4 The Consequences of Climate Change and Extreme Weather Events

This chapter looks at vulnerability analyses for a large number of sectors and areas. Generally, each section is structured as follows:

- Description of the system and background information.
- Current vulnerabilities and past major events.
- Consequences and costs of climate change and extreme weather events.
- Adaptive measures and considerations.
- Research and development needs.
- Recommendations.

Section 4.8 summarises the consequences and measures in economic terms.

4.1 Communications

4.1.1 Roads

The consequences of climate change on the road network are considerable. Increasing precipitation and increased flows lead to flooding, the washing away of roads, damaged bridges and an increased risk of land collapse, landslide and erosion. With increased temperatures damage moves from being frost-related to heat and water-related, though concrete bridge maintenance costs are reduced.

Division of responsibility

The overall objective of transport policies is to secure an economically efficient and highly sustainable transport system for citizens and businesses throughout the country, which places great demands on accessibility, passability and safety. The Swedish Road Administration is the agency responsible for this sector. The road maintainer is legally responsible for the roads, and this includes ensuring that the roads are passable for third-party/passing traffic. State subsidies are given to private road maintainers for the maintenance of approximately a quarter of the private roads. In the event of major damage, those responsible for private roads can apply to the Swedish Road Administration for financial compensation, such as for wear.

The road network today

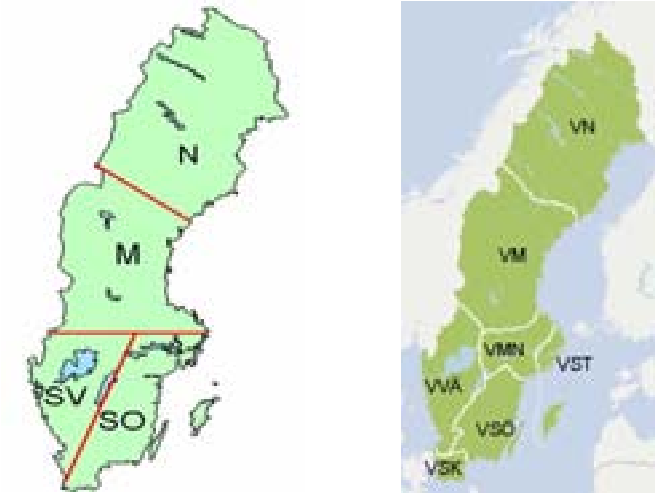
Sweden's roads can be broken down according to responsibility, significance or importance to the country as a whole. Breaking down the road network according to responsibility gives 98,000 km of state roads, 37,000 km of local authority roads and 280,000 km of private roads, 150,000 km of which are forest roads. The state road network is split into European, national and county roads. Moreover, the Swedish government has defined *a backbone road network* of national interest in accordance with the Swedish Environmental Code, largely comprised of European and national roads. The Swedish European roads are part of the trans-European transport network.

The road network is divided into five components when considering climate impact:

- Roads (surfacing, pavement, subgrade and culverts).
- Bridges.
- Tunnels.
- Ferry berths.
- Operation and maintenance.

Lifetimes vary greatly, from the technical lifetime of road surfacing of about 20 years to the more than 100 years of bridges and tunnels. The vulnerability analysis is based on the existing road system and a geographic distribution that largely corresponds to the Swedish Road Administration’s organisation and the natural boundaries that can be construed from climate change, primarily the dividing line between the southeast and southwest parts of the country and dividing line between the southern part and Mälardalen.

Figure 4.1 Geographic division of the country applied in the vulnerability analyses and the Swedish National Road Administration’s regional divisions



Source: Swedish National Road Administration's Report to the Transport Group of the Climate and Vulnerability Committee.

Large parts of the sparse state road network lack viable diversion routes. Densely populated areas lacking larger topographic barriers generally offer good alternatives for traffic diversion in the event of problems. In rural areas traffic can be diverted from newer stretches of road to older ones, if they remain. In the event of long-term disruptions temporary roads and bridges can be built to minimise losses to society.

The analysis presented in the *Swedish Road Administration's Report to the Commission on Climate and Vulnerability*, appendix B 1, includes the state network. It does not, however, include local authority and private roads and streets. Forest roads have been studied in brief in the analysis for the forestry sector (section

4.4.1). The vulnerability analysis is based primarily on the global ECHAM4 model, emission scenario A2 and the 2071-2100 time span. Other scenarios are taken into account if there are considerable differences. The focus is on road network components judged to be most affected by climate change.

Sensitive climate factors and past extreme events

The primary climate factors affecting the road network are precipitation, high flows, icing, temperature, sea level and wind.

Precipitation affects road systems mainly through the build up of ground water and runoff into watercourses immediately after rain or due to snow melt. Persistent rain raises the ground water level and increases pore pressure in the soil, which impairs natural slope stability. High flows in large and medium-size watercourses give rise to an erosion risk that affects watercourse embankments and an accompanying risk of landslide, as well as impact on bridge trestle work and superstructures. High flows are seen in southern Sweden mostly in late autumn, early winter and early spring, while in northern Sweden they are mostly seen during snow melt. Heavy rain leads to high flows in small watercourses, primarily in summer and autumn, with the risk of erosion, flooding, the washing away of roads and impact on, for instance, culverts. Heavy rain also entails a risk of flooding, for example, in and around underpasses.

Snow or supercooled rain on the road affects passability and traffic safety. Ground frost and moderate and high temperatures are of significance to road load bearing capacity and durability. Temperature fluctuations also affect bridge constructions, as do wind and ice. Sea levels affect ferry services and low-lying tunnels.

Heavy precipitation was recorded for most years between 1994 and 2001. During this period there were some 200 events involving major damage caused by high flows. The damages break down as follows: flooding 25 percent, roads washed away 50 percent, landslides 20 percent and undermined *bridge trestle* work 5 percent. The greatest number of incidents was reported in western Götaland and Värmland up to central Norrland. The cause of the damages was a combination of extreme weather events and geological and topographical conditions.

A few major incidents have occurred since 2001. Several high road embankments were washed away in Hagfors in 2004 after heavy rain. The total costs exceeded SEK 20 million. In the summer of 2006 a road embankment near Ånn was washed away after heavy rain and an accompanying high flow. The road was repaired after two weeks at a cost of SEK 6 million. In December 2006 there was a large landslide south of Munkedal. The landslide encompassed an area measuring 550 metres by 250 metres in a depression through which the E6 trans-European road runs. The repairs took almost two months. The direct costs for repairing the road network, including the restoration of bypass roads and ferry services provided during the disruption, totalled some SEK 120 million, excluding the cost of restoring the Taske river. Costs for diversions and other incidentals comprised more than 50 percent of the direct costs. The indirect consequences were extensive. The two allocated diversion routes for long-distance traffic entailed extra journeys of 40 and 55 km respectively. The indirect costs have been estimated at the same magnitude as the direct costs. The costs of all major incidents due to high flows and landslides the past 12 years are estimated at SEK 1,200 million.

Work is underway at the Swedish Road Administration to produce new specification requirements for construction and improvement work. These will include risk-based performance specifications regarding high flows and take into account the consequences of damage. A risk survey and a risk analysis of the existing road network have been initiated. The emphasis is on erosion and landslide risks, as well as stretches of road vulnerable to closure. Methods to find road culverts exhibiting high risk levels during heavy rain are under development. The methods used to determine the water flow and water levels to be considered in the design process are being revised. A review of the rules for erosion protection is also planned.

Consequences of climate change and extreme weather events together with damage costs – precipitation, flows and sea level

In the scenarios, winter, spring and autumn precipitation generally increases throughout the country. Snow pack duration and total water content decrease throughout the country. Snowfall declines in the southern parts of the country, while a slight short-term increase, which will eventually show a gradual decline, is seen in the northern parts. In all, this increases effective precipitation (precipitation minus evaporation), synonymous with runoff. A lower incidence of ground frost due to higher temperatures will lead to increased ground water formation during winter, affecting susceptibility to landslide. Figure 4.2 shows the change in effective precipitation during the different annual seasons and figure 4.3 shows the change in maximum return period of today's 100-year flow together with the changed average runoff.

Figure 4.2 **Change in effective precipitation, mm/season (precipitation minus evaporation), 2071–2100 compared to 1961–1990 (RCA3-EA2). The bars show, from left to right: winter, spring, summer, autumn (appendix B 1)**

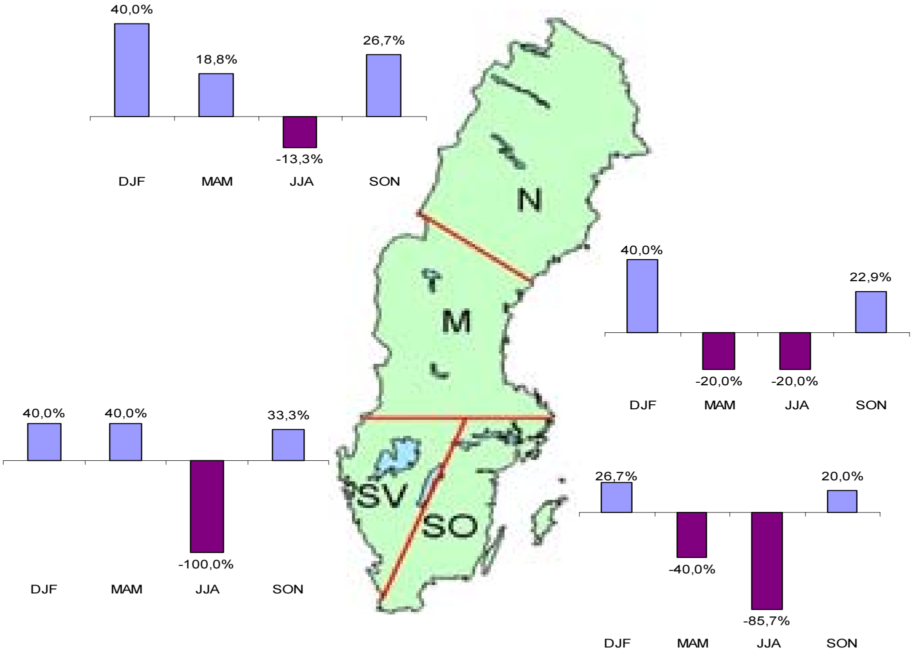
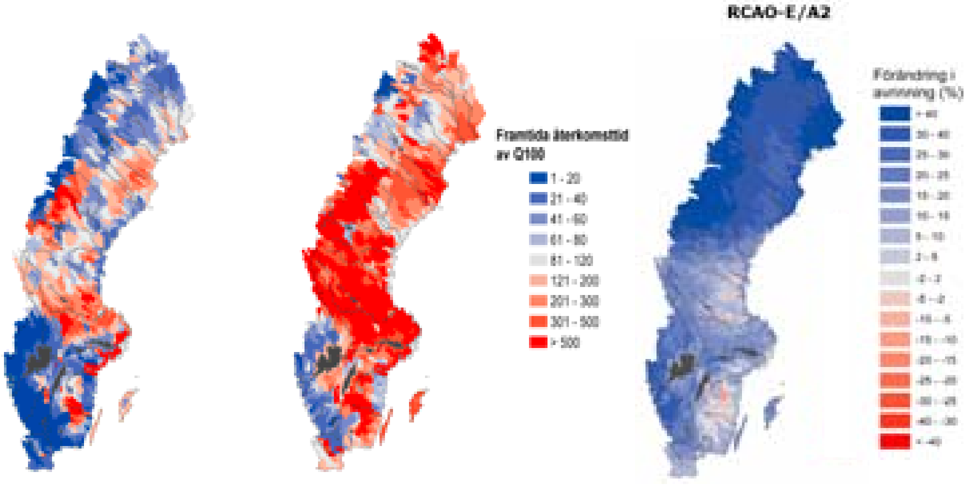


Figure 4.3 **Changed maximum return period 2071–2100 for today's local 100-year flows (RCAO-EA2, RCAO-EB2, RCAO-HA2, RCAO-HB2) and changed local average runoff 2071–2100 compared to 1961–1990 (RCAO-EA2)**



Shortest **Longest** Future return period of Q100 **Change in runoff (%)**

Source: Andréasson et al, 2007b and appendix B 14; Bergström et al, 2006b.

