedbør på Østlandet fra pluviometer og radar data	Authors: Karianne Ødemark, Eirik Førland, Jostein Mamen, Christoffer A. Elo, Anita V. Dyrrdal (MET) and Steinar Myrabø (JBV)	978-82-410-0866-5	MET: Rapport 14/2012, 2012:12:17 NVE: Jan. 2013
2012 -80	Naturfareprosjektet (DP 6) Kvikkleire. Likestilling mellom bruk av absolutt material-faktor og prosentvis forbedring	Authors: Erik Tørum & Stein Christensen (SINTEF) and Håvard Narjord & Roar Skulbørstad (Multiconsult)	978-82-410-0860-3	SINTEF: SBF 2012A0309, 2012:11:30
2013 -01	Naturfareprosjektet (DP 1) Naturskade-strategi. Roller i det nasjonale arbeidet med håndtering av naturfarer	Authors: Erlend Falch, Jonas Vevatne, Bård Vestøl Birkedal (Rambøll)		Rambøll: Jan. 2013
2013 -21	Naturfareprosjektet (DP 6) Kvikkleire. Utstrekning og utløps-distanse for kvikkleire-skred basert på katalog over skredhendelser i Norge.	Authors: Jean-Sebastien L'Heureux and Inger-Lise Solberg (NGU)	978-82-410-0889-4	NVE/NGU: Rapport 2012.040, 2012:11:21
2013 -22	Naturfareprosjektet (DP 6) Kvikkleire. Forebyggende kart-legging mot skred langs strandsonen i Norge. Oppsummering av erfar-inger og anbefalinger	Authors: Louise Hansen, Jean-Sebastien L'Heureux, Inger-Lise Solberg and Oddvar Longva (NGU)	978-82-410-0890-0	NVE/NGU: Rapport 2012.046, 2012:11:28
2013 -23	Naturfareprosjektet (DP 6) Kvikkleire. Nasjonal database for grunnundersøkelser (NADAG) – forunder-søkelse	Authors: Inger-Lise Solberg, Per Ryghaug, Bo Nordahl, Hans de Beer, Louise Hansen and Jan Høst (NGU). Comments: NVE, SVV, JBV, NGI & Oslo County	978-82-410-0891-7	NVE/NGU: Rapport 2012.054, 2012:12:11

No.	Title	Editor/Author	ISBN/ ISSN	Status or Reference
2013 -26	Naturfareprosjektet (DP 6) Kvikkleire. Vurdering av kart-leggingsgrunnlaget for kvikkleire i strandsonen	Author: Jean-Sebastien L'Heureux (NGI)		NGI: 20120754-01-R, Dec. 2012
2013 -31	Naturfareprosjektet (DP 6) Kvikkleire Overvåking ved akutte skredhendelser	Authors: Lene Kristensen, Thierry Oppikofer, Tore Bergeng (Åknes/Tafjord Beredskap IKT og NGU)	978-82-410-0899-3	Åknes rapport 02 2013
2013 -33	Naturfareprosjektet (DP 6) Kvikkleire. Saltdiffusjon som grunn-forsterking i kvikkleire	Author: Tonje Eide Helle (SVV)	978-82-410-0901-3	NVE
2013 -37	Naturfareprosjektet (DP 6) Kvikkleire. Skånsomme installa-sjonsmetoder for kalk-sementpeler og bruk av slurry	Author. Astri Eggen (NGI)	978-82-410-0906-8	NGI: 20120746-1-R, Dec. 2012
2013 -38	Naturfareprosjektet (DP 6) Kvikkleire. Q-Bing – Utløpsmodell for kvikkleireskred: Karakterisering av historiske kvikkleire-skred og inputparametere for Q BING	Authors: Jean-Sebastien L'Heureux (NGI) (Norwegian version of Report 2013-39)	978-82-410-0907-5	NGI: 20120753-02-R, Nov. 2012
2013 -39	Naturfareprosjektet (DP 6) Kvikkleire. Q Bing – Utløpsmodell for kvikkleireskred: Characterization of historical quick clay landslides and input parameters for Q-Bing	Author: Jean-Sebastien L'Heureux (NGI) (English version of Report 2013-38)	978-82-410-0908-2	NGI: 20120753-02-R, Nov. 2012
2013 -40	Naturfareprosjektet (DP 6) Kvikkleire. Skred ved Døla i Vefsn. Undersøkelse av materialegenskaper	Author: Ragnar Moholdt (NGI)	978-82-410-0909-9	NGI: 20120853-01-TN, Nov. 2012
2013 -41	Naturfareprosjektet (DP 6) Kvikkleire. State of the art: Blokkprøver	Authors: Kjell Karlsrud, Vidar Gjelsvik, Reidar Otter (NGI)	978-82-410-0910-5	NGI: 20120866-01-R, Dec. 2012

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2013 -42	Naturfareprosjektet (DP 6) Kvikkleire. Innspill til "Nasjonal grunnboringsdatabase (NGD)" – forunder-søkelse	Author: Eivind Magnus Paulsen (NGI)	978-82-410-0911-2	NGI: 20120867-01-TN
2013 -43	Naturfareprosjektet (DP 6) Kvikkleire. Styrkeøkning av rekon-solidert kvikkleire etter skred	Author: Ragnar Moholdt (NGI)	978-82-410-0912-9	NGI: 20120853-01-TN, Jan. 2013
2013 -46	Naturfareprosjektet (DP 6) Kvikkleire. NIFS-N1 Q-Bing – Ut-løpsmodell for kvikk-leireskred: Back-analyses of run-out for Norwegian quick-clay landslides	Authors: Dieter Issler, José Mauricio Cepeda, Byron Quan Luna (NGI) and Vittoria Venditti (ICG/ Università di Bologna)	978-82-410-0917-4	NGI: 20120753-01-R, Nov. 2012
2013 -55	Naturfareprosjektet (DP 6) Kvikkleire. Workshop om bruk av anisotropi ved stabilitets-vurdering i sprøbrudd-materialer	Summary by Frode Oset (SVV). Lectures in annex to report.	978-82-410-0925-9	NVE: 05 07 2013
2013 -57	Programme plan 2012-2015 for the Government Agency Programme "NATURAL HAZARDS – infrastructure for floods and slides (NIFS)"	Editors: Bjørn Kristoffer Dolva and Marie Haakensen (SVV). Authors: Ragnhild Wahl, Brigt Samdal, Roald Aabøe, Solveig Kosberg and Art Verhage	978-82-410-0931-0	NVE: 09 2013
2013 -60	Naturfareprosjektet (DP 5) Flom og vann på avveie. Flood estimation in small catchments	Editor: Anne K. Fleig (NVE) Authors: Anne K. Fleig, Donna Wilson (NVE)	978-82-410-0929-7 1501-2832	NVE: 10 2013
2013 -65	Naturfareprosjektet (DP 4) Overvåking og varsling. Snøskred-varslingen. Evaluering av vinteren 2013	Editor: Solveig Kosberg (NVE) Authors: Karsten Muller, Solveig Kosberg, Emma Barfod, Birgit Katrine Rustad, Markus Landrø	978-82-410-0933-4	NVE: 08 2013

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2013 -66	Naturfareprosjektet (DP 5) Flom og vann på avveie. Vannførings-stasjoner i Norge med felt mindre en 50 km^2	Author: Seija Stenius (NVE)	978-82-410-0937-2 1501-2832	NVE: 09 2013
2014 -03	Naturfareprosjektet (DP 5) Flom og vann på avveie. Dimensjonerende korttidsnedbør for Telemark, Sørlandet og Vestlandet	Authors: Eirik Førland, Jostein Mamen, Karianne Ødemark, Hanne Heiberg(MET) and Steinar Myrabø (JBV)	978-82-410-0950-1	MET: Report 28/2013
2014 -04	Naturfareprosjektet (DP 7) Skred og flom-sikring. Sikringstiltak mot skred og flom. Befaring i Troms og Finnmark h 2013	Editor: Knut A. Hoseth (NVE) Authors: Knut Aune Hoseth (NVE), Lene Lundgren Kristensen and Gunne Håland (SVV).	978-82-410-0953-2	NVE: 27 01 2014
2014 -13	Naturfareprosjektet (DP 5) Flom og vann på avveie. Karakterisering av flomregimer. Delprosjekt. 5.1.5	Authors: Seija Stenius, Per Alve Glad, Donna Wilson (NVE)	978-82-410-0961-7	NVE: 01 2014
2014 -14	Naturfareprosjektet (DP 6) Kvikkleire. En omforent anbefaling for bruk av anisotropi-faktorer i prosjektering i norske leirer	Editor: Vikas Thakur (SVV) with work group Frode Oset (SVV), Margareta Viklund (JBV), Stein-Are Strand (NVE), Vidar Gjelsvik (NGI), Stein Christensen (SINTEF) and Odd Arne Fauskerud (Multiconsult)	978-82-410-0962-4	NVE: 01 2014
2014 -22	Naturfareprosjektet (DP 3.1.) Hvordan beregne ekstremverdier for gitte gjentaksinter-valler? Manual for å beregne returverdier av nedbør for ulike gjen-taksintervaller (for ikke-statistikker)	Authors: Galina Ragulina, Andrea Taurisano (NVE)	978-82-410-0970-9 1501-2832	NVE: 03 2014

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2014 -26	Naturfareprosjektet (DP 1) Naturskade-strategi. Sammenligning av risikoakseptkriterier for skred og flom. Utredning for Naturfare-programmet (NIFS)	Author: Unni M. K. Eidsvig (NGI)	978-82-410-0962-4	NGI: 20120800-01-R, March 2014 / Rev. 1 NVE: 05 2014
2014 -27	Naturfareprosjektet (DP 6) Kvikkleire. Skredfarekartlegging i strandsonen – videre-føring	Author: Jean-Sebastien L'Heureux (NGI)	978-82-410-0974-7	NGI: 20130701-01-R, Dec. 2013 NVE: 05 2014
2014 -28	Naturfareprosjektet (DP 5) Flom og vann på avveie. "Kvistdammer" i Slovakia. Små terskler laget av stedegent materiale; erfaringer fra studietur for mulig bruk i Norge	Editor: Bent C. Braskerud (NVE) Authors: Knut A. Hoseth, Tone Israelsen, Torgeir Kval, Steinar Myrabø, Sven-Håkon Nordlien and Joar Skauge (NIFS partners)	978-82-410-0975-41501-2832	NVE: 05 2014
2014 -34	Naturfareprosjektet (DP 6) Kvikkleire. Skredfarekartlegging i strandsona – ei opp-summering	Authors: Odd Are Jensen and Trude Nyheim (NVE)	978-82-410-0974-6	NVE
2014 -35	Naturfareprosjektet (DP 5) Flom og vann på avveie. Karakterisering av flomregimer. Revi-sjon av rapport 13-2014	Authors: Seija Stenius, Per Alve Glad, Donna Wilson (NVE)	978-82-410-0937-2 1501-2832	NVE: 03 2015
2014 -37	Naturfareprosjektet (DP 4) Overvåking og varsling. Preliminary regionalization and susceptibility analysis for landslid early warning purpuses in Norway	Authors: Graziella Devoli, Mads-Petter Dahl (NVE)	978-82-410-0985-3	NVE: 05 2014

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2014 -39	Naturfareprosjektet (DP 6) Kvikkleire. Effekt av progressiv bruddut-vikling for utbygging i områder med kvikkleire: Sensitivitetsanalyse basert på data fra grunn-undersøkelser på veg-strekningen Sund-Bradden i Rissa	Authors: Petter Fornes, Hans Petter Jostad (NGI)	978-82-410-0988-4	NGI: 20092128-00-6-R, May 2014
2014 -40	Naturfareprosjektet (DP 6) Kvikkleire. Effekt av progressiv bruddut-vikling for utbygging i områder med kvikkleire: Sensitivitetsanalyse-1	Authors: Petter Fornes/ Hans Petter Jostad (NGI)	978-82-410-0989-1	NGI: 20092128-00-6-R, May 2014
2014 -42	Naturfareprosjektet (DP 5) Håndtering av flom og vann på avveie. Dimensjonerende kort-tidsnedbør for Møre & Romsdal, Trøndelag og Nord-Norge.	Authors: Erik Førland, Jostein Mamen, Karianne Ødemark, Hanne Hieberg (MTE) and Steinar Myrabø (JBV)	978-82-410-0991-4	MET: March 2014 NVE: Apr. 2014
2014 -43	Naturfareprosjektet (DP 4) Overvåking og varsling. Terskelstudier for utløsning av jord-skred i Norge. Opp-summering av hydro-logiske terskelstudier ved NVE i perioden 2009 til 2013	Authors: Søren Boje, Herve Colleuille, Graziella Devoli (NVE)	978-82-410-0992-1 1501-2832	NVE: 05 2014
2014 -44	Naturfareprosjektet (DP 4) Overvåking og varsling. Regional varsling av jordskred-fare: Analyse av historiske jordskred, flomskred og sørpeskred i Gudbrandsdalen og Ottadalen	Authors: Nils Arne K. Walberg, Graziella Devoli (NVE)	978-82-410-0993-81501-2832	NVE: 05 2014
2014 -46	Naturfareprosjektet (DP 6) Kvikkleire. Mulighetsstudie om utvikling av en nasjonal blokkprøvedatabase	Author: Eivind Magnus Paulsen (NGI)	978-82-410-0995-2	NGI: 20130760-01-R, Dec. 2013

