

**UIC Project**

**ARISCC**  
**Adaptation of Railway Infrastructure  
to Climate Change**

**Final Report**  
(6<sup>th</sup> draft version)

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## 1. Executive Summary

ARISCC focuses on an integrated management of weather and climate related natural hazards in a way that keeps and improves railway infrastructure performance and avoids or minimizes damage to railway infrastructure assets. It starts with natural hazard management under today's weather conditions and develops solutions and strategies to prepare for the changed climate and weather conditions of the future.

ARISCC covers a wide range of weather and climate related natural hazards such as such as flooding, severe storms, landslides, rock fall, avalanches etc. and the respective risks for railway infrastructure.

The results of ARISCC comprise the update and extension of an existing survey on the current status of adaptation of European railways to climate change, a guidance document on integrated natural hazard management, an extensive collection of good practices and two case studies using regional climate models for the identification of future regional climate loads and existing vulnerabilities of railway infrastructures.

The ARISCC guidance document for Railway Infrastructure Managers for an integrated natural hazard management comprises the following elements:

1. Weather Information and Weather Warning
2. Documentation & Assessment of past Weather Events
3. Natural Hazard Mapping
4. Monitoring and Documentation of the Status of Infrastructure Assets
5. Vulnerability Mapping
6. Risk Assessment and Risk Management
7. Regional Climate Models and Future Climate Loads
8. Adaptation Recommendations

For each of these eight elements, recommendations for the development and implementation of the respective systems and measures as well as good practice examples are given.

### General Recommendations

According to current climate models and projections, higher frequencies and intensities of extreme weather events are to be expected in the future. This holds with a certainty for very high temperatures, heat waves and intense short time as well as extended rainfall events. Without an adaptation strategy and adaptive action, the present resilience of railways could prove to be insufficient in the near and midterm future. Therefore it is recommended to develop a proactive adaptation strategy and systematically build up adaptive capacity. The strategy should comprise short term as well as mid-term and long term adaptation goals and measures and has to take into account affordability. The guiding principle of the integrated strategy should be the three Rs

- Readiness - To be well prepared for extreme weather events
- Resilience - To systematically increase the resilience of the whole system
- Recovery - To have contingency plans allowing for fast and full recovery

Adaptation strategies should benefit the management of today's extreme weather. This guarantees a strong direct link to every day operation of railway infrastructure and to the actual problems faced in connection with severe weather events and impacts. Furthermore, it allows the exploitation of efficiency potentials through the concentration and focussing of resources which can be widely distributed over

different business units. At the same time, adaptive capacity is systematically built up.

As a short to mid term option engineering specifications should be reviewed to pave the way for an improved resilience of the railway system. Changing specifications are most likely to be expected for the dimensioning of drainage systems, flood protection and for protection against heat waves.

When measures are assessed and prioritised the objective should not solely be the strengthening of single assets or railway lines but the improvement of system resilience.

### **Specific Recommendations**

It is highly recommended to develop weather information and weather warning systems tailored to the needs of railway infrastructure operators. These systems allow a much more efficient disposition of resources, longer pre-warning times for severe weather events and so a higher awareness and better preparedness.

Past extreme weather events and their impact on the railway infrastructure should be systematically documented and assessed as one important approach to identify the vulnerabilities of the system. In parallel, the appropriate metrics for measuring the impacts should be developed. For easy access and convenient handling the data should be stored within a central “event database” and visualized by using a GIS.

Systematic hazard mapping allows the identification of potentially dangerous situations for the railway infrastructure and the locations of potential impact. This provides an evidence base for identifying vulnerable assets. By using the output of climate models, hazard mapping can be extrapolated into the future and thus used for adaptation purposes.

A central asset database for all relevant kinds of railway infrastructure assets with detailed information about the current general and maintenance standard for each asset provides a solid basis for assessing vulnerabilities. In order to standardise and simplify assessment procedures, different status classes reflecting the urgency of mitigation measures should be defined.

Merging natural hazard maps with knowledge about past extreme weather events and the general status and maintenance standard of infrastructure assets allows the identification of the vulnerable parts of the railway system. The output of the merging process should be made available as vulnerability maps. These can provide a good basis for the selection of appropriate adaptation measures.

A systematic risk assessment for weather and climate related events should be implemented taking into account possible impacts on railway infrastructure assets in five dimensions – safety, damage to assets, people, environment, reputation and financial losses. The assessment should be based on the above mentioned hazard and vulnerability maps and should integrate expert knowledge about expected frequencies of hazardous events. A convenient way to standardize the assessment process is the use of a risk matrix.

Regional climate models should be used to identify expected future climate loads since they allow the calculation of possible impacts on the railway infrastructure. Relevant direct output of the models are trends for climate and weather parameters and – with less certainty - intensities and return periods for extreme weather events.

### **Recommendations for the Implementation of Adaptation Procedures**

One of the core parts of an efficient natural hazard management system is a well structured and integrated database. This database can be gradually developed by interconnecting existing databases for asset management, maintenance planning

and disruptions as well as digitised railway network data. Provision can be made for missing elements such as event and incident databases which should be incorporated as available.

For current operation, adaptation to climate change aspects should be integrated into current maintenance planning and especially priority setting timing decision procedures. Keeping good maintenance standards is already a first important step towards higher system resilience.

For future projects, adaptation to climate change aspects should be integrated into the design of assets. This can be achieved by integrating adaptation into the early stages of current planning processes and especially into the standard vulnerability and risk analysis of project planning. Integration of adaptation aspects is highly relevant for long living railway assets.

There is a wide range of practical adaptation measures ranging from warning systems and monitoring to improving maintenance standards, reinforcement of protective structures and the change of standards for future projects. Priorisation of measures and finding the optimum combination for a project or a railway line depends on many factors such as types of assets, time horizon, importance of the route, financial constraints, cost benefit ratio etc. “Soft measures” such as real time monitoring of vulnerable sections and rapid alert systems can have much better cost benefit ratios than “hard engineering solutions” such as the reinforcement of protective structures.

The implementation of an integrated natural hazard management starts a process of capacity building for the adaptation of the company to climate change. This process can be improved and accelerated by better knowledge exchange inside the company and between different infrastructure managers as well as with external stakeholders and partners. Good practices and pilot projects in the different areas should be openly communicated and actively shared. It makes also much sense to learn from those who are facing now the conditions you expect for your region in the future.

The future role of UIC in strengthening and improving the adaptation of railway infrastructure to climate change could comprise the following measures and actions:

- Facilitate and coordinate knowledge sharing e.g. by hosting the ARISCC web platform and by organising adaptation workshops
- Facilitate the development of appropriate metrics for impact and vulnerability assessment
- Support the development of appropriate governance approaches for adaptation

## **2. Objectives**

The objectives of ARISCC are to

- Give the current Status of Adaptation of Railway infrastructures to climate change
- Provide a guidance document for railway infrastructure managers for an integrated natural hazard management covering weather warning systems, event databases, hazard and vulnerability mapping, asset databases and risk assessment procedures.
- Give recommendations of adaptation to climate change strategies and measures
- Investigate the vulnerabilities of railway infrastructure within the framework of two case studies

## **3. Approach**

The project ARISCC (Adptation of Railway Infrastructure to Climate Change) focuses on an integrated and efficient management of weather and climate related natural hazards such as flooding, severe storms, landslides, rock fall, avalanches etc. in a way that keeps and improves railway infrastructure performance and avoids or minimizes damage to railway infrastructure assets. In order to use the existing knowledge and ressources in this field and to guarantee a high acceptance of the approaches and measures, ARISCC starts with natural hazard management under today's weather conditions and develops solutions and strategies to prepare for the changed weather and climate conditions of the future.

## 4. Scope

ARISCC covers the following weather and climate related factors, associated natural hazards and respective risks for railway infrastructures:

Factor	Effect	Impact on Railways/Assets
All listed factors/events will occur more often and their impacts will be more severe according to the existing climate models		
<b>1. Temperature</b>	<b>change of distribution patterns, higher average and maximum temperature</b>	
1.1 High temperatures and heat waves	overheating	infrastructure equipment rolling stock equipment
1.2 Sudden temp changes	tension	track buckling
1.3 Intense sunlight	overheating	track buckling, slope fires, signaling problems
1.4 Freezing and thawing cycles	soil erosion	damage to embankments, earthwork
<b>2. Precipitation</b>	<b>change of distribution patterns, more extreme events</b>	
2.1 Intense rainfall	soil erosion, land slides, flooding	damage to embankments, earthwork
2.2 Extended rain periods	slower drainage, soil erosion	other infrastructure assets, operation
2.3 Flooding: coastal, surface water, fluvial	landslides	drainage systems, tunnels, bridges
2.4 Drought	desiccation	earthworks desiccation
2.5 Snow and Ice	heavy snowfall, avalanches	restrictions/disruption of train operation
<b>3. Wind</b>	<b>change of distribution patterns, more extreme events</b>	
3.1 Storm/gale (inland)	higher wind forces	damage to installations, catenary
	uprooting of trees	restrictions/disruption of train operation
3.2 Coastal storms & sea level raise	Coastal flooding	embankments, earthwork, operation
<b>4. Lightning strikes and thunderstorms</b>	Overvoltage	catenary and signaling
<b>5. Vegetation</b>		vegetation management



## 5. ARISCC Results

### 5.1 Current Status of Adaptation of Railway Infrastructures to Climate Change

Within the framework of the project, an existing survey on the current status of adaptation of European railways to climate change from 2009 has been updated and expanded in 2011.

#### 5.1.1 Geographical coverage of the survey

In total 20 questionnaires were returned - 18 from European infrastructure managers, 1 from India and 1 from Canada. This is a very good feedback indicating a high interest in the topic. The following table illustrates the geographical coverage of the survey in Europe.

Country	Symbol	Infrastructure Manager
Austria	A	ÖBB
Belgium	B	InfraBel
Bulgaria	BG	NRIC
Czech Republik	CZ	SŽDC
Finland	FIN	RHK
France	F	RFF
France	F	SNCF
Germany	D	DB Netz
Hungary	HU	
Italy	I	RFI
Norway	N	Jernbaneverket
Netherlands	NL	ProRail
Poland	PL	PKP Polskie Linie Kolejowe S.A.
Portugal	PT	REFER
Romania	RO	CFR
Sweden	S	Banverket
Switzerland	CH	BSL
United Kingdom	UK	Network Rail

#### 5.1.2 Adaptation to Climate Change as a Company Issue

Adaptation to climate change is clearly an upcoming strategic issue for the railways. The majority of infrastructure managers (14 out of 20) classify adaptation to climate change as a very important or important issue in the company and 12 out of 20 have already established task forces or have dedicated experts for this field. 8 companies plan to establish cross department groups for adaptation issues.

Adaptation to CC is	very important in 5 companies (A, FIN, D, N, CH) important in 7 companies (BG, F, HU, I, PL, S, GB)
Established Task forces	3 companies (A, D, S)
Dedicated experts	7 companies (A, F, D, I, N, NL, CH, UK)
Planned cross-department groups:	8 companies (BG, FIN, D, HU, N, PT, S, GB)

**5.1.3 Ranking of the impacts of climate change on railway infrastructure and of the vulnerability of assets**

A ranking of the importance of the different impacting factors of climate change yielded the following results:

- 1. Flooding
- 2. Storms/gale (inland)
- 3. Intense short time period rainfall  
Extended rain periods (widespread)
- 4. High maximum temperatures
- 5. Lightning strikes and thunderstorms
- 6. Sudden temperature changes

The highest impacts on the railway infrastructure were attributed to flooding events, storms an gales and intense short time period rainfall as well as extended rain periods over wider areas.

In accordance with this ranking, the most vulnerable railway infrastructure assets were identified as follows:

Railway Infrastructure Asset	Vulnerability Ranking
Embankment	1
Substructure	2
Drainage system	3
Water passages (Culverts)	3
Bridges	3
Catenary	4
Rails, Fastenings,	5
Signaling system	5
Ballast and Ballast formation	6
Telecommunication system	7
Tunnels	8
Stations	9
Shunting yards	10
Maintenance Depots	10
Coastal defenses	11
Sleepers	11

**5.1.4 Adaptation Activities of European Railways**

Within the European Railway community there is a wide spectrum of ongoing and planned activities concerning the adaptation to extreme weather situations and climate change ranging from monitoring and mapping efforts to assessments of the impacts of extreme weather events on railway infrastructure assets.

The activities can be divided into four major areas:

- 1. Weather Information and Weather Warning**
- 2. Hazard Mapping, Vulnerability Mapping and Risk Management**
- 3. Monitoring & Documentation of Status of Infrastructure Assets**
- 4. Engineering Work (Maintenance, Upgrading, New Infrastructure)**
- 5. Company Policies & Adaptation Strategies and Programs**

### **5.1.5 Competences & Experiences**

The current experiences and competences of European Railways regarding natural hazard management and adaptation to climate change are summarized in the following table:

### **5.2 Guidance Document**

ARISCC provides a guidance document for Railway Infrastructure Managers for an integrated natural hazard management comprising the following elements:

1. Weather Information, Weather Warning and Weather Monitoring
2. Recording, documentation & assessment of past weather events (“Event Database”)
3. Mapping of natural hazards which can potentially impact the railway infrastructure (including the locations of possible impacts)
4. Monitoring and documentation of the status of infrastructure assets (e.g. bridges, drainage system, tracks, earthworks, signalling system...) including protective measures (“Asset Database”)
5. Assessment of the vulnerability of railway assets with respect to the different natural hazards (“Vulnerability Maps”)
6. Assessment and management of the risks associated with different natural hazards – risks to asset integrity, railway operation, environment, railway image and safety risk (“Risk Management”)
7. Assessment of future weather and climate related natural hazards by using regional climate models

The processes and information flows for an integrated natural hazard management taking into account potential changes of natural hazards due to climate change are shown in the following picture:

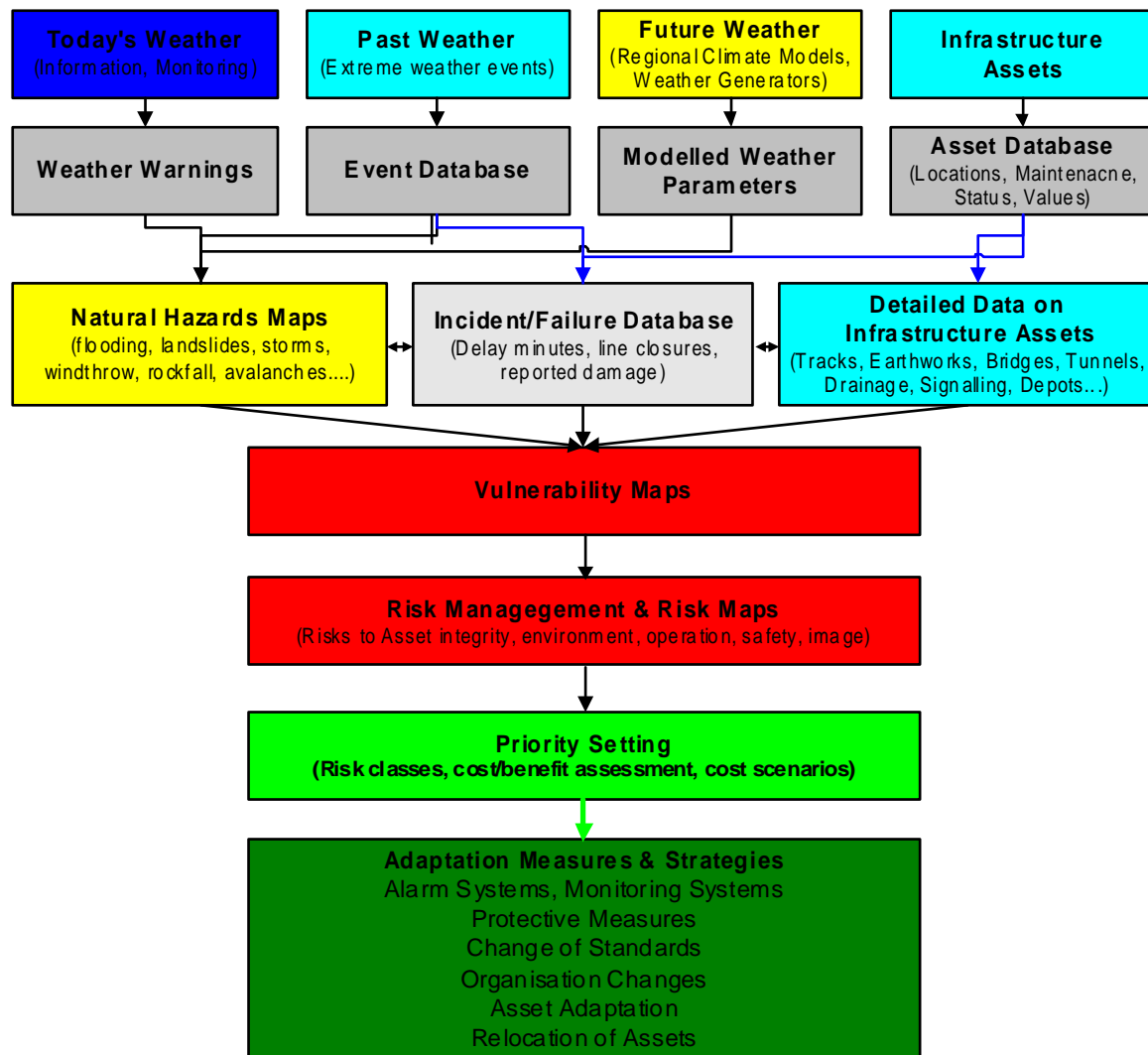


Figure 1: Elements, processes and information flows for an integrated natural hazard management including adaptation to climate change aspects.