Landslide frequency is expected to increase in areas already at high risk, namely western Götaland and western Svealand, as well as along most of the east coast. The situation is judged to be particularly serious in the Göta valley, Bohuslän and along some of the tributaries to Lake Vänern, although the situation can also turn serious in other parts of the country. The landslide risk assessment is based on an analysis by the Swedish Geotechnical Institute on changed soil stability due to climate change (see also section 4.3.2). (Fallsvik et al, 2007).

This section and the following one, which includes consequence assessments, are based on the *Swedish Road Administration's Report to the Commission on Climate and Vulnerability*, appendix B 1.

A number of different consequences can be expected in the different parts of the road network. The older road network is judged to be particularly exposed due to high pore pressure not being fully considered during engineering work. It is largely unknown which sections of road have insufficient safety margins.

Local heavy rain showers are increasing throughout most of the country. The number of days with heavy rain in autumn, winter and spring are increasing. This can lead to roads, parts thereof, being washed away due to erosion. Damage due to backwater most often occurs in intersecting culverts and small tubular bridges, which today are designed for 50-year flows. The area from western Götaland and Värmland to central Norrland is judged to be most affected. In the case of larger bridges and roads near watercourses damage due to heavy rain and extreme local inflow could increase considerably in western Götaland and the western Vänern area. The risk of personal injury cannot be overlooked.

We can expect an increased frequency of the flooding of roads and underpasses near small watercourses throughout the country and of low-lying roads near medium-size/large watercourses in southern and western Götaland. In addition to the consequences for traffic, flooding entails a risk of personal injury and increased maintenance needs due to impaired load bearing capacity.

Appendix B 1 includes an estimate of future major damage to the road network occurring annually and every few years. The cost of damages is difficult to assess due to differences between possible scenarios. Similarly, the frequency of major serious events is difficult to assess. Major landslides resulting in damage costs in excess of SEK 100 million are expected to increase in the future. These are not included in the summary. Section 4.3.2 covers the changed risks of land collapse, landslide and erosion.

Table 4.1 **Damage costs for the road network for major damage caused by flooding, erosion and landslide (current monetary value). In the long-term, damage costs comprise an additional cost to today's costs due to climate change. Major future landslides are not included (appendix B 1)**

	Damage costs 1994–2006 (SEK millions)	Indirect costs 1994-2006 (percent of damage costs)	Increase in damage costs long term (SEK millions)
Flooding, erosion	65	5–15	50–150
Land collapse, landslide (not Munkedal)	15	5–25	20–50

The change in snowfall is not judged to cause any additional costs. It will mostly cause a redistribution of money from the southern to the northern parts of the country in the long term.

The extent to which low-lying bridges are affected by high flows depends on bridge height above the highest high water (HHW), which for modern bridges is calculated using the 50-year flow. Most exposed are bridges built during the past twenty years and older bridges shorter than 8 metres. When building these bridges, the headroom requirement was 0.3 metres. If the water climbs above the bottom edge of the bridge, one possible consequence is that the road embankment is washed away or that the bridge superstructure shifts laterally. Similar conditions apply to bridges over small watercourses. Bridges built on foundations resting directly on underlying soil are sensitive to erosion. Bridges that are constructed freely, that is, not fixed with trestle work or adjoining span, are especially sensitive to erosion.

A rise in sea level combined with wind is assessed to cause problems for low-lying underpasses and roads in southern Sweden, such as the Tingstad and Göta tunnels in Gothenburg and the E6 motorway near Ljungskile. In addition to the flood risk there is a risk of the construction being lifted. Adaptive measures are required to prevent damage. It is, however, difficult to assess the extent of any possible damages or measures. Ferry berths, mostly on the west coast, may also need to be adapted. No direct damage is expected, according to Appendix B 1, though there are economic consequences if traffic cannot be maintained.

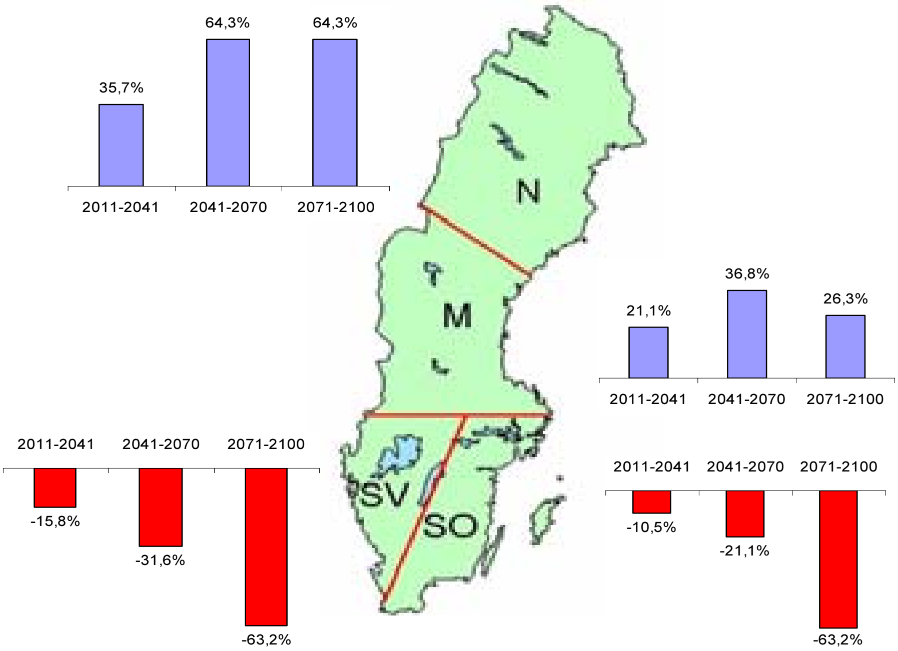
As mentioned above, the analysis only covers the state road network. Our very rough assessment is that the local authority and private road networks are affected by similar consequences to those affecting the state road network as regards increased precipitation, flows and sea levels with flooding, roads being washed away, land collapse, landslide and erosion.

Consequences of climate change and extreme weather events together with damage costs – temperature and wind

According to Appendix B 1, increased temperatures and reduced frost penetration will lead to different consequences for road paving and road surfacing. A shorter frost period means reduced deformation in the paving and subgrade, but may demand greater maintenance if the frost is used as a means. Wear on surfacing may also decrease. Higher temperatures and ground water levels mean increased rutting through deformation. Rutting maintenance is expected to increase by five percent, with the exception of the north which with its low traffic density will see maintenance decrease by five percent. Irregularities are expected to drop by ten percent. Generally speaking, measures will shift from being frost-related to heat and water-related.

Concrete constructions are sensitive to salt and repeated freezing cycles. The number of zero crossings – the number of days when the temperature passes freezing point – is significant to the road network, bridges and winter road maintenance (see figure 4.4).

Figure 4.4 **Change in the number of zero crossings 2011–2040, 2041–2070, 2071–2100 compared to 1961–1990 during the winter season (RCA3-EA2), (appendix B 1)**



The number of zero crossings is increasing in Norrland and northern Svealand in winter, but is otherwise decreasing. Due to the change in zero crossings, concrete repair costs are expected to drop by SEK 50–100 million a year. However, any salting of ice and snow in Norrland's interior may cause an increase.

The temperature interval between the highest and the lowest temperature does not increase in the climate scenarios and no other seasonal change will affect bridges. Knowledge is currently lacking on daily temperature fluctuations due to climate change and the effects concrete bridges. Parts of the country where the climate becomes damper may see a shortening in the lifetimes of wooden bridges. A number of large suspension and diagonal cable bridges on the west coast and the high coast are occasionally affected by icing, which presents a danger to traffic. In the analysis icing is assumed to depend on zero crossings. On the west coast, zero crossings are declining, reducing the need to divert traffic. The consequences for the high coast are difficult to assess.

Large suspension and diagonal cable bridges are also sensitive to strong winds, which can create problems with swaying. In total, it is judged that 10–20 high bridges could be affected by higher wind loads and speeds than today. An increased frequency of the wind forces currently considered strong, on the other hand, does not entail increased risk.

Our overall assessment is that the local authority road network is affected by similar consequences to those affecting the state road network as regards temperature change, such as wear, rutting, deformation and concrete repairs. The private road network is similarly affected to a certain extent.

Adaptive measures and considerations

The analysis in appendix B 1 shows that road maintenance will be affected considerably. The natural disasters of 2006 illustrate what we can expect in the future.

We consider it very important that recommended measures, as described in appendix B 1, are taken to increase the safety of the road network. Measures to be given first priority are those that reduce the risk of land collapse, landslide and the washing away of roads and road embankments, considering the possible serious consequences of such incidents. Climate change ought to be included as a given. Areas expecting increased flows ought to be prioritised first. This means:

- Continued development and use of the model for risk-based performance specifications.

- Risk survey of sensitive sections of road in the existing road network.
- Greater consideration to the risk of landslide when engineering and carrying out road constructions.
- Intensify and bring forward studies on measures for blocked culverts and small tubular bridges.
- Requirements on road heights in relation to water levels in new planning.
- Review of specification requirements for roads as regards flow return periods and levels, as a proposal based on the 100-year flow return period rather than that of the 50-year flow.
- Increased monitoring and following up of new constructions.

Measures for bridges and their vulnerability to increased flows in a changed climate are also high priority. This means:

- Survey of bridges with headroom <0.3 metres above HHW throughout the country.
- Survey of bridges with headroom <0.5 metres above HHW in areas where increased flows are expected.
- Review of requirements on headroom above water level for alterations and new constructions, as a proposal based on the 100-year flow return period rather than that of the 50-year flow.
- Review of erosion protection regulations.
- Survey of damage to erosion protection devices and accompanying action plan as regards vulnerability to high flows.
- Supplement the bridge management system database with relevant information about water.

The Swedish Road Administration and the Swedish Rail Administration ought to cooperate on the review and development of height requirements for headroom above water for alterations and new constructions.

In the survey of the risks of flooding, land collapse, landslide and erosion, the general maps produced by the Swedish Rescue Services Agency will provide a good starting point.

Land development can, among other things, considerably change runoff conditions, with consequences, for example, that affect infrastructure. It is our opinion that cooperation and the sharing of information between different players must increase to reduce the risks affecting vulnerable constructions.

Other players in the road sector, local authorities and private road maintainers, ought to conduct a similar review of the road network's vulnerability to climate change within their areas of responsibility.

The subject of climate change ought to be included in basic technical university and college education to increase knowledge about how climate change can affect bridge and road construction. Knowledge of how geotechnical conditions are affected by climate change is also important to include in course programmes.

Cost of adaptive measures

Appendix B 1 presents the Swedish Road Administration's cost estimates for adaptive measures in greater detail. The cost of preventing serious erosion and flood damage has been estimated at SEK 150–500 million in the short term. The corresponding cost to prevent landslide totals at least SEK 200 million. Cost estimates for the longer term are less certain, and depend on whether the measures can be taken in conjunction with normal alterations. One assessment estimates measures to prevent damage from erosion, flooding and landslide at SEK 1,000–2,000 million in the long term.

Adaptation of winter road maintenance requires increased contingency in the northern parts of the country. The total cost is estimated to remain unchanged with a northwards shift.