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2014 -47	Naturfareprosjektet (DP 6) Kvikkleire. Detektering av sprø-bruddmateriale ved hjelp av R-CPTU	Authors: Alberto Montafia, Rolf Sandven (Multiconsult)	978-82-410-0996-9	Multi-consult: 415559-RIG-RAP-002, Dec. 2013
2014 -54	Naturfareprosjektet (DP 1) Naturskade-strategi. Samarbeid og koordinering vedrørende naturfare. Ministudie av fellesprosjektet E6 – Dovrebanen og Follobanen	Authors: Erlend Falch, Marianne Holmesland og Jørgen Biørn (Rambøll).	978-82-410-1006-4	Rambøll: June 2014
2014 -55	Naturfareprosjektet (DP 6) Kvikkleire. Effekt av progressiv bruddut-vikling for utbygging i områder med kvikkleire: A1 Numerisk metode for beregning av udrenert brudd i sensitive materialer	Authors: Hans Petter Jostad and Gustav Grimstad (NGI)	978-82-410-1107-1	NGI: 20092128-00-4-R, May 2014
2014 -56	Naturfareprosjektet (DP 6) Kvikkleire. Effekt av progressiv bruddut-vikling for utbygging i områder med kvikkleire: A2 Tilbakeregning av Vestfossenskredet	Authors: Hans Petter Jostad and Gustav Grimstad (NGI)	978-82-410-1008-8	NGI: 20092128-00-5-R, June 2013
2014 -57	Naturfareprosjektet (DP 6) Kvikkleire. Sikkerhet ifm utbygging i kvikkleireområder. Effekt av progressiv-brudd i raviner	Authors: Petter Fornes and Hans Petter Jostad (NGI)	978-82-410-1009-5	NGI: 20130275-01-R, May 2014
2014 -58	Naturfareprosjektet (DP 6) Kvikkleire. Sikkerhet ifm utbygging i kvikkleireområder. Sannsynlighet for brudd med prosentvis for-bedring	Authors: Petter Fornes and Hans Petter Jostad (NGI)	978-82-410-1010-1	NGI: 20130275-02-R, May 2014

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2014 -59	Naturfareprosjektet (DP 6) Kvikkleire. Likestilling mellom bruk av absolutt materialfaktor og av prosentvis forbedring – bruk av spenningsendring for å definere lokalskred og områdeskred	Authors: Stein Olav Christensen, Anders Samstad Gylland (SINTEF)	978-82-410-1011-8	SINTEF SBF 2013A0274, Oct. 2013
2014 -62	Naturfareprosjektet (DP 5.1.6) Flom og vann på avveie. Regionalt formelverk for indeksflom og frekvenskurver	Authors: Per Alve Glad, Trond Reitan og Seija Stenius (NVE)	978-82-410-1014-9	NVE: June 2014
2014 -63	Naturfareprosjektet (DP 3.2) Datasamordning En studie av samordning og deling av flom- og skreddata for tre samarbeidende etater	Authors: Knut Fossestøl og Eric Breit (AFI - Arbeidsforsknings-instituttet)	978-82-410-1015-6	AFI: (r2014:6), May 2014
2014 -64	Naturfareprosjektet (DP 2) Beredskap og krisehåndtering. Delrapport 1 – Beredskapsplaner og krisehåndtering	Authors: Bjørn Stuedal (eget firma) Kari Øvrelid (NVE), Trond Sandum (JBV), Hein Gabrielsen (SVV)	978-82-410-1016-3	NVE: May 2014
2014 -67	Naturfareprosjektet (DP 6) Kvikkleire. Effekt av lagringstid på prøvekvalitet	Authors: Jean-Sebastien L'Heureux, Yunhee Kim, Tone Solem (NGI)	978-82-410-1019-4	NGI: 20130672-01-R, May 2013 NVE_ Oct. 2014
2014 -68	Naturfareprosjektet (DP 6) Kvikkleire. Effect of storage time on sample quality	Authors: Jean-Sebastien L'Heureux, Yunhee Kim, Tone Solem (NGI)	978-82-410-1020-0	NGI: 20130672-01-R, Dec. 2013 NVE_ Oct. 2014
2014 -70	Naturfareprosjektet: Status høsten 2014 Resultater og veien videre	Authors: Project and work package managers)	978-82-410-1020-0	NVE: Oct. 2014

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2014 -76	Naturfareprosjektet (DP 2) Beredskap og krisehåndtering. Del-rapport 2 – Beredskaps-planer og krisehåndtering Krisestøtteverktøyet CIM – Anbefalinger	Authors: Bjørn Stuedal (own company), Kari Øvrelid (NVE), Trond Sandum (JBV), Hein Gabrielsen (SVV)	978-82-410-1027-9	NVE: 2014
2014 -77	Naturfareprosjektet (DP 6) Kvikkleire. Valg av karakteristiske Cua-profil basert på felt- og laboratorieundersøkelser (under revisjon!!!)	Authors: Frode Oset (SVV), Margareta Viklund (JBV), Odd Arne Fauskerud, (Multiconsult), Stein Christensen (SINTEF), Steinar Nordal (NTNU), Stein-Are Strand (NVE), Vidar Gjelsvik (NGI), Vikas Thakur (SVV)	978-82-410-1028-6	NVE: May 2015
2014 -79	Naturfareprosjektet (DP 4) Overvåking og varsling. Snøskred-varslingen. Evaluering av vinteren 2014	Author: Emma Barfod (NVE)	978-82-410-1030-5	NVE: Nov. 2014
2014 -80	Naturfareprosjektet (DP 4) Overvåking og varsling. Norwegian Avalanche Warning Service. Program review	Authors: Grant Statham, Emma Barfod (NVE)	978-82-410-1031-6	NVE: March 2015
2014 -87	Naturfareprosjektet: Kartlegging av status og potensiale for drone-basert teknologi. Anvendelser innen naturfare og infrastruktur	Author: Esten Ingar Grøtli, Aksel A Transeth, Anders Gylland, Petter Risholm, Ida Soon Brøther Bergh (SINTEF IKT)	978-82-410-1036-1	SINTEF IKT: A26527, Nov. 2014 NVE: 2014
2014 -88	Naturfareprosjektet (DP 6) Kvikkleire. NGIs anbefalinger for krav til effekt av sprøbrudd-oppførsel	Author: Petter Fornes (NGI)	978-82-410-1037-8	NGI: 20140075-01-R, Nov. 2014 NVE: Dec. 2014
2014 -90	Naturfareprosjektet (DP 3) Kartlegging Analyse av historiske jordskred, flomskred og sørpeskred i Troms	Author: Graziela Devoli (NVE)	978-82-410-1039-2	NVE: March 2015

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2014 -92	Naturfareprosjektet (DP 6) Kvikkleire Pre-study: Ground improvement for marginally stable slopes	Author: Minna Karstunen, (Chalmers University of Technology)	978-82-410-1041-5	Chalmers: Nov. 2014 SVV: 2014
2014 -93	Naturfareprosjektet (DP 6) Kvikkleire. Skredet ved Nord - Statland. Utredning av teknisk årsakssammen-heng (NVE-rapport som nyhetssak for oss)	Authors: Stein-Are Strand and Einar Lyche (NVE) Co-authors: Ragnar Moholdt (NGI), Steinar Nordal (NTNU), Vikas Thakur & Frode Oset (SVV), Margareta Viklund (JBV)	978-82-410-1042-2	NVE: Dec. 2014
2015 -01	Naturfareprosjektet (DP 3.1.) Sammen-fatningsrapport. Gjennomgang av skred-fareutredninger ut-arbeidet av konsulenter i perioden 2011-2014	Authors: Galina Ragulina, Andrea Taurisano (NVE)	978-82-410-1045-31501-2832	NVE: Jan. 2015
2015 -13	Naturfareprosjektet (DP 5.1.6) Flom og vann på avveie. Nasjonalt formelverk formelverk for flomberegning i små nedbørfelt. Rev av rapport 62-2014	Authors: Per Alve Glad, Trond Reitan and Seija Stenius (NVE)	97882410 10606 15012832	NVE: Feb. 2015
2015 -00	Naturfareprosjektet (DP 7) Skred og flom-sikring. Felthåndbok ved flom og skred	Vivian Caragounis, Knut Aune Hoseth & Helge Leif Nordvik (NVE), Heidi Bjordal & Lene Lundgren Kristensen (SVV), and Margareta Viklund (JBV). In cooperation with, technical experts from partners and Police	978-82-7704-145-2	Published March 2015.
2015 -61	Naturfareprosjektet (DP 7) Skred og flom-sikring. Studietur Sveits	Authors: Gunne Håland and Audun Langelid	978-82-410-1108-5	NVE: June 2015
2015 -62	Naturfareprosjektet (DP 3.3) ROS-analyser i Arealplanlegging. Anbe-falinger til samhandling mellom transportetatene	Authors: Lars Berggren (JBV), Peer Sommer Erichson (NVE) & Jan Otto Larsen (SVV/UNIS)	978-82-410-1109-2 1501-2832	NVE: June 2015

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2015 -65	Naturfareprosjektet (DP 3) Kartlegging. Kvalitetskontroll, analyse og forslag til oppdatering av historiske kvikkleireskred og andre leirskred registrert i Nasjonal skredhendelses-database (NSDB)	Editor: Inger-Lise Solberg (NGU) Authors: Ewa Solkalska (SVV), Graziella Devoli (NVE), Inger-Lise Solberg & Louise Hansen (NGU), Vikas Thakur (NTNU)	978-82-410-1112-2	NVE: July 2015
2015 -66	Naturfareprosjektet (DP 4) Overvåking og varsling. Snøskred-varsling med nærnabo-metoden. Test av den Canadiske nærnabo-modellen på skreddata fra Senja	Editor: Eivind Juvik (SVV) Authors: Eivind Juvik, Katharina Kahrs and Tore Humstad (SVV).	1501-28322 978-82-410-1113-9	NVE: Aug. 2015
2015 -73	Naturfareprosjektet (DP 3) Kartlegging. Snøskred i bjørkeskog – Testforsøk i Abisko	Editor: Hedda Breien (NGI) Authors: Øyvind A. Høydal og Hedda Breien (NGI)	978-82-410-1114-6	NGI 20130918-01-R, Dec. 2014 NVE: Aug. 2015
2015 -78	Naturfareprosjektet (DP 4) Overvåking og varsling. Snøskred-varslingen. Evaluering av vinteren 2015	Editor: Emma Barfod (NVE) Authors: Karsten Müller, Solveig Kosberg, Emma Barfod, Birgit Katrine Rustad, Markus Landrø, Ragnar Ekker, Andreas Haslestad, Rune Engeset and Erik Johnsen	978-82-410-1125-2	NVE: Sept. 2015
2015 -79	Naturfareprosjektet (DP 6) Kvikkleire. Utvidet tolknings-grunnlag for vingebor. Resultater fra forprosjekt ved NTNU	Aithor: Anders Samstad Gylland (NTNU)	1501-2832	NTNU: 11.12.2014 NVE: Sept. 2015
2015 -81	Naturfareprosjektet (DP 6) Kvikkleire. Tolkning av aktiv udrenert skjærfasthet fra vingebor	Author: Anders Samstad Gylland (NTNU)	978-82-410-1132-0	NTNU:2015 NVE: Sept. 2015

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2015 -86	Naturfareprosjektet (DP 5) Vann på ville veier. Sammenligning av metoder for flomberegn-inger i små uregulerte felt	Editor: Seija Stenius Authors: Seija Stenius, Per Alve Glad, Trond Reitan, Thea Caroline Wang, Anne Kristina Tvedalen, Petter Reinemo, Sølvi Amland	978-82-410-1137-5	NVE: Sept. 2015
2015 -04X	Føre-var, etter-snar eller på-stedet-hvil? Hvordan vurdere kostnader ved forebygging opp mot gjenoppbygging av fysisk infrastruktur ved naturskade og klima-endringer?	Authors: Carlo Aall, Marta Baltruszewicz & Kyrre Groven (Vestlands-forsking), Anders-Johan Almås (SINTEF) & Frode Vagstad (Vagstad Prosjektservice)	978-82-428-0355-9	Vestlands-forskning: KS FoU 08 2015, June 2015
2015 -90	Naturfareprosjektet (DP 1) Naturskade-strategi. Terminologi for naturfare	Editor: Lene Lundgren Kristensen (SVV) Authors: Lene Lundgren Kristensen, Jan Otto Larsen(SVV), Aart Verhage, Odd Are Jensen, Graziella Devoli, Birgit Katrine Rustad (NVE) and Margareta Viklund (JBV)	978-82-410-1141-2	NVE: Oct. 2015
2015 -91	Naturfareprosjektet (DP 7) Skred og flom-sikring. Registrering av flom- og skredsikrings-tiltak i NVE, SVV og JBV	Editor: Heidi Bjordal (SVV) Authors: Marianne Myhre Odberg, Kristin Skei, Silje Skarsten, Lene Lunddgren Kristensen, Heidi Bjordal (SVV) *et al*	978-82-410-1142-9	NVE: Oct. 2015
2015 -93	Naturfareprosjektet (DP 5) Vann på ville veier. Samfunns-økonomisk kostnader av Gudbrandsdalsflommen 2013	Author: Christoph Siedler (JBV)	978-82-410-1145-0	NVE: Oct. 2015
2015 -97	Naturfareprosjektet (DP 5) Vann på ville veier Anbefalt metode for flomberegning i små uregulerte felt	Authors: Seija Stenius & Per Alve Glad (NVE)	978-82-410-1149-8	NVE. Nov. 2015