All important elements of an integrated natural hazard management taking into account aspects of climate change are described in the following chapters.

### 5.2.1 Weather Information, Weather Warning and Weather Monitoring

Most railways rely today on the standard weather information which is available from the national weather services. Despite the fact the coverage of weather stations in Europe is rather good, the standard service has some disadvantages:

- Information about weather conditions and developments have to be actively searched for by the people who work with them within the railways
- Weather information is rather general and not related to the line section topology of railway infrastructure
- Weather warnings are very general. Often the spatial and temporal resolution and/ or the reliability are rather low
- Pre-warning times are rather short leaving little time to act
- There is no prioritisation of those data which are especially relevant for the railways

To overcome these limitations, some railways have introduced dedicated weather information and weather warning systems. A very important feature of the good practice examples in the field is the filtering and focus of those weather information relevant for the operation of railway infrastructure and rolling stock such as expected gales and storms, events with heavy or prolonged precipitation, sudden temperature changes or leaf fall. Another feature of those systems is the automatic transmission of important weather information to the relevant people within the railway company – either by e-mail, GSM(-R) mobile communication network or both. Thus, the number of people informed and the quality level of information about actual weather conditions and projections could be significantly improved.

In regions with a pronounced topography and areas sensitive to natural hazards and thus, very specific local weather conditions like the Alps, the spatial coverage of public weather stations has proved to be not sufficient for railway purposes. Therefore the Austrian Railways decided to invest into additional weather stations in order to close the gaps. These weather stations are operated by an external service provider and have proved their usefulness over the last couple of years – especially with regard to the prediction of natural hazards such as snow avalanches, fluvial flooding and mud slides. In addition to the implementation of new weather stations the meteorological forecasting model for improved in order to produce more reliable forecasts with a higher spatial and temporal resolution.

More advanced dedicated weather information systems feature clearly defined warnings with regard to extreme weather situations such as storms and gales, potential flooding, heat waves, snow avalanches etc. The respective warning levels are associated with concrete threshold values and are based on experiences. They can differ according to the region concerned and the capacity of the local personnel to deal with the corresponding situation. A certain amount of snowfall in the mountains can be totally harmless, whereas the same amount in the lower lands might already constitute a hazard.

A colour coding of the different warning levels and a visualization of this information in a GIS based system is especially helpful and makes the data much easier to handle by the relevant people within the organisation. An exceptionally good example for this approach is the system Infra.Weather implemented by ÖBB. An example for the visualisation of natural hazards within the framework of this system is shown in the following figure:

The main features of dedicated weather information and weather warning systems for railways can be summarized as follows:

1. Temporally and spatially highly resolved weather information related to the line section topology of railway networks
2. Generation of reliable weather warnings with coded warning levels
3. Automated distribution of weather information by e-mail and sms to all relevant users inside the organisation
4. Provision of additional tailored weather information relevant for the operation of railway infrastructures and rolling stock, such as water level in rivers, amount of local snowfall, information on leaf fall (slipperiness)...
5. Weather information is easy accessible via a dedicated online portal
6. Visualisation of weather data, predictions and warnings using a GIS-based overlay of railway tracks and meteorological data

The aspect of adaptation to climate change can be integrated into dedicated weather information and weather warning systems by an assessment of the current warning levels and their projection into the future taking into account the expected climate loads. These can be derived e.g. from high resolution regional climate models. The most interesting output for this purpose is the change of return periods and intensity of extreme weather events. When warning levels have to be adapted it has to be evaluated if the response processes linked with the warning levels are still appropriate under the changed conditions.

### Example: *InfraWeather* from ÖBB

A dedicated weather information and weather warning system has been developed and implemented at ÖBB. Preparative work included the installation of additional weather stations for better spatial coverage, the development of regional meteorological model, GIS-based overlay of railway tracks and meteorological data as well as GIS-based delineation of flood risk.

#### Information system including online portal

The *InfraWeather* online portal gives access to general weather information, forecasts as well as weather warnings. A map shown on the user interface gives an overview over the Austrian railroad system with the most important weather information; beside the diagrams the information is also given in textual form with a 3h interval of forecasts.

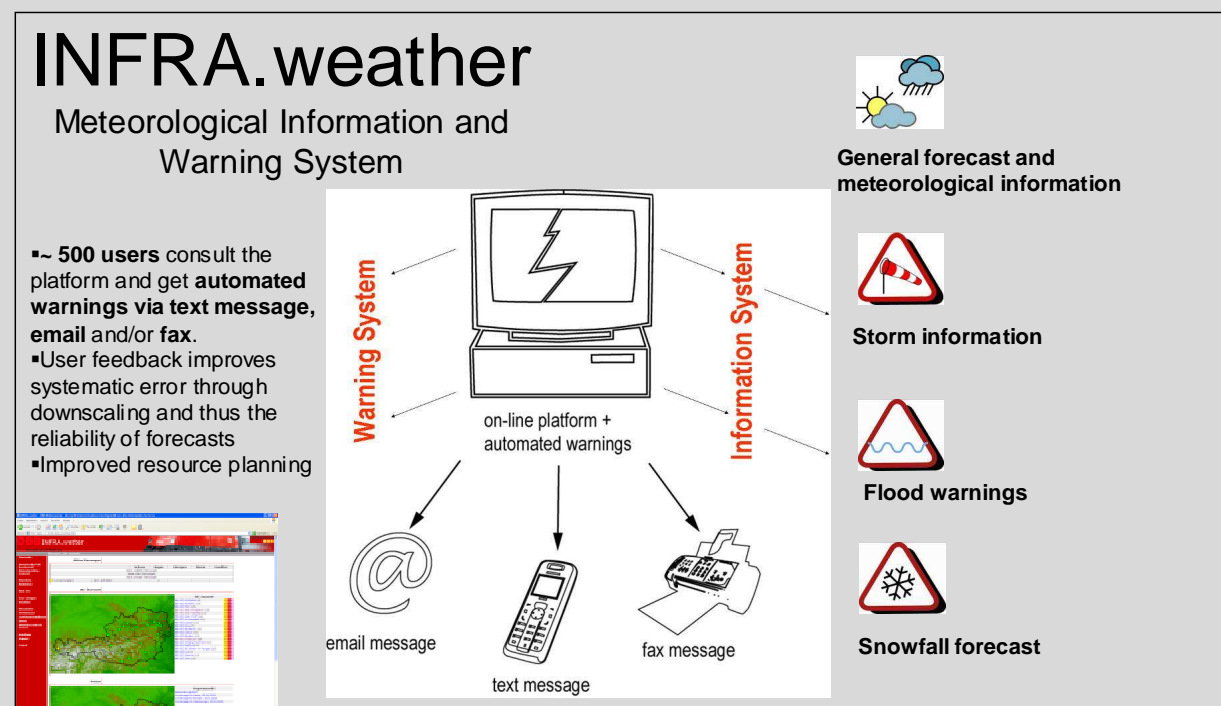


Figure 2: Overview over *InfraWeather* - the dedicated weather information and weather warning system of ÖBB

#### Storm forecast

With the new forecast models and radar techniques weather extremes can be forecasted on a scale of 10 km, partly even lower. This is possible due to the definition of natural areas, units with similar natural conditions. These are

meteorological divides, crests, valleys etc.

### Flood forecast and warnings

The forecast of floods integrates the water level of the rivers and the meteorological data so that the warnings can be sent 12 hours in advance.

### Snowfall forecast

The snowfall forecast includes the amount of snowfall in the next 24 to 72 hours for each warning point.

### Weather warning system

InfraWeather has a dedicated operational warning service, which provides also real-time severe weather warnings. Extreme weather events covered by the warning system are thunderstorms, flood events and heavy snowfall. The forecast of disastrous thunderstorms is provided by using 'nowcasting' techniques, where the track of thunderstorms can be forecasted 20 - 60 minutes in advance.

When predefined warning levels are reached, alert messages are automatically generated by the system and sent via sms, email, fax and telephone to all responsible people inside the company.

### Warning levels

In the following table, an example for the definition of warning levels is given:

warning level	snow / wind situation	measures
A	Less than 10 cm of snow in the next 12 hours, low wind speeds	Clearing of customer areas
B	10-20 cm of snow in the next 12 hours, low wind speeds; less than 10 cm + wind > 40 km/h	Shift operation, restricted use of side tracks
C	20-30 cm of snow in the next 12 hours; 20 cm of snow + wind speed > 40 km/h	Like B, heavy snow removal equipment is in use
D	30-40 cm of snow in the next 12 hours; 30 cm of snow + wind speed > 40 km/h	All capacities are on duty; restricted use of platforms, side tracks and some main tracks
E	More than 40 cm of snow in the next 12 hours; 30 cm of snow + wind speed > 60 km/h	Emergency mode

### Benefits of tailor made weather warning systems

An important benefit of tailored weather warning systems for railways infrastructure managers is the increased pre-warning time for different kinds of natural hazards which can be used for a better preparation and more efficient response. Another aspect is an improved management of personnel and machinery. Personnel costs can be saved by optimising disposition well in advance and by means of pre defined response plans. Costs can also be saved on equipment rental since it is the more expensive the shorter the notice. Further costs savings can be achieved due shorter durations of speed restrictions and line closures since warnings and following clearances can be timed and localised much more accurately.

Since situations in the future which are similar to those already experienced in the past can be handled much more efficiently, the planning options for response measures to severe weather events are significantly improved because over time. This capacity building process should be actively managed.



**5.2.2 Recording, documentation & assessment of past extreme weather events (“Event Database”)**

One way to identify vulnerable parts of the railway infrastructure is the detailed analysis of past extreme weather events and their impacts on infrastructure assets. In the following figure, a map with examples of extreme weather events in Europe within the last decade is shown:

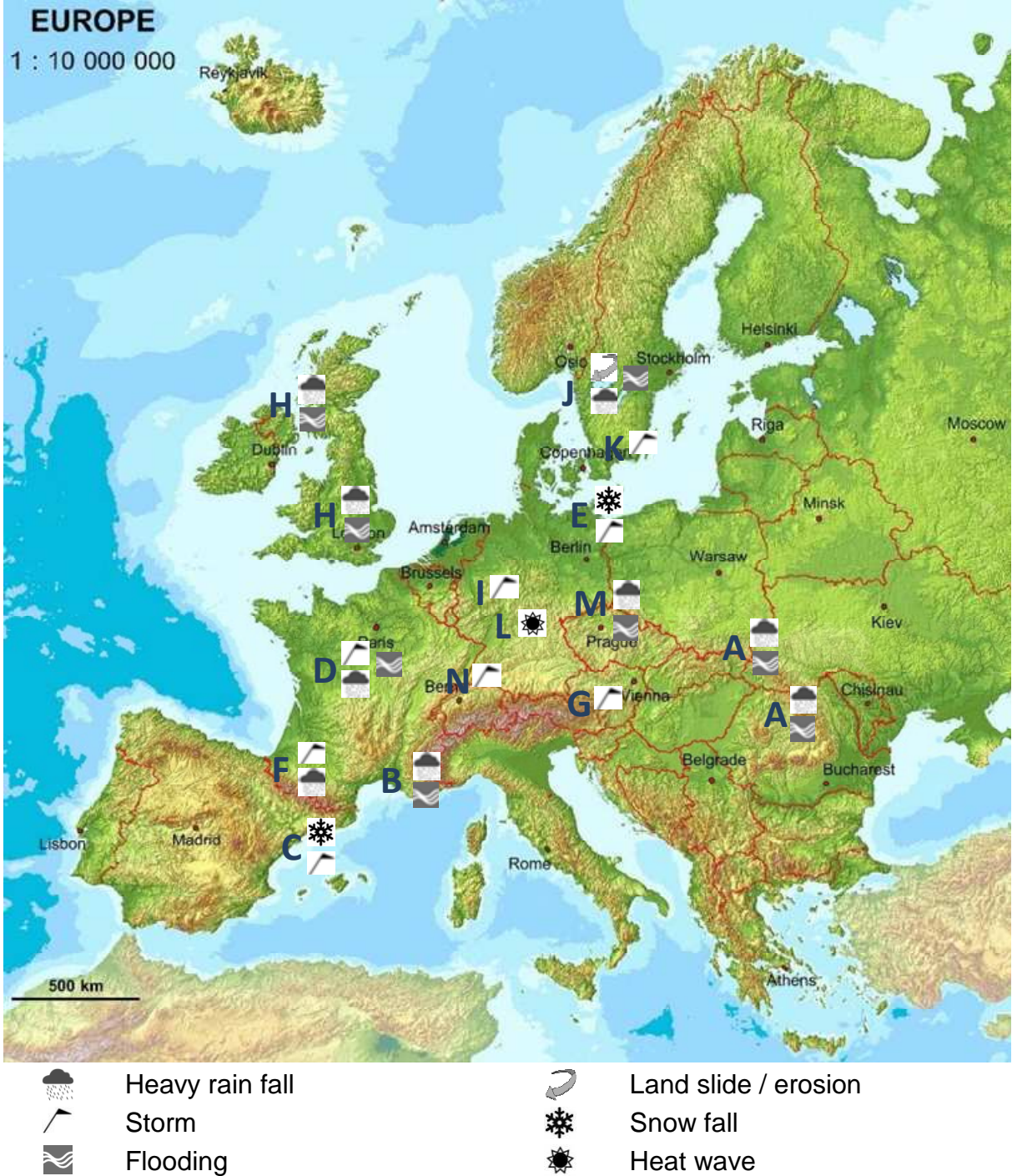


Figure 3: Overview map of extreme weather events in Europe between 1999 and 2010

The events covered are listed in the following table:

A	2010: June till August	Flooding in Romania (Poland; Ukraine) caused seriously damages and destruction of rail lines and bridges
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B	2010: 17th June	Flash floods caused by torrential rain in South Eastern France (Worst downpours in the region since 1827); Train services along the coast were cut off.
C	2010: 7th March	"Low Andrea" caused wind speed up to 150 km/h and heavy snow fall with up to 60-70 cm in North Eastern Spain (Barcelona Region with most heavy snowfall since 25 years; also other Mediterranean Sea Area); No bus transport in Barcelona and almost no railway services.
D	2010: 26/28th February	Winter storm "Xynthia" with hurricane-force wind speeds up to 238 km/h and torrential rains with flooding in Western and Central France (South Western Germany), caused tree felling and roads and railway lines to be cut off
E	2010: 8/11th January	Winter storm "Daisy" with wind speeds of more than 100km/h, with snow fall and snow drifts, freeze in North Eastern Germany (Eastern and Northern Europe); caused road and railways closings
F	2009: 25th January	Winter storm "Klaus" with wind speed up to 200km/h and torrential rains in South Western France, Northern Spain (Andorra 216 km/h) and Italy caused forest damages and thus 48 hours no rail traffic
G	2008: 29th Feb. till 2 <sup>nd</sup> March	Winter storm "Emma" with wind speed between 100 till 230 km/h in Austria; coming from Germany with wind speed between 126 till 140 km/h
H	2007: 1st June till 28th July	"UK floods": After a long rainfall period, more than one hundred flooding or bank-slip incidents on the rail network in the whole UK (wettest summer ever). This caused widespread delays and temporary rail line closures
I	2007: 18/19th January	Winter storm "Kyrill" with wind speed up to 225 km/h caused massive tree felling, particularly in North Rhine-Westphalia, Germany. Coming from Northern England via the North Sea to the Baltic Sea/ Baltic States; also other Eastern European States
J	2006: 20th December	Intensive rain upstream, caused a high flow and erosion in Western Sweden (South of Munkedal covering the E6 road and the Bohus rail line; Ånn in Jämtland, washed away a road and rail embankment).
K	2005: 8/9th January	Winter storm "Gudrun" with wind speed up to 150 km/h in South and Western Sweden (Ireland, UK, Norway, Finland, Russia); caused storm felling of forests and a closure of the rail network due to fallen overhead lines, damaged or destroyed pylons).
L	2003: 1st till 13th August	Heat wave ("High Michaela") with maximum temperatures of 35 to more than 40°C (longest heat wave since 1950) in Germany (France, UK etc.)
M	2002: 12/13th August	Elbe flooding in Eastern Germany, due to heavy rainfall of up to 312 mm within one day in the catchment area (Czech Republic)
N	1999: 26th December	Winter storm "Lothar" with wind speeds of more than 200 km/h in France, Switzerland and South Western Germany

The in-depth analysis of extreme weather events requires a systematic recording and documentation of past events. In order to guarantee easy access and a structured analysis, all relevant information should be stored in a centralized “event database”. All those events should be covered which either caused delays in train operation, line closure or damage of infrastructure assets.

The recording should be done in a systematic way using a standardised template. This template should contain general information such as time of the event, location (line section) etc., information about the weather event (type of event, duration, intensity etc.) using predefined criteria and a detailed description about the impact on the infrastructure.

As a second step in the process of event documentation, the entered data and impact descriptions should be assessed by an expert or a by a team of experts. This insures the correct classification of the cause of the incident as well as a well founded impact analysis.

For a better accessibility and usage of the data in further stages of the vulnerability analysis, the assessed data sets should be visualised using a graphical information system (GIS).