Bridges over small watercourses and larger bridges with headroom above HHW of less than 0.5 metres in areas with a risk of increased flows may need earlier replacement. The additional costs of replacing 20 percent of these bridges is estimated at SEK 720 million spread over the period 2011–2100. The rest of the country has a number of small tubular bridges with headroom of less than 0.3 metres above HHW. Applying the same assumptions gives a increase in costs of SEK 20 million for these bridges. Measures against increased wind loads are costly. Measures may need to be taken for a small number of large bridges. It has not been possible to calculate the cost of these adaptations.

It may be necessary to reconstruct a number of ferry berths, mostly on the west coast. No total cost has been specified, although the average cost for a ferry berth is estimated at about SEK 10 million.

Research and development

We believe current research on forecast methods for assessing ground water pressure and pore pressure in a changed climate ought to be broadened to include methods for assessing changed land use, as this is of significance to slope stability.

Research and development on sensors for monitoring conditions in, for example, road embankments to provide advance warning of subsidence or landslide ought to be prioritised.

Recommendations

- The directive for the Swedish Road Administration must clearly state that the agency is assigned responsibility for adapting to climate change within its area of responsibility (see section 5.10.2).
- The Swedish Road Administration ought to be tasked with surveying and, if necessary, taking measures against the risk of land collapse, landslide, roads being washed away, flooding and erosion due to changed precipitation and increased flows that can affect the road network. The assignment ought to include reviewing the specification requirements for flows and heights and developing models to aid risk assessment. A plan ought to be presented to aid coming transport policy decisions.

4.1.2 Railways

Climate change can seriously impact the railway network. Increased precipitation and heavier precipitation lead to flooding, the flushing of track constructions with a risk of accompanying landslide. Increased flows entail an increased risk of erosion on trestle work and adjacent railway embankments. The increased temperature reduces the risk of rail failure in the winter, but increases maintenance needs in the summer. Stronger winds and an increased risk of wind-felled trees have consequences for power supply.

Division of responsibility

The Swedish National Rail Administration is the responsible agency with collective responsibility for railway sector development in line with transport policy objectives. This responsibility encompasses operating and maintaining state track systems, coordinating local, regional and interregional railway traffic and assisting research efforts. Railway construction planning is regulated by the Swedish Act on Railway Construction. The planning process aims to link railway construction to other community planning and environmental legislation. The Swedish Environmental Code requires that the legality of certain railway construction plans be examined.

The railway network today

The Swedish railway network is comprised of almost 12,000 rail kilometres. The Swedish National Rail Administration manages approximately 90 percent of these rails. Other administrative bodies include Inlandsbanan AB, Arlandabanan and Öresundskonsortiet. The capillary network is owned by local authorities and private enterprise. The railway network is comprised of railway tracks, ballast, track subgrade, subgrade, points, drainage facilities, bridges, retaining walls and tunnels. Overhead lines, power supplies, signalling systems, cables and trenches, culverts and more are required to operate the railway network. Some overhead lines have been designed for particularly high wind loads. There are a small number of landslide and avalanche warning systems. The Swedish National Rail Administration also owns properties that may have polluted land.

The lifetime of the different installations is affected by traffic intensity, maintenance frequency and year of construction. Signalling systems have short lifetimes due to rapid technology developments. *Points* have a 20-year lifetime, culverts and bridges up to 100 years. The Swedish National Rail Administration maintains and develops the railways to meet stakeholder demands, which are primarily focused on higher speeds, heavier trains, increased environmental considerations, noise and vibration levels and more.

The vulnerability analysis is based on existing systems – installations on backbone lines with a maximum permitted speed of 200 km/h, maximum permitted load per axle of 25 metric tons and with appropriate lifetimes, regular maintenance and the replacement of operating supplies. Rolling stock and indoor equipment is not included in the analysis.

System redundancy comprises diversion to other lines, double tracks and close proximity between stations with traffic management capabilities. About 70 percent of the network is single track and this is mostly found in northern Sweden. From Västerbotten there are insufficient diversion opportunities for traffic in upper Norrland.

Railway operation is extremely dependent on electricity. Essentially all traffic comprises electrically-powered vehicles. Tolerance for disruption is already assessed as relatively low without extreme weather events, due to factors such as a third of the network carrying traffic approaching maximum capacity.

Figure 4.5 The Swedish railway network

Source: Swedish National Rail Administration, 2007.

Sensitive climate factors and past extreme events

The railway network is sensitive to climate factors of a very intense nature such as precipitation and high flows, persistent precipitation and heavy snowfall. Higher temperatures, especially together with higher humidity, an increased number of zero crossings, higher wind speeds and changes in thunderstorm frequency are also significant factors.

The southern and western line regions were badly hit by the storm Gudrun in 2005 due to wind-felled trees, damaged overhead lines and power failures. The lack of functioning telecommunications and electricity supplies delayed repairs. The storm Per in

2007 also caused major damage, though not to the same extent as Gudrun. Damage costs amounted to SEK 132 million and SEK 50 million respectively. A programme for tree safety has been drawn up and entails logging or shortening trees along railway lines. Additional subsidies of SEK 50 million have been requested for the period 2008–2009. Once this initiative has been completed the costs to maintain the improvements are estimated at SEK 5 million a year.

In the summer of 2006 a railway embankment in Ånn collapsed after heavy rain upstream caused a high flow with accompanying erosion then collapse. A train passed the incident site shortly before the collapse. An incident involving mortal danger or personal injury is therefore not far off. Restoration cost SEK 7 million. In December the same year there was a large landslide near Munkedal. The landslide encompassed an area measuring 550 metres by 250 metres in a depression through which, for instance, the Bohus Line runs. Restoration cost SEK 23.5 million. The railway network is also affected by flooding, such as in Mölndal in December 2007, an incident that cost SEK 5 million.

The following general estimate is for disruption time caused by damages. A railway embankment that has been washed away can normally be restored within a few days to a few weeks. Replacing a small but severely damaged bridge takes about 6–12 months. Severe damage to a large bridge can require two or three years before the replacement is complete. Temporary connections can often be made using reserve bridge supplies.

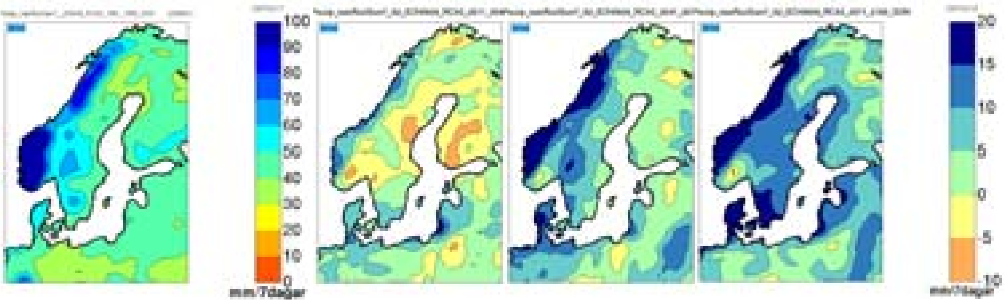
After the collapse in Ånn the Swedish government assigned the Swedish National Rail Administration the task of reporting, for example, which measures had been taken or planned in order to assess and prevent risks of land collapse, landslide and erosion. The submitted recommendations for short-term measures include increased monitoring, maintenance and improvements, supplementing the railway installations register, in-service training and the development of a system for risk-based status assessment of installations similar to the system used by the Swedish National Road Administration. The recommendations made for the middle and long-term concern increased knowledge and research, the adaptation of regulations and methods to new conditions and changed design principles. (Swedish National Rail Administration, 2006).

The consequences of climate change and extreme weather events

Both positive and negative consequences are expected based on the different climate scenarios. The consequences described in *Climate and Vulnerability Report – Impact on the Railway System,* appendix B 2, comprise a composite assessment based on the different climate scenarios and time spans, and mainly applies to the country in general.

According to the different scenarios, precipitation will increase in most parts of the country, especially during the autumn and winter, as will precipitation intensity. Increased precipitation means an increased risk of infiltration and erosion of ballast and track subgrade and, subsequently, reduced load bearing capacity. Figure 4.6 shows the maximum precipitation over a seven-day period, which mostly affects small and medium-size watercourses.

Figure 4.6 **Changed maximum precipitation over a seven-day period for the periods 2011–2040, 2041–2070, 2071–2100 compared to 1961–1990 (RCA3-EA2)**



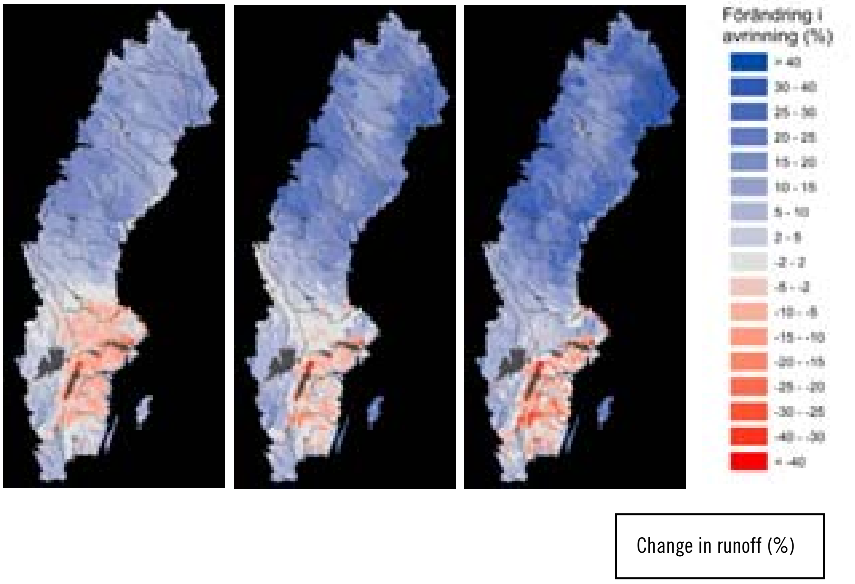
mm/7 days

Source: SMHI, 2007.

Sudden large flows risk flushing the track bed and subgrade with accompanying landslide. On mountain slopes this increases the risk of mud flows. Increased flows also entail a greatly increased risk of erosion on trestle work, abutments and adjacent railway embankments. The conditions for erosion, land collapse, landslide and mud flows are expected to increase in several parts of the country (see also section 4.3.2).

Low-lying tunnels, which are relatively insensitive to other climate factors, can be affected by flooding. Electronic equipment is also sensitive. In the event of the flooding of polluted areas there is an increased risk of the leaching of hazardous substances. Figure 4.7 shows changes in the average flow, local runoff, in a changed climate.

Figure 4.7 **Changes in local flows for the three future periods 2011–2040, 2041–2070, 2071–2100 compared to 1961–1990 (RCA3-EB2)**



Source: Bergström et al, 2007.

Snow pack extent and total water content will generally drop throughout the country. In Norrland, on the other hand, snowfall will increase in December, January and February until the 2020s, after which it will drop, which may entail greater snow clearing needs and larger snow melt volumes.

The higher summer temperatures mean an increased risk of heat distortion. A warm climate could lead to more foliage in the forests, leading to more leaves on the line and accompanying traffic disruptions, as well as greater humus content in ballast and in drainage systems, requiring increased maintenance. Increased winter temperatures, closer to freezing point, may affect point mobility, as ice from vehicles can loosen more easily and clog the points. A positive consequence of higher winter temperatures is a reduced risk of rail failure. Icing of overhead lines is not expected to increase. Icing can otherwise entail an increased risk of traffic disruption in upper Norrland, combined with higher winds.