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2015 -98	Naturfareprosjektet (DP 7) Skred og flomsikring. Erfaringer med felthåndboka for flom og skred	Authors: Margareta Viklund (JBV), Knut Aune Hoseth (NVE), Heidi Bjordal (SVV), Lene Lundgren Kristensen	978-82-410-1150-4	NVE: Nov. 2015
2015 -100	Naturfareprosjektet: Veslemannen høsten 2014 – Overvåking og beredskap	Authors: Lars Harald Blikra and Kari Øvrelid (NVE)	978-82-410-1152-8	NVE: Nov. 2015
2015 -101	Naturfareprosjektet (DP 6) Kvikkleire. Detektering av kvikkleire vha R-CPTU og elektrisk vingebor. Resultater fra feltstudie	Editor: Hanne B. Ottesen (SVV) and Ingrid Havnen (NVE) Authors: Rolf Sandven, Alberto Montafia (Multiconsult)	978-82-410-1153-5	NVE: Nov. 2015
2015 -104	Naturfareprosjektet (DP 6) Kvikkleire. Workshop om sikker-hetsfilosofi	Editor: Margareta Viklund (JBV) Authors: Frode Oset (SVV), Hanne B. Ottesen (SVV), Kristian Aunaas (SVV), Einar Lyche (NVE), Stein-Are Strand (NVE), Trude Nyheim (NVE), Margareta Viklund (JBV)	978-82-410-1156-6	NVE: Nov. 2015
2015 -105	Naturfareprosjektet (DP 2): Beredskap og krisehåndtering. Infor-masjonsutveksling under øvelser og hendelser	Authors: Bjørn Stuedal (own company), Kari Øvrelid (NVE), Trond Sandum (JBV), Hein Gabrielsen & Camilla Røhmne (SVV), Olianne Eikenæs (NVE) og Roger Steen	978-82-410-1157-3	NVE. Dec. 2015
2015 -106	Naturfareprosjektet. Kommunikasjonsplan for FoU-programmet Natur-fare, infrastruktur, flom og skred 2012-2016	Editor: Marie Haakensen Authors: Project management and Kjell Solem (SVV), Dag Svinsås (JBV), Erik Due (NVE)	978-82-410-1158-0	NVE. Dec. 2015
2015 -107	Naturfareprosjektet (DP 7) Skred og flom-sikring. Sammenligning av modelleringsverktøy for norske snøskred	Editor: Gunne Håland (SVV) Authors: Gunne Håland, Knut Inge Orset, Harald Norem og Martine H. Frekhaug (SVV)	978-82-410-1159-7	NVE: Dec. 2015

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2015 -114	Naturfareprosjektet (DP 4) Overvåking og varsling. Deformasjons-analyse av bratt fjellside ved bruk av dronebasert fotogrammetri	Authors: Leif Erik Blankeenberg (TerraTec as) *et al.*	978-82-410-1166-5	NVE: Dec. 2015
2015 -115	Naturfareprosjektet (DP 7) Sikringstiltak mot skred og flom. Befaring i Hordaland og Sogn og Fjordane mai 2014	Authors: Knut Aune Hoseth (NVE), Lene L. Kristensen, Gunne Håland (SVV), Margareta Viklund (JBV), Heidi Bjordal (SVV)	978-82-410-1167-2	NVE: Dec. 2015
2015 -120	Naturfareprosjektet (DP 1) Naturskade-strategi – På alerten mot naturfare	Editor: Sverre Kjetil Rød (NVE) Authors: Sverre Kjetil Rød, Gordana Petkovic (SVV), Knut Sørgaard, Odd Are Jensen, Aart Verhage, Hallvard Berg (NVE) and Per Lars Erik Viréhn	978-82-410-1172-6	NVE: Dec. 2015
2015 -122	Naturfareprosjektet (DP 3) Kartlegging. Satellittbasert radar-interferometri (InSAR) for naturfare, skred og infrastruktur	Authors: Line Rouyet, Tom Rune Lauknes, Kjell-Arild Høgda	978-82-410-1174-0	NVE: Dec. 2015
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2015 -124	Naturfareprosjektet: Delprosjekt 5.3 Flom- og skredhendelsen Frida på Sørlandet 2012	Editor: Maria H. Olsen (NVE) Authors: Maria H. Olsen, Agathe A. Hopland, Steinar Myrabø, Per Viréhn, Per A. Glad (NVE), O.E. Almenningen and E. Traae (NVE)	978-82-410-1176-4	NVE: Dec. 2015

No.	Title	Editor/Author	ISBN/ ISSN	Status or Reference
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Large Rockslides in Norway: Risk and Monitoring

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Introduction

Landslides are a challenge in many areas of Norway. Most of them can be dealt with by having good detailed knowledge of hazard areas and, if needed, implementing physical mitigation. Large landslides, however, are more difficult to handle due to their long run-out distance and their extensive secondary effects. They can generate disastrous tsunamis or create large landslide dams with possible dam collapse in areas where drainage systems and lakes are regulated for hydroelectric power plant purposes and water supply. The run-out of debris flows can travel particularly long distances along valley floors. The rockslide events in Loen in 1905 and 1936, and in Tafjord in 1936, were some of the most serious natural disasters in Norwegian history (Bjerrum & Jørstad, 1968), where rockslide-induced tsunamis killed a total of 174 people (Figure 1).

The main strategy for coping with large rockslides in Norway has been to implement high-quality monitoring systems for unstable areas that can generate such events (Blikra, 2008; 2012). A national mapping project is ongoing in order to perform hazard and risk classification of such areas. This classification is the basis for deciding which areas need real-time monitoring and operational early-warning systems.

This paper gives an overview of rockslide monitoring in Norway. It also highlights critical geological knowledge needed in order to implement reliable early-warning systems. Examples of monitoring technology and displacement data are given. The handling of critical events is highly dependent on close interaction between the geological team in charge of monitoring and the responsible authorities (Municipality, County Governor, Police). A recent case from the rock face Mannen in Romsdalen in 2014 exemplifies the use of monitoring data in early warning, and the importance of close interaction with responsible agencies, authorities and the media. Finally, the chapter emphasises the importance of research and knowledge, and considers future needs.

Monitoring large rockslides

The investigation, monitoring and early warning procedures that have been designed and implemented for Norwegian rockslides follow requirements set out in national codes and international standards for geotechnical design (Blikra & Kristensen, 2011). Potential rockslides at Åknes, Hegguraksla (Tafjord) and Mannen (Romsdalen) in western Norway and Jettan and Indre Nordnes in northern Norway are at present the sites where monitoring and early-warning systems have been installed by the Norwegian Water Resources and Energy Directorate (NVE) (Figures 2 and 3). The basic concept for using monitoring and early warning for reducing risk is the fact that large rockslides usually develop incrementally, experiencing periods with increased movement before the slide event (Crosta & Agliardi, 2003). There have been relatively many historical events demonstrating this. A schematic displacement curve for the development of a landslide is thus used as a basis for defining the hazard (Figure 4), which in turn is the basis for the societal response (Blikra, 2008).

A proper handling of monitoring of large landslides includes both detailed geological knowledge of the unstable area and reliably functional and robust instrumentation. Evaluation of threshold values for establishing warning criteria is an important issue.

Geological knowledge

Rockslides are controlled by geology, and especially by the orientation and dip of fractures, foliation and faults (Braathen *et al*., 2004; Jaboyedoff *et al*. 2011). Detailed understanding of the structural control is the basis for the interpreted location of sliding planes and release fractures, which again are critical for analyses regarding stability, geometry, volume, run-out distance and related secondary effects like landslide dams and tsunamis (Ganerød *et al.*, 2008). Most rockslides are characterised by prominent cracks in their upper part, as shown for example by the Åknes rockslide (Figure 3).

Many rockslides are studied primarily by surface geological mapping and remote sensing (LIDAR, photogrammetry), with only limited subsurface data. The structural control of the sliding surface and other release structures is thus frequently interpreted on the basis of surface structures. In order to achieve proper knowledge and understanding of large and complex landslides it is of vital importance to acquire subsurface geological data as well, including the depth of the instability and the related deformation (Blikra *et al.,* 2013). Geophysical measurements have been used in order to be able to build a proper 3D model of large landslides. Borehole instrumentation is essential both for the investigation of subsurface characteristics (sliding planes, depth, etc.) and for real-time operative early-warning. The subsurface data from boreholes include drill cores, structural data from optical cameras (televiewer, see Figure 5) and the recording of displacement from borehole sensors. Stability modelling should also be utilised for prediction and to support

discussion of alternatives (e.g. Kveldsvik *et al.*, 2008). Geomechanical analysis of rock samples and stability modelling are also used to obtain a better understanding of rockslides.

In summary, an investigation programme for large rockslides should be comprised of the following main parts: (1) Surface investigations; (2) Ground (subsurface) investigations; (3) Analysis and modelling; (4) Evaluation of possibilities for physical mitigation; and (5) Documentation.

Instrumentation and monitoring systems

The design and implementation of monitoring systems follows the following main concepts: (1) Sensors on the surface and in boreholes to provide sufficient data about movements; (2) Sensors giving information about mechanisms that control movements (meteorological stations and water pressure gauges); and (3) Backup systems for all critical sectors by deploying different types of monitoring system. The infrastructure including power-supply system and data communication from the site is designed to fulfill the demand of redundancy.

In order to establish a robust, reliable and redundant continuous monitoring network, a range of methods and instrumentation are used, both on the surface and in boreholes (Figure 6) (Blikra & Kristensen, 2011). The array of sensors is chosen to provide the most complete information possible in order to cover the entire zone of unstable slopes, including all key sectors, see example of the final established monitoring system at Åknes (Figure 7). However, there are a series of practical limitations in terms of distance from measured points to the monitoring instrument, local slope conditions, rockfall and snow-avalanche hazard and problematic atmospheric conditions. The changing atmospheric conditions along fjords and especially measurements across the fjord can be particularly demanding.

Based on historical data from the site and information from historical rockslide events elsewhere, velocity-based hazard levels have been embedded in the operational system (Figure 4). Threshold values have been evaluated for individual sensors in terms of daily monitoring. These threshold values are from both surface monitoring systems (lasers, ground-based InSAR, extensometers, total station and GPS) and subsurface borehole inclinometers and piezometers (DMS).

The Veslemannen event in Romsdalen

In September 2014, a small part of the monitored unstable rock slope at Mannen in Romsdalen displayed large movements. This was discovered during a short periodic measurement campaign using a ground-based radar system (see Figure 6, lower left). The area was documented and located in only a week of measurements. The instrument is capable of measuring and scanning large portions of steep and inaccessible mountain walls, and is thus an effective method to quickly gain an overview of the stability conditions over large areas (Figure 8).

It was estimated that between 120,000 and 180,000 m^3 of rocks were active, and a small rockslide from this area could threaten some farms and the railway. Several phases of increased movement and acceleration at the end of October led to evacuation of people and livestock, and the railway line was closed. The rock movements were closely controlled by precipitation. Displacements from selected points in the area are shown in Figure 9. The event demonstrated the challenge of using monitoring to reduce risk. Even if the rate of movement was large, and the acceleration indicated an impending rockslide, the conditions then changed and the displacements were reduced, and the area stabilised for the winter.

The event attracted overwhelming media attention, not only in the region, but also nationally and in other countries. It was quickly clear that there was a need for close co-operation and interaction between the municipality, police and the organisation in charge of the monitoring. A scientific challenge was the dissemination of uncertainty. *When will the rock slope fail?* was the main question from the media. The critical aspect of using monitoring to reduce risk is how we can achieve trust among people living in the hazard zones, who may need to be evacuated several times, year after year. The experiences from this event stress just how important it is to communicate factual information and ongoing risk assessments, and maintain close dialogue between the experts and the evacuated people.

Norwegian research and future needs

Dealing with geohazards requires knowledge and expertise across a wide spectrum of geoscientific disciplines. Norway is a small country and successful co-operation and interaction is crucial in developing high quality education and research. Several important initiatives and projects have been launched the last 10–15 years. One of the most significant was the establishment of the 10-year International Centre for Geohazards, a centre of excellence financed by the Norwegian Research Council and set up in 2003 (Solheim *et al.,* 2015). Also several EU projects have been focused on these topics, like the SAFELAND project led by NGI.

A multidisciplinary approach is especially important for the handling of large complex landslides. It includes different geoscience disciplines including geomorphology, structural geology, engineering geology, hydrogeology and geophysics. It also needs people with competence in physics, stability modelling, run-out modelling and wave theory. When the first project on monitoring large rockslides in Norway started in 2004, a series of research projects was initiated. The Åknes/Tafjord project initiated wide co-operation with national and international scientific groups in order to ensure that the work was on the right track (Blikra, 2008). Today, several scientific groups are working on topics related to coping with large rockslides in Norway. The following main issues are thought to be the most important:

- Different geological and geophysical methods for constructing reliable 3D geological models.
- Engineering geological investigations, stability modelling and run-out analysis.

- Use of different remote sensing methods for detailed mapping and analysis of terrain and movements. These include LIDAR, ground-based InSAR and satellite-based InSAR.
- Use and improvement of different instrumentation systems, both on the surface and in the subsurface.
- Laboratory experiments of rockslides plunging into lakes and fjords in order to develop and ensure the quality of numerical tsunami modelling (Figure 10) (Harbitz *et al.*, 2014).
- Explore and better understand the role of water and temperature in influencing displacements causing large rockslides. Permafrost and climatic change are important research aspects.
- Improve the design of a total monitoring system including instrumentation, power supply and data communication.

The stability of large landslides is known to be largely influenced by weather conditions, especially rainfall and snowmelt leading to increased water pressure. This is a typical effect at the Åknes rockslide site (Grøneng *et al.*, 2011). The displacement and stability of the Jettan rockslide in northern Norway, however, is controlled more by the temperature regime (Figure 11). There the movements demonstrate a systematic seasonal trend with displacements initiating during snowmelt in mid-May, decreasing during the late autumn and early winter and with low deformation rates until spring. The seasonal changes are thought to be controlled by changing shear strength of the brecciated sliding planes due to rising ice temperatures within the detachment zones and/or variations in water infiltration from local ice bodies to the unsaturated sliding zones (Blikra & Kristensen, 2014). One important future research challenge is to better understand the driving forces for large landslides, and also the effect of a changing climate.

There is still only a limited knowledge base linked to several aspects of importance for the understanding of large rockslides. To develop the Norwegian research capacities, there is a need for increased concentration by the different universities and research organisations, especially in the basic research areas. An evaluation of the geoscientific institutions conducted in 2014 by the Research Council of Norway concluded that also improved co-operation among organisations was required, including between the research community and governmental agencies.

Summary

The investigations, monitoring and early warning initiatives that have been designed and implemented for Norwegian rockslides follow the requirements and guidelines by national building codes and international standards for geotechnical design. The high risk posed by a rockslide that has large run-out distances and can dam rivers and generate disastrous tsunamis has been the fundamental driver for the requirements and the design. The main aim has been to achieve a reliable knowledge

base of the geology and the deformation model, in addition to robust and redundant monitoring systems and related infrastructure for early warning. The work has shown the importance of including both surface and subsurface investigations and monitoring. The established real-time monitoring systems and related infrastructure have reduced the risk to an acceptable level.