#### Example: Systematic Event Recording at SBB

##### Data recording using DERI NR

DERI NR is an instrument to record and document natural hazards at SBB. The core part of the system is a central database where all relevant current events are being recorded. Gradually, historic event data are being integrated into the database. The recording process follows a 2-step approach:

- Registration of key data of an event & submission to specialist
- Full documentation by a specialist and evaluation

##### Visualisation in WEB GIS

After evaluation of an entry the data from DERI NR taken over into the GIS of SBB.

This system allows

- Queries about ice falls and avalanches at the Gotthard line
- Comparison with previous recordings in the area
- Use of natural hazard maps modelled by SILVAPROTECT (Bafu).



Figure 4: Example for the visualization of a past weather event recorded in DERI NR in the GIS System of SBB

### Outlook

The data base will be developed into a system for evaluation of risk sites. For this purpose, an inventory of protective systems showing the status of each protective measure will be integrated. On the basis of risk data, hazard maps and taking into account defined protection targets, appropriate protection measures can be planned in the future.

### 5.2.3 Mapping of natural hazards which can potentially impact the railway infrastructure (including the locations of possible impacts)

An equally important approach for the identification of vulnerable parts of the railway infrastructure as the analysis of past events is the identification of current and future natural hazards and their potential impact on infrastructure assets.

In order to keep the effort for hazard mapping reasonable, a multi level approach is highly recommended.

- 1<sup>st</sup> level: Screening - Identification of those parts of the network with a high exposure to natural hazards (priority areas)
- 2<sup>nd</sup> level: Investigation of priority areas by modelling efforts, development of maps of potential natural hazards
- 3<sup>rd</sup> level: Detailed investigation of priority areas by on site inspections and modelling approaches, development of high resolution natural hazard maps

#### 1<sup>st</sup> level: Screening - Identification of priority areas:

This first phase of hazard mapping can be carried out by using the outcome of the analysis of past extreme weather events (see chapter A2) and their impact on the railway network – especially on train delays and infrastructure damage. A second line of assessment is the use of the output of regional modelling of major hazards such as flooding (flood maps).

As a result of this screening phase, a very rough, large scale general hazard map can be produced which shows which part of the network have a potentially high

exposure to the different natural hazards such as flooding, landslides and mud slides, rock fall, snow avalanches and wind throw and which therefore should be assessed in more detail. For an example see the following figure.

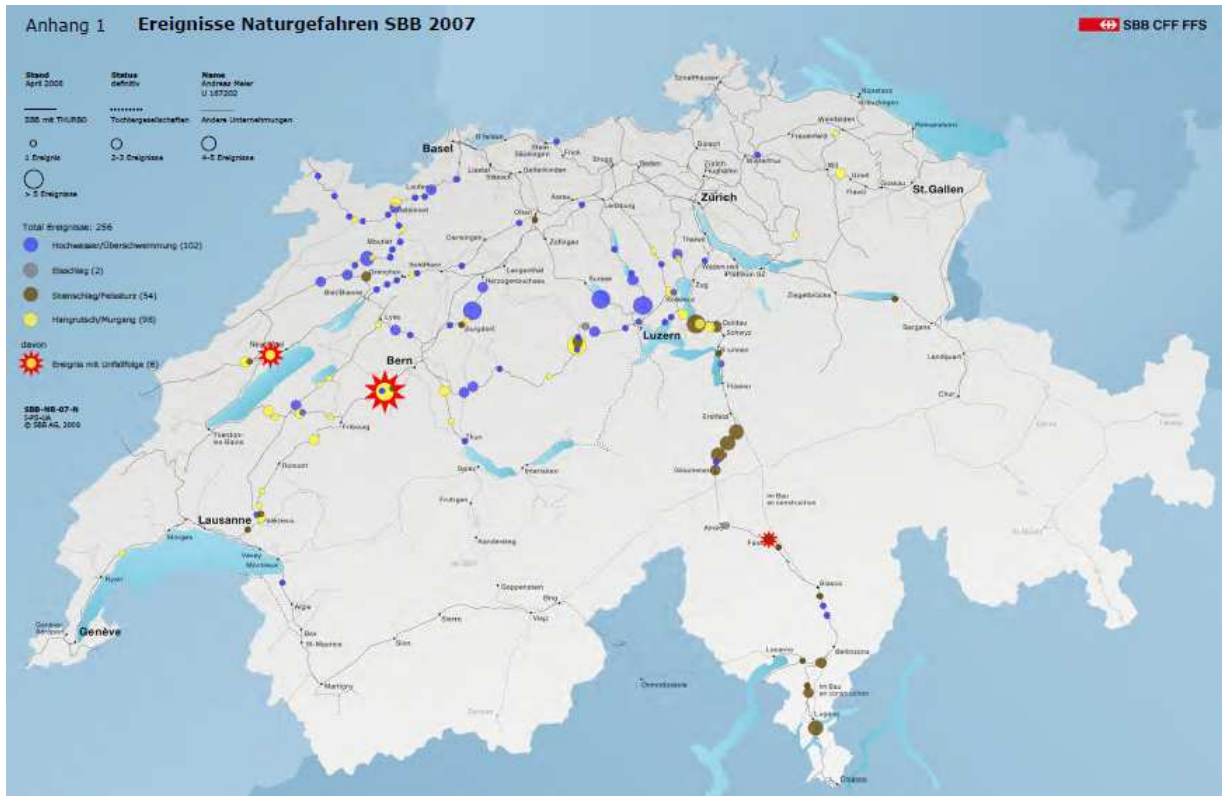


Figure 5: Accumulated weather related events and incidents in 2007 in the SBB network.

2<sup>nd</sup> level: Further investigation of priority areas by modelling efforts, development of maps of potential natural hazards:

Once the priority areas have been identified, modern modelling techniques can be used to simulate natural hazards and their potential impacts. For each type of natural hazard a dedicated modelling approach has to be used.

- Fluvial flooding: Flood maps with different flood intensities (typically 50 year, 100 year and 250 year flood events) are available for many European countries with a high spatial resolution and mostly in digitalized form. In order to identify the line sections with the highest exposure to fluvial flooding, these high resolution digital flood maps have to be linked with the digitalized railway infrastructure data.
- Surface flooding: On the basis of accurate surface relief data (e.g. obtained by laser scanning) and using a mathematical model of rolling balls it can be calculated with an excellent spatial resolution where water potentially accumulates. When the output of this modelling is merged with the digitalized network data, the line sections and infrastructure assets such as tunnels, railway stations, bridges etc. can be identified which have a high risk of exposure to surface flooding.
- Rock fall: Specialized rock fall models allow to calculate, if falling rocks or rock avalanches have the potential to reach the railway line and if their energy is high enough for causing damage. Using the outcomes of the models, line sections can be classified according to potential rock fall exposure.

- d) Snow avalanches: Snow avalanche models work similar to those for rock avalanches. The destructive energy of a potential avalanche highly depends on the slope of the terrain.
- e) Landslides and mudslides: The modelling approach uses elevation models as well as models for soil characteristics and composition. Especially important in this respect are the drainage properties of the soil.
- f) Wind throw: Wind and storms are very difficult to model with a good spatial resolution. Therefore, the identification of line sections which have a high exposure to wind throw is mostly done by analysing data from past weather events.

The modelling effort for all above mentioned natural hazards results in maps for potential hazards. Whether real hazards can develop or not depends on the real situation in the identified area as well as on the existence and status of protective structures and/or protective forest. An area potentially exposed to rock fall hazard is e.g. likely to be highly endangered if the rock faces are eroded and rock fall barriers do not exist.

As an example for the 2<sup>nd</sup> level the potential hazard maps used at SBB are described in more detail:

Maps of potential hazards have been developed by the Swiss Federal Office for the Environment FOEN for all Swiss regions. The following natural hazards have been included:

- Rock fall
- Landslides
- Debris flow/mudflow
- Snow avalanches

Areas of potential rock fall have been modelled with a high resolution. A potential hazard is indicated on the maps if rock fall processes can impact railway tracks, roads and settlements on cause damage.



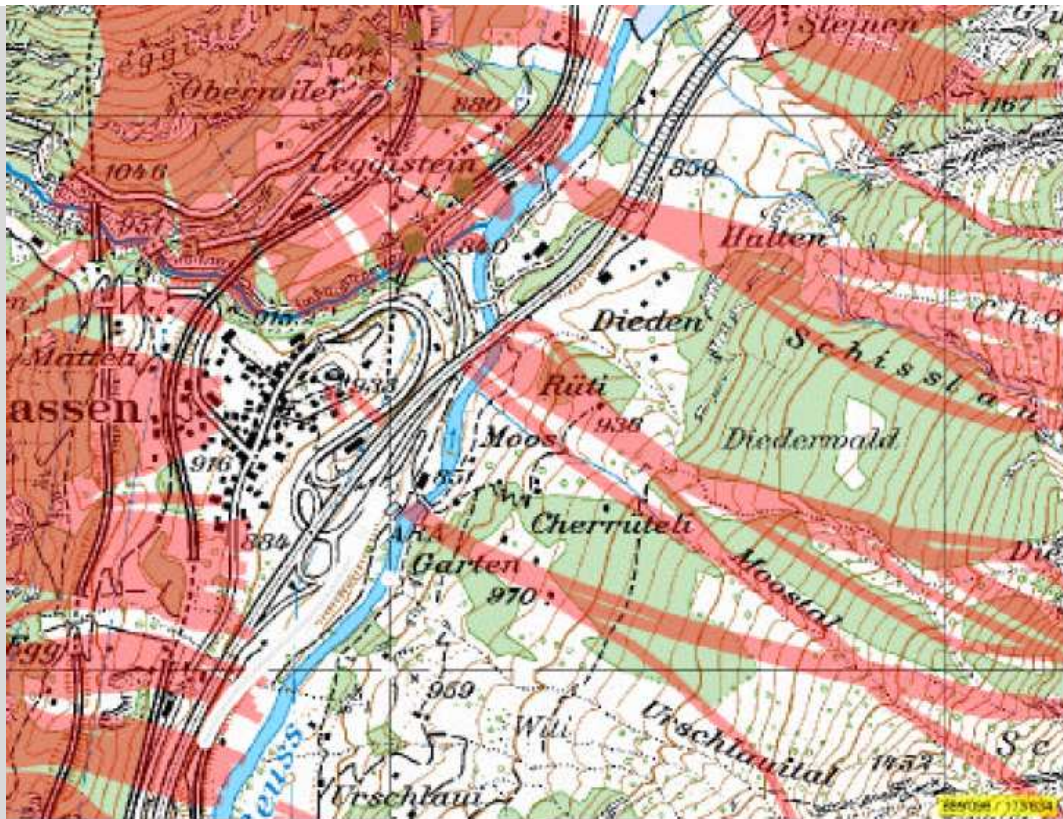


Figure 6: Map for potential rock fall hazard in Switzerland.

A similar set of maps of potential hazards (Gefahrenhinweiskarten) is available for all regions in Switzerland for landslides, mudslides and snow avalanches. For the modelling, detailed digital relief data and slope data as well as data for the composition of the earth and precipitation data were used. Potential hazards were only indicated if the relevant processes could reach infrastructure assets, settlements etc. The following figure shows areas of potential landslides in yellow:

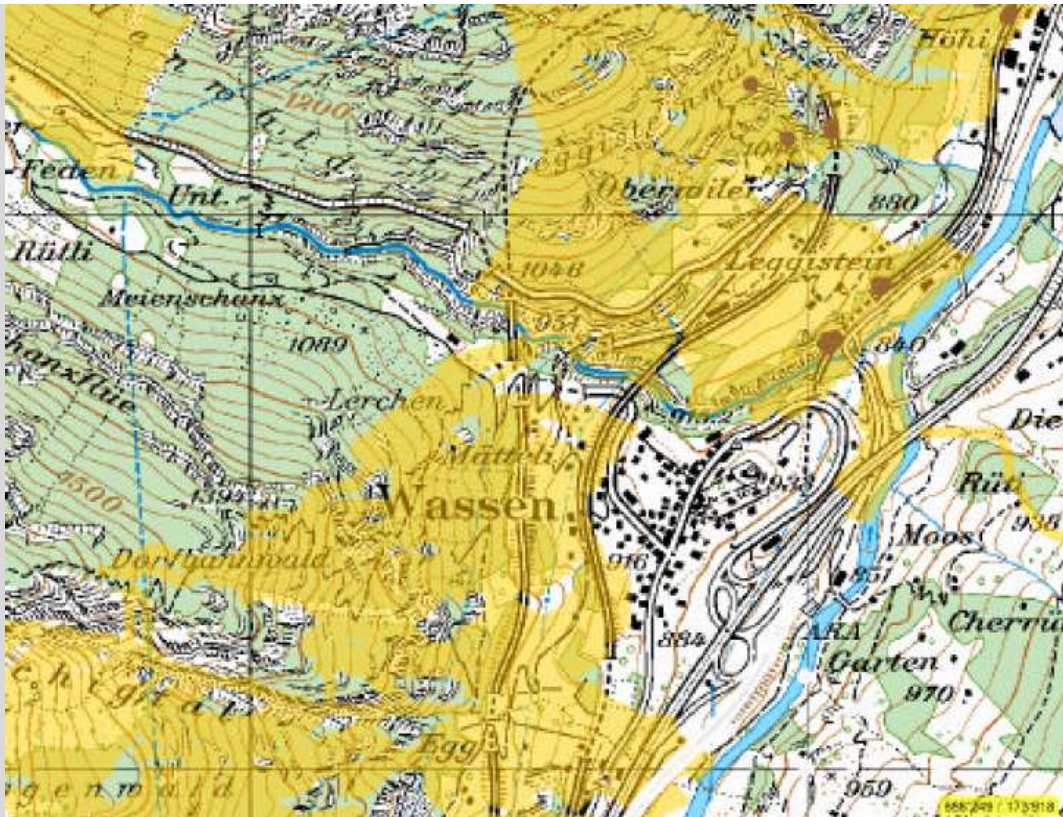


Figure 7: Map for potential land slide hazard in Switzerland.

If these data of potential natural hazards are merged with the digitalized railway network data, maps highlighting those line sections with the potentially highest exposure to the different types of natural hazards can be generated.

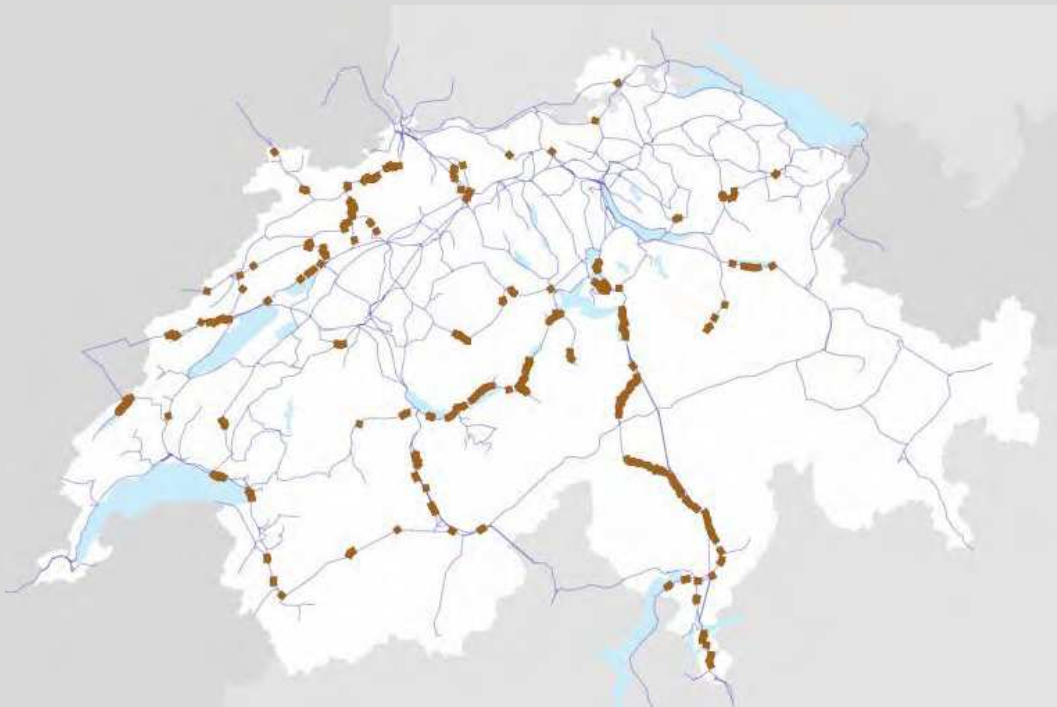


Figure 8: Map of potential rock fall -prone main line railway track in Switzerland (incl. Lötschberg route but without other privately operated routes).



### 3<sup>rd</sup> level: Integration of on-site knowledge including data about protective measures

The maps of potential hazards from the 2<sup>nd</sup> level can be further improved by integrating knowledge about the real situation in the relevant areas including information about protective measures and structures. This requires a survey program with dedicated on-site inspections, preferably by teams with expertise in geosciences.

The survey program should focus on those line sections with the highest potential exposure natural hazards in order to keep the effort reasonable. Furthermore, the on-site inspections should be highly standardized and a well structured and easy to use template should be used to record the results.

The inspections should both cover the real status of the areas where hazardous processes could get started and the status of protective structures and measures if existing. For the different types of natural hazards the following aspects should be assessed:

- Rock fall: Actual status of the rock faces, type of rock, degree of erosion, status of protective nets...
- Landslides and Mudslides: Detailed data on soil composition, status of protective forest, status of drainage system.....
- Snow avalanches: Detailed data on soil properties, slopes, precipitation data, status of protective structures
- Flooding: Detailed data on soil composition, precipitation data, status and capacity of drainage system

When merging this field knowledge with the output from the modelling of potential natural hazards and the digitalized railway network data, real hazard maps for railway use can be generated.