Different climate models give different results as regards wind. In general, however, they lean towards a small increase in average winds. The ECHAM4 model predicts an increased maximum wind gust in most parts of the country, with the greatest increases in coastal areas, southern Sweden and northern Norrland. The frequency of squalls will increase somewhat, mostly along the southern and southwestern coastlines. This can entail increased demands on stronger structures and overhead lines. Moreover, this also increases the risk of falling trees (see section 4.4.1) and thus the need to log trees on third-party land to reduce damages.

There is no climate data for thunderstorms. It has thus not been possible to assess the consequences. Thunderstorms comprise a factor that can affect both electricity supplies and electronic systems with no EMP (electromagnetic pulse) protection.

Adaptive measures and considerations

The railway network is sensitive to a number of climate factors. Disruptions to operation have serious consequences for society and the general public. Analyses of changed conditions for different soil movements in a changed climate affect different technical systems, including the railway network. The land collapses and landslides that occurred last year emphasise the importance of preventative measures.

Appendix B 2 suggests different measures. The need for system changes is said to mainly concern the technical development of the railway system with a focus on robustness and safety considerations in all planning, and the system should be designed to handle disruptions of a larger scale than is currently the case. A streamlined system is said to not guarantee passability in a future climate.

We consider it very important that recommended measures, as described in appendix B 2 and in accordance with the recommendations the Swedish National Rail Administration makes in its previously mentioned report for the government, are taken to increase the safety of the railway network. It is our opinion that the measures to prioritise are those concerning the risk of damages due to increased precipitation and increased flows on account of climate change, considering the serious consequences these can have as regards land collapse, landslide, erosion and the risk to human life. This means:

- Survey of risk areas.
- Additional resources for inspection, maintenance and track improvements as regards existing installations, such as drainage systems.
- Improved erosion protection near bridges, culverts and other locations with large flows.
- Development of a model for risk-based assessment and identification of risk objects, such as objects under greater loads than for which they are designed and objects exposed to high flows.
- Review of specification requirements as regards return periods and flow levels taking into account climate change.
- In-service training.

The Swedish Road Administration and the Swedish National Rail Administration ought to cooperate on the review and development of height requirements for headroom above water for alterations and new constructions.

In the survey of the risks of flooding, land collapse, landslide and erosion, the general maps produced by the Swedish National Rescue Services Agency will provide a good starting point.

It is also our opinion that other measures ought to be taken, as stated in the appendix. This applies to the review of the standard specification requirements for overhead line installations, the review of trees lining electrified lines and continued efforts for an increased focus in planning on creating robust and safe systems in accordance with the Swedish National Rail Administration's handbook. The measures are of importance in reducing damages caused by increased wind speeds.

Land development can, among other things, considerably alter runoff conditions, with consequences, for example, that affect infrastructure. It is our opinion that cooperation and the sharing of information between different players must increase, such as between landowners and those responsible for operating and maintaining the railway network, to reduce the risks affecting vulnerable constructions.

The subject of climate change and its effects ought to be included in basic technical university and college education to increase knowledge about how climate change can affect railway construction. An important area of significance to track constructions is how climate change affects geotechnical conditions.

The Swedish National Rail Administration's assessment of the initial cost of preventative measures is presented in table 4.2.

Table 4.2 Cost of adaptive measures, SEK millions a year, 2007 (appendix B 2)

Measures	Cost
Drainage systems, erosion protection	10
Maintenance cost (inspection, extended measures)	15
Tree safety	50 (2008–2009) 5 (as of 2009)
Training	1

Research and development

The Swedish National Rail Administration currently pursues its own research in the sector as regards materials and determining loads and speeds. It is our opinion that this research ought to take into account specification requirements in the case of changed flows.

The Swedish National Rail Administration currently participates in research on monitoring infrastructure with the aid of sensors that monitor the status of embankments, tracks and bridges to provide advance warning of subsidence and landslide. This research is important with consideration for increased precipitation and increased flows.

We consider it important to calculate additional climate indices of importance to the railway system. At present, there is no index for thunderstorms as regards frequency and intensity. There is also a need for additional and more reliable scenarios as regards wind.

Recommendations

- The directive for the Swedish National Rail Administration must clearly state that the agency is assigned responsibility for adapting to climate change within its area of responsibility (see section 5.10.2).
- The Swedish National Rail Administration ought to be tasked with surveying and, if necessary, taking measures against the risk of land collapse, landslide, roads being washed away, flooding and erosion due to increased precipitation and increased flows that can affect the railway network. The assignment ought to include reviewing the specification requirements for flows and heights and developing models to aid risk assessment. A plan ought to be presented to aid coming transport policy decisions.
- The Swedish National Rail Administration ought to be tasked with reviewing the standard specification requirements for overhead line installations and the additional measures that may be required to increase robustness, primarily as regards strong winds.

4.1.3 Shipping

Shipping is not affected to any greater extent by climate change. A reduced occurrence of sea ice, as regards both the seasons and extent, are beneficial to shipping. Higher water levels may have a negative impact on port operations along Sweden's southernmost coasts. A possible increase in extreme winds could entail problems for shipping.

System description of shipping

Shipping mainly comprises the following system components:

- Harbours (mostly ports owned by local authorities, wharfs owned by industry and pleasure boat harbours and marinas).
- The Swedish Maritime Administration is charged with responsibility for shipping lanes, canals, ice-breaking, geographic maritime information, navigation information, piloting, sea rescue

and marine surveying (the channels in Lake Mälaren and Lake Hjälmaren were covered in SOU 2006:94).
- Shipping companies (Swedish and foreign) as well as subcontractors and service companies.

There are some 50 public harbours along the Swedish coastline. In addition to these there is a considerable number of harbours owned by industry, of which at least a dozen are of significance to Swedish trade and industry. Harbours that currently see extensive ferry and/or cruise liner traffic include, on the west coast, Gothenburg, Halmstad and Varberg, on the south coast, Helsingborg, Malmö, Trelleborg, Ystad, Karlshamn and Karlskrona, and on the east coast, Oskarshamn, Nynäshamn, Stockholm and Kapellskär. Combined passenger/cargo ferry traffic represents about 30 percent of foreign trade measured in tonnage, or about 60 percent measured in value. Of these harbours, Gothenburg, Trelleborg and Stockholm represent two-thirds of the volume of goods.

The Swedish ferry network in the form of coastal and archipelago shipping lanes comprises about 6,000 nautical miles, equivalent to about 11,000 kilometres. In addition to this, there are about 300 nautical miles (550 km) of inland waterways. The safety measures in place in these waterways comprise 1,100 lighthouses and 5,000 buoys and beacons. The harbours are usually responsible for activities within a delimited harbour area. There are also a large number of detention centres adjacent to harbours that are administered by the Swedish Maritime Administration, the public harbours or other responsible authorities, such as the local authority.

Shipping accounts for about 90 percent of Swedish foreign trade. There is no real alternative for the import of crude oil, petroleum products and other energy goods. The same applies to the export of ore, steel and forestry products. The development and integration of logistical and transport systems into intermodal transportation systems, with demands on safe and regular flows adapted to the tides in order, for example, to avoid stockpiling, have meant that the entire transport chain has generally become more sensitive to disruptions. Under present conditions, local transport, energy and communication systems can be knocked out by unexpected bad weather.

The consequences of climate change and extreme weather events together with costs

The climate factors of most significance to the shipping sector are changed water levels and changed wind and ice conditions (see *Climate and Vulnerability Report Data for Shipping,* appendix B 3).

Generally speaking, in terms of marine safety, high sea levels are better than low. A higher sea level increases safety margins in shipping lanes and docks. In the long term land uplift, in northern Sweden poses a problem as the safety margins between the lowest point on the ship and the bottom of the shipping lane gradually decrease. For especially sensitive stretches of shipping lane it is therefore important to prepare monitoring schemes to ensure the necessary safety margins. In some cases, such as certain shipping lane stretches in Lake Mälaren, the permitted draught will have to be reduced.

The high scenario with a rise in global sea level of 88 cm and 100-year sea level in 2071–2100 provides, with consideration for land uplift/subsidence, a high tide in southern Sweden almost 2 metres above today's average sea level (see section 3.5.4). The ports cannot operate if sea level reaches above the top of the quays, which are currently about 2.0–2.5 metres above the average sea level, in some cases lower. In such a scenario, not only quays but even access roads are under water. The consequence is that port operations cease. For safety reasons, ships should not remain tethered to mooring equipment that lies under water. With the future 100-year sea level the described consequences could affect ports in the southernmost parts of the country. In other areas along the coast and in the case of a lower rise in sea level, the consequences are judged to be small, according to appendix B 3. Fixed buoys are placed so as to be above sea level even at very high tides. Shipping lanes are fully navigable even at very high sea levels.

In many places climate change is increasing the risk of high water levels in lakes and other watercourses. With a water level equal to the 100-year level, for example, shipping on Lake Vänern would be seriously disrupted and at even higher water levels the problems are accentuated (see SOU 2006:94).

The consequence of isolated disruptions is a temporary stop in production. Recurring disruptions, on the other hand, can cause serious problems and affect confidence in shipping. However, in relation to other regions of the world, our region will not be particularly hard hit by climate-related disruptions. A more detailed analysis of the costs resulting from disruptions is difficult to conduct due to the uncertainty about which industries will be affected.

At present there are restrictions on the highest permissible wind force and wave height at which different types of vessel may call in to or depart from port and pass sensitive stretches of shipping lane. Such restrictions, which depend on the characteristics of the shipping lane and its exposure to weather and wind, are applied when piloting vessels. Special restrictions apply to passenger ships, ferries and cruise liners, as well as to car ferries, which with their large superstructures are more sensitive to wind than other vessel types.

With increased winds, traffic to and from certain ports will be forced to accept relatively long disruptions and, subsequently, increased traffic irregularity as a result. For combined passenger/cargo ferry traffic this could have a major impact on Swedish foreign trade and entail a risk of consequences for the entire transport chain, from producer to consumer.

Sea ice is expected to decrease considerably, in terms of both extent and seasonal length. At the end of the century, only the Gulf of Bothnia will see any noteworthy sea ice, and then only during one or two months of the year depending on the climate scenario (see section 3.5.4). This means that winter shipping in Swedish ports will be better facilitated, especially in Gävle and the ports north of there. The need for ice-breaking assistance, and consequently ice-breaking costs for the Swedish Maritime Administration and the ports, will drop. Today, the Swedish Maritime Administration's ice-breaking costs vary from about SEK 150 million for a mild winter through SEK 200 million for a normal winter to about SEK 250 million for a bad winter. The cost effects resulting from reduced sea ice coverage are dependent on when contingency measures can be reduced, which is currently difficult to judge from the climate scenarios. Another positive effect is that the time delays that winter shipping usually experiences, the result of increased waiting times and reduced speeds, will be cut, which in turn means a reduced need, for example, for stockpiling.

According to appendix B 3, increased winds can place greater demands on the sea rescue conducted by the Swedish Maritime Administration. This also applies to the navigation information intended to increase maritime safety.

Adaptive measures and considerations

Climate change will most likely entail no major consequences for shipping. High water levels may have an impact on port operations along Sweden's southernmost coasts. An increase in wind force could increase the frequency of closures of certain ports with consequences for the transport sector. The Swedish Maritime Administration ought to be tasked with taking a closer look at how increased wind force and higher water levels could affect port operations in Sweden.

Research and development

An important climate factor for shipping is wind. The climate data from the Rossby Center is limited as regards this factor. We consider it important that research on the wind aspects of climate change continue.

Recommendations

- The directive for the Swedish Maritime Administration must clearly state that the agency is assigned responsibility for adapting to climate change within its area of responsibility (see section 5.10.2).
- The Swedish Maritime Administration ought to be tasked with investigating the risk of port closures as a result of higher water levels and possibly higher wind forces and, where necessary, recommend measures.