Extensive research related to these topics has been carried out during the last 10 years in order to ensure a high quality and robust monitoring and early warning system that will protect the population. However, there are still major challenges related to the proper understanding of the geological processes leading to and involving the release of large rockslides. There is a need for increased co-operation and interaction between Norwegian universities, research institutes and governmental expert agencies.

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Figure 1. From Loenvatn after the large rockslide and disastrous tsunami of 13th September 1936. The maximum tsunami run-up was 74 m and 74 people died. (Photo credit: Knudsen (1936). Reproduced with permission from "fylkesfoto-arkivaren".)

Figure 2. Locations of rock-slope failures in Norway with installed monitoring and early-warning systems.

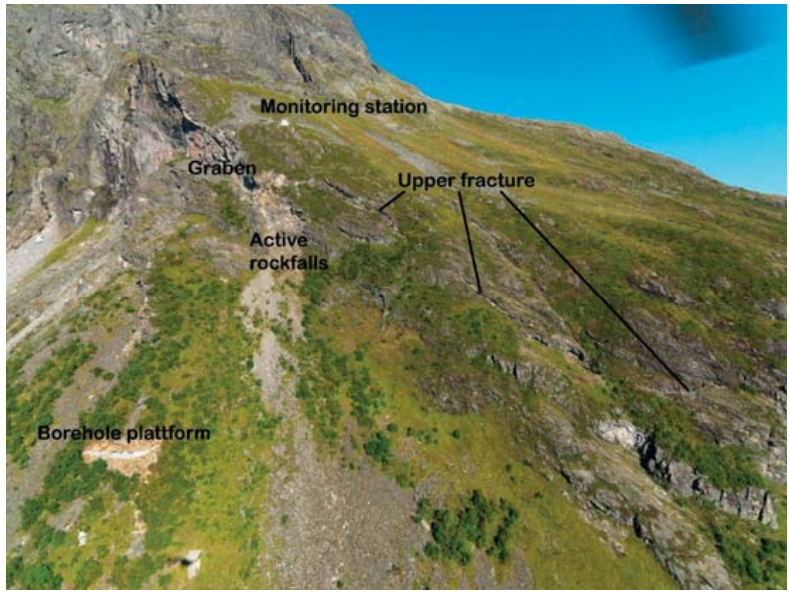

Figure 3. Overview of the upper part of the Åknes rockslide.

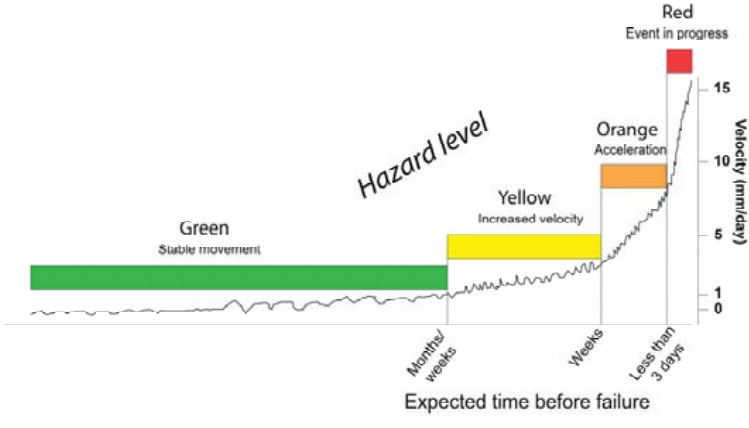

Figure 4. Schematic diagram showing early-warning levels together with a possible development of the Åknes rockslide (revised after Blikra, 2012).

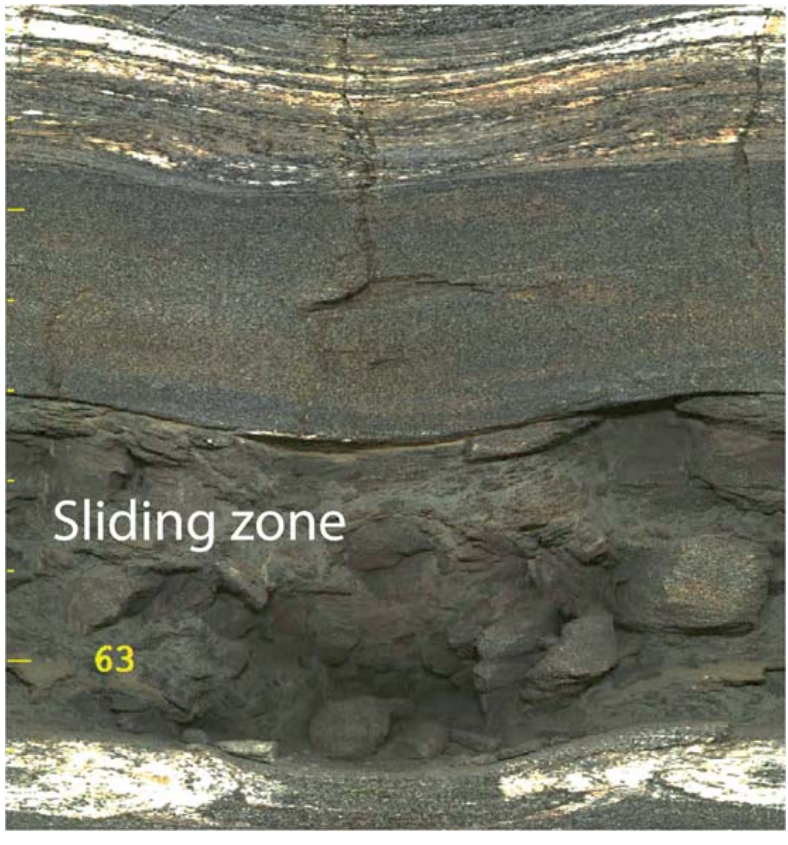

Figure 5. Photograph from the sliding zone at 63 m depth within a borehole at Åknes captured by an optical camera (Televiewer). The 360º image shows the entire borehole wall at this position. The camera is oriented, so it also gives the directions (north, east, south and west). The layering is the foliation in the gneissic bedrock, while the crushed zone is the sliding zone within the rockslide.

Figure 6. Example of monitoring systems: Upper: Single laser (left), GPS antenna (inset) and web camera and radio antenna (right). Lower: Ground-based radar, GB InSAR (left), extensometer (middle) and photo of a more than 100 m long borehole instrument (DMS column) (right).

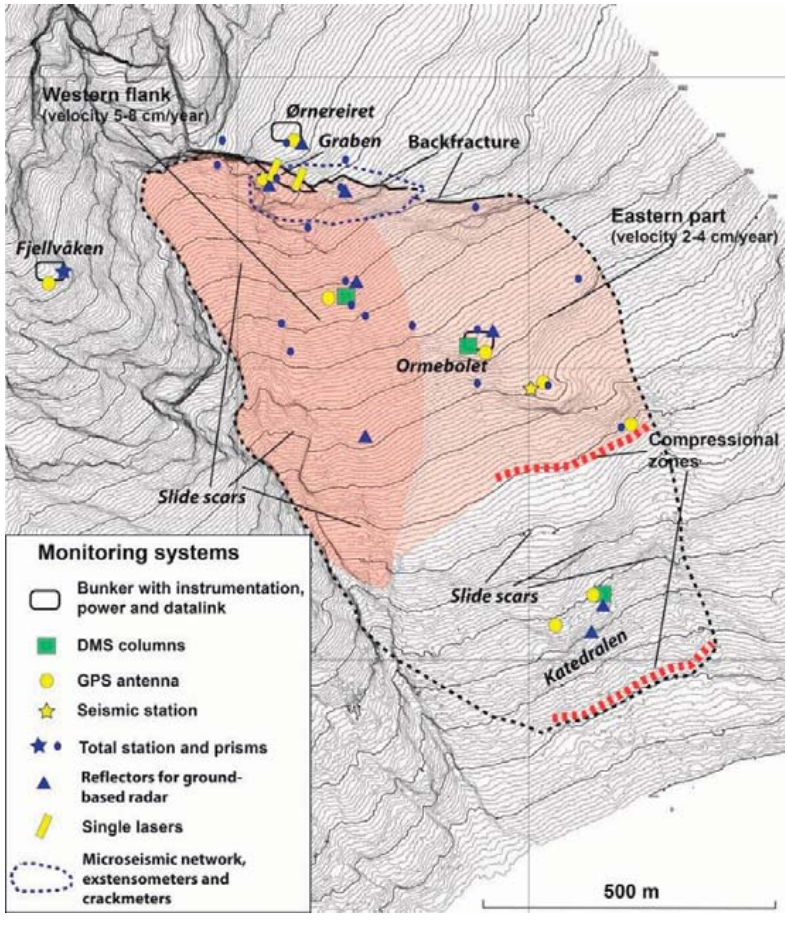

Figure 7. The Åknes rockslide with the main scenarios in different colours, geomorphological features and the instrumentation spread (modified from Blikra, 2012).

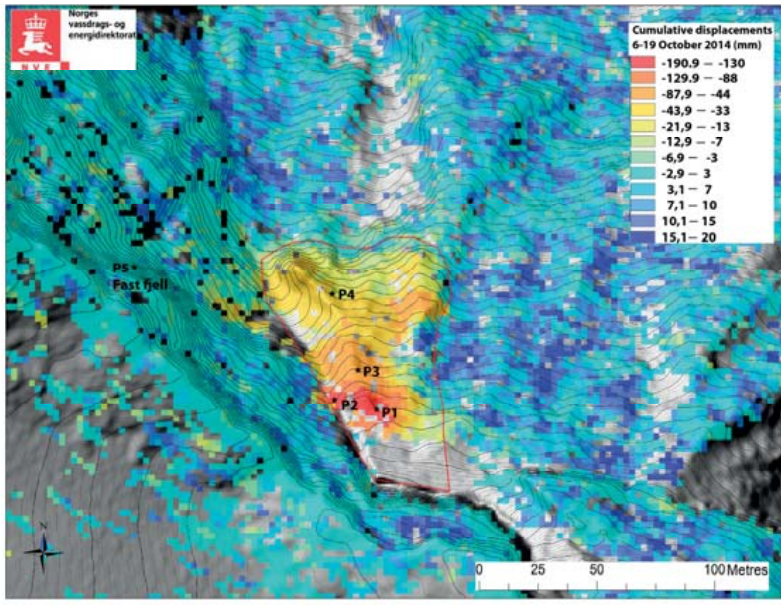

Figure 8. Results from the ground-based radar at Veslemannen in Romsdalen. It shows the total displacements (mm) over a 3-week period in October 2014.

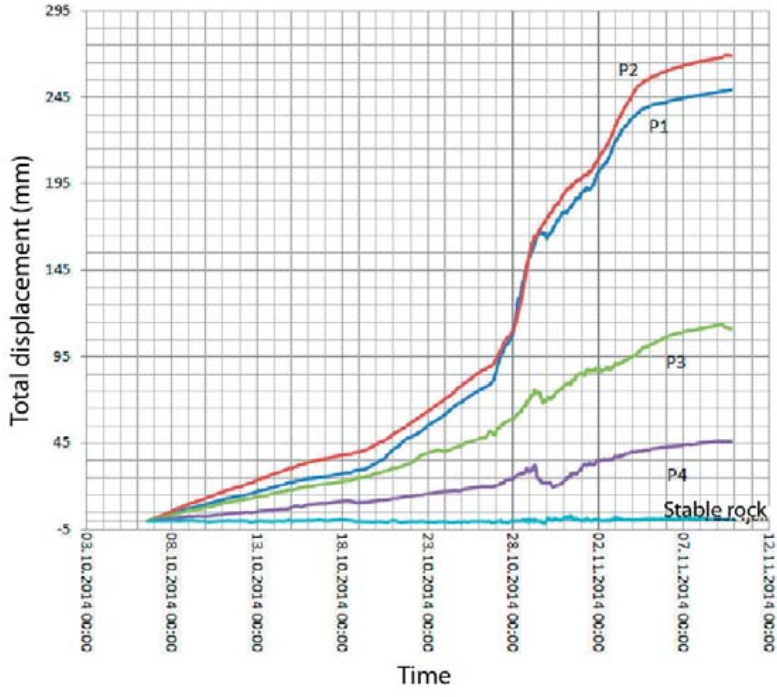

Figure 9. Displacements from the unstable Veslemannen area from the 6th October until the 10th November 2014. See location of points in Figure 8.

Figure 10. Set-up of the tsunami laboratory experiments at SINTEF.

Figure 11. The active main back fracture at the unstable rock slope Jettan in northern Norway. The deep fracture is at this time, 2nd May 2013, filled by snow. Permanent ice and cold conditions are found in deeper parts below 20 m depth.

The Large Fire in Lærdal, January 2014: How did the Fire Spread and what Restricted the Fire Damage?

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Background

In the evening of the 18th of January 2014 a fire started in a private home in the small municipality of Lærdal, which lies far inland at the head of a tributary fjord to Sognefjord in central western Norway. There were strong winds, there had been very little precipitation during the last month, the ground was dry and without any snow. The fire spread quickly, heavy showers of glowing sparks and pieces of burning material spread the fire from house to house and to the vegetation in the hillsides around the community. There was considerable risk that the fire would spread to a large area comprising listed cultural heritage wooden buildings dating from the 18th and 19th centuries. The telecom building was damaged by the fire at an early stage, which disrupted telecommunication and severely complicated the organisation of the various services involved. Several fire brigades, the Civil Defence, Red Cross and many private volunteers put in a tremendous effort to control the fire and succeeded in protecting many residential homes and most of the listed buildings. Despite their efforts 40 buildings burnt down, including 17 residential homes and 3 listed buildings. 681 people were evacuated during the fire. Fortunately, no-one was seriously injured during the blaze.