Figure 9: Example for a hazard map: Flooding hazard in Canton Zug in Switzerland for a return period of 30-100 years.



## 5.2.4 Monitoring and documentation of the status of infrastructure assets

The identification of potential natural hazards is the first step of a vulnerability assessment. The second one is the integration of detailed knowledge about the current status of the assets, because natural hazards can only cause damage if the railway infrastructure asset in question is not resilient enough to withstand a certain load – either due to a general lack of resistance or e.g. due a poor standard of maintenance.

A central asset database for all relevant kinds of railway infrastructure assets such as track, earthworks, bridges, tunnels, drainage systems, protective structures, signalling etc. with detailed information about the current general and maintenance standard for each asset provides a solid basis for assessing vulnerabilities. In order to standardise and simplify assessment procedures, different status classes reflecting the urgency of mitigation measures should be defined.

Following the example of SBB, six status classes are proposed:

Status Class	Asset Integrity	Description & mitigation measures
Status class 1	good	Asset has no or only minor damage. No measures are necessary
Status class 2	acceptable	Asset has damage which does not endanger people or operation in a short or mid-term perspective. No measures are necessary
Status class 3	damaged	Asset has damage which endangers people or operation in a mid-term perspective and/or causes high follow-up costs when not repaired. Damages have to be repaired in the short or medium term.
Status class 4	poor	Asset has damage which endangers people or operation in a short -term perspective and/or causes high follow-up costs when not repaired. Damages have to be repaired in the short term.
Status class 5	alarming	Asset has damage which immediately endangers people or operation. Damages have to be repaired either immediately or immediate measures for significantly reducing the danger have to be taken.
Status class 6	unknown	Asset can not be inspected and the it's status is therefore unknown. Measures have to be planned based on risk estimations. If possible, measures have to be applied which allow inspections in the future.

Depending on the status class of an asset, the exposition to natural hazards and the potential damage the appropriate monitoring measure has to be defined ranging from normal observation (e.g. by passing train drivers) and regular inspections to online monitoring.

The complete spectrum of monitoring measures and activities comprises the following options:

- Observation (e.g. by train drivers)
- Targeted observation (usually in defined intervals)
- Normal inspections (intervals depending on the status class and the priority of the asset)
- Interim inspections (for high priority assets and for status classes 3)
- Extraordinary inspections (for assets with status class 4 or 5)
- Online monitoring (for selected cases with high risk potential)

The central asset database should be used not only for identifying vulnerabilities and respective risks but also for maintenance planning and especially for priority setting of maintenance measures.

#### Example 1: Central asset database of SBB

SBB has developed a central asset database based on SAP which is in service now for 3 years. It contains basic asset data (material, dimensions, exact locations.....), status classes, results of inspections, messages from observations, monitoring measures (e.g. inspection cycles), details for planning of maintenance and mitigation measures, financial aspects of projects and measures and also prioritisation of measures and financial resources.

For assets with status classes 4 (poor) and 5 (alarming) there are already some links to damage incidents and data. The impacts of severe incidents are documented for such cases in the database and additional messages are recorded. These links will be successively intensified. In the near future, protective structures and their status will be integrated into the central asset database as well as project progress and details. Another important development is the establishment of links between the central asset database and the central event and incident database DERI NR (see chapter xxyy).

The central asset database is a very good instrument for asset, management and asset stewardship.

#### Example 2: Online monitoring of bridge foundations with potential exposition to flooding at SBB

The foundations of selected bridges which are located in flood plains are monitored online at SBB in order to detect bridge scour in the very early stages. Before the online monitoring was introduced, the foundations of these bridges had to be inspected by diver teams after a flooding event in order to decide about the duration of the bridge closure and possible repair measures. The old procedure was slow, involved high costs and closure times were unnecessary high. The new sensor based online monitoring solution is much more time and cost efficient. The status of bridge foundations can be immediately assessed and appropriate measures taken such as speed limitations or temporary line closure can.

### 5.2.5 Vulnerability mapping

As already mentioned above, vulnerability mapping is the integration of information about potential hazards (see hazard mapping) and the detailed knowledge about the status of infrastructure assets.

In a first step assets with exposition to natural hazards have to be identified. This can be efficiently done using GIS based hazard maps and combining these with GIS data of railway assets and their exact location. As an example, railway bridges which are potentially vulnerable to flooding can be identified by merging flood planes and digital infrastructure maps with exact bridge locations.

In a second step of the assessment vulnerabilities can be identified for two different cases:

- a) If the general resilience of an asset is not sufficient, e.g. because of a relatively low engineering standard used (this could be the case for a non priority assets)
- b) If the general resilience of the asset is ok but the current maintenance status is not good and therefore the actual resilience is not sufficient.

Detailed information for both cases – i.e. on the general resilience of an asset and its maintenance status - can be directly taken from the central asset database as discussed in the previous chapter. To simplify the procedure, standardised definitions and values such as asset classes should be used.

By merging the two different information streams – the information about the exposition of an asset to different kinds of natural hazards and the information about the status class of an asset including the maintenance standard – vulnerabilities of the railway infrastructure are clearly identified and classified. If all relevant data are available in digital form digital vulnerability maps can be generated as the main output of this process. These maps are the basis for a detailed risk analysis as well as for the planning and prioritising of mitigation and adaptation measures.

#### Example: Vulnerability Mapping at ÖBB

In 2007 ÖBB has launched an ambitious project for an integrated and standardized hazard and vulnerability mapping of the whole railway infrastructure. The project has three distinctive levels:

##### **Level I: Overview Study (Cursory Analysis)**

Duration: April 2007 – October 2007

Within this level, an overview over the vulnerability of the railway network regarding natural hazards was produced and regions with immanent danger were identified. The investigation covered 1.500 km out of a total of 6.000 km of railway track in Austria. The mapping has been performed on a scale 1:25.000, i.e. relatively large sections of track have been chosen. Both exposition to natural hazard and the status of the assets (e.g. protective structures) has been investigated. The work was contracted to an engineering company with geological and engineering expertise. Data were collected by means of targeted interviews and selected on-site inspections. As the output of level 1 vulnerability maps on a scale 1:25.000 were developed, indicating the segments of ÖBB tracks which are vulnerable to different kinds of natural hazards (avalanches, landslides, mudslides, rockfall).

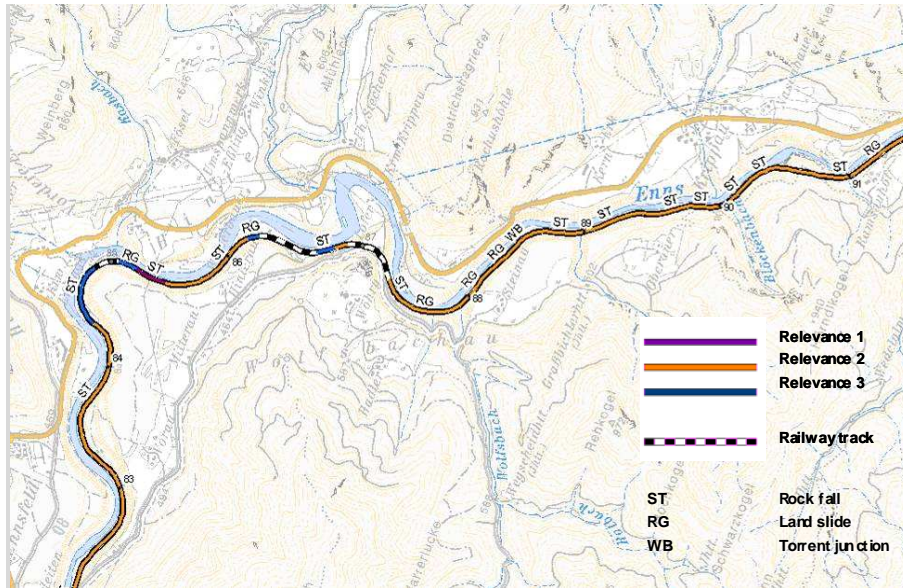


Figure 10: Example for a level I hazard/vulnerability map.

## Level 2: Detailed investigation of sections with high endangerment

Duration: May 2008 – 2012

Based on the results of level I, line sections with high endangerment (“highly relevant” and “relevant” sections of endangerment) are investigated in much more detail including the assessment of process activities as well as the location, maintenance standard and usability of existing protective structures. Levels of process activity are divided into 5 levels ranging from 5 (moderate to high recent activity) to 1 (no process possible). Levels of exposition of the railway track are also divided into 5 levels (from 5 - direct crossing of transport or starting zone to 1 - no impact possible).

For each protective structure the protective effect is determined as the combined effect of process activity, exposition of railway track and usability of protective structures and documented in the form of a lack of protection or “protection deficit” which can assume the following values:

protection deficit	level
5	very high
4	high
3	moderate
2	low
1	no lack of protection

The mapping is performed on a much more detailed scale than in level 1 (1:5.000). The main instruments of the analysis are standardized on-site inspections with structured forms, regular team meetings as well as detailed assessments of all gathered information at ÖBB headquarters. The output of level 2 are standardized worksheets, a matching geo-database and sets of base maps with essential information about protection deficits – i.e. vulnerabilities. Options to query and display relevant data for specific questions are also provided.

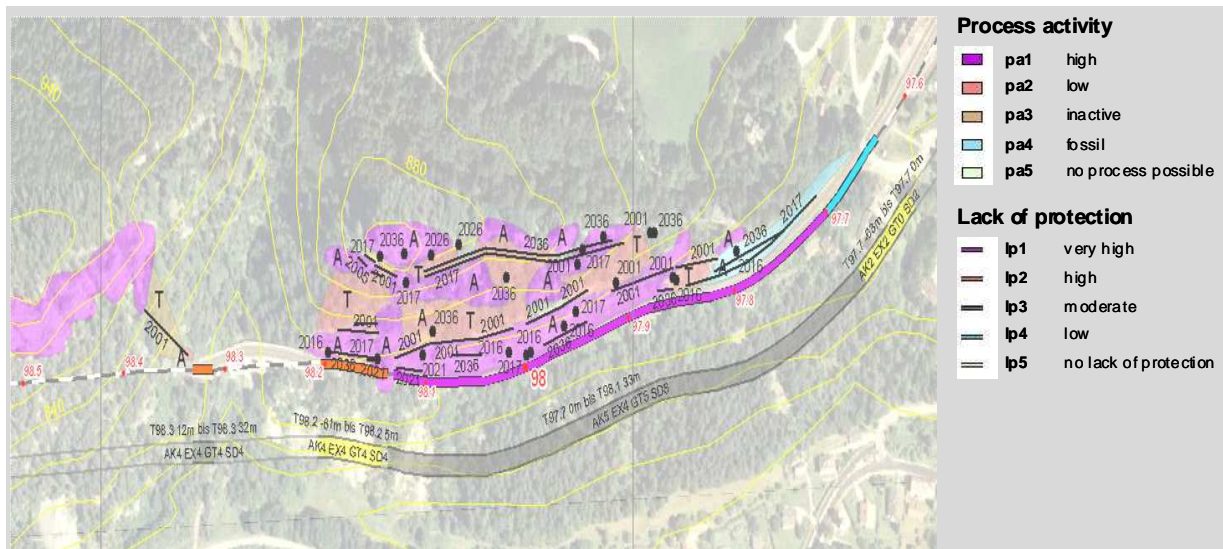


Figure 11: Example of an investigated section at Level II (Semmering pass Level II)

### Level 3: Quantification of dynamic processes

Started in 2010

Based on the level 2 vulnerability maps, dynamic processes such as rockfall, snow avalanches and mud slides are quantified by means of modelling the relevant natural hazards and their impacts. Furthermore, targeted inspections of highly vulnerable route segments including in-depth investigations of the relevant protective structures will be performed. Finally, organizational mitigation measures and structural mitigation measures on the design scale will be developed and implemented. Based on the outcome of level II investigations, the following new developments are planned:

1. Rapid alert system as a combination of natural hazards maps/ vulnerability maps and meteorological data
2. Real time monitoring of line sections of high endangerment
3. Integration of numerical models for the prediction of magnitude and scale of natural hazards and their impacts

The new integrated system of identifying and mapping vulnerable parts of the ÖBB infrastructure has many advantages over the old approach. Whereas the old system was only reactive and covered only those locations and assets where events with significant impact had already taken place, the new one is proactive and covers the whole ÖBB network. With the introduction of standardized protection deficits, the integrated approach can be used to plan and prioritize preventive measures in the short, medium and long term. From a methodological point of view the integrated approach breaks new ground for the prevention of natural hazards.

### 5.2.6 Risk assessment and risk management

Within the last two decades a slow shift from reactive to proactive dealing with natural hazards can be observed. But with only very few exceptions the reactive approach which is characterised by measures taken after a severe event has occurred is still dominant within the railways.

The modern pro-active approach is based on the concept of integral risk management which consists of 4 phases:

- 1) Inventory and Identification of Risks
- 2) Risk Analysis
- 3) Risk Evaluation
- 4) Risk Management

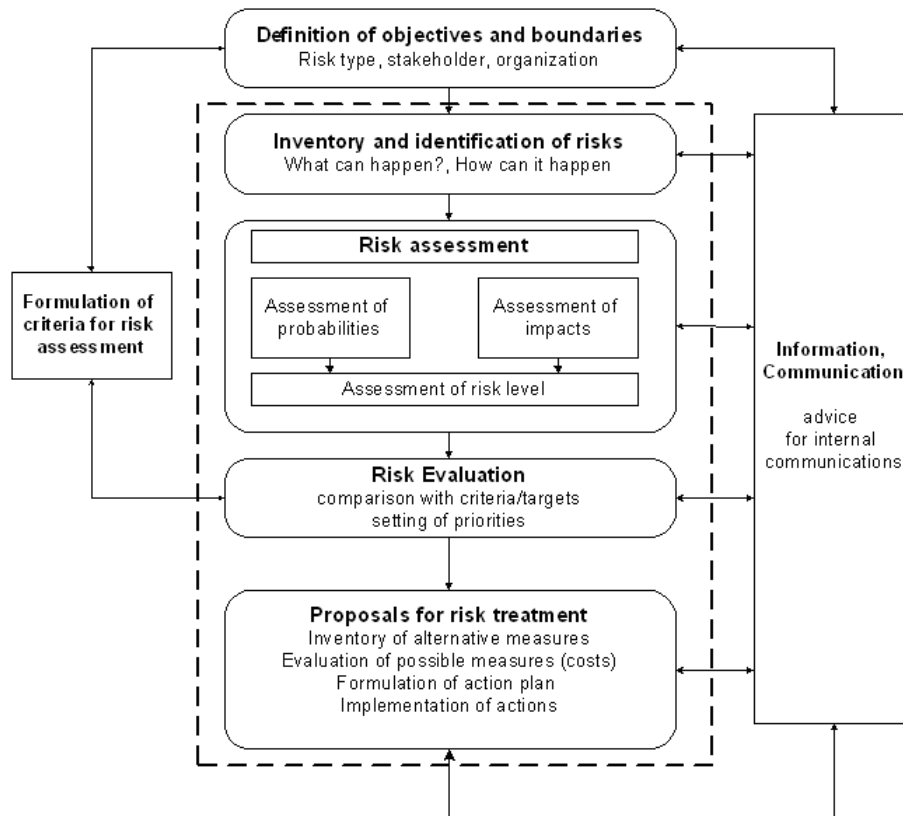


Figure 12: Integrated risk management

### Inventory and Identification of Risks

As a prerequisite for risk analysis and evaluation, all possible risks related to natural hazards have to be identified and documented in an inventory. The inventory should be based on the evaluation of past events as well as on the output of hazard mapping (see chapter 4.2.3). Risk which have to be considered are risks to asset integrity, safety risks, risks for the environment as well as risks for railway image and for railway operation.

### Risk analysis

This first phase identifies vulnerabilities of assets and potential amounts of damage as well probabilities for the occurrence of severe events. Thus, it has to answer the following questions:

- What can happen at concrete locations and assets?
- How often and with what potential damage can it happen?

The first question is directly answered by the vulnerability analysis (see chapter 4.2.5). Frequencies and intensities of current events are mainly derived from past

experiences (e.g. from the evaluation of meteorological data and from event databases). For future events, frequencies and intensities have to be calculated based on regional climate projections and additional modelling efforts taking into account local geography and other specific conditions.

For the determination of potential damage, asset specific damage models have to be used which take into account the actual status of the relevant asset and its maintenance standard.

The next step in the risk analysis is the definition of impact classes taking into account all 5 dimensions of possible damage:

### 1) Property

- damage in rail transport: rail, bridges, underground structures, vehicles, cargo, pipelines and other installations etc.
- damage in the environment: land, buildings, facilities

### 2) People

- damage in rail transport: staff and costumers
- damage in the environment: damage to third parties

### 3) Environment

- primarily damage to natural resources and natural/ cultural environments

### 4) Reputation

- damage to the rail transport system: direct cost to implement transportation and expenses due to delays or non-transport
- damage in the environment: social and economic damage due to disruption / interruption for other infrastructure (road, electricity, telecommunications, water and sewage, etc.) and indirect cost to society / industry, because of delays / cancellations in rail transport

### 5) Finances (transport operation)

- image loss, loss of trust on different scales etc.