Recommendations should also be given concerning bathymetric data, which is described further in:

- Section 5.2.7: Databases in different sectors and geographic areas of responsibility.

4.1.4 Aviation

Aviation is not affected to any serious extent by climate change. A warmer climate may affect ground frost depth with consequences for airfield load bearing capacity. Increased precipitation burdens airport storm water systems and can cause planned alteration work to be brought forward. The need for de-icing and skid prevention will fall in the southern parts of the country, though it will increase in the northern parts.

Division of responsibility

The Swedish National Civil Aviation Administration, or LFV, is a public enterprise that is to contribute to achieving transport policy objectives. LFV's primary tasks are the operation and development of state-owned airports, air traffic control in peacetime, civil and military aviation and air traffic controller training.

On 1 January 2005, the Swedish Aviation Safety Authority and the Swedish Aviation and Public Sector Department were unbundled from LFV. These departments formed a new agency, the Swedish Civil Aviation Authority. The Swedish Civil Aviation Authority is responsible for civil aviation, which includes overall responsibility for the environmental adaptation of the air transport system.

System description and current vulnerability

At present there are 42 Swedish airports for civil aviation. Scheduled flights also operate out of airports owned by parties other than LFV. Most of the administration's airports were built between the years 1930 and 1960.

Table 4.3 List of airport owners (appendix B 4).

Airport owner/operator	Number	Millions of passengers 2005	%
LFV, wholly-owned	14	27.6	86.3
LFV, military airports	2	1.1	3.4
Local authority/private airports	26	3.3	10.3
Total	42	32.0	100

The airports have extensive support systems. Storm water management is important to airfield surface drainage. Other necessary support systems include, for example, water and waste water systems, power supply, computer and telecommunication systems and technical support systems for aircraft, including fuel supply.

Some of the existing storm water systems at LFV's airports are old and/or undersized. They are in need of gradual renovation and auxiliary capacity. The systems are not completely redundant in terms of electrical power supply.

About 60 percent of Swedish airports catering to civil aviation and located near watercourses can be affected by flooding. Those most exposed are:

- Sundsvall-Härnösand Airport in the delta of the river Indalsälv.
- Kalmar Airport.
- Gothenburg-Säve Airport with high ground water and located near the river Osbäcken, which is prone to flooding.
- Västerås Airport is exposed to water levels too close to a critical level at the 100-year level. At the specified level air traffic would be limited, as sections of the runway and traffic control system would be affected (SOU 2006:94).

The major airports Arlanda, Landvetter and Luleå have reserve runways, though these are not viable alternatives for longer disruptions.

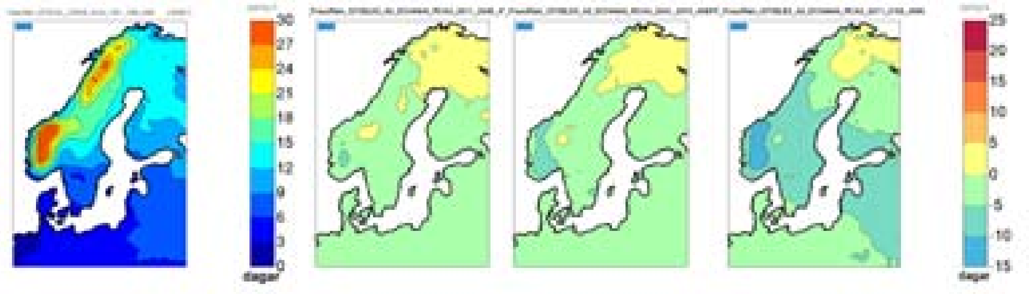
In the past 10–12 years several extreme weather events have disrupted air traffic (such as the storm Gudrun in 2005 and flooding in central Norrland in July 2000). Air traffic was, however, only affected for shorter periods during these incidents. It is easier to find transport alternatives for goods than for passengers.

The consequences of climate change and extreme weather events together with costs

The vulnerability analysis is mainly based on the global ECHAM4 model, emission scenario A2 and the time spam 2071–2100 (see *Vulnerability Analysis Report for the Aviation Sector,* appendix B 4). The analysis focuses on the types of installation judged to be most affected by climate change. The considerable differences between the scenarios have been taken into account.

Sensitive climate and weather factors for the aviation sector are: heavy snowfall, heavy precipitation, high flows, rising sea level, icing, very strong crosswinds, fog, ground frost and thunderstorms. Figure 4.8 shows the risk of icing, expressed as the number of days the maximum temperature is below freezing and precipitation is greater than 0.5 mm.

Figure 4.8 **Changed icing, number of days a year, for the periods 2011–2040, 2041–2070, 2071–2100 compared to 1961–1990 (RCA3-EA2)**

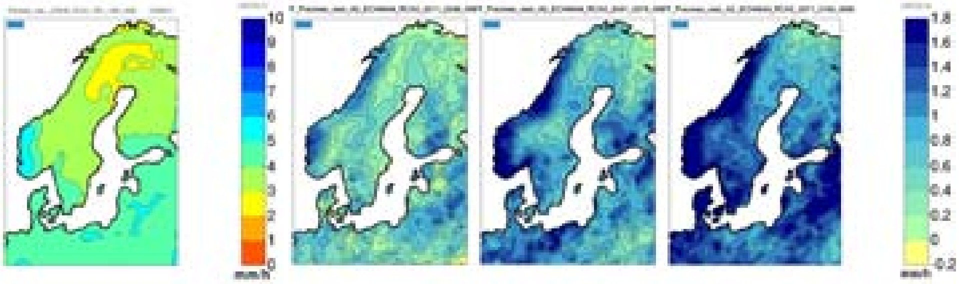


Source: SMHI, 2007.

The need for de-icing and skid prevention is expected to fall in southern Sweden in a warmer climate. The need will, however, increase in the north. The major airports are located in the southern parts, which is why the total need for de-icing and skid prevention ought to drop. The drop in de-icing needs is estimated to reach 50–75 percent by the 2050s, corresponding to cost savings of about SEK 35–40 million a year. Skid prevention is estimated to drop by about 70–90 percent, corresponding to cost savings of SEK 18–20 million a year.

The negative consequences include an increased frequency of heavy rain, affecting low-lying airports and airport storm water systems (see figure 4.9). Storm water system capacity is already strained and will be further burdened by a future climate.

Figure 4.9 Changed heavy rainfall, mm/h and year, for the periods 2011–2040, 2041–2070, 2071–2100 compared to 1961–1990 (RCA3- EA2)



Source: SMHI, 2007.

Kalmar Airport's drainage waterpurification plant is affected by an increased water level and increased frequency of heavy rain. Sundsvall-Härnösand Airport's runway can be affected negatively by greater discharge with increased erosion.

Increased precipitation, higher ground water levels and increased water flows can affect airfield load bearing capacity negatively, which is why effective storm water systems will be of increasing importance in the future.

When designing an airfield's superstructure, that is, the part of the road construction that, among other things, is to distribute the traffic load, the depth of penetration of ground frost is often the determining factor for how thick the overall superstructure must be and not the effect of loads. A warmer climate could mean reduced ground frost penetration, which in turn affects the design of the airfield's superstructure.

Increased thunderstorm frequency causes problems for air traffic. Future air traffic is expected to be more dependent on electronics and, subsequently, more vulnerable to thunderstorms. However, it has not been possible to assess the consequences of thunderstorms as data on changes in thunderstorm frequency is not available.

Fog can have a local impact on airports. However, climate change is not expected to affect the incidence of fog to any larger extent.

Adaptive measures, costs and considerations

Appendix B 4 indicates that the airports are assessed to be in use even in the long time span applied in the report, that is, into the 2080s. Up until the 2050s, no special measures are planned as regards climate change. Instead, normal maintenance is expected to be conducted alongside ongoing adaptations to the prevailing climate. Aircraft, which have a normal lifetime of 30 years, are replaced as needed. The maintenance measures that have been discussed are thicker superstructures to increase airfield load bearing capacity and improvements to storm water systems due to changed ground frost penetration and increased precipitation.

Changed frost conditions may affect the load bearing capacity of airfields. Theoretically, the need for thicker superstructures for existing asphalt surfaces as a result of reduced frost could entail additional costs of about SEK 300 million up until 2080. A large proportion of these measures are expected to be taken within the scope of ongoing maintenance or other improvement work.

Increased precipitation will place an even greater burden on the currently undersized storm water systems. Planned alterations may need to be brought forward. The 2002–2003 renovation of the storm water system at Kiruna Airport, which is an average-size airport, cost about SEK 5.5 million. Based on the cost of renovating Kiruna Airport, it can be assumed that the renovation of all airport storm water systems in southern Sweden would entail costs of the order of many hundreds of millions of Swedish krona. As the storm water systems are already undersized, the cost is not entirely attributable to climate change.

The airports in Kalmar, Västerås and Sundsvall-Härnösand may need measures to reduce the risk of flooding. Adaptive measures, in the form of increased erosion protection, at Sundsvall-Härnösand Airport are estimated to cost a few tens of millions of Swedish krona. A new purification plant at Kalmar Dämme is expected to cost about SEK 15-20 million.

It is our opinion that the Swedish Civil Aviation Authority, together with LFV, ought to be tasked with conducting a vulnerability analysis on changes to the load bearing capacity of runways due to changed ground frost and ground water conditions. The data on changes in ground frost due to climate change is judged to be insufficient for a relevant analysis. It is also our opinion that the possible need to bring forward the renovation of existing airport storm water systems due to increased precipitation in a changed climate ought to be examined.

The indirect costs to society caused by airport closures are difficult to quantify. Airports are often kept open, despite poor weather conditions. Passengers, on the other hand, can have difficulties in reaching the airport. A rough estimate of the order of the indirect costs that can arise if Arlanda Airport is closed for 24 hours has been calculated based solely on the estimated cost of passengers' lost time. A four-hour delay per passenger has been estimated to incur costs of SEK 50 million a day. If loss of income for the airport is also included, this would mean another roughly SEK 50 million a day and an equal amount for airlines etc., making a total of SEK 150 million. For a medium-size airport the figures are roughly fifty times smaller, or about SEK 3 million a day (see appendix B 4).

The air transport sector is extremely dependent on electricity. Climate change could entail an increased risk of disruptions to the electricity supply. We recommend that each head of operations for air traffic is assigned explicit responsibility for ensuring that the necessary reserve power is available to maintain operations at the airports.

Research and development

Important climate factors for aviation are wind, thunderstorms and ground frost. The climate data from the Rossby Center is limited as regards these factors. We consider it important that research on these aspects of climate change continue.

Recommendations

- The directive for the Swedish Civil Aviation Authority and LFV must clearly state that the agencies are assigned responsibility for adapting to climate change within their areas of responsibility (see section 5.10.2).
- The Swedish Civil Aviation Authority ought to be tasked with conducting a vulnerability analysis on changes to the load bearing capacity of runways due to changed ground frost and ground water conditions and to examine the need to bring

forward the renovation of existing airport storm water systems due to future increased precipitation.

4.1.5 Telecommunication

An increased risk of wind-felled trees affects systems with overhead lines and even masts. Overhead lines will be around for some years to come even if development is towards wireless connections and underground cables. Electronic communication is also highly dependent on electricity. Taking into account climate change, forest conditions and the ongoing rebuilding of the electricity supply system, disruptions will most likely continue to affect electronic communication.

Division of responsibility

Electronic communication comprises an increasingly important part of our social infrastructure. In Sweden deregulation began at the beginning of the 1990s. The Swedish National Post and Telecom Agency, or PTS, is the central administrative agency responsible for this sector, which means, for example, promoting the availability of safe and effective communication, supervising the sector, deciding on obligations and strengthening society's contingency for serious disruptions to electronic communication. Today about 500 telecom operators are registered with PTS, and of these a small number own infrastructure. According to the Swedish Act on Electronic Communication, parties providing public networks or services must ensure that the associated operations fulfil reasonable demands on good functionality and technical reliability, as well as persistency and availability during extraordinary events in peacetime.