The Norwegian Directorate for Civil Protection (DSB), which is the authority with an overall responsibility for fire brigades and preparedness, carried out an evaluation of how the firefighting was organised and executed in this fire (DSB 2014). The co-operation between the different parties involved in the firefighting has also been assessed by a consultancy company (PwC 2014). Our work, however, is concerned with the technical and scientific aspects of the fire; how, when and why the fire spread as it did in the area, and how damage was limited (Steen-Hansen *et al*. 2014). In this paper we will present some of the findings from our analysis.

Objectives of the project

The main goal of our project was to describe how the fire spread from the first house to the nearby buildings and further on. We also aimed to identify factors that helped restrict the spread of the fire, and factors that contributed to preventing buildings in critical positions from being ignited. Such factors may relate to either fire preventive measures or to firefighting efforts.

The purpose of this work was to obtain new knowledge, both regarding fire spread mechanisms and measures that may prevent or restrict damage in large fires like this. Another objective leading on from this, was to identify areas where more knowledge is needed for tackling future fires. The risk of large fires, both wildfires and fires in the built environment, is regarded as relatively high in periods with dry and windy weather, which in Norway can be considered a consequence of a changing climate.

Methods

Several methods were used to obtain information about the fire in Lærdal and the surroundings and to collect up-to-date knowledge about the spread of large fires in general. By applying the different methods we were able to put together pieces of the complete picture that describes the fire. Our study does not include assessment of the firefighting efforts from fire brigades or other organisations or volunteers. Assessment of the cost effectiveness of the various fire preventive and mitigating measures has not been attempted.

Literature study

A review of relevant literature was performed to obtain state-of-the-art knowledge within the field of fire spread in large fires. The literature included articles and reports on wildfires, fires in built environments and on wildland urban interface (WUI) fires, as well as literature on firefighting and fire preventive measures.

Inspection of the fire scene

Lærdal was inspected by us about 12 weeks after the fire. It would of course have been helpful to inspect the area immediately after the fire, but due to administrative reasons this was not possible. We found that most of the fire debris had been removed, and repair of damaged buildings was under way. However, we were able to get an impression of the geographical extent of the damage and much information about the fire itself from key persons involved during the incident, who also described their experiences during the fire.

Retrieving information from witnesses

A limited number of interviews with witnesses were conducted, via video or telephone calls. The interviews of journalists who were present during the fire were especially useful, because they had documentation of where they were at different times through their photo and video material.

Study of photo and video material

Information about the fire was also collected through searches on the web, and sources of relevant photo and video material were contacted. Altogether we had access to about 1500 photos and 10–20 videos from the fire. This material was examined to identify where, when and from which angle the photo was taken, and which buildings were observed. The time recordings on the photo material were synchronised and calibrated against actual time to ensure that the timing of the different events during the fire was correctly assessed. Information from the photographers was of great value in this work. We made a system for defining at which stage of the fire the buildings in the photos showed, to be able to analyse the fire spread. An example of a building photographed during three different stages in the fire development is shown in Figure 1.

We did not have access to photos of every building involved, or photos from every stage of the fire development during the fire. The time of ignition was especially difficult to assess with great certainty, because most photos either showed a building that was not ignited, or showed a building in an early stage of the fire. The time of ignition would be somewhere in between.

Photos taken before the fire were, as far as possible, used to study details of the buildings and the surroundings.

04:53 Ignited | 05:24 Fully developed fire | 06:29 Nearly burnt down

Figure 1. Three different stages of the fire development in a single building. The photos are taken from two different directions. Photos: Elias Dahlen/Bergens Tidende.

Mechanisms of fire spread

Large fires can spread in vegetation and the built environment by a number of mechanisms, these can occur separately or in different combinations:

- Firebrands
- Thermal radiation
- Direct flame exposure
    - flame contact from building fire
    - flame contact via vegetation

Firebrands can be defined as:

> Any source of heat, natural or manmade, capable of igniting wildland fuels. Flaming or glowing fuel particles that can be carried naturally by wind, convection currents, or by gravity into unburned fuels (FEMA 2002).

The definition should be expanded to also include sources of heat that are capable of igniting any type of combustible material, e.g. construction materials. It has been observed that firebrands are able to spread wildfires over distances of up to 20 km (2009 Victorian Bushfires Royal Commission). A large amount of research has focused on how fires may spread from wildfires to buildings, and how this can be prevented (Wang 2011, Manzello *et al.* 2007). Research in Japan has considered how firebrands from burning buildings can spread the fire to other buildings (Manzello *et al.* 2011a). A study of the size distribution of flying brands from a wildland-urban interface fire in California showed that most firebrands in general were small, i.e. with a diameter less than 1 cm (Foote *et al.* 2011). It was, however, stated that there is a potential for larger firebrands in these fires. Larger firebrands will have a larger ignition potential than smaller firebrands, and the potential is higher if more than one firebrand lands on a combustible target (Manzello *et al.* 2011b, Waterman and Takata 1969). Large firebrands contain more energy than the smaller ones, and are more likely to burn after being transported over large distances. Because large firebrands are more potent ignition sources than small firebrands, they will be more capable of igniting exterior surfaces of buildings. On the other hand, smaller firebrands may be able to penetrate the building envelope through openings in the roof, cladding, vents etc., and may ignite combustible materials in voids and enclosed spaces.

Spot fires are described as extreme incidents in a fire development, and are caused by firebrands that start new fires outside the area where the main fire is able to ignite combustible materials (FEMA 2002). There are many historical examples where spot fires have jumped borders thatwere expected to act as barriers – fire defence lines – capable of stopping the fires from spreading (Koo *et al.* 2010). Strong wind is the most critical factor for fire spread by firebrands over large distances. Strong wind increases the primary fire and also the buoyancy of the fire plume, which in turn increases the probability of transport of larger firebrands.

Thermal radiation from a fire in a single family domestic building will normally not spread the fire at distances over 20 metres. Ignition of materials exposed to radiated heat may be caused by spontaneous ignition or piloted ignition. In the latter case, the material is also exposed to an additional ignition source like an ember, spark or a flame. This ignition source could very well be a firebrand. Normal wood may ignite by piloted ignition at a radiative heat flux density exposure of 13–18 kW/m^2. While 12.5 kW/m^2 is often used as a dimensioning heat flux density value for piloted ignition of wood, for practical applications a value of 15–18 kW/m^2 has been recommended as a dimensioning parameter (Carlsson 1999). Spontaneous ignition of untreated wood requires a radiative heat flux density of 30–33 kW/m^2 (Babrauskas 2001).

Building codes often require a minimum distance between buildings, based on the anticipated level of radiative heat flux density from a neighbouring building on fire. In Norway the required minimum distance between buildings is 8.0 m (Norwegian Building Code 2010). This may be sufficient if the fire in the next building is confined to one room and the fire brigade arrives relatively soon after flashover, but in many cases it will not be sufficient to prevent fire spreading to other houses once a building is fully ablaze.

Direct flame contact. A building fire may lead to direct flame exposure of combustible materials in e.g. vegetation or nearby buildings. The flames from a broken window in a room after flashover may lead to ignition of neighbouring structures less than about 2 metres apart. If the building is completely ablaze, the fire may spread across gaps of more than 2 metres. Wind will affect how far the flames may reach. Fires in built-up areas may also spread via vegetation like grass, bushes and trees between buildings.

Wind is one of the most important factors for fire spread in wildfires and will affect both the combustion rate and the speed of fire spread (FEMA 2002). Wind increases the oxygen supply, influences the direction of fire spread, dries the unburnt fuels, carries sparks and firebrands ahead of the main fire and preheats fuels ahead of the fire.

Local wind conditions can be created because of local temperature differences and the geometry of the surroundings. The topography can also affect the wind direction and wind speed. In narrow canyons the wind will follow the direction of the canyon. Sharp bends may result in eddies and upslope air movements that can lead the fire spread in unexpected directions (FEMA 2002). Sudden gusts of wind can appear when there is strong wind in the mountains and the wind flows down into steep valleys (Engen 2014). The wind is unpredictable because the wind direction varies.

A large fire will also affect the air draughts in the surroundings. Hot smoke and air flows upwards and air from areas outside the fire will then be drawn along the ground into the flames. This can be thought of as *the bonfire effect* (Wighus *et al.* 2003).

Wind may bend fire plumes and in this way increase the heat exposure downstream of the fire. Strong wind will also effectively mix fresh air into the fire plume. In very large fires there may be a deprivation of oxygen in the centre of the fire, which leads to lower temperatures and a less intense fire in the central zone. Strong wind may prevent this oxygen deprivation from developing and more complete combustion with high temperatures results. The flame zone will be more concentrated and have higher temperatures when exposed to strong wind than without wind exposure.

Moisture content in building materials of wood may have been an important factor leading to the rapid fire spread. The weather in Lærdal had been very dry the month before the fire, and the relative air humidity (RH) the last days before the fire was steady at about 31–33%. It was relevant to our study to consider how this could have affected the moisture content of vegetation and construction materials. Wood with low moisture content will ignite more easily than wood with higher moisture content (Janssens 1991), and will burn fast with a high intensity. The moisture content of wood in construction materials is normally expressed as a percentage of the mass of the wood when oven-dry (Bergmann 2010). Wind will affect the drying of wood materials because it removes moisture from the surface. Moisture from the material below will then be transported towards the surface. The drying effect will work until the wood fibres are saturated with moisture – until the so-called *fibre saturation point* is reached. Thereafter wind will not significantly affect the moisture content in the wood material (Esping 1992). Drying of the wood beyond the fibre saturation point depends on the relative humidity (RH) of the air and the air temperature, and will go on until the equilibrium moisture content has been reached. The equilibrium moisture content of wood in interior and exterior materials will depend on the climate, and the normal variation between different parts of Norway is large. For a RH of 30% (as was measured in Lærdal the week before the fire) and a temperature in the range 0–25°C, the equilibrium moisture content in wood materials can be estimated to 6–7% (Glass and Zelinka 2010).

Description of the Lærdal fire

The following description is based on information from our inspection, interviews with witnesses and study of the photo material. A map over the affected area is shown in Figure 2.

The buildings

The building where the fire started and those in the area nearby were all built in the 1950s, and can be described as typical Norwegian residential detached houses. The cultural heritage area with the listed houses from the 18th and 19th centuries is located to the west of the fire area shown in Figure 2. All the houses in the area were built mainly of wood, and with exterior wood cladding. Most roofs were probably covered with tiles and slates, this could be seen from the photos taken before the fire.

One interesting case was the third house to the west of the one where the fire originated (address Kyrkjeteigen 2 in the map in Figure 2). This house survived the fire with little visible damage, although both the neighbouring houses were completely destroyed. The reason for this is complex. We believe that the shape of the roof led the wind with the flying brands over the house, and thereby prevented ignition. The fact that the house recently was renovated meant that external surfaces were smooth, without cracks and openings where glowing embers could collect and ignite the building. The roof was also of new materials, and ventilation openings were protected to avoid intrusion of unwanted elements – which also excluded intrusion of embers. The phenomenon of large fires and wildfires "saving" houses from damage has been experienced in a number of fires internationally, and was also seen in the large fire of Ålesund in 1904.

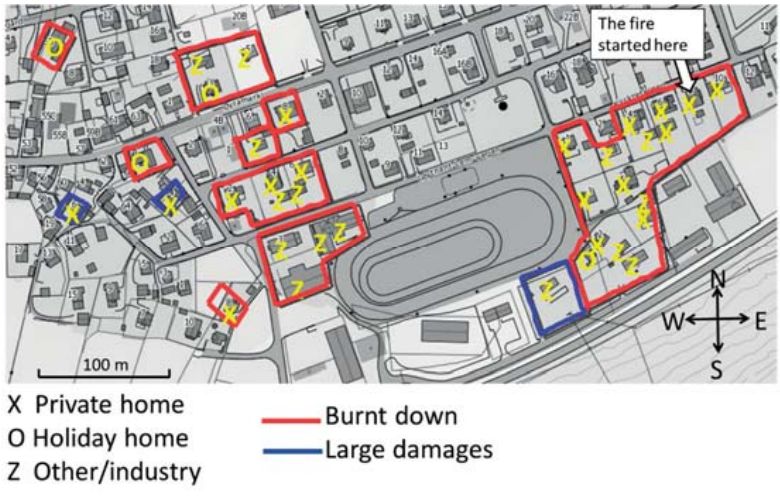

Figure 2. Map of the fire area with indication of houses that were completely destroyed (red lines), and houses that were badly damaged (blue lines). The label "X" indicates houses where there were people at home, while "O" indicates empty houses. The sports field is shown as an oval shape in the centre. The wind came from the east. The map is used with permission from the Norwegian Mapping Authority.

Weather conditions before and during the fire

There is normally not much precipitation in Lærdal. The last month had been windy, with very little precipitation, which led to very dry materials in buildings and dry vegetation. The relative humidity of the air was about 30% the week before the fire, and the temperature about 0°C. Wind conditions are often turbulent because of the

steep hillsides. The wind during the night of the fire came from the high mountains in the north east, where a storm was reported that night. The maximum values of wind speed measured at the weather station closest to Lærdal were between 12 and 15 m/s, which are in the range of strong breeze to near gale. The wind direction at the fire scene was unpredictable, and characterised by sudden gusts.

The fire

The fire started in a single family house Saturday 18th of January 2014 and the local fire brigade was called at 22:54. When the first fire engine arrived 22:59, the building was already fully ablaze. It was observed that the fire spread through heat radiation, embers, direct flame contact and also through the ground vegetation. The grass was dry and especially the tall grass burnt well. Burning objects of different types were observed flying through the air, together with a shower of embers. Burning spheres of glass flying through the air were mentioned by some witnesses, but none of these were collected and stored after the fire.

The buildings were ignited from the outside, and the time was relatively short between ignition and the house being fully ablaze. Witnesses observed that buildings were mostly ignited at roof level, e.g. under the ridge at the gable end, where it ignited the cladding and spread into the building. A photo from the early phase of the fire is shown in Figure 3.