The ranges of damage or impact classes are commonly defined by financial parameters:

<b>1) Property/Assets</b>		<100.000 €	<1 Million €	<10 Million €	>10 Million €
<b>2) People</b>		light	moderate	1-5 casualties	> 5 casulties
		accidents	accidents	severe accidents	severe accidents
<b>3) Environment</b>		small temp	temporary	permanent	severe permanent
<b>4) Immaterial</b>	image/confidence	local	regional	national	severe national
<b>5) Financial/</b>	priority 1			1 - 7 days	> 7 days
<b>Operation</b>	priority 2		1 - 7 days	7 - 30 days	> 30 days
	priority 3	1 - 7 days	7 - 30 days	> 30 days	
<b>Total impact</b>		<b>&lt;100.000 €</b>	<b>&lt;1 Million €</b>	<b>&lt;10 Million €</b>	<b>&gt;10Million €</b>



Based on the impact and damage classes defined above and taking into account the relevant frequency/return periods, the final quantified output of the risk analysis for each type of hazardous events can be shown as a risk matrix:

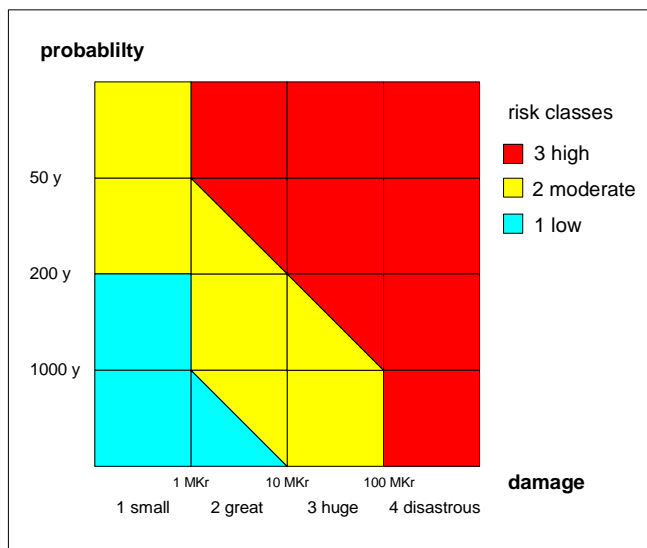


Figure 13: Risk matrix with 3 risk classes: high, moderate and low risk

### Risk evaluation

Based on the results of the risk analysis, the risk evaluation has to answer the question, which risks are tolerable and which are not. The assessment has to include social, economic, legal and ecological criteria. It is basically a normative process of evaluating and balancing different interests. The outcomes are well defined protection objectives (Schutzziele) which can be interpreted as limit values for protective efforts fixing acceptable risk levels. Since protection objectives allow to identify and quantify protection deficits they constitute the basis for decisions about appropriate countermeasures and their priorities.

### Risk management

Within this final phase of the integrated risk management, measures for risk mitigation have to be identified and priorities have to be defined. Risk mitigation measures are any actions intended to reduce risk by reducing either the probability of occurrence and / or the consequence of the incident. The risk management has to guarantee that the level of safety of operation and availability of railway infrastructure defined by the protection objectives can be reached in a cost effective way.

Risk mitigation measures can and should be applied before, during and after hazardous incidents. Preventive measures such as protective structures (rock avalanche and snow barriers, additional drainage capacities etc. ) can reduce the frequency of incidents and / or the magnitude of possible damage. Appropriate measures during incidents are based on detailed contingency plans and focus at minimizing damage by means of rapid and targeted intervention.

The results of risk analysis and risk evaluation are highly dependent on the user's knowledge and that people with different skills work together. Since the analysis is largely based on systematic assessments, it is important that the user has both deep methodological knowledge and local experience. Risk inventories and analysis is



carried out preferably in a smaller group of people consisting of a responsible coordinator, an operating person as well as a geotechnical and an environmental expert.

Example: Guideline for a cursory risk analysis and evaluation for specific railway tracks developed for Banverket/Trafficverket

According to the methodology developed for Banverket (2008), the work flow for the cursory risk analysis and evaluation can be expressed as follows:

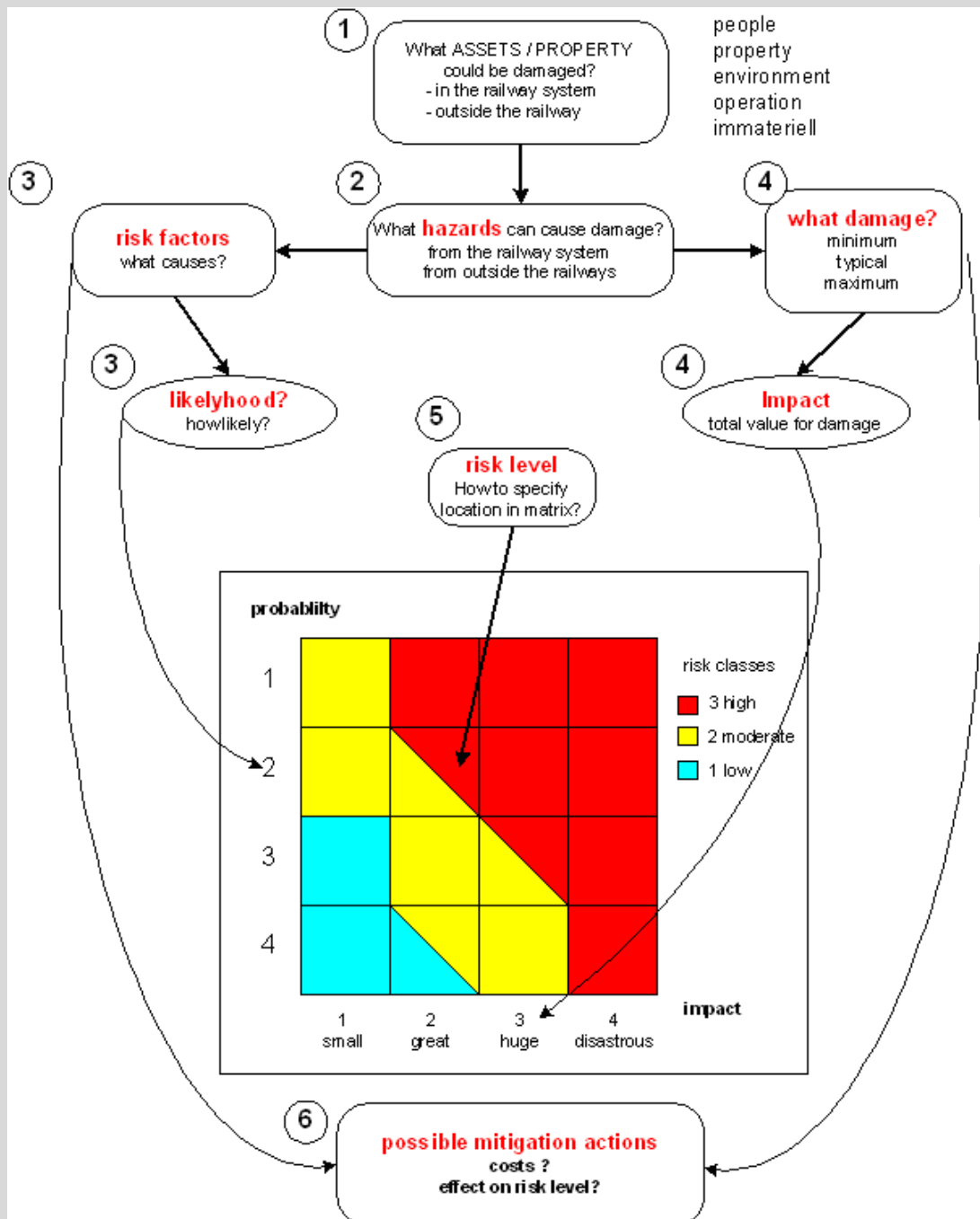


Figure 14: Work flow for the risk analysis. The numbers correspond to the different steps of the workflow as described in the text.

## **1. Identify what interests / assets can be damaged**

In identifying the interests to be harmed, it has to be distinguished between

- a) interests in the railway system
- b) interests outside the railway system.

Interests and possible damage are divided into the 5 dimensions People, Property, Environment, Immaterial and Financial (transport operation). Interests are usually linked to a particular place and/or an object. It is therefore useful to identify the locations where one or more interests could be damaged.

When identifying which objects are to be considered one looks for the combination of large values that can be threatened and a great vulnerability to current events. The size of the area for the inventory is determined primarily by how vulnerable the items are for events on or near the track. The vulnerability is primarily determined by distance, natural protection and existing barriers. For railways the objects can be defined elements of the infrastructure where events can cause major damage to traffic security, personal injury and / or high costs for restoration. The damage size of e.g. disruption depends on the traffic flow, how long the disruption lasts and if options for traffic diversion exist.

Examples of objects in the railway system are railway tracks, bridges, embankments, earthworks, tunnels, signalling systems etc. Examples of objects in the surroundings are e.g. areas where many people reside (hospitals, schools, shops, community centres...), infrastructures outside the railway facilities (roads, waterways, power lines, telecommunications, water and sewage infrastructure), natural resources and natural as well as cultural environments.

The identification of interests and objects/assets should be based on a broad approach is and use also the results of existing inventories as e.g. general risk inventories carried out by municipalities, flood risk maps, landslide and stability investigations etc. The results of the identification can be preliminary presented in map form.

## **2. Identify the events that may harm the interests / objects**

For each asset or object one has to look for the events that can cause harm. Certain events can obviously affect both the railway system and the surroundings. For some events it may be difficult to determine whether they belong to a structure in the railway system or surroundings. An event from the railway system may have its cause in environmental factors. Use imagination and experience in the identification of events.

There is a great variety of natural events that can damage railway system and surroundings. To facilitate a structured approach and cover some of the most significant natural risks in a limited inventory, a number of events has been defined, e.g. landslides, mudslides, washed away railway tracks, flooding of railway bridges and flood damage of railway bridges.

## **3. Identify the risk factors that may cause danger and make an overall assessment of the likelihood that the events and hazards occurs**

Analyze the dominating risk sources for each event. For the events described above, a number of associated hazards can be described as well as the conditions for which the events could occur. Then make a subjective assessment of the probability of the current event (probably grade 1-4) and describe plausible events and coverage.

For some events, statistics can be used as a basis for the estimations. In most cases specific conditions for hazards and objects form the basis for assessing probability. In

many cases, standard values for the assessment of the probability of hazardous events can be used.

Development and magnitude of an event must in most cases be described separately for each individual event because geotechnical and other conditions are rarely the same. When assessing the probability and the impact take into account the possibility that normally exists to prevent an event or influence from developing an acute stage. If possible, use the risk matrix scale for the determination of risk probability.

#### 4. Describe the extent of damage / impact for each asset class for all hazards

Describe the injury and damage scale of each interest assuming the assessed developments. Describe the expected damage for each interest (typical damage) as  $L \cdot P_i \cdot U_i$ , where  $U_i$  is possible injury/damage outcome, and  $P_i$  is the probability of each outcome given that the injury/damage occurs. Provide also information about the greatest possible injury/damage outcome (maximum damage).

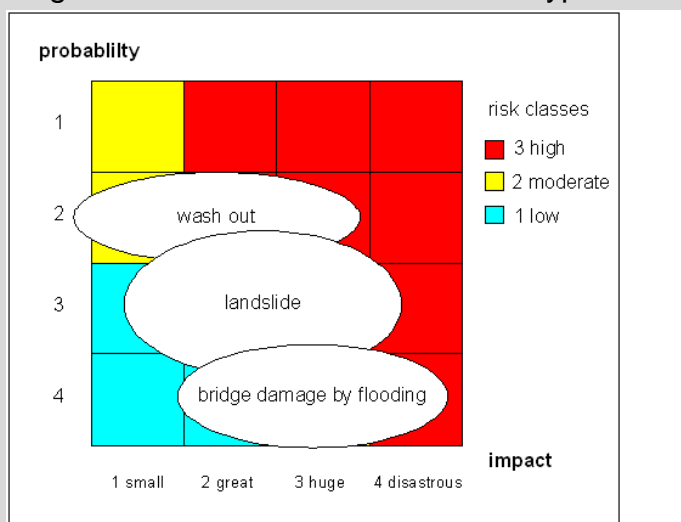
Describe the consistency of the respective interest value for typical damage (M or description in words for their interest). If possible, use the risk matrix scale for the impact class.

Then summarize the implications for all interests. Integration is made easier if all consequences are expressed in million €. If you take the total impact on the interests be sure that the class of the summed effects is the same as the one for the most affected interest because the impact scale of the matrix is logarithmic.

For a cursory analysis it is sufficient to describe damage extent and impact solely for the interests that are most affected.

#### 5. Describe the overall risk level

Determine the overall risk level (risk class 1-3) for the current event using the risk matrix definition, i.e. the expected probability class and impact/damage class for the summed effects on interests. Remember that the risk or hazard class indicates the urgency of risk mitigation measures. Risk classes for typical events can typically look as follows



#### 6. Indicate possible mitigation measures

Assess the justification of risk mitigation measures in terms of costs and risk mitigating effects. Based on this assessment the impact on injury outcomes (impact of mitigation measure, possible injury prevention) should be identified. Measures which reduce risks to the lowest risk category can sometimes be justified. On the basis of the risk analysis measures to limit risks are adopted and implemented.

## 5.2.7 Assessment of future weather and climate loads by using regional climate models

The output of climate models and especially regional climate models and projections can be used for identifying the expected future climate loads for railway infrastructure assets. Within the last years, high resolution regional climate models have been developed and made available for most European and many other countries. There are two basic types of climate models - statistical and dynamic models.

### Statistical Models

The modelling is based on a statistical analysis of past climate data and statistical projections into the future. For each specific model run temperature trends and 3 different realizations of humidity (dry, medium, wet) are set. Input data are based on weather stations and projections are calculated for exact locations and later extrapolated to surrounding areas. Output data are averaged over many runs and typically over 30 years in order to eliminate stochastic variations and to identify stable trends in climate development. Statistical models have resolutions of 10 to 25 km and are embedded into large-scale dynamical climate models.

The direct output of statistical models are daily values for temperature, humidity, precipitation, wind speed, radiation etc. The most stable and reliable output are temperatures and precipitation. Wind is more problematic since it is more dependent on local conditions, but improved projections can be derived by postprocessing the data with special wind models.

### Dynamic Models

Dynamic models are general circulation models using physical equations for processes in the atmosphere and oceans, e.g. for radiation, thermodynamics etc. Normally they work on big scales (1.000 km x 1.000 km). Although they use the same algorithms as modern weather forecasting, input data, scale and runs are different. Dynamic models use historic data as an input. In a first step they run from past to today and have to reproduce actual climate conditions. In a second step they run from today into the future until stable states are reached. A well known example for a big scale dynamic model is Echem5. Regional Dynamic Models work on scales down to 8 km x 8 km and are integrated into large dynamic models.

The output data are stored in huge three-dimensional data bases (geographical grid + time). Exemplified runs are available for commonly accepted IPCC climate scenarios from (A1B, A2, B). Some output data are already available in map form – especially temperature and precipitation trends. For special output - e.g. extreme weather events – tailored scripts have to be used for assessment of stored data.

To enhance the quality and reliability of the output data, typically both statistical and dynamic models are analysed.

### Relevant output of climate models for adaptation to climate change strategies

The most important output of climate models regarding adaptation to climate change are the expected future climate loads. From these loads the possible impacts on the railway infrastructure can be calculated. The relevant direct output can be divided into 2 groups: trends for climate and weather parameters and intensities and return periods for extreme weather events.

#### 1) Trends for important climate/weather parameters

- Temperature (average, maximum, minimum, for seasonal)
- Precipitation (average, maximum, minimum, for seasonal)
- Wind speeds

## 2) Intensity and return periods for extreme weather events

- Heat waves
- Heavy Rain events
- Long rain events
- Heavy storms
- Frost periods, freezing and thawing cycles
- Intense snow fall
- Dry periods

Based on the direct output and using further modelling which also integrates local geography and conditions, effects of extreme weather events can be assessed. Most important for railway infrastructures in this respect are flooding events, land slides, mud slides, storm damage to trees and long-term changes of vegetation.

Once the possible range of future climate loads is identified, these data can be fed into hazard mapping, vulnerability mapping as well as risk assessment processes (see chapters above).

### Example: UK Climate Projections 2009

An excellent example for easily available and ready to use regional climate modelling and projections are the UK Climate Projections 2009 (<http://ukclimateprojections.defra.gov.uk>). The projections are presented for three different future scenarios representing high, medium and low greenhouse gas emissions.

The types of climate information provided are:

- Observed climate data
- Climate change projections
- Marine & coastal projections

The projections are available in the form of numerical data that can be explored and downloaded with a purpose-built User Interface; this can also be used to visualise the data in the form of maps and graphs.