The telecom networks today

Electronic communication networks are systems and equipment for the transmission, connection or routing of signals via wires, radio waves or optical media. In principle, the systems are comprised of user terminals, access networks, transport networks and central support systems. Access networks connect terminals to transport networks and in the fixed telephony network often comprise copper wire. Radio links between mobile telephones and base stations comprise another form of access network. Transport networks bridge long distances and such connections are often made over optic fibre or radio link. The transport networks are generally the same for different services, whether electronic communication or telecom and data traffic.

The range of access methods provides redundancy. Infrastructure is better in densely populated areas, although in more sparsely populated areas today there is often more than one mobile network and infrastructure continues to be built.

Telecommunication is extremely reliant on electricity. Large nodes have reserve power units with sufficient capacity for about one week of operation. Smaller stations, such as concentrators in the fixed telecommunication network and base stations in mobile networks, have battery backups of varying capacity, from three or four hours and above.

A joint emergency services radio system, called Rakel, is under construction. System users include police, safety and health sector personnel. The system has its own separate mobile stations, base stations, exchanges and centrals, but will mostly use masts in the existing communication network. Like other networks, the radio system is dependent on electricity, but has higher capacity reserve power than other networks.

Alongside its supervisory role, PTS also cooperates with operators, such as on different robustness projects in order to bolster the infrastructure to cope with extraordinary situations that lack commercial motivation. Reserve power stations, mobile base stations, redundant connections and the development of cooperation between energy companies and telecom operators are a few examples of such measures. Measures have been taken, for example, with consideration for strong winds. Other measures have had indirect effects that counter the consequences of strong winds. The current strategy has been extended and is valid until 2008 (PTS, 2003). PTS has a budget for measures to improve robustness of about SEK 200 million a year.

PTS does not consider it possible to assess development in the time spans covered by the report due to the rapid changes and development seen in the sector in recent years. However, PTS expects the use of overhead lines to have declined by the 2020s, the shortest time span used in the report. The trend is towards optic fibre and wireless access, which are not as affected by weather.

Sensitive climate factors and past extreme events

The overhead lines of the fixed network and the masts and aerials of the mobile network are affected foremost by strong winds, icing, thunderstorms, heavy precipitation and high flows with accompanying flooding. Station buildings in the network can also be exposed. Many of the larger stations are located in protected shelters that are not affected by weather.

The storms Gudrun and Per hit telecommunication systems hard and several hundred thousand subscribers were left without communications. The fixed network was the hardest hit, and in some places the disruptions lasted a week a more. The mobile networks were mostly affected by reliance on electricity. A large part of the mobile network was back in operation after a few hours, other parts after a few days. Operators have backup systems for private customers depending on the length of the disruptions, while entered contracts apply for corporate customers. System availability is strongly geared to the price of services.

Most of the fixed access networks were rebuilt after the storm Gudrun, but not after the storm Per. These were instead replaced by wireless access, which is not as susceptible to weather as overhead lines. Operators prioritise the rebuilding of mobile systems, not the fixed network. The assessment from the telecom sector is that the consequences of disruptive weather are increasingly less as the transition from overhead lines to radio links and underground cables progresses. The lack of fixed access should however entail a reduction in redundancy. The storm Gudrun is estimated to have cost Telia about SEK 500 million in direct costs and rebuilding. The indirect costs have not been calculated.

The consequences of climate change and extreme weather events

According to *Electronic Communications – Telecommunication and Data Communication Systems. Possible Effects of Climate Change and Changed Weather Conditions in the Longer Term*, appendix B 5, PTS's assessment for the shortest time span of the report, even if individual system components are knocked out by weather conditions, together the robustness and redundancy of the different systems will lead to a decline in disruptions. . The equipment used in the systems is replaced so frequently that no equipment is expected to be in use for more than 10–12 years. As such, even extensive climate change would not have any serious consequences as successive adaptation is expected to take place, all according to PTS.

Our assessment based on the climate scenarios is that the risk of wind-felled forest will increase as a result of changed forest conditions, reduced ground frost and increased extreme wind speeds, which will mostly affect systems with overhead lines, but even masts (see section 4.4.1). The short time span used in the report covers 2011–2040. Even if development is towards radio links and underground cables, overhead lines will remain in use for at least part of this period. Subsequently, this can entail continued disruptions to electronic communication with serious consequences for important public functions and the general public.

Electronic communication, fixed as well as mobile, is highly dependent on electricity. Even if a great many cables are relocated underground over the coming years, it is the opinion of the electricity sector that overhead lines will remain in the southern and central parts of Sweden for about another 20–25 years. The electricity network in the northern parts of the country will continue to mostly comprise overhead lines even in the future, although they will be isolated to a greater extent. (Gode et al, 2007). Taking into account climate change and the ongoing rebuilding of the electricity supply system, it is our opinion that disruptions will most likely continue to affect electricity distribution. Assessing the extent, however, is difficult. This means consequences for other systems, such as the telecom systems.

According to appendix B 5, high flows in watercourses and lakes comprise an uncertainty factor that could have consequences for installations near water. It is our opinion that flooding could prove a serious problem, especially along certain watercourses in south-west and west Sweden. However, no consequence analysis has been made into what could be affected or what levels of disruption could be seen. The committee's interim report indicated the existence of stations and electricity supply mains near water that could be exposed (SOU 2006:94).

Cables and masts are especially sensitive to a combination of strong wind, heavy precipitation and temperature fluctuations around freezing point. It has not been possible to analyse changes in this combination of weather parameters, so no assessment has been made of the consequences such weather conditions could present.

Adaptive measures and considerations

Parts of the network for the transmission of electronic communication are sensitive to weather. Transmission is also very dependent on electricity. The electricity supply system is also sensitive to weather. Paragraph 3 of the *Statute (1997:401) with Instructions for PTS* states that PTS shall promote the availability of reliable and effective electronic communication in accordance with the objectives stated in the Swedish Act (2003:389) on Electronic Communication. According to this act, PTS is the supervisory authority, a role that includes ensuring that the operators' electronic communication services are kept technically reliable and in good working order. Experience from the storms of recent years shows that the telecommunication networks are not secure. Increased redundancy and greater reliability with separate electricity supplies reduce the risk of disruptions to electronic communication. We consider it important that PTS be delegated clearer responsibility to ensure that the telecommunication networks be made more robust, whether by agreement with the operators or other means.

Our assessment, based on the climate scenarios, is that the risk of wind-felled forest can increase with an accompanying increased risk of power failure. We recommend that each head of operations is assigned explicit responsibility for ensuring that the necessary reserve power is available to maintain operation of their particular installations.

PTS also ought to be tasked with further analysis of the telecom sector's vulnerability to extreme weather events, including recommending measures for, among other things, the consequences of future higher flows and water levels. The study suggested by PTS on the effects of disruptions on third-parties due to climate factors (see appendix B 5) ought to be given special attention.

Many installations are in isolated locations. We are of the opinion that network owners ought to ensure that the necessary agreements between landowners and access road owners are in place to ensure access to the installations.

Research and development

Sensitive climate factors for the transmission of electronic communication are wind and thunderstorms, as well as the combination of strong wind, heavy precipitation and temperature fluctuations around freezing point. We consider it important that climate research on these factors continue.

Recommendations

- PTS ought to be delegated clearer responsibility to ensure that the telecommunication networks be made more robust against climate change and extreme weather events, whether by agreement with the operators or other means.
- The directive for PTS must clearly state that the agency is assigned responsibility for adapting to climate change within its area of responsibility (see section 5.10.2).
- PTS ought to be tasked with analysing the telecom sector's vulnerability to extreme weather events such as storms, flooding and landslide, and recommend measures. Disruptions affecting third-parties should be given special attention.

4.1.6 Radio and TV distribution

Radio and TV distribution is not expected to be affected to any significant extent, though it is important that the climate change issue and possible effects on the system continue to be considered. Radio and TV broadcasts are dependent on electricity. Climate change could entail more wind-felled forest with consequences for electricity distribution and hence indirectly for radio and TV distribution.

Division of responsibility

Teracom AB is a state enterprise responsible for mediating terrestrial radio and TV from the public service companies. The company has a nationwide link network that in 2007 covers 99.8 percent of all Swedish households. Teracom is responsible for mediating important messages to the public and nuclear power-related alarms. The Swedish National Post and Telecom Agency, or PTS, regulates the frequencies Teracom can use.

System description and current vulnerability

Programme broadcasts for radio and TV are initiated from Kaknästornet in Stockholm and distributed via the national link network to 54 high-power stations, intermediate stations and slave stations, from which the broadcasts are sent. High-power stations have 320 metre high masts, while intermediate station masts are 100 metres high. The installations are on high ground to achieve maximum coverage.

High-power stations have a lifetime estimated at 60 years. Due to rapid global developments in the field, Teracom states that it is difficult to predict future infrastructure developments. One assessment is that the need to install transmission equipment on masts will increase, while transmission over fibre or satellite may comprise a future alternative.

The link network is built with requirements on redundancy. Teracom has one reserve installation and reserve routes for some of Kaknästornet's functions. In the event of the failure of a high-power station, local masts can be redirected to a certain extent and backed up with mobile masts. However, full coverage cannot usually be attained. In the case of intermediate stations the possibility to maintain coverage is greater. Teracom's stations have reserve transmitters that can be activated in the event of power failure. High-power stations can be compensated with reserve power, while smaller facilities generally lack reserve power.

During the storm Gudrun, the network was essentially functional. Some local radio/TV links fell out of alignment, disrupting the link. Broadcasts in certain small areas were knocked out on the frequency assigned to the area, though nearby stations covered this through broadcasts on other frequencies. Broadcasts are dependent on the electricity supply and the slave stations lacking reserve power ceased to function. Many stations are in isolated locations and there were needs for transport to repair stations, mobile reserve power, service and fuel. Poor accessibility on the roads after the storm was a problem. Communications were also made difficult by the lack of functioning telecommunication systems.

Sensitive climate factors

The link network is sensitive to strong winds and icing, and of course to the two combined, which can cause a heavy load with a risk of damage. Strong winds with airborne debris, such as trees, can also bring down the stay wires on masts. Winds that generate natural resonance, or high-frequency oscillations, in stay wires rapidly reduce service life, and also increase the risk of damage. In the event of unfavourable weather conditions, such as stratification in the atmosphere, fading can occur, which interferes with broadcasts. The stations are also sensitive to thunderstorms. Acid rain and salt affect masts through corrosion, which shortens service life.

The geographic aspect is significant. Exposed regions are the west coast with its salt from seaward winds and the high coast and mountain regions with icing at high altitudes.

The consequences of climate change and extreme weather events

Wind data is difficult to assess and different climate models produce different results, though they do all indicate a small increase in average winds. The maximum wind-gust increases somewhat in ECHAM4, primarily along the coasts, but also in the southern parts of the country and northern Norrland. According to *Report to the Climate and Vulnerability Committee from Teracom AB*, appendix B 6, no consequences other than those arising from normal variations in squalls are expected to be seen. The assessment may be changed in the future if new data is forthcoming. The same assessment applies to icing.

According to appendix B 6, scenarios for thunderstorms, high-frequency winds and salt are lacking and no quantitative assessment of the consequences of these factors has been possible. An increase in the squalls along the southern coastline could, however, possibly cause an increased risk of salt coatings. Heavy precipitation is judged to be able to weaken roads and obstruct access to installations.

The overall assessment, according to appendix B 6, is that based on the available scenario data radio and TV distribution is not affected to any significant extent.