Witnesses experienced the fire spread as relatively random and it was advancing on more than one front. The fire brigades had expected the fire to stop when it reached a sports field that was 190 m long, but spot fires ignited houses on the other side of the field about 90 minutes after the first alarm. The timing was documented by a photo from a journalist, where flames across the sports field could be observed, see Figure 3. Another example was a fire that started on a roof approximately 200 m northwest of the main fire area and was detected by members of the Civil Defence who were passing by to collect more water.

Firebrands ignited vegetation on the southern hillside in several places, but resources could not be diverted to extinguish those fires.

The firefighting

Large quantities of water were taken from fire hydrants, and many private persons also used their garden hoses to fight the fire. The water supply system was not dimensioned for this extremely high usage and the water pressure dropped to very low during the fire. Extinguishing water was also collected from the river and from the fjord.

Large firebrands and large hot metal plates from roofs and sheds represented a particular problem for the firefighters, because some of these objects damaged fire hoses and other equipment when they fell down. Such objects were also a danger to persons.

Figure 3. The fire started in the house in the centre of the photo. The photo is taken about 90 minutes after the fire brigades were called. The fire had then already spread 190 metres across the sports field. Photo: Morten Sortland, Sogn Avis.

A fire-fighting lance was used to extinguish fire that had spread inside a building and the house was saved from the flames. A fire engine with heavy fire-fighting foam arrived from Sogndal airport across the fjord later in the fire development, when the fire threatened to spread to the area with cultural heritage buildings. Buildings at risk of being ignited were covered with the foam, which stayed in place on the surface despite the strong wind. House walls were also continuously sprayed with water to prevent ignition. Figure 4 shows a successful example of these efforts.

Farmers in the area contributed to the firefighting by filling their liquid manure spreaders with water from the river, and used them to wet the ground between houses and to spray water on the glowing fire debris from burnt houses.

A number of different types of extinguishing equipment and methods were used, like ordinary fire hoses for exterior use, extinguishing lance for interior firefighting, extinguishing foam to cover undamaged buildings, water curtains between buildings to prevent fire spread, and the use of manure spreaders to wet the ground and extinguish heaps of embers. A water cannon was also applied during the fire. In addition, private persons and volunteers did an important job by removing and quenching embers, extinguishing small fires, wetting houses and gardens etc.

It was not possible to use a helicopter for firefighting because it was dark, the wind was strong, and because the hillside was alight. It was considered to use a digger to create a fire defence line but it was too uncertain if it would have any effect and there was a risk that water supply pipes could be destroyed, so the proposal was turned down.

The situation during the fire was experienced as chaotic and complex with a more or less random fire spread and an extremely fast fire development from ignition of a building until it was completely burnt down. The last building was ignited between 05:30 and 06:00 in the morning. The fire was defined as under control 16:45 the same afternoon.

Figure 4. Fire brigades managed to prevent the fire from spreading further into the area with cultural heritage houses by covering the house to the right in the photos with extinguishing foam and by applying a water wall between the buildings. The burning building was a listed cultural heritage house from 1840. Photos: Elias Dahlen (Bergens Tidende)/Anne Steen-Hansen.

Figure 5. Overview over the fire spread with indication of time when the fire spread from building to building. The fires started in the house marked with a star in the upper right corner of the map. The arrows show when and where the fire spread; the darker the arrow, the later in the fire. A larger version of the map is available in the project report (Steen-Hansen et al. 2014).

Fire spread

Based on the analysis, a map has been constructed (Figure 5) showing where and when the fire spread during the night. Another map, showing the different fire spread mechanisms, was also made. Both maps are available in the project report (Steen-Hansen *et al.* 2014).

What did we learn from the Lærdal fire?

The first lesson learned was that large fires can still happen in Norway, even in winter time. This was one of three large fires during the winter of 2014. Can we expect more large fires with future climate changes?

The second lesson learned was the high rate of fire spread between Norwegian houses by ignition from embers and firebrands, and how chaotic a fire like this may be. The combination of strong wind, fire brands and radiated heat from burning houses was critical.

The third experience was that it is possible to stop such a fire from spreading by applying efficient details in the building structure, by the implementation of effective fire mitigating measures and by strategic fire extinguishing activities.

Based on the analysis of the fire spread, several fire-restricting measures can be recommended. The efforts from the fire brigades were crucial together with the effort from all the other organisations, volunteers and private persons who took part in the firefighting. The different methods for extinguishing fire were all useful parts in the large picture. It is not possible to point out one single measure that had greater effect than the others; they were all important in limiting the fire spread. There are examples where the fire jumped over buildings where one or more efforts were applied, and started a new fire in houses further away from the main fire area.

Owners of private homes can increase the resistance against ignition by embers and sparks through simple preventive measures, and when building new houses or renovating existing ones cladding and roof construction can be upgraded.

The use of fire preventive and restricting measures has to be thoroughly planned. Many countries have guidelines available that help communities to make good plans for this type of fire preventive work.

More fire research is needed

During our work we have seen clearly the need for more research on many topics connected with both large fires in built environments and wildfires. We need a better understanding of the fire phenomena involved, and investigation of the efficiency of existing technical and organisational fire protective measures should be undertaken. These should also be aimed at developing new fire safety measures built on today's knowledge and modern technology.

Some topics that should be investigated are:

- Is the risk of large fires like the Lærdal fire increased in Norway because of climate changes – e.g. more wind and dry weather?
- Has the fire risk changed because of changes in society with regards to human behaviour, interior furnishing, building methods and construction materials?
- How large is the fire exposure from neighbouring houses engulfed by flames?
- What is the state-of-the-art of prevention and fighting large fires in other countries? Is this knowledge relevant for Norwegian conditions?
- Development of cost-effective extinguishing systems and fire safety measures.
- The effect of different fire safety measures should be investigated:
    - simple measures for new and existing buildings
    - fixed firefighting systems for exterior use
    - different extinguishing media and techniques

We sincerely hope that fire research will be on the agenda in future research programmes. There are many fire safety challenges – both in Norway and in the rest of Europe – that can be solved through dedicated research. We do not want to see another fire like the one in Lærdal.

Acknowledgements

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Climate change adaptation in Copenhagen

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The past 20 years Copenhagen has undergone tremendous development. From a city with a very poor economy and declining population, the city has been transformed to a vibrant city with a growing population, a strong economy, an international reputation for implementing green solutions and for being one of the most liveable cities.

The city has set ambitious Climate Action goals and aims to be carbon neutral by 2025, but recent weather events have also raised awareness for the need of climate change adaptation.

Climate Challenge

The main climate challenge that Copenhagen is facing is an increase in precipitation. It is estimated that general rainfall will increase by about 30% and heavy thunderstorms – especially during the summer – will also increase. To verify the vulnerability of the city for both the present and the future climate challenge, a calculation of the risk was carried out.

The city has already had a taste of what the future will bring (Figure 1). A massive cloudburst with 150 mm of rain in two hours in July 2011 revealed just how vulnerable the city is to the future climate. Massive traffic disruption with closed roads, power cuts at hospitals, etc. showed the need for action.

Located on the sound that separates Denmark and Sweden, the city will eventually also face the problem of rising sea-levels. The narrow entrances to the sound limit the effects of tides for the city – and with a general location at 1.5 m above sea level this makes the city relatively well protected. But with rising sea levels the risk and frequency of storm surges will increase.

The Climate Adaptation Plan

In 2009 the city decided to start working on a Climate Adaptation Plan to prepare for a future with a warmer, wetter climate with an increase in extreme weather events. The plan mapped the risks that the city could expect facing given the various scenarios, and defines the strategy for the work that has to be carried out over the

next 30–50 years to ensure that Copenhagen, despite the changing climate, continues to be a great place to live, work and invest in.

The risk analysis (Figure 2a and 2b) showed that Copenhagen today is sensitive to heavy rains and that the risk will increase significantly in the future. The risk of damage from storm surges from the sea is small today, but will rise sharply in the future if the sea level continues to rise in the coming years.

The basic philosophy behind the Adaptation Plan is to make adaptation a precondition in the future urban development of the city. Resilience must be a part of all the work that will be undertaken – and not just from a negative, problem-fixated point of view. No, the idea is to look for synergies and possibilities and develop solutions that will improve the recreative qualities of the city – and the quality of life for the Copenhageners.

Another important issue is to use the adaptation work as an innovation platform for creating jobs and growth in the city. New technology, new solutions and the construction work itself will have a significant impact on the city's economy over the coming years.

The cloudburst in 2011 – and the Cloudburst Management Plan

Originally the city planned to implement the Adaptation Plan gradually over a period of between 30–50 years. But on the 2nd of July 2011 a massive cloudburst hit Copenhagen. More than 150 mm of rain fell over the city in less than 2 hours causing massive flooding, disruption of traffic, breakdown of communication infrastructure and even threatened the two main hospitals in the city because of power cuts. The cloudburst cost more than 800 mill. euros in insurance claims alone.

This one event was a game changer. The city allocated money for adaptation and emergency measures and has already implemented the first cloudburst management projects – especially in the inner city.

Another critical problem was the financing of cloudburst measures – especially since the city wanted to work with a mixture of traditional stormwater management measures (underground pipes and reservoirs) and surface solutions. In Denmark stormwater management is handled by the water companies and paid for through water charges. But mixing urban infrastructure with stormwater management was not possible within the national legislation. The city lobbied hard and finally managed to push for a change of national legislation to enable financing of new types of adaptation measures.

The Cloudburst Management Plan was prepared in 2012. This plan sets up the future service level for stormwater management in the city. Basically, business case models showed that if cloudburst water management was combined with normal stormwater management, this gave the most effective and economically viable results (Figure 3). And the analyses also showed that economically it would make most sense to develop a stormwater management system that could handle a 100 year event – also in 2110! But Copenhageners will have to accept water in the streets in

these situations. Up to 10 cm is an acceptable level that will still allow the city to continue to function also in these situations.

The Cloudburst Plan divides the city into 7 water catchment areas – and detailed plans for each area will provide the basis for the future work, and the local dialogue with the citizens and stakeholders over the coming years.

Using the green and blue to adapt Copenhagen to the climate

We must start where the city is developing and changing and where the need is greatest. This can be done by focusing on areas where there is increased risk of flooding or other challenges posed by climate change, and on public buildings and land, kindergartens, schools, homes for the elderly, community centres and parks. In addition, we must prioritise projects and measures which will be a source of new knowledge and inspiration for the city. Work in the coming years will be about taking into consideration rainwater collection, seepage, biodiversity and prevention of heat islands simultaneously, in the work to establish a greener city.

Green and blue surface solutions give the city a unique opportunity to improve life quality of the Copenhageners by creating green and blue recreational areas and a more diverse city (Figure 4). The first projects have been completed – and over the next 20 years more than 300 projects will change not only the way the city manages the water, but also how the city will look.

But the surface solutions also take up room in the city. Room that is also wanted for bicycles, parking and cars. So over the next years as the implementation progresses, there will be a continuous discussion on how we prioritise the use of urban space in the city and combine the realization of the plan with the city's other needs.

Knowledge and skills

Through the work on climate adaptation, Copenhagen has been building up knowledge and expertise in climate adaptation, innovation and growth. This is the case partly because climate adaptation creates a need for interdisciplinary knowledge and interdisciplinary collaboration with research and industry on specific initiatives and selected demonstration projects. Climate adaptation of the city can promote Copenhagen as a showcase for green growth and help to generate new knowledge and new professions.

At the same time there is a strong demand that the environmental standard in Copenhagen will not suffer from the adaptation measures. It is the aim that sewer overflows to streams, lakes and the sea will be further reduced by the climate adaptation measures when the rain water is separated from the sewers. So in the future Copenhageners will still have the opportunity to swim in the harbour and enjoy the clean water in lakes and streams.

Although the challenge is great, we feel confident that we can implement our plans, while the solutions can give a big boost to the city's development in terms of

improved urban spaces, more growth, and last but not least, increased co-operation with other cities in the development of innovative solutions.

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http://international.kk.dk/artikel/climate-adaptation
http://www.kk.dk/artikel/klimatilpasning-i-k%C3%B8benhavn

Figure 1. Flood in central Copenhagen, July2, 2011 (Photo Thomas Melbye).

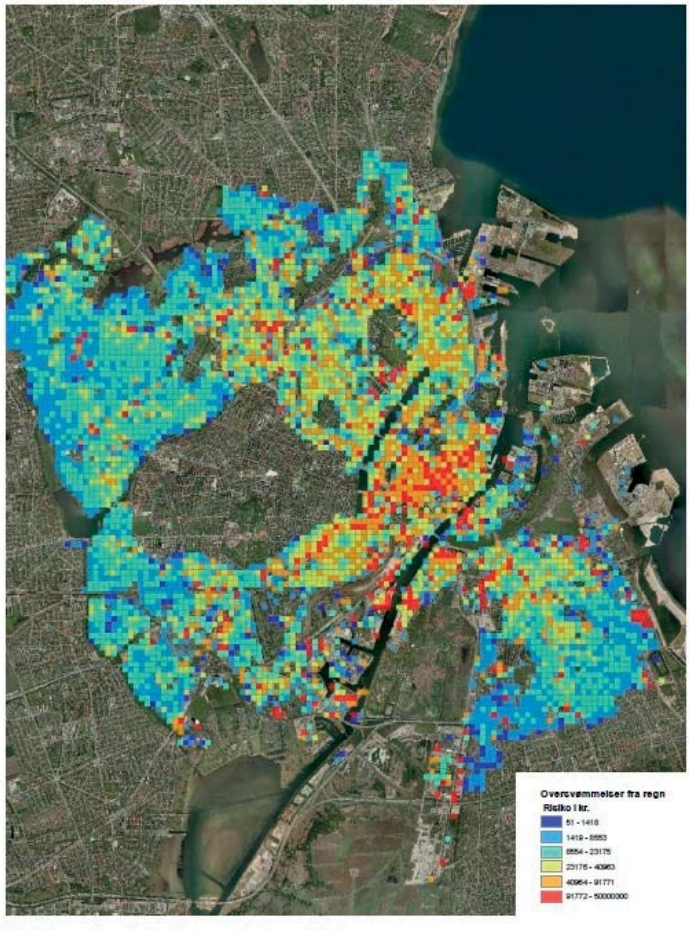

Figure 2a. Risk map for flooding of Copenhagen due to heavy rain.