## **5.3 Recommendations for Adaptation to Climate change**

### **General Recommendations**

According to current climate models and projections, higher frequencies and intensities of extreme weather events are to be expected in the future. This holds with a certainty for very high temperatures, heat waves and intense short time as well as extended rainfall events. Without an adaptation strategy and adaptive action, the present resilience of railways could prove to be insufficient in the near and midterm future. Therefore it is recommended to develop a proactive adaptation strategy and systematically build up adaptive capacity. The strategy should comprise short term as well as mid-term and long term adaptation goals and measures and has to take into account affordability. The guiding principle of the integrated strategy should be the **three Rs**

- 1) **Readiness** (to be well prepared for extreme weather events)
- 2) **Resilience** (to systematically increase the resilience of the whole system)
- 3) **Recovery** (to develop contingency strategies and plan which allow for a fast and complete recovery of the whole system)

### Strategies for the adaptation of railway infrastructures to climate change

Since it is very important for developing acceptance within the company for an adaptation to climate strategy, the first objective should be to improve the management of today's extreme weather by means of integrated natural hazard management. This guarantees a strong direct link to the every day operation of railway infrastructure and to the actual problems people are facing in connection with severe weather events and impacts. Furthermore, it allows the exploitation of efficiency potentials through the concentration and focussing of resources which can be widely distributed over different business units and strengthening communication processes. When the integrated natural hazard management is introduced gradually, synergies can be exploited in this process and funds can be allocated more effectively. At the same time, adaptive capacity is systematically built up.

#### Raising Awareness for Adaptation to Climate Change

Awareness for adaptation to climate change issues should not only be raised inside the company, but also for external stakeholders like railway administrations, local authorities, national governments and the European Commission. By means of positive lobbying for adaptation strategies their importance on the political agenda should be increased.

#### Adaptation of engineering specifications

As a short to mid term option engineering specifications should be reviewed to pave the way for an improved resilience of the railway system. Changing specifications are most likely to be expected for the dimensioning of drainage systems, flood protection and for protection against heat waves. In order to keep the extra costs caused by stricter requirements in a reasonable range, regionally differentiated specifications should be considered.

#### Focus on system resilience

When measures are assessed and prioritized the objective should not be the strengthening of single assets or railway lines but the improvement of the resilience of the whole system.

### **Area specific Recommendations**

#### Weather information and weather warning

It is highly recommendable to develop weather information and weather warning systems tailored to the needs of railway infrastructure operators. These systems allow a much more efficient disposition of personnel and machinery, longer pre-warning times for severe weather events and generally for a higher awareness and better preparedness.

#### Assessment of past weather events

Past extreme weather events and their impact on the railway infrastructure should be systematically documented and assessed as one important approach to identify the vulnerabilities of the system. In parallel, the appropriate metrics for measuring the impacts should be developed. For easy access and convenient handling the data should be stored within a central "event database" and visualized by using a GIS.

#### Hazard Mapping

Systematic hazard mapping allows the identification of potentially dangerous situations for the railway infrastructure and the locations of potential impact. This provides an evidence base for identifying vulnerable assets. By using the output of regional climate models, hazard mapping can be extrapolated into the future and thus used for adaptation purposes.

### Monitoring the status of infrastructure assets

A central asset database for all relevant kinds of railway infrastructure assets with detailed information about the current general and maintenance standard for each asset provides a solid basis for assessing vulnerabilities. In order to standardise and simplify assessment procedures, different status classes reflecting the urgency of mitigation measures should be defined.

### Vulnerability Mapping

Merging natural hazard maps with knowledge about past extreme weather events and the general status and maintenance standard of infrastructure assets allows the identification of the vulnerable parts and assets of the railway system. The output of the merging process should be made available as vulnerability maps. They provide a good basis for the selection of appropriate adaptation measures.

### Risk Assessment and Risk Mapping

A systematic risk assessment for weather and climate related events should be implemented taking into account possible impacts on railway infrastructure assets in all five dimensions - damage to assets, people, environment, image and financial losses in railway operation. The assessment should be based on the above mentioned hazard and vulnerability maps and integrate expert knowledge about expected frequencies of hazardous events. A convenient way to standardize the assessment process is the use of a risk matrix.

### Use of Regional Climate Models

Advanced regional climate models should be used to identify expected future climate loads since they allow the calculation of possible impacts on the railway infrastructure. Relevant direct output of the models are trends for climate and weather parameters and – with less certainty - intensities and return periods for extreme weather events.

## **Recommendations for the Implementation of Adaptation Procedures**

### Integration of different data bases and information streams

One of the core parts of an efficient natural hazard management system is a well structured and integrated database. This database can be gradually developed by interconnecting existing databases for asset management, maintenance planning and disruptions as well as digitised railway network data and detailed terrain data and harmonizing their interfaces. Provision can be made for missing elements such as event and incident databases which should be incorporated as available.

### Integration into asset stewardship and especially maintenance processes

For current operation, adaptation to climate change aspects should be integrated into maintenance planning and especially priority setting procedures. As examples for negligence of drainage systems and vegetation management show, system resilience can rapidly deteriorate. Keeping good maintenance standards is already a first important step towards higher system resilience.

### Integration of adaptation aspects into current planning processes

For future projects, adaptation to climate change aspects should be integrated into the early stages of planning processes and especially into the standard vulnerability and risk analysis of project planning. Measures have to be asset specific taking into account the physical vulnerabilities as well as the life time of assets and the duration of innovation cycles. Integration of adaptation aspects is highly relevant for long living railway assets. Technical equipment like signalling and telecommunications with

much shorter lifetimes and much shorter innovation cycles are very likely to be adapted to changing climate conditions in an evolutionary way.

#### Priorisation of adaptation measures

There is a wide range of practical adaptation measures ranging from warning systems and monitoring to improving maintenance standards, reinforcement of protective structures and the change of standards for future projects. The optimum combination of measures for a project or a railway line depends on many factors such as types of assets, time horizon, importance of the route, financial constraints, cost benefit ratio etc. Depending on the concrete situation, “soft measures” such as real time monitoring of vulnerable sections and rapid alert systems can have much better cost benefit ratios than “hard engineering solutions” such as the reinforcement of protective structures.

#### Capacity Building for Adaptation to Climate Change and Knowledge Transfer

The implementation of an integrated natural hazard management starts a process of capacity building for the adaptation of the company to climate change. This process can be improved and accelerated by better knowledge exchange inside the company and between different infrastructure managers as well as with external stakeholders and partners such as other modes of transport, local authorities, universities and other research institutions, other critical infrastructures (power supply, water management) etc. Good practices and pilot projects in the different areas should be openly communicated and actively shared. It makes also much sense to learn from those who are facing now the conditions you expect for your region in the future.

The relevant staff of railway infrastructure managers should be systematically trained in hazard management and adaptation issues in order to develop the needed skills for addressing all aspects of adaptation properly and efficiently. This includes intensifying networking efforts and exchange of experiences by means of round tables, web-platforms, cross department working groups etc.

The cooperation between infrastructure managers and the manufacturers of infrastructure equipment and rolling stock should also be intensified in order to commonly address future challenges and identify appropriate solutions.

The future role of UIC in strengthening and improving the adaptation of railway infrastructure to climate change could comprise the following measures and actions:

- Facilitate and coordinate knowledge sharing e.g. by hosting the ARISCC web platform and by organising adaptation workshops
- Facilitate the development of appropriate metrics for impact and vulnerability assessment
- Support the development of appropriate governance approaches for adaptation

#### **5.4 Good Practice Collection**

ARISCC provides a broad collection of good practice examples for integrated natural hazard management and for the adaptation of railways to the impacts of climate change and thus facilitate the exchange of knowledge in all relevant areas from weather warning, monitoring and hazard mapping to vulnerability mapping, risk assessment and adaptation measures. The main areas and respective numbers of good practice examples covered by the present collection are shown in the following figure:



Area covered	Number of good practice
Weather Warning	3
Event Recording/Database	6
Impact Assessment	5
Vulnerability Mapping	5
Risc Assessment & Risk Management	10
Asset inventory	4
Asset Management	3
Regional Climate Modelling	2

As of July 2011, the good practice collection comprises the following examples:

Risk analysis for railway route	S	Drainage Engineers' network	GB	Bridge Scour Monitoring System	CH
Inventory of Drainage System (culverts)	S	Network Rail Dedicated Weather Website	GB	Vulnerability maps	CAN
High Speed Rail Service for Sweden	S	Track Buckle Risk Management	GB	CC Adaptation for London's Transport System	UK
Risk Models & Risk Assessment	S	Water Risk on Earthworks Assessment	GB	UKCIP2009 – Climate Projections	UK
Copenhagen-Ringsted CC Impact Assessment	DK	INFRA.wetter	A	FUTURENET	GB
DB Süd Weather Information & Warning	D	Event database (incidents and damage)	A	The Financial Risk of Climate Change	GB
Analysis Delays vs. Extreme Weather Events	D	Full scale asset inventory	A	Klima Atlas	D
Dedicated Weather Warning System	FIN	Vulnerability maps	A	Paramount	EC
Online Wind Monitoring at East coast Main Line	GB	Mapping of potential hazards	CH	CALAR	EC
Assessment of coastal defenses at Dawlish	GB	Natural Hazard Event Maps (per year)	CH	Monitor I	EC
Drainage integrated policy	GB	Vulnerability Maps	CH	Monitor II	EC
TraCCa	GB	Event database & evaluation + GIS	CH	RIMADIMA	EC

For each good practice example short fact sheets and more detailed documentations can be found on the ARISCC homepage ([www.ARISCC.org](http://www.ARISCC.org)).

As an illustration, the fact sheets for the Weather Information and Warning System of ÖBB – InfraWeather and of the UK study “Impact of climate change on coastal rail infrastructure” are shown

## ARISCC Good Practice Collection

# Infra.Weather – The dedicated weather information and warning system of ÖBB

Duration: system was implemented in 2008

A dedicated weather information and weather warning system has been developed and implemented at ÖBB. Preparative work included the installation of additional weather stations for better spatial coverage, the development of regional meteorological model, GIS-based overlay of railway tracks and meteorological data as well as GIS-based delineation of flood risk.

The implemented system is tailored to the needs and conditions of railway infrastructure and operation with the following features:

- Information system including online portal
- Storm forecast
- Flood forecast and warnings
- Snowfall forecast
- Operational weather warning service with well defined warning levels

### Information system including online portal

The *InfraWeather* online portal gives access to general weather information, forecasts as well as weather warnings. A map shown on the user interface gives an overview over the Austrian railroad system with the most important weather information including a 3h interval of forecasts.

### Storm forecast

With the new forecast models and radar techniques weather extremes can be forecasted on a scale of 10 km, partly even lower.

### Flood forecast and warnings

The forecast of floods integrates the water level of the rivers and the meteorological data so that the warnings can be sent 12 hours in advance.

### Snowfall forecast

The snowfall forecast includes the amount of snowfall in the next 24 to 72 hours for each warning point.

### Weather warning system

InfraWeather has a dedicated operational warning service, which provides also real-time severe weather warnings. Extreme weather events covered by the warning system are thunderstorms, flood events and heavy snowfall. The forecast of disastrous thunderstorms is provided by using ‘nowcasting’ techniques, where the track of thunderstorms can be forecasted 20 - 60 minutes in advance.

When predefined warning levels are reached, alert messages are automatically generated by the system and sent via sms, email, fax and telephone to all responsible people inside the company.

As an example for the more detailed good practice templates available on the ARISCC homepage, the UK Climate Projections 2009 (UKCP09) is shown here:

Projects & Good Practise Examples		UK Climate Projections 2009 (UKCP09)			
ID	Questions	Answers			
<b>General Information</b>					
	Project Type	Risc Assessment	and/or	Data & Knowledge Management	and/or Other (please describe below)
	Project Title/ Name	UK Climate Projections 2009 (UKCP09)	[optional & additional comments]		
	Company	Department for Environment, Food and Rural Affairs			
	Geographical coverage (countries, regions...)	Great Britain	[optional & additional comments]		
	Project Duration	2009	[optional & additional comments]		
<b>Project Information</b>					
	Project Focus	Regional Climate Models and Projections for the UK			
	Which tools	climate/weather modelling	and/or	other	and/or other
	Which natural hazards are covered?	heat waves	and/or	storms/gales	and/or flooding
	Which company divisions are affected/ involved?	Department for Environment, Food and Rural Affairs	and/or	Met Office	and/or
	Which infrastructure subsystems are affected/ covered?	Agriculture, Biodiversity & nature conservation, Build	and/or		and/or
	If Infrastructure, which infrastructure subsystem(s) are included?		and/or		and/or
	What are the project aims?	The UK Climate Projections (UKCP09) provide a basis for studies of impacts and vulnerability and decisions on adaptation to climate change in the UK over the 21st century.			
	Short summary	The UK Climate Projections provide scenarios and projections for the future development of regional climate in the UK as a basis for impacts and vulnerability studies and decisions on adaptation. The projections provide current climate data and climate change projections (land and marine/coastal).			
	Project Description	<p>The projections have been designed as input to the difficult choices that planners and other decision-makers will need to make, in sectors such as transport, healthcare, water resources and coastal defences, to ensure the UK is adapting well to the changes in climate that have already begun and are likely to grow in future. The underlying projections are in the form of numerical data that can be explored and downloaded with a purpose-built User Interface; this can also be used to visualise the data in the form of maps and graphs.</p> <p>The Projections are presented for three different future scenarios representing High, Medium and Low greenhouse gas emissions.</p> <p>The types of climate information provided are:</p> <ul style="list-style-type: none"> <li>Observed climate data</li> <li>Climate change projections</li> <li>Marine &amp; coastal projections</li> </ul> <p>Another important feature is the Weather Generator.</p>			
	Project results (preliminary/ final/ expected)	The UK Climate Projections show what the major changes to the UK's climate would most likely be in the absence of such action to cut global emissions. These can be characterised as warmer and wetter winters, hotter and drier summers, sea level rise, and more severe weather.			
	Used methods	climate modelling techniques	[optional & additional comments]		
<b>Further Information</b>					
	Attachments	[optional & additional comments]			
	Contact persons	http://ukclimateprojections.defra.gov.uk/ Defra, Nobel House, 17 Smith Square, London, SW1P 3JR webmaster@defra.gsi.gov.uk			[optional & additional comments]

A second highly relevant example for the good practice collection is the Copenhagen-Ringsted Climate Change Impact Assessment which was undertaken for a project on expanding the track capacity between Copenhagen and Ringsted in Denmark. The assessment shows that increased precipitation and water flow in watercourses can impact on the railway infrastructure. Taking into account the projections for precipitation, the new line will have a 30% greater drainage capacity than current standards would require.

Projects & Good Practise Examples		Copenhagen-Ringsted Climate Change Impact Assessment			
ID	Questions	Answers			
<b>General Information</b>					
Project Type	Research Project	and/or	Please choose from the list ...	and/or	Please choose from the list ...
Project Title/ Name	Copenhagen-Ringsted CC Impact Assessment				
Company	Danish Ministry of Transport				
Geographical coverage (countries, regions...)	DK				
Project Duration	2008				
<b>Project Information</b>					
Project Focus	Impact of climate change on railway routes				
Which tools	modification/adaptation of standards	and/or	infrastructure retrofitting/strengthening	and/or	adaptation strategies
Which natural hazards are covered?	flooding	and/or	flooding	and/or	
Which company divisions are affected/ involved?		and/or		and/or	
Which infrastructure subsystems are affected/ covered?		and/or		and/or	
If Infrastructure, which infrastructure subsystem(s) are included?					[optional & additional comments]
What are the project aims?	The aim of the impact assessment was to investigate a future rail track's robustness to climate change over a 100-year operating period.				
Short summary	Since increased precipitation and increased water flow in watercourses can affect the new railway line between Copenhagen and Ringsted, a climate change impact assessment has been carried out. Based on the results of the assessment, the new track will have a 30 per cent greater capacity for water flow than today's norm.				
Project Description	In connection with the project on expanding the track capacity between Copenhagen and Ringsted on Zealand, the Public Transport Authority has carried out a climate change impact assessment for the project in order to investigate a future rail track's robustness to climate change over a 100-year operating period. The assessment shows that especially increased precipitation and increased water flow in watercourses can impact on railway constructors, whilst other factors such as increasing temperatures, rising sea levels and rising groundwater will not have a significant impact. Of particular importance is an expected 20 per cent increase in the intensity of rainfall in heavy downpours in the year 2100. This means that during heavy downpours more rain per second will fall than in the past. This has implications for the size of railway drainage ditches.				
Project results (preliminary/ final/ expected)	Because of the expected increasing intensity of rainfall in heavy downpours in the year 2100, the new track between Copenhagen and Ringsted will have a 30 per cent greater capacity for water flow than the norm that is used at present.				
Used methods	<ul style="list-style-type: none"> <li>- Climate modelling</li> <li>- Impact assessment</li> <li>- Revision of standards</li> </ul>			[optional & additional comments]	
<b>Further Information</b>					
Contact persons	Ministry of Transport Natascha Krogager Carlsson Phone: +45 3392 3309 nkc@trm.dk			[optional & additional comments]	

## 5.5 Case Studies

Within the framework of two case studies ARISCC investigates in detail what elements of the railway infrastructure are impacted by today's extreme weather and what elements are potentially vulnerable under future climate conditions. Regional Climate Models will be used to quantify the expected climate loads for the 2030ies, 2050ies and 2080ies. The first case study covers the railway lines in the Rhine Valley – from the Alpine regions at the source to the flatlands at the estuary. The second case study is the West Coast Main Line running from London to Glasgow in the UK. By means of alternative cost scenarios the pros and cons of early and late adaptation measures are being discussed.

### 5.5.1 Case Study 1: Rhine Valley

#### Map



Figure 15: Location of the railway line for the case study Rhine Valley.

#### Expected Climate Loads for the Rhine Valley (2050/2080)

##### 1) Temperature changes



The expected changes of the average temperature until the 2050ies for the Rhine Valley are between +1,5 and +2°.