Adaptive measures and considerations

Based on existing climate data, it is our opinion that at present there is only a limited need for adaptive measures in radio and TV distribution as regards climate change. We believe that in the future Teracom ought to take into account the effects of climate change and extreme weather events on the distribution of radio and TV.

Radio and TV broadcasts are highly dependent on electricity and telecommunication. Climate change could entail stronger and more frequent strong winds with increased incidences of wind-felled trees and the accompanying risk of power failure. It is therefore our opinion that Teracom ought to have the necessary reserve power at its installations in order to maintain radio and TV broadcasts during power failures.

Radio and TV distribution is dependent on road maintenance and the accessibility of roads to isolated installations. It is our opinion that Teracom ought to secure the necessary agreements to ensure the accessibility of roads to Teracom's installations.

Damage costs in the event of, for example, mast damage vary enormously from the low up to tens of millions of Swedish krona. The possible costs of measures to increase redundancy, for mobile backup equipment, alternative distribution techniques between Kaknästornet and other masts, and the replacement of weak links in the system are of the order of SEK 10–100 million.

Research and development

It is important that climate research on extreme weather events in a changed climate continues, so that future building standards and other data for the design of, for example, masts can take into account such changes. Important climate factors for radio and TV broadcasts are wind, ice, thunderstorms and changed salt and acid concentrations in the environment. Reliable data on these factors is required in order to prepare a strategic action plan for the adaptation of radio and TV distribution to meet future climate change.

4.2 Technical support systems

4.2.1 Electricity supply systems and power potential

Climate change means increased precipitation, which creates favourable conditions for a gradual increase in hydropower production. This will, however, require certain investments in power stations. Wind power production is also expected to increase somewhat. Increased wind-felling due to changed forest conditions, reduced ground frost and stronger winds will most likely continue to have a negative impact on the electricity supply network, despite ongoing efforts to lay cables underground.

Division of responsibility

On 1 January 1996 the electricity market in Sweden was reformed and new regulations were introduced. This entailed introducing competition to the production and trade of electricity. The power grid remained a regulated monopoly.

The Swedish Energy Agency is the central administrative authority for the use and supply of energy. The agency shall work in both the short and the long term to secure the supply of electricity and other energy sources on internationally competitive terms. The Energy Markets Inspectorate falls under the Energy Agency and monitors and supervises the electricity, natural gas and district heating markets. The Energy Markets Inspectorate is also the expert body in electricity trading issues. The inspectorate issues regulations, reviews tariffs and approves concessions for running power grid operations. Power grid companies must comply with concession obligations.

Svenska Kraftnät administers and operates the Swedish national grid, including associated installations and connections to neighbouring countries. Svenska Kraftnät is responsible for the system, for monitoring the short-term balance between supplied and utilised electricity in the Swedish power grid, with similar responsibility for natural gas. Svenska Kraftnät is the authority responsible for electricity supply contingency, charged with meeting the country's electricity needs in times of crisis or war. Svenska Kraftnät has the right of command over circumstances to secure an electricity supply that functions to as great an extent as possible in strained situations.

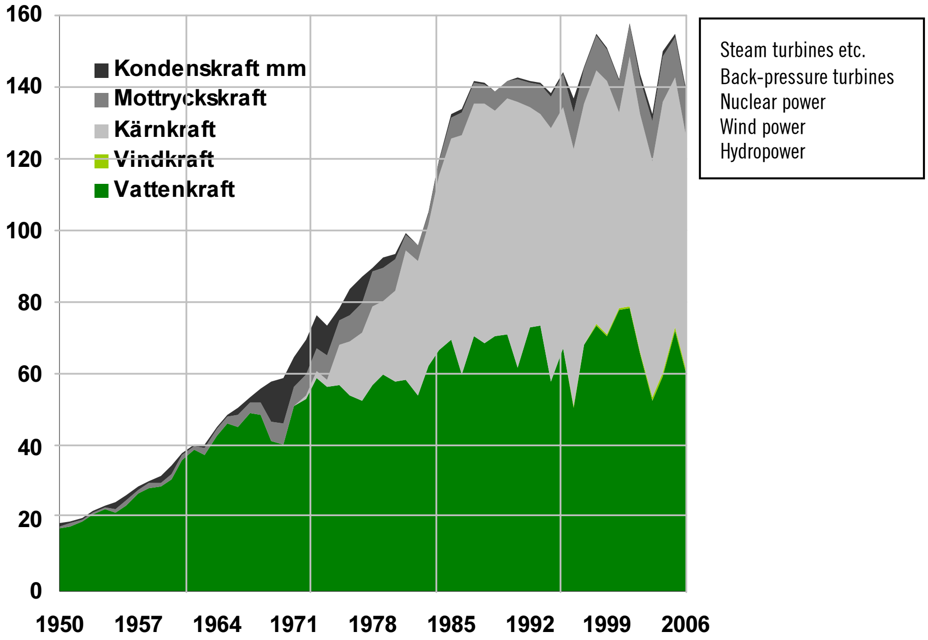
Electricity production is based on an environmental permit in compliance with the Swedish Environmental Code. County administrative boards are responsible for ensuring that the Environmental Code is followed, and in certain cases so is the Swedish Meteorological and Hydrological Institute, or SMHI, as regards hydropower. In accordance with the Swedish Nuclear Energy Act, the Swedish Nuclear Power Inspectorate is the government supervisory authority for nuclear power production.

The following vulnerability analysis focuses mainly on hydropower production and the power grid.

Power production today

Electricity production in Sweden is dominated by hydropower and nuclear power (see figure 4.10). The expansion of wind power has increased in recent years, though production is still low. Thermal power sourced from fossil fuels and biomass fuels (steam turbines, back-pressure turbines and so on) comprise about 5–10 percent, with the proportion generated from renewable sources having increased in recent years. The Nordic electricity market and electricity exchange with neighbouring countries have become essential elements of Sweden's electricity supply. Large, integrated systems provide advantages through the use of each other's production apparatus, but also reduce reserve capacity, which can be problematic in the event of power or energy shortfalls. In terms of power and energy output, electricity production is evenly distributed throughout the country. Hydropower dominates in the north and nuclear power in the south. Electricity use in Dalarna County and south comprises about 80 percent of all use. Electrical power transmission from the north to the south of the country is therefore considerable.

Figure 4.10 Electricity production in Sweden according to method, TWh/year

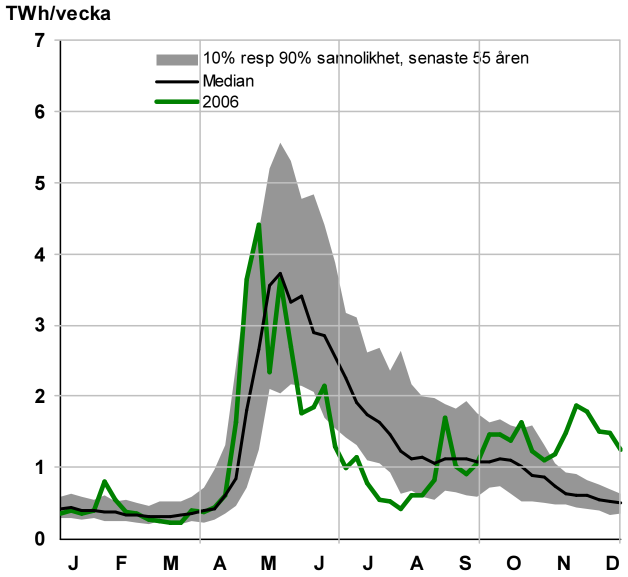


Source: Appendix B 8.

Nuclear power is estimated to have a maximum lifetime of about 60 years, that is, until about 2030 at the most. Combined heat and power plants are used mostly during the winter due to the production of both heat and power. The lifetime of a combined heat and power plant is about 20–30 years. Installations with steam turbines have long lifetimes, mostly due to not being a part of regular power production and therefore being run for shorter periods. Wind power provides most energy during the winter. The variations in wind power output must be balanced with other power sources, mostly hydropower. Wind turbines have a lifetime of 20–30 years. In Sweden, solar collectors are used to a limited extent in heat production, while solar cells are used in electricity production. Solar cells are undergoing relatively rapid technical development, but still have difficulty in competing with other electricity production techniques.

Hydropower is used all year round, and is also used as regulating power. If the national grid fails, the plan is to use hydropower to restart the network. The larger hydropower stations were built in the 1950s and 60s. The installations require continual renovation. Hydropower stations have very long lifetimes, though some components must be replaced at set intervals. Today, there are some 1,800 hydropower stations, mostly in southern Sweden, though most power is generated in the north. Variations in operating hours are great and depend on how large the power station is relative to local inflow. Hydropower production varies considerably from year to year depending on precipitation and inflow. Reservoir volumes in Sweden currently amount to total 35 TWh. Variations can be balanced out by multi-year reservoirs, mostly found in Norway. Figure 4.11 shows the variation in inflow over the year.

Figure 4.11 Inflow variation in rivers used in hydropower production 2006. Black line – median value; green line – 2006; grey area – inflow with an assessed probability of 10–90 percentiles the past 55 years



TWh/week
10% and 90% probability respectively, past 55 years
Median
2006

Source: Appendix B 8.

According to the latest government bill on energy, the use of renewable energy sources shall increase and energy use shall be optimised. According to the Swedish Energy Agency biomass-based and natural gas-based combined heat and power plant production is expected to increase. The use of fossil fuels shall decline. The goal for wind power up to 2015 is to increase the current output of 1 TWh to 10 TWh, primarily via wind power farms at sea and in the mountain regions.

Systems for the transmission and distribution of electricity

The Swedish electricity supply network can be split into three levels, local and regional electricity networks and the national grid. The local low-tension electricity supply networks have 5.2 million connected users while the local high-tension electricity supply networks have about 6,500 connected users. The local networks are connected to the regional networks, which are then connected to the national grid. In total, the Swedish electricity supply networks comprise 528,000 km of cable (see table 4.4).

Table 4.4 The Swedish electricity network structure, 2007 (km; appendix B 8)

Electricity supply system	**Local networks**		**Regional networks**	**National grid**	
	Low-tension (400/230 V)	High-tension (10-20 kV)	40-130 kV	220 kV	400 kV
Overhead lines	95,000	114,000	36,000	4,400	10,600
Underground cable	200,000	68,000	-	-	-

The national grid covers the entire country, connecting the different production and transmission facilities (see figure 4.12). The national grid has 135 stations, mostly for connection and transformation. The national grid is connected via overhead lines to Norway and Finland and via submarine cable to Själland and Jylland in Denmark, Poland and Germany. The national grid also has an associated nationwide telecommunication network over optical fibre and provides a framework for the operation, control and monitoring of the national grid.

Figure 4.12 The power network in northwestern Europe

Source: Appendix B 7.

The largest expansion of the national grid took place during the period from the 1960s to the 1980s. Cables lifetimes are estimated to vary from 80 to more than 100 years while stations are expected to last 15–50 years. Two stations are replaced each year. In *Consequences of Climate Change on Svenska Kraftnät's Installations*, appendix B 7, Svenska Kraftnät's assessment is that over the next 25–30 years, up to 2030–2040, the national grid will not undergo any major changes, with most overhead cables remaining above ground. Some expansion will be needed to cope with demand and to ensure redundancy.

The national grid was previously only designed for *simultaneous wind and ice loads*. The *wind without ice load* scenario with higher wind pressure/speed was introduced in 1993. Power lines in the mountains and on the west coast are designed for higher wind pressure/speed and in some cases even for larger ice loads. Today, when new power lines are erected an analysis is made of the maximum wind gust for the next 30 years. The national grid and the 130 kV regional networks comprise power line corridors cleared of trees, which means corridor widths in excess of 24 metres. When designing national grid stations, ice and wind loads are taken into account.