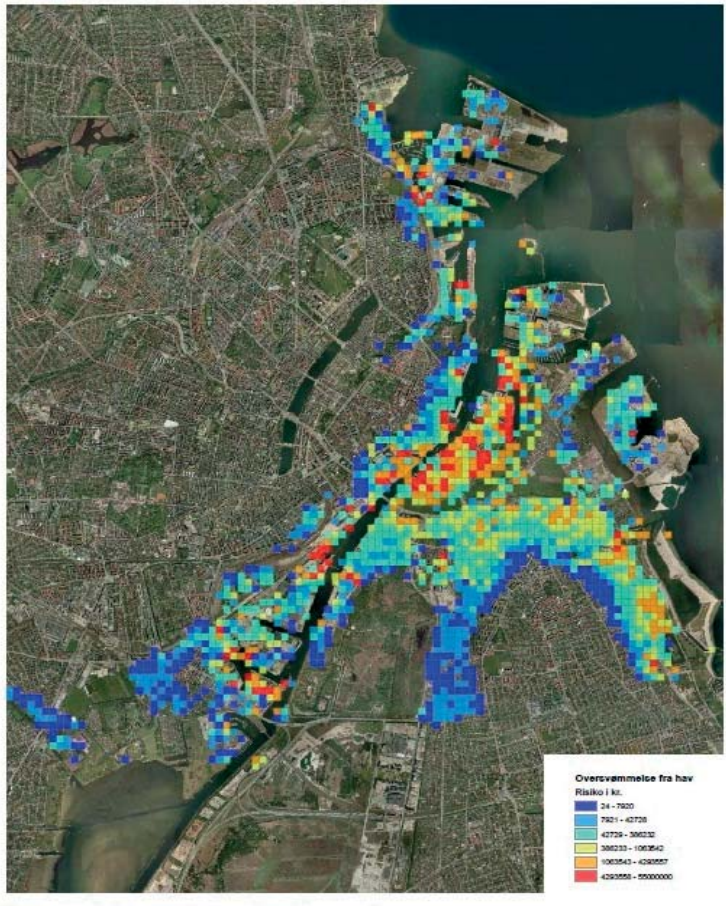

Figure 2b. Risk map for flooding of Copenhagen due to surge from the sea.

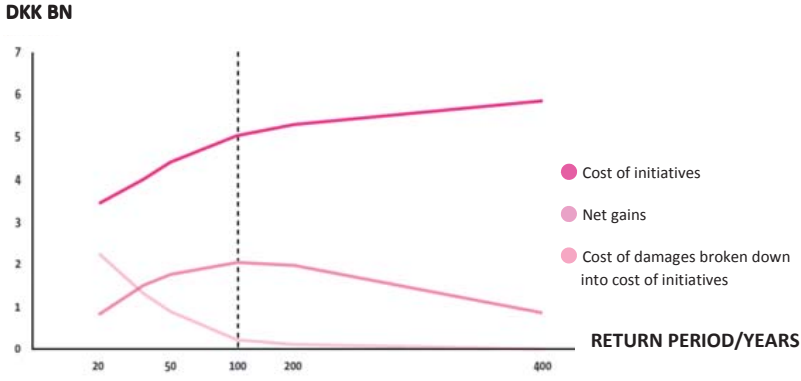

Figure 3. Calculation of the most cost-effective service level.

Figure 4. The first water square in Copenhagen (Taasinge Square) opened in December 2014. (Photo Louise Molin Jørgensen).

Natural Disasters and Societal Security: How to Prepare for an Uncertain Future

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Abstract

The Intergovernmental Panel on Climate Change (IPPC) has claimed that climate change will affect all people and countries throughout the world in the future. Unfortunately, however, no country, including Norway, is adequately prepared for climate change, whether it is in the western part of the world or other parts of the globe. Increasingly extreme weather is one consequence of the climate change Norwegian society will have to be prepared for in the future. How this extreme weather will turn out on a local level in Norway and how it will influence the societal safety of Norwegian citizens is a question without a straight answer. This contribution discusses how society and people relate to crises such as climate change, and examines their ability and willingness to prepare for natural disasters and mitigate their consequences. For a long time, research within the field of risk and safety has acknowledged that societies and organisations need to build resilience to prevent and deal with unwanted events and crises. Central to this research is how to classify, plan for and manage events with low probability and major consequences, such as severe natural disasters. Norwegian municipalities are required to do risk and vulnerability assessments in relation to future climate change. However, current risk analysis tools have done little to facilitate the process of dealing with "black swans" – surprising, extreme events – in spite of the background knowledge accumulated in this domain. To include black swan events in the risk analysis and build resilience could lay the foundation for better climate change adaptation.

Introduction

How to plan for an uncertain future and events with low probabilities and high impacts on society is a question scholars have tried to answer since Aristotle's time (Bernstein and Boggs, 1997). This question also applies to the current challenges modern societies face when dealing with extreme weather caused by climate change. The Intergovernmental Panel on Climate Change (IPPC) has claimed that climate change will affect all people and countries throughout the world in the future (EU Commission, 2009; Pachauri *et al.*, 2014). However, no country is adequately

prepared for climate change, whether it is in the western part of the world, including Norway, or other parts of the globe.

Compared to other countries, the outlook for the Nordic region is relatively favourable because climate change impacts are not expected to be as severe there as in many other parts of the world. Additionally, Norway`s robust institutions and economy provide a strong foundation for building the capacity to adapt (Ministry of the Environment, 2010; Goodsite *et al.*, 2013). This is fortunate as Norwegian society will have to be prepared to confront more extreme weather as one impact of climate change. How this future extreme weather will evolve in Norway, and how it will affect the societal safety of Norwegian citizens, are questions for which there are no clear answers.

This contribution draws on theories from risk and safety research in order to discuss challenges the municipalities in Norway will face in adapting to future extreme weather. Adaptation, along with mitigation, is essential in addressing the challenges and opportunities associated with climate change. Mitigation refers to efforts to limit both the man-made causes and the effects of climate change. Adaptation involves taking action so society can be more resilient to the current and future climate, less susceptible to the impacts of future climate change, and in a position to take advantage of any opportunities it brings (EU Commission, 2009).

We will discuss what type of risk and crises climate change are, and how the characteristics of such crises might contribute to inadequate mitigation and management of such risks. At the local level, the municipalities bear specific responsibility for adapting to climate change, and are obliged to conduct risk and vulnerability analyses with regard to future climate change. Some shortcomings of related risk analysis tools are discussed, among which is their inability to confront the challenges of "black swans" – surprising extreme events – and help build better resilience, which could lay the foundation for better climate change adaptation.

Uncertainty regarding the future climate in Norway

According to the IPPC, if the emission of greenhouse gases is not reduced, the estimated average temperature around the globe will increase by 3.7 to 4.8 degrees Celsius in the future (Pachauri *et al.*, 2014). Accordingly, the magnitude of climate change will depend on the extent to which the international community succeeds in limiting emissions of greenhouse gases. Although a considerable amount of research has aimed to estimate the extent and impacts of global warming, little is known about how this increase in temperature will affect individual regions. In fact, the smaller the geographical area under consideration, the greater the uncertainty regarding the actual outcomes of climate change.

The Norwegian Green Paper and White Paper on Climate Change Adaptation (Ministry of the Environment, 2010, 2013) describe a range of three detailed prognoses for future climate change in Norway, based on different scenarios. These indicate mean annual temperature increases of 2.3 °C to 4.6 °C by 2100, with the greatest increase occurring during winter and the least during summer. They also

predict major regional differences – the northern regions will warm up the most, and western Norway the least. Annual precipitation could increase by 5 % to 30 %, accompanied by major seasonal and regional variations, and more frequent precipitation, including massive snowfalls. Ocean temperatures and acidification are expected to increase, and the sea level along Norway's southern and western coasts is projected to rise by 50–100 cm. Sea level increases of 40–90 cm are expected in northern Norway and 20–70 cm in the areas of the Oslo and Trondheim fjords, with corresponding increases in storm surge heights. The Green Paper and White Paper also highlight Norway's vulnerability to climate change and state that the extent of this vulnerability will depend on the ability of the natural environment and Norwegian society to meet such change in the future.

Norwegian society is used to dealing with severe weather in a rough Nordic climate with many people living in remote areas. However, the anticipated frequency and magnitude of the severe weather caused by climate change will probably be new and thus unprecedented in terms of previous experience. The bottom line is that despite the fact that most climate researchers today foresee considerable climate change, we do not really know the pace of such change and what type of natural disasters Norway will have to be prepared for. The impact of climate change will have diverse regional implications, meaning most adaptation measures will need to be applied regionally. Since climate change and its effects will not be equal even at the local level in Norway, the authorities and other stakeholders operating on a local level will face a great deal of uncertainty over what type of natural disasters their community will have to build resilience against.

The municipalities' responsibility in climate adaptation

Policy documents on several levels have acknowledged that in order to build resilience against future natural disasters caused by climate change, climate adaptation measures will have to be implemented on international, national and local levels (Ministry of the Environment, 2010, 2013; Goodsite *et al.*, 2013; Pachauri et al., 2014). The White Paper on Climate Change Adaptation states that everyone is responsible for climate change adaptation – individuals, business, industry and the authorities (Ministry of the Environment, 2013). However, the local character of the impacts of climate change puts the 428 municipalities in Norway in the front line for ensuring safe communities for Norwegian citizens. To enable the municipalities to ensure resilient and sustainable communities in the future, adaptation to climate change has been made an integral part of municipal responsibilities. The Planning and Building Act (2008) and Civil Protection Act (2010) require municipalities to carry out risk and vulnerability analyses (Furevik, 2012). These assessments are seen as crucial in clarifying issues and areas of risk relevant to each municipality and for recommending initiatives to be taken by various parties in order to reduce vulnerability to climate-induced events.

Our perceptions of risks and crises influence our willingness to act upon the risks

Although the municipalities have been given special responsibility for ensuring that their communities are safe and resilient against all kind of threats, including climate change, some risks are easier for a municipality to deal with than others.

Among various types of risk identified by Renn (2008) are *simple risks*, in which the cause is well known, the potential negative consequences are obvious, the uncertainty is low, and there is hardly any ambiguity with regard to the interpretation of the risk. Simple risks are recurrent and unaffected by ongoing or expected major changes. Consequently, statistics are available and the application of statistics to assess the risks is meaningful.

Renn draws attention to the fact that not all risks are simple: they cannot all be calculated as a function of probability and effect. Such risks are called *systemic risks*. The term systemic describes the extent to which a risk is embedded in the larger contexts of societal processes. The management of systemic risks, such as climate change, requires a more holistic approach to hazard identification, risk assessment, and risk management because investigating systemic risks goes beyond the usual agent-consequence analysis. Systemic risks are not confined to national borders or a single sector and do not fit the linear, mono-causal model of risk. They are complex (multi-causal) and surrounded by uncertainty and/or ambiguity (van Asselt and Renn, 2011).

According to Renn's classification of risks, climate change is an example of systemic risk. The causes of climate change and how climate change will evolve in the future are disputed. Although multiple statistical data are available relating to the conservation of climate, it is not necessarily meaningful to use these data to describe future climate. Consequently, the issue of climate change is a risk characterised by uncertainty, ambiguity and complexity. For such risk, there is a need for a much broader perspective than just normative decision making based on traditional risk and vulnerability analysis. This implies that decision making and institutional challenges are posed not only by the complex behaviour of socioecological systems, but also by how citizens, politicians, mass media, and non-state participants frame and respond to rapidly unfolding cascading ecological crises (Hajer, 1995; Rosenthal, Boin and Comfort, 2001). This type of risk is much more open to political negotiation concerning mitigation and response.

In parallel with efforts to describe different typologies of risk, considerable scholarship has been devoted to identifying and categorising different types of crisis. The literature has tried to explain why some crises gain more attention and resources than others. Rosenthal *et al.* (2001) proposed a typology of four patterns of crisis, depending on their speed of escalation and termination. A specific attribute of a slow-burning crisis such as climate change is that it develops gradually, which makes it difficult to identify when it begins and when it ends. Most estimates and predictions of future climate change anticipate climate in a 100-year perspective. However, in order to implement sufficient climate change adaptation measures,

Norway's municipalities would have to implement measures in a much shorter time perspective. This poses a challenge to the municipalities; when can they expect the climate change to occur, and at what pace will it occur? These are questions to which there are no obvious answers, and that makes it challenging to plan and prepare for a slow-burning crisis. Because of the gradual development of this type of crisis, it does not gain the same attention as a fast-burning crisis. Given the uncertainties of when the crisis begins or if there is a crisis at all, these crises tend to be normalised, which means the extraordinary becomes the ordinary. Although climate change itself might be considered a severe risk, the lack of means to reduce the risks and mitigate against the impacts, in addition to the ambiguity over when the crisis will occur, means this type of risk might not be prioritised on a local level. Municipalities simply lack the knowledge to meet such a challenge.

Challenges of including black swans in risk and vulnerability analysis

The lack of proper means to meet the threat of more severe weather also applies to the risk- analysis tools available to municipalities. Traditional risk analysis tools estimate risk on the basis of probabilities and consequences – a perspective used to estimate risks on the municipality level (Furevik, 2012). However, an increasing number of researchers and risk analysts find the probability-based perspective on risk too narrow, and believe it ignores and conceals important aspects of risk and uncertainty. In recent years, several perspectives on risk have been developed where probability is replaced by consequences and uncertainty in their definitions (Aven, 2015; Aven and Krohn, 2014; Aven, Renn and Rosa, 2011). These perspectives regard probability as a tool to describe uncertainty, and suggest that the concept of risk extends beyond this and its evaluation should therefore not be limited to this tool. They also claim that more weight should be attached to the knowledge dimension, the unforeseen and potential surprises, than is allowed for in traditional perspectives. A key point is that the probabilities could be the same in two situations, but the knowledge and strength of knowledge supporting the probabilities could be completely different. These perspectives are proposed for use in the risk management of "black swan" incidents (Aven, 2015) because traditional perspectives to risk cannot capture the complexity of such risks, given the lack of knowledge associated with these risks.