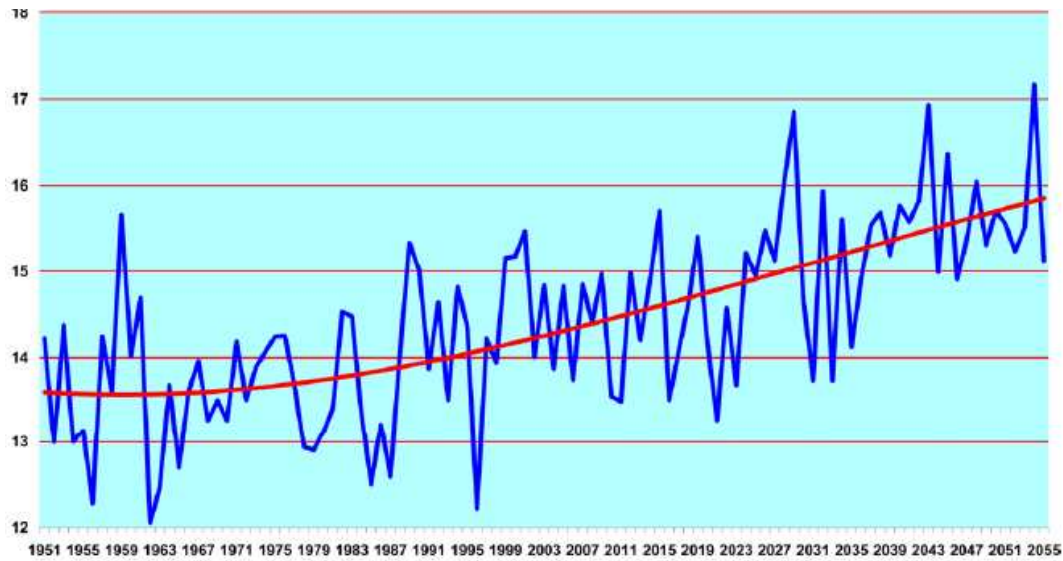


Figure 16: Past development and projection of the average temperature until 2055 for the Rhine valley, WettReg 2007.

The regional variation of the temperature changes for the same period is shown in the following figure for the German Federal State North Rhine-Westphalia (NRW):

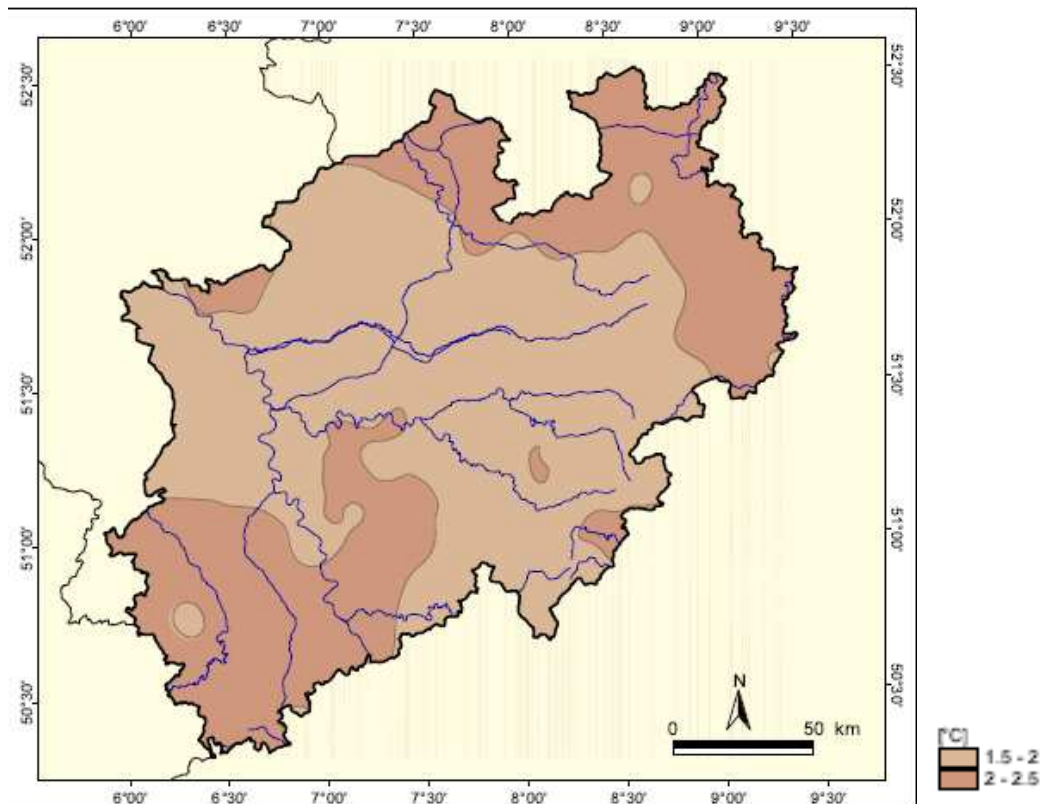


Figure 17: Projected changes in daily maximum temperature in NRW from 1951-2055 to 2046/2055, WettReg 2007

The most significant changes can be seen in the expected number of so called “event days”, which are indicators for extreme weather events. The following changes are projected:

- Subzero days: -12....-30 days!, average –20 (30%)
- Summer days ( $T > 25^\circ$ ) + 9....+26 days, average: +63% ( max: +100%)!
- Hot Summer days ( $T > 30^\circ$ ), +2...+12 days, av: +136%, m ax > 150%

There is a clear trend towards warmer and hotter summers and a significant increase in warm and hot days. A more detailed analysis shows that the likelihood of heat waves increases considerably:

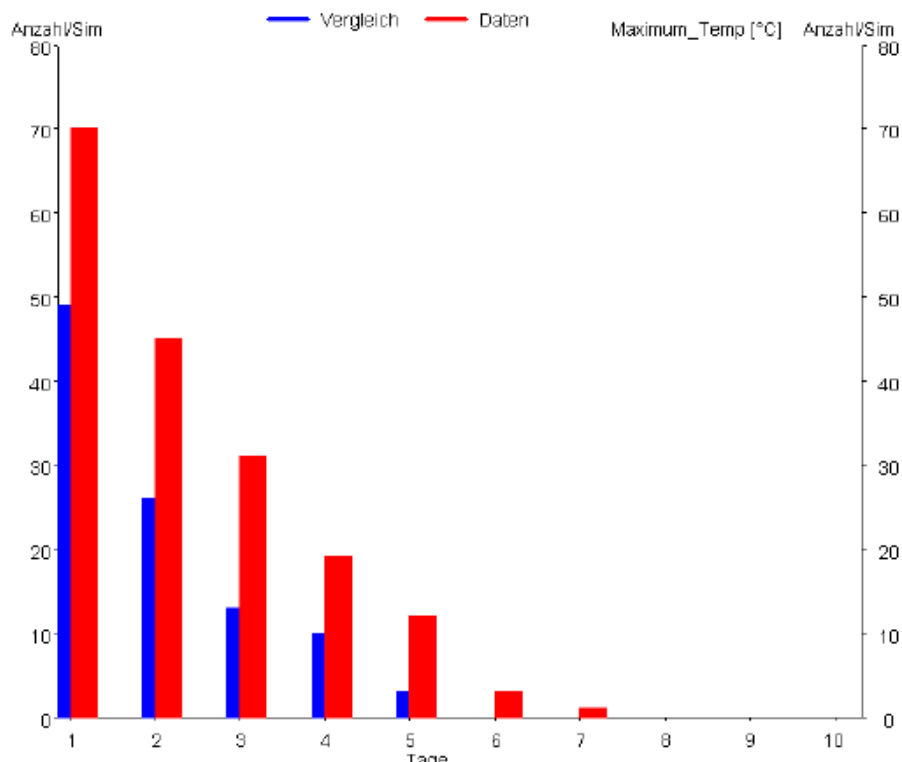


Figure 18: Periods with maximum temperature > 30°C in the decade 1981/90 (in blue) and 2091/2100 (in red) for the upper Rhine Valley; Source: WettReg 2007.

## 2) Precipitation

The expected changes in precipitation are also significant. Especially in winter, there are considerable increases in the amount of precipitation projected.

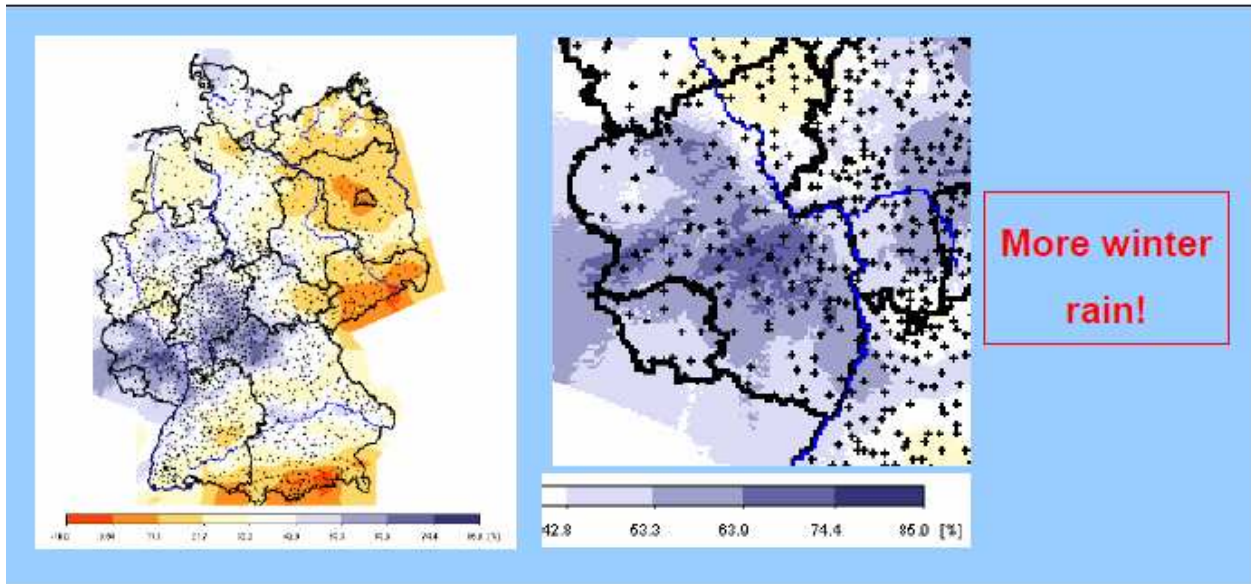


Figure 19: Changes in Winter Precipitation for the period 2071-2100 in comparison to 1961-1990 for the Mountain Ranges along the Rhine Valley.

Especially for the Mountain Ranges on the left side of the Rhine, increases of more than 60% are possible. Consequently, the risks of fluvial as well as surface flooding could increase dramatically.

### 3) Storms and gales




From regional climate modelling there is evidence of a significant change in the frequency and intensity of storms over Germany in future decades. The resulting increase in annual average losses for North Rhine Westphalia (NRW) are +8% for the A1B and +19% for the A2 scenario, respectively. In regional terms, the largest changes in insured losses are found for north and north eastern NRW, where the annual average losses may increase by up to 36%. When considering only storms with return periods above 20 years, loss expectations may increase by a factor of 2.

### Past extreme weather events

The following list gives an overview over past extreme weather events which have heavily affected the operation of railway infrastructure and sometimes even the integrity of infrastructure assets.

- ⚡ **2010 – 26<sup>th</sup> to 28<sup>th</sup> February**  
 „Storm Xynthia“ with wind speed above 100 km/h; causing severe problems in rail services (partly no services in Rhineland-Palatinate, North Rhine-Westphalia).
- ⚡ **2007 – 18<sup>th</sup>/19<sup>th</sup> January**  
 „Storm Kyrill“ with wind speed up to 200 km/h; led to tree fellings i.a. at the Lower Rhine in North Rhine-Westphalia
- ❄️ **2005 – 26<sup>th</sup>/27<sup>th</sup> November**  
 Heavy snowstorms with snow heights of up to 50 cm (with heavy and wet snow) in North Rhine Westphalia and Eastern Netherlands; causing damages of electricity poles and tree felling and thus interruptions in rail services



-  **2005 – 20<sup>th</sup> till 23<sup>rd</sup> August**  
„Alpes flooding“ due to heavy rain fall with up to 280 mm within 48 hours; causing landslides in Western Austria, which again damaged catenaries and led to a total breakdown of rail services
-  **2003 – August**  
Heat waves as a result of the extraordinary hot summer, caused by temperatures up to 40°C in the Upper Rhine Valley
-  **1999 – 26<sup>th</sup> December**  
„Storm Lothar“ with wind speed up to 200 km/h in France, Switzerland and SW-Germany; causing felling of trees and thus railway line to be cut off
-  **1994/1993 – January/December**  
„Rhine flooding“

## Vulnerability Study for the Rhine Valley

### a) Screening Process

Parts of the Rhine Valley Route which are situated in areas with increased likelihood of natural hazards and therefore have potentially higher vulnerabilities will be identified within the framework of a screening process. The screening will be performed on the basis of flood risk maps (see GIS of DB AG) and hazard maps for vegetation (wind/storm throw). A first rough assessment indicated that the line sections between Koblenz and Troisdorf are particularly interesting, since considerable parts of the railway tracks are located directly within flood planes and surrounded by mountain slopes and are therefore potentially prone to the impacts of surface and fluvial flooding as well as land- and mudslides.

### b) Analysis of past vulnerabilities

The parts of the route identified by the screening process will be investigated more deeply. An important step is the detailed analysis of the data base for delay minutes, focussing on weather related delays in the concrete route segments. The spatial resolution of the enquiry (exact location of the delay/disturbance) should be as good as possible in order to allow the linkage of hazards to concrete infrastructure assets. Later in the process, these data will be complemented by data from database where damages to the infrastructure are recorded.

### c) Analysis of current and future vulnerabilities

On the basis of the results of step 1 and 2, interviews with the people responsible for the route segments will be carried out. The current status of the infrastructure assets will be analysed. It will be discussed in detail, how future climate loads can impact the local railway infrastructure. Especially vulnerable infrastructure assets will be identified.

d) Measures for the improvement of infrastructure robustness will be identified and discussed in more detail.

- Integrated hazard management
- Weather warning
- databases

- Maintenance planning
- preparedness
- more details from interviews

### 5.5.2 Case Study 2: West Coast Main Line, UK

Map



Figure 20: Location of the railway line for the case study West Coast Main Line, UK.

Expected Climate Loads for the West Coast Main Line (until 2050s)

1) Temperature changes

The expected changes of the average temperature until the 2050s for Western England and Scotland are +2° like in most European regions. The expected increase for the warmest days is more pronounced – up to +4° - which increases the likelihood of extremely hot days and heat waves quite considerably.

The following figure shows the expected changes in the maximum temperature in summer for a medium emission scenario, based on calculations within the framework of the UK climate projections 2009.

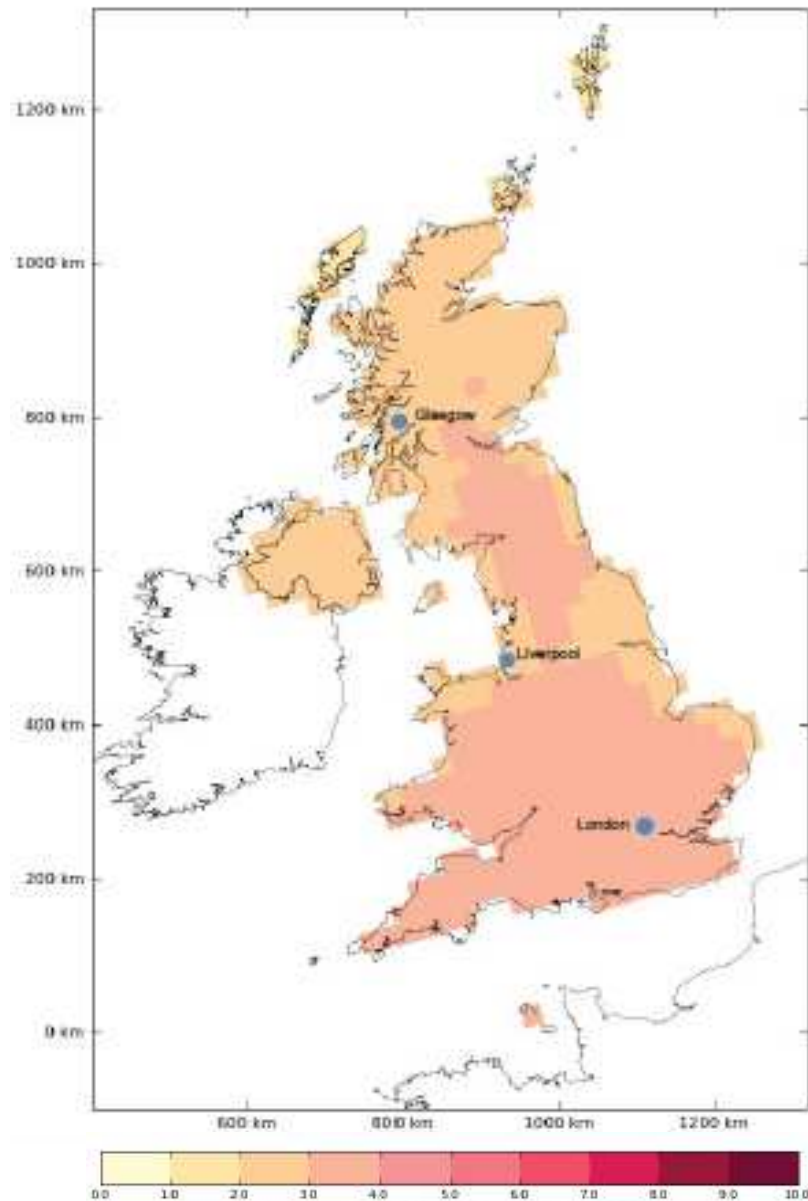


Figure 21: Projected changes in daily maximum temperature in the UK from today until the 2050s (2040-2069), Source; UK Climate Projections 2009.