There are 168 local electricity supply network operators in Sweden. The size of these companies' electricity supply networks varies enormously, from 3 to 115,000 km. In *Climate and Vulnerability Report, Electricity Supply in Sweden*, appendix B 8, Swedenergy estimates the economic lifetime of local and regional electricity supply networks at about 25–40 years. The technical lifetime is longer. The main problem behind power failures caused by bad weather stems from the original approximately 57,000 km of non-insulated 10–20 kV cable running through forestlands. In 20–25 years, the local high-tension electricity supply network (10–20 kV) is expected to comprise isolated overhead lines north of the river Dalälv, and to its south mostly underground cables. The regional network is expected to mostly comprise overhead lines throughout the country (Gode et al, 2007). The larger part of the low-tension network is assumed to comprise underground cable by that time.

Current vulnerabilities and past extreme events

Table 4.5 shows the geographic areas of Sweden currently most exposed to troublesome weather conditions. The assessments cover storms, snow, salt coatings and thunderstorms. A weighted assessment of the different risks has also been made by Swedenergy. (Appendix B 8).

Table 4.5 **Risks in relation to meteorological conditions (appendix B 8)**

Regions / Type of weather	Mountain regions	Norrland's interior, Dalarna and northern Värmland	Southern Norrland coastal areas and northern Uppland	Mälardalen and Götaland's interior	Northern Kalmar County	Jönköping region and Dalsland	West coast	Västra Götaland, eastern Halland, eastern Skåne and Gotland
Thunder	low	moderate	moderate	moderate	low	**high**	moderate	**high**
Snow	**high**	**high**	**high**	moderate	**high**	**high**	low	moderate
Storms	**high**	low	low	moderate	moderate	moderate	**high**	**high**
Salt	moderate	moderate	low	low	low	moderate	**high**	moderate
Total risk	**high**	moderate	moderate	moderate	moderate	**high**	**high**	**high**

Pylon damage has been seen in the national grid. In four cases the damage was due to extremely high winds and this has occurred in the counties of Norrbotten, Jämtland and Västmanland and along the east coast of Skåne County. In another four cases the damage was due to extreme ice loads and occurred in Norrbotten County and Dalarna County. In another two cases it was due to ice and wind, also in Dalarna County. At the most, eight pylons have collapsed. Damage due to extreme ice loads has been local and has occurred in upland terrain. One reason for these collapses has been the use of the maximum load span lengths in power line corridors in upland areas. None of the afore-mentioned collapses have disrupted the electricity supply. The formation of ice loads has been shown to be due in part to recently made clearings. (Appendix B 7).

It is mostly local networks that are susceptible to high winds. The storm that caused the greatest consequences was Gudrun in

2005. Many counties in southern and central Sweden were affected. The mild weather and the lack of ground frost made the forest more susceptible to the hard winds, which led to extensive windthrow. The two largest network operators suffered from a joint total of 30,000 km of damaged cable, nine percent of which needed complete replacement. Regional networks were also knocked out. The extent of the damage did not differ especially much between insulated and non-insulated power lines. A total of 730,000 subscribers were affected. A week after the storm many people were still without electricity. In some rural areas the disruption lasted as long as 45 days. Damage costs amounted to SEK 1,950 million and compensation to subscribers totalled SEK 650 million.

During major disruptions the network operators and Svenska Kraftnät cooperate through the Electricity Cooperation Organisation. Svenska Kraftnät also has agreements with the Swedish Armed Forces on assistance during major disruptions, such as the storms Gudrun and Per.

After the storm Gudrun the Swedish parliament decided to tighten legislation, including:

- Performance specifications to be introduced as of 2011, meaning power failures may not exceed 24 hours.
- As of 2006, electricity supply network customers are entitled to compensation for power failures exceeding 12 hours.
- The electricity supply network operators must provide information on reliability of supply and conduct risk and vulnerability analyses, as well as other measures.
- Regional networks to be protected from wind-felled trees as of 2006.

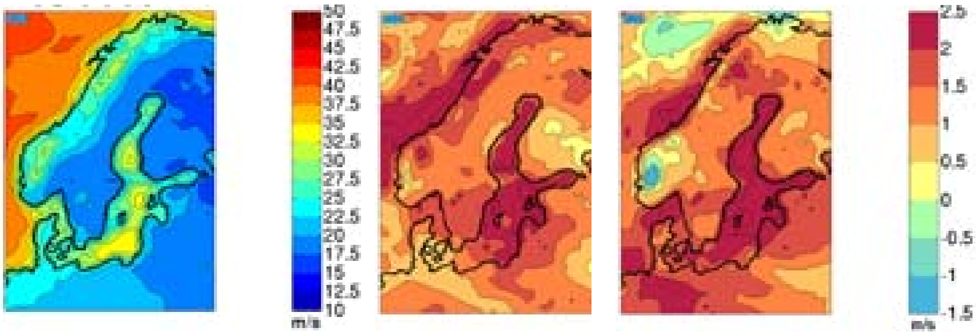
In order to secure the electricity supply networks, network operators will first replace overhead lines with underground cables and then replace non-insulated overhead lines with insulated overhead lines. Today, a total of SEK 10 billion is invested each year, half of which is used for the accelerated plans to protect the network from wind-felling and extreme weather. This investment rate means that about 20 percent of the power lines running through forestlands and now classed as critical are secured each year. The electricity industry expects most of these critical power lines to be secured before the end of 2010. (Appendix B 8).

Sensitive climate factors for electricity supply networks and power production

Important climate factors for national grid cables are storms leaving ice coatings, extreme ice loads with moderate winds, extremely high winds without ice and saltwater icing. The factors affecting stations are storms leaving ice coatings and extremely high winds. Changed thunderstorm frequency and intensity may also comprise a sensitive factor. Vulnerable climate factors for other network types are strong winds, ice formation, thunderstorms, salt coatings and underground water supplies.

Whether winds will increase or not has not been fully established, as different models provide different results. The maximum wind gust speed is significant to the electricity supply networks. ECHAM4 predicts some increase in most of the country, with the greatest increase in Götaland, the mountain regions and northern Norrland (see figure 4.13). No climate data has been produced for combined ice formation and wind.

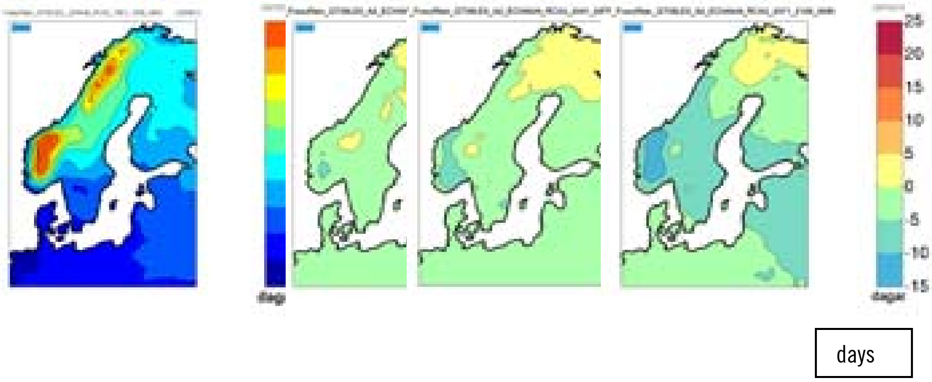
Figure 4.13 Change in maximum wind gust speed over a year, 2041–2070 and 2071–2100 compared to 1961–1990 (RCA3-EA2)



Source: SMHI, 2007.

Power stations for wind power and natural gas platforms are also sensitive to extreme winds. Wind turbines are also susceptible to icing. Both the ECHAM4 and HadAM3H climate models predict a decline in the number of days with sub-zero temperatures together with rain, which can be used as an indicator for the risk of icing (see figure 4.14).

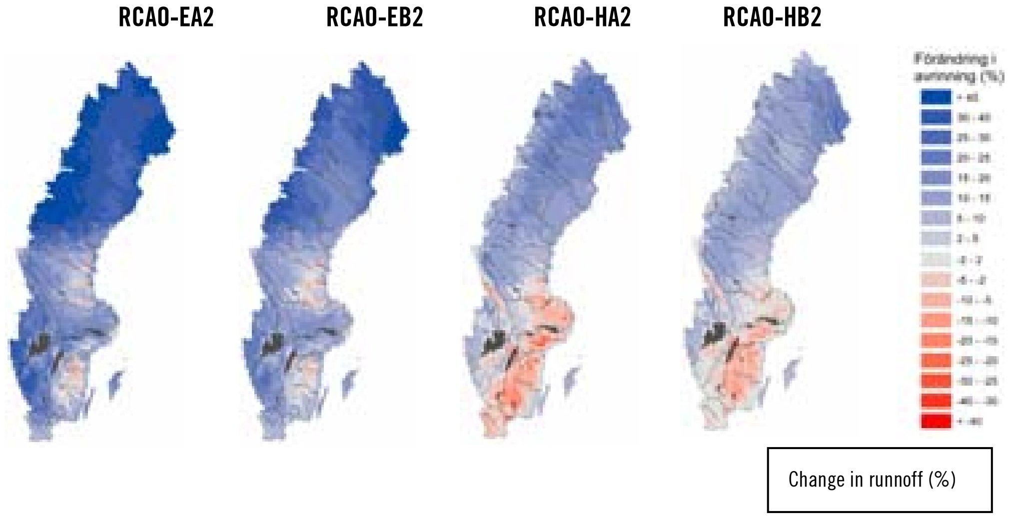
Figure 4.14 Changed number of days with risk of icing for 2011–2040, 2041–2070 and 2071–2100 compared to 1961–1990 (RCA3-EA2)



Source: SMHI, 2007.

The degree to which hydropower production can be regulated is affected by changes in precipitation. Hydropower stations are designed for a certain average flow. The size of the spring flood, the distribution of precipitation over the year and the ability of watercourses to handle the flows help determine the inflow that can be used. According to the climate scenarios, rainfall will increase during the summer, with the exception of southern Sweden. Runoff will increase in western Götaland, western Svealand and in much of Norrland (see figure 4.15). The number of days with extreme precipitation will increase throughout most of the country, leading to local extreme flows. The 100-year flows will increase mostly in western Götaland and western Svealand, but also in some mountain regions and on the east coast. Snow pack extent and water content will generally fall throughout the country. Snowfall in northern Sweden may increase somewhat in the short term and later decline.

Figure 4.15 **Change in local average runoff 2071–2100 compared to 1961–1990 during a normal year**



Source: Bergström et al, 2006b.

Nuclear power is sensitive to high sea temperatures. The average annual temperature of the Baltic Sea is expected to increase by two to four degrees centigrade depending on the climate model and emission scenario. The increase is somewhat larger during the summer.

The consequences of climate change and extreme weather events for power potentials

Changes in the climate and the hydrological cycle lead to changed conditions for hydropower. According to test cases conducted in five areas of Sweden, the average inflow can be expected to increase in the long term (see table 4.6 and section 4.2.2). The climate scenarios predict successive increases in precipitation throughout the century. As early as 2020, we can most likely expect a considerable increase in inflow (see table 4.7).

Table 4.6 **Change in average inflow as a percentage in five test areas and four climate scenarios, 2071–2100 compared to 1961–1990**

	Suorva	Torpshammar	Trängslet	Vänern	Torsebro
RCAO-HA2	12	9	13	1	-6
RCAO-HB2	8	10	12	3	-2
RCAO-EA2	53	22	18	22	17
RCAO-EB2	35	17	15	16	12

Source: Andréasson et al, 2006

Table 4.7 **Change in average inflow as a percentage in five test areas, 2011–2040 compared to 1961–1990, calculated by linear interpolation of table 4.6, average values for the A2 and B2 scenarios**