The metaphor and concept of the *black swan* has gained a lot of attention recently and is a hot topic in many forums that discuss safety and risk. In the scientific community, it has also come under scrutiny following the publication of Nassib Taleb's book, "The Black Swan". Taleb refers to a black swan as an event that has the following three attributes: First, it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme impact. Third, despite its outlier status, in hindsight, people come up with explanations for its occurrence after the event, making it explainable and, importantly, predictable.

Aven (2015) has further developed the concept of black swans and claims that *black swans are surprisingly extreme events relative to current knowledge*. Hence, the concept always has to be viewed in relation to whose knowledge we are talking about, and at what time. This means one type of natural disaster at one point in time or in a particular geographical area can be seen as a black swan, but not in another area. According to Aven and Krohn (2014), there are three main types of black swan events.

The first type of black swans encompasses known events judged to have a negligible probability of occurring, and thus are not expected to occur, or to only occur very rarely. An example of this type of event is a flood that is expected to occur once every 1000 years. These are natural disasters we know can occur, but due to their low incidence, emergency preparedness measures are not scaled to necessarily meet the extreme threats they pose. Another example of this type of black swan would be an earthquake in Norway's densely-populated areas (The Directorate for Civil Protection, 2015b). We know that this type of scenario could occur, but its probability is considered negligible.

The second type of black swans includes events associated with a great amount of uncertainty. These events might be known to some, but not all, stakeholders. Examples of such black swans are the fires in Lærdal and Flatanger in 2014. These fires occurred during winter in Norway – which is usually not very dry. However, due to extremely dry weather conditions, the fires spread rapidly and caused major damage to surrounding buildings. In the aftermath of these events, several researchers claimed there is a lack of knowledge in Scandinavia concerning this type of fire and that climate change could contribute to the occurrence of similar fires in the future (Steen-Hansen *et al*. 2016, this volume).

The third type of black swans are events that are completely unknown to decision makers. Examples of such events would be tornadoes of great magnitude, major ice storms, or severe hailstorms. These are weather phenomena that occur annually in North America, but if they were to occur in Norway, they would be considered black swans of the type "unknown unknown".

New perspectives on risk management acknowledge that black swan events should also be a part of risk analysis. To classify different scenarios according to the three types of black swan could be an exercise to anticipate scenarios of extreme weather becoming a reality in the future. Broadening the range of scenarios would also be beneficial to building capacity, or resilience, to meet a greater variety of threats.

How to build resilience against future climate change

In recent years, the resilience concept has been used on a societal level in reference to how societies can "bounce back" in the face of a disturbance. The image of an uncertain world, in which new types of risks and threats can become a reality in the future, has moved the focus away from safety from one type of threat to society`s ability to tackle all kinds of possible scenarios that might unfold. As a consequence,

several governments and the United Nations have introduced the concept of resilience as a disaster preparedness strategy to enable countries to improve their ability to handle crises through their societies and to enhance empowerment in line with sustainable development (Comfort, Boin and Demchak, 2010; Manyena, 2006).

The definition and content of the concept of resilience has been contested, but the essential characteristic of a resilient system is its ability to adjust its functioning so it can succeed in different situations. According to the resilience engineering perspective, this implies four main aspects or dimensions; knowing what to do, knowing what to look for, knowing what to expect, and knowing what has happened (Hollnagel, Woods and Leveson, 2007; Woods, Leveson and Hollnagel, 2012).

First, resilience is knowing what to do in critical situations. This means responsible parties should not only know what their responsibilities are in a crisis, but also their real capacities. It also means knowing what resources are not available, and the limits that represents. The tasks and responsibility for dealing with natural disasters are often discussed in relation to public and private parties on different levels. However, the role of private citizens is often neglected in the planning process. The public's reactions in crises are generally not characterised by panic, helplessness and looting; most citizens act rationally and help their fellow citizens in a crisis (Tierney, Bevc and Kuligowski, 2006). Bystanders are the ones who are there when a crisis occurs, and they are therefore the ones who actually rescue people, as exemplified by the Longyearbyen avalanche on Svalbard in December 2015. This means citizens should be educated by also having access to updated knowledge, and they should be seen as a resource in a crisis. Most of the municipalities in Norway are not located in large city areas, and people in these country areas have traditionally been accustomed to helping each other in crises caused by natural disasters.

Second, resilience is also to know what to look for. This means not only monitoring vulnerabilities in local communities, but also keeping an eye on natural disasters that are happening in other parts of Norway or Europe. This implies that risk analysis and emergency plans continuously need to be updated and should always incorporate the latest knowledge concerning vulnerabilities and threats.

Third, resilience is knowing what to expect. This means anticipating future developments in natural disasters caused by climate change. To develop emergency plans that work for the endless array of complex scenarios that could unfold is neither desirable nor possible. Consequently, capacity building is important in order to achieve resilience. In addition to capacity building, it is also important to be able to envisage a wide range of possible scenarios including black swan events. To gain resilience, municipalities should envisage all three types of black swan event described in this article. These skills can be utilised to envisage different scenarios, including complex and non-plausible events. This means being *open* to the future, not trying to predict a predetermined future, but exploring how the future might evolve in different ways.

Fourth, resilience is also to know what has happened, meaning people can learn from experience not only about natural disasters that have taken place in the

local community, but also how other communities have addressed the challenges of natural disasters. This means learning after a natural disaster what went wrong, and knowing what worked well.

The four characteristics of a resilient system are all related to knowledge concerning possible scenarios, vulnerabilities, and the means a local community has available in a crisis to utilise the resilience it has developed. If we consider that black swan events are related to the level of knowledge, one of the most important strategies in adapting to climate change is to gain knowledge and update it, and ensure that stakeholders at all levels – including the municipalities who carry the responsibility of implementation, have access to this knowledge.

Challenges for municipalities managing the risks related to climate change

Municipalities are in the front line in the challenge to adapt to climate change in Norway because extreme weather always hits on a local level, and it is the stakeholders at this level who know about and understand the vulnerabilities and risks involved (Ministry of the Environment, 2013). Municipalities are also obliged to include risks related to climate change in their risk and vulnerability analysis and incorporate this knowledge in the city, town and country planning processes. Although, theoretically, this seems adequate in confronting and dealing with the effects of climate change, there are several challenges related to the responsibility vested in municipalities in addressing climate.

For example, it is not obvious to a municipality how a local community should respond to a climate threat which is characterised by uncertainty, ambiguity and complexity. The municipalities are also responsible for economic growth in the region. To enhance safety due to current and future climate changes is just one of their many responsibilities. Risk and vulnerability analysis has not always been used to make safe decisions. Several studies have shown that risk and vulnerability analysis often has been used to safeguard existing operations, rather than to decide whether or not an activity should be established (Tierney, 1999; 2014).

Management of risks and hazards often relies on partial analysis which considers only a limited period. This may lead to a paradoxical situation in which risk management and extended use of risk analysis could hamper long-term sustainable development. Sustainable development indicates that long-term decisions need to be made. From this perspective, climate mitigation and adaptation should be considered in a long-term perspective, anything from a decade to a century (Olsen, Langhelle and Engen, 2006).

Risk analysis is also often limited to specific areas or sectors, so conducting cross-sector risk analysis or risk analysis that covers broader geographical areas has proved to be a challenge in Norway and other countries. In Norway, municipalities have been obliged to conduct an overall risk analysis for the whole municipality. Although this has been the responsibility of individual municipalities since 2010, many municipalities in Norway have not yet conducted such an analysis (Directorate

for Civil Protection, 2015a). Hence, it is important to acknowledge that giving a municipality the responsibility of conducting risk and vulnerability analysis related to climate change does not solve the challenges related to climate change adaptation if the relevant municipality does not carry out the analyses.

Several studies have shown that risk analysis and other emergency plan strategy documents are often produced to meet the legal requirements, but not necessarily implemented to ensure that safe, optimal safety decisions are made. This has led to such documents being labelled "fantasy documents" (Clarke, 1999). To ensure the best possible decisions are made in building resilience to climate change, a better knowledge foundation needs to be established in how to deal with the consequences of climate change and how they could affect local communities. However, there is also a need to develop risk and vulnerability analysis and emergency plans that take into account which resources are actually available to meet these threats. Increased awareness is needed regarding which resources are lacking. Furthermore, emergency preparedness plans should involve an analysis of vulnerabilities and what measures can reduce these vulnerabilities. Such documents need to be updated in accordance with the latest knowledge, including that learned from the experiences of natural disasters that have occurred.

Conclusion

Adaptation for tackling future natural hazards involves acknowledging that the climate is changing, understanding how such change may affect nature and society, and making choices that will minimise the negative aspects of the impacts, while at the same time taking advantage of possible opportunities that arise from a changing climate. Knowledge about future climate change – how fast and to what extent the climate will change – is neither complete nor certain. Current climate change research does not provide any definite answers. Accurate predictions and estimates cannot be provided but, in most cases, informative risk descriptions can, and this has to be recognised. This means that in order to build resilience against future natural disasters, there is a need to gather knowledge about the impacts of climate change, how this change will impact communities on a local level, and how these communities can achieve societal security for their citizens. Knowledge sharing and involvement should be implemented at all levels, and should include government bodies across sectors. These stakeholders should aim to gain experience and share lessons learned from adaptation actions and results in their attempts to increase and maintain capacity building at various levels. To include black swan events in the risk analysis, and to build better resilience, might lay the foundation for better climate change adaptation.

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Closing Comments

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The Norwegian Academy of Science and Letters, the Norwegian Academy of Technological Sciences and the Research Council of Norway together took the topical initiative to arrange this worthwhile seminar on the topical subject of "Natural Disasters and Societal Safety". The lecturers and participants came from a broad spectrum of highly specialised scientific experts, practitioners and stakeholders, and authorities with expertise in co-operation and co-ordinated action.

Society needs meeting arenas such as this cross-disciplinary seminar. Academia needs to be reminded of the urgency and the experience from practice, be it from the Norwegian Public Road Administration, the Norwegian National Rail Administration and energy companies, or emergency responders to everyday hazards such as the fire authorities, the police authority and the Norwegian "Search and rescue" organisation. Conversely, the practitioners need the scientific contribution and feedback from academia. Furthermore, research is needed across discipline boundaries, and to promote radical innovation. The seminar successfully demonstrated such needs, and that that there is a basis in Norway for even greater synergy.

There was wide consensus on the need to strengthen the knowledge base on natural hazards and societal safety. My personal recommendation is that scientific/societal co-ordination and co-operation be strengthened in parallel, and that common actions be recognised as more than co-ordination and co-operation. Successful common actions also require operative resources at both the regional and local plan.

My hope is that the initiative taken by the scientific community and the research organisations to promote co-operation, sharing of knowledge and co-ordination among academia, practitioners and public stakeholders will continue and be strengthened in the future. The Ministry of Justice and Public Security has an earmarked responsibility in the management of risks and the mitigation of consequences associated with natural hazards. Furthermore, research organisations and individual researchers need to recognise their responsibility to advance the knowledge in this field, and to make this knowledge available for society. The seminar has stimulated a sharing of know-ledge and contributed to strengthening the trust among politicians, decision-makers, stakeholders, industry and scientists and will thereby contribute to increased public safety.

Vote of Thanks

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Your Majesty
Deputy Minister
Mayor of Oslo
Honoured guests

In these few minutes, on behalf of the two scientific Academies and the Research Council of Norway, I wish to extend our thanks to many. First, a special expression of gratitude to His Majesty King Harald for his interest and his participation to the symposium.

The spirit of our annual joint symposium is research communication along the axis between politics and science, where Norway's leading researchers meet face to face with community leaders and decision-makers. The theme for this 2015 symposium is absolutely timely, in light of recent events in Norway and in many other parts of the world.

Our gratitude also goes to Deputy Minister Hans J. Røsjorde for setting the scene at the start of the symposium, and to Mayor Fabian Stang for his presence at the symposium. We see as a privilege to be able to inform the Norwegian Government and City Hall of the activities of our two scientific academies.

The Organizing Committee also wish to thank each and all of the lecturers. The oral lectures have now been formalised in text form in this publication. Both hard copy and digital versions on the web are available.

Such scientific counsel from national scientific academies has a long tradition abroad. For example, the National Academy of Sciences and the National Academy of Engineering in the USA have acted as counsel to the president over 100 years, starting as early as 1916. The two US academies publish annually over 200 publications such as this one!

In closing, I wish to ask for one more applause, this one for King Harald.

About the Authors

Hans J. Røsjorde, now retired, was Deputy Minister in the Justice and Public Security Ministry in Norway. He is Candidatus realium in marine biology from the University of Oslo, and also has completed his officer training. From 1970 to 1987, he was both high school teacher and regional manager of the Stord Home Guard (HV). From 2001 to 2011, he was County Governor in Oslo and Akershus. Between 1981 and 1989 he was Deputy in the Hordaland political leadership. He became Member of Parliament for Hordaland in 1989, a responsibility he held until 2011. During his tenure as Member of Parliament, he had several responsible positions, including Chair of the Parliament Administrative Board, President of Lagting, Chair of the Defence Committee and Parliamentary Vice-President. From 2011 to 2013 he was member of the Parliament's Commission on "Scrutiny of the Intelligence and Security Service". He also held several political responsibilities for the Progressive Party ("Fremskrittspartiet") in Norway.

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Landslide in sensitive clay causing failure of pillar on Skjeggestad Bridge, February 2 2015
(Photo: Teknisk Ukeblad, 2015)