## 2) Precipitation

The projected changes in precipitation are most significant for the winter season. In general wetter winters are to be expected with an average increase of precipitation around 20%. In some locations, an increase of over 30% is likely.

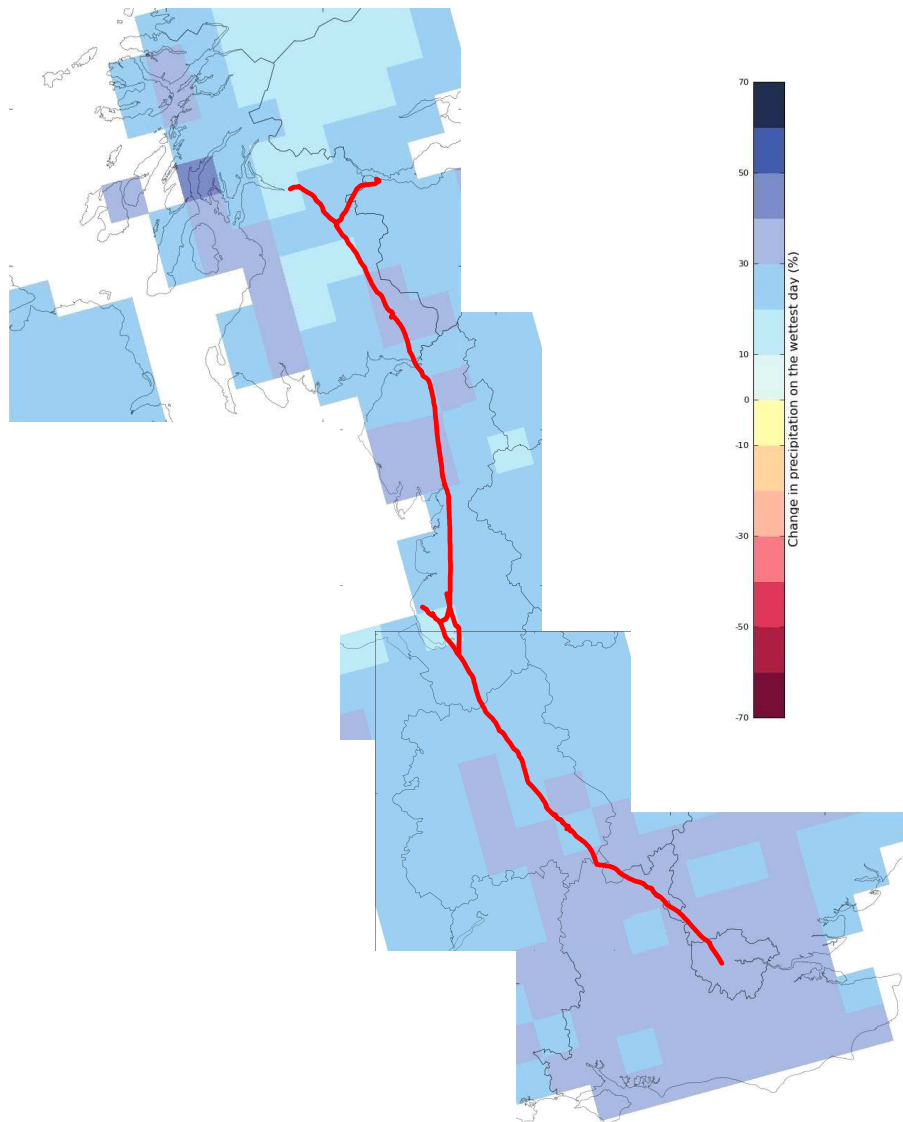


Figure 22: Changes in Winter Precipitation for the period 2040-2069 in comparison to today for the West Coast Main Line.

The University of East Anglia in Norwich and the University of Newcastle, UK, performed a study investigating possible changes in extreme rainfall across the UK until 2070/2100. The results show, that for short duration extreme rainfall events (1–2 days), the event magnitude at a given return period will increase by 10% across the UK. For longer duration extreme rainfall events (5–10 days), event magnitudes show high increases of up to 30%, especially in Scotland.

Future weather will not only have wetter winters, but most likely also be characterized by more extreme rainfall events and, thus, significantly increase the risk of surface and fluvial flooding.

### 3) Storms and gales

With current regional climate models, the modelling of storm intensities and return periods is much more difficult and controversial than modelling of temperature and precipitation distributions. Nevertheless, there are some indicators suggesting an increasing number of severe storms for the mid-term future. In a study of AIR Worldwide Corp. and the Met Office undertaken for ABI in 2009, the consequences

of a 1.45° southward shift in storm track across the UK were analysed. It was found that under these assumptions the average annual insured wind losses in the UK could rise by 25% to £827 million. At the regional level, increases range from 17% to 29% as can be seen in the following figure.

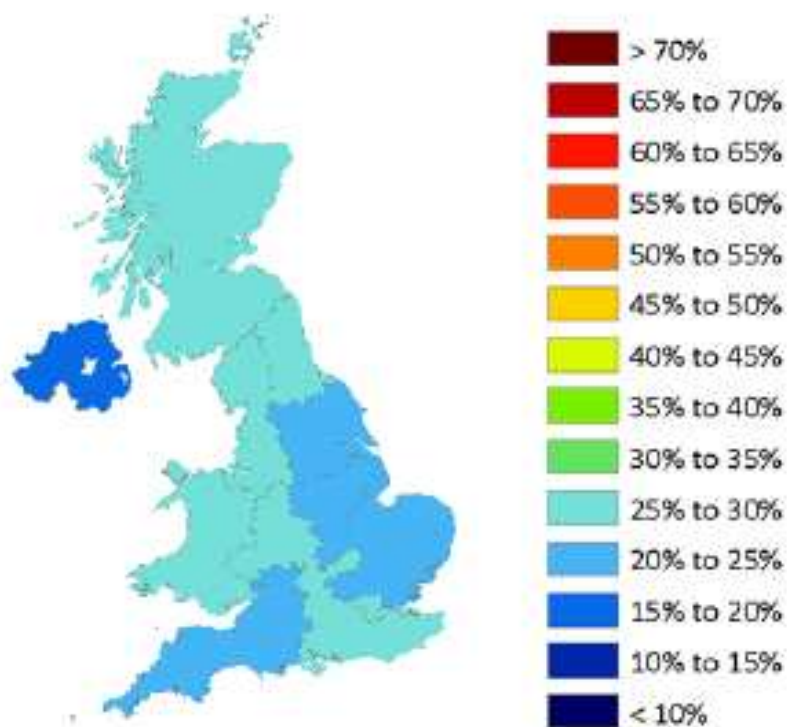


Figure 23: Regional response of average annual loss to a 1.45 degrees outward shift in the mean track of windstorms for the UK. Source: AIR Worldwide Corp. 2009.

### Past extreme weather events

An overview over past extreme weather events which have heavily affected the operation of railway infrastructure and even the integrity of infrastructure assets is given in the following list:

- ❄️ **2009/2010 – December to January**  
Heavy snow fall with freezing temperatures – One of the heaviest winters in the UK during the last decades; causing severe delays in rail traffic.
- 🌊 **2008 – 10<sup>th</sup> March**  
Atlantic storms with wind speed up to 130 km/h approaching Wales and Southern England; causing delays due to partial closing of bridges
- 🌊 **2007 – 1<sup>st</sup> June till 28<sup>th</sup> July**  
„UK floods“ – After a long rainfall period, more than one hundred flooding or bank-slip incidents on the rail network in the whole UK (wettest summer ever); causing widespread delays and temporary rail line closures
- ☔ **2005 – 8/9<sup>th</sup> January**  
„Storm Gudrun“ crossed parts of the UK and caused heavy rainfalls above 100 mm of precipitation in NW Scotland and Northern Wales; causing over

100 flood warnings by the UK Environment Agency

☀ **2003 – 3<sup>rd</sup> August**

*European heat waves* caused in the UK rail speed restrictions where rail tracks buckled in the heat (above 30°C); causing again delays and cancellations for UK rail travellers

⚡ **1990 – 25/26<sup>th</sup> January**

„*Storm Daria*“ – In terms of incidents one of the strongest storms of the last 50 years.

## Vulnerability Study for the West Coast Main Line

### a) Screening Process

Within the framework of the first phase of the project Tomorrow's Railway and Climate Change Adaptation (TRaCCA) RSSB investigated the most relevant weather and climate related factors and their impact on railway infrastructure assets. This screening process involved seven workshops with the participation of railway asset management specialists from Network Rail from the Engineering, Operations and Maintenance departments of NetworkRail as well as experts from ATOC. Taking into account the effects of projected climate change, potential risks to the railway were identified. The outcome of the workshops was further qualified by an expert review and moderation exercise which especially focused on prioritising the findings.

In a second feedback round the summary list of priorities from the review and moderation exercise was commented, modified and finally confirmed by the experts. The results of this process is a table of risks structured by climate impact groups and infrastructure clusters that are likely to pose the greatest threat to the railways, taking into account the impact of climate change. These 'priority topic areas' in respect of the impact of climate change on performance and safety of railways are shown in the following table.

Climate Impact Group	Cluster	Consequence
Heat	Track	Management of track buckle risk
Heat	Track	Reduced window of opportunity to carry out maintenance/ renewals work due to heat
Heat	People	Passenger health and impact on freight from train failure in extreme temperatures, including heat and cold
Heat	People	Staff working conditions, eg: use of heat watchmen
Heat	Power/ Telecoms/ Signalling	Floating electrical earth leading to stray earth currents caused by dry ground/ low groundwater; heat (solar gain) affecting lineside equipment; sag in tethered overhead line systems at terminal stations
Rainfall	Fluvial flood	Track and lineside equipment Failure
Rainfall	Groundwater flood	Track and lineside equipment Failure
Rainfall	Pluvial flood	Track and lineside equipment Failure
Rainfall	Fluvial flood	Scour and water effects at bridges
Rainfall	Fluvial flood	Scour at embankments due to high river levels and culvert washout
Rainfall	Fluvial flood	Safety of workforce carrying out inspections during an extreme flood event
Rainfall	Pluvial flood	Landslips
Rainfall	Fluvial flood	Accessibility of fleet and of maintenance depots
Insolation/ heat/ rainfall/wind	Vegetation	Change in type, falling trees causing obstructions, poor adhesion, and track-circuit non-activation
Sea level rise and storms	Coastal and estuarine defences	Wave overtopping and flooding at defended coastal and estuarine railways

RSSB

*Table: Confirmed priority topic areas with respect to impact of climate change on performance and safety of railways. Source: TRaCCA 2010.*

#### b) Analysis of current and future vulnerabilities

In the next phase of the TRaCCA project, Network Rail will investigate the priority topic areas in respect of the impact of climate change on performance and safety of railways in more detail. This will be done by modelling the most important hazards such as extensive heat and heat waves, river and surface flooding, landslips and



storm throw for the West Coast Main Line and assessing the impact of these events on the different railway infrastructure assets. As a result of this assessment, vulnerability maps for the West Coast Main Line will be developed.

In addition to vulnerability maps, the second phase of TRaCCa will generate the following output:

<b>Phase 2</b>
<b>Mathematical models for the priority topic areas for the Detailed specifications and costings for Phase 3</b>
<b>A high-level impact assessment as required by Government for 30th September 2010</b>
<b>Recommendations for potential 'quick wins' in terms of adaptation and procedural options for dealing with the impacts of current weather patterns</b>
<b>Preliminary recommendations for asset management policy and planning for Control Periods CP5 - CP8</b>
<b>decades 2010s, 2020s, 2030s, 2040s</b>
<b>A specification for a tool to enable the rail industry to evaluate policy options (Adaptation Policy Evaluation Tool) for adaptation and weather resilience for priority and other topic areas</b>
<b>A climate change adaptation seminar to raise awareness and to inform the rail industry of likely climate change issues.</b>
<b>A report summarising the above</b>

c) Measures for the improvement of infrastructure robustness will be identified and discussed in detail.

**5.6 Adaptation of engineering specifications**

ARISCC will also provide useful information about current activities regarding the adaptation of engineering specifications for new and for existing infrastructure due to expected impacts of climate change in different European countries. First examples show that adaptation of specifications currently focuses mainly on the dimensioning

of drainage systems and on the height of dams and flood barriers due to expected increases in rainfall intensity and duration (especially in winter). They also show the increase and differentiation of temperature specifications (e.g. the stress-free temperature for tracks) due to expected increases in average and especially in maximum temperature in future climates.

## **6. ARISCC partners**

The most active and contributing partners for ARISCC are DB, Network Rail, ÖBB, SBB and UIC headquarters. Representatives from Traficverket and South Korean Railways have also given valuable input. Recently SNCF, ProRail, Infrabel and the Finnish Rail Administration have joined the project and input from Middle and Eastern Europe (PL, CZ, HU) and Southern Europe (P, ES) was integrated. We invite all other infrastructure managers to actively participate in ARISCC and thus broaden the knowledge base about integrated natural hazard management and adaptation of railway infrastructure to climate change.

### **6.1 Contact**

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## 7. References

1. Arkell, B.P. and Darch, G.J.C.: Impact of climate change on London's transport network, 2006
2. Australian Greenhouse Office: Assessing and mapping Australia's coastal vulnerability to climate change: Expert Technical Workshop, 2006
3. Australian Greenhouse Office: Economic Issues Relevant to Costing Climate Change Impacts, 2004
4. Australian Greenhouse Office: The IPCC climate change scenarios, 2006
5. Australian Greenhouse Office: How reliable are climate models?, 2005
6. Baker, C.J. et. al.: Climate change and the railway industry: a review, 2010
7. Berggren, Bo and Berglund, Christina: CALAR - Concerted action on forecasting, prevention and reduction of landslide and avalanche risks, 2000
8. Committee on Climate Change and U.S. Transportation: Potential Impacts of Climate Change on U.S. Transportation, 2008
9. Dale Cooper and Stephen Grey: Climate change impacts and risk management, 2006
10. Defra: UK Climate Projections, 2009
11. Quantifying the effects of an increasingly warmer climate with a view to improving the resilience of the GB railway network: Is a new stressing regime an answer, thesis, submitted to the University of Birmingham, February 2010
12. Dobney, K. et. al: Quantifying the Effects of High Summer Temperatures due to Climate Change on Buckling and Rail Related Delays in the UK, 2006
13. Lane, John and Dora, John, Tomorrow's Railway and Climate Change Adaptation (TRaCCA), WCRR 2011, Lille
14. Essowes, M.J. et.al.: Railway Safty Implications of Weather, Climate and Climate Change: Final Report, 2003
15. Hennessy, Kevin et. al.: Climate change scenarios for initial assessment of risk in accordance with risk management guidance, 2006
16. HMSO: The Climate Change Act 2008, Her Majesty's Stationary Office, 2008,
17. Information Center for Climate Change Adaptation Denmark: Adapting railways to climate change, 2008
18. IPCC: Special Report on The Regional Impacts of Climate Change - An Assessment of Vulnerability, 2007
19. Ministry for Environment NRW: Climate change in North Rhine Westphalia, 2007
20. Nelson, Frederick E.: Climate change, permafrost, and impacts on civil infrastructure, 2003

21. Parkman, M.: An investigation of the impact of climate change on the safety and performance of the railway coastal and estuarine defence assets, 2007
22. Parkman, M.: Assessing the Impact of Climate Change on Transport Infrastructure, 2008
23. Pinto, J.G. Estimation of wind storm impacts over Western Germany under future climate conditions using a statistical–dynamical downscaling approach, 2009
24. Rachoy, C. and Spazierer, M.: Meteorological information and warning system for railway infrastructure decision support for natural hazards management. In Proceedings of the World Congress on Rail research, Seoul, Korea, 2008
25. Research and Analysis Division Infrastructure Canada, Adapting infrastructure to climate change in Canada's cities and communities, 2006
26. RSSB: Tomorrow's railway and climate change adaptation – TraCCa, phase 1 report, 2010.
27. Siegel, Hubert (ed): MONITOR - Hazard Monitoring for Risk Assessment and Risk Communication, final brochure, 2008.
28. Stern, Nicolas: Stern Review on the Economics of Climate Change “Stern-Report”, 2006
29. The Allen Consulting Group: Climate change risk and vulnerability, Working paper for the Australian Government; Further research and response options, 2005
30. UK Department for Transport: The changing climate: its impact on Department for Transport, 2005
31. Umweltbundesamt: Development of high resolution weather data for Germany and regional climate scenarios with WETTREG, 2007
32. University of Birmingham: FUTURENET - Future Resilient Transport Network, 2009
33. Willi, Christina, Schutzziele Naturrisiken – Grundlagen zur Erarbeitung von Schutzziele für die SBB, SBB Dokument NR 015, 2009
34. Woller, Sarah: The changing climate: its impact on Department for Transport, 2005
35. Zebisch, Marc et. al.: Climate Change in Germany - Vulnerability and Adaption of Climate sensitive Sectors, 2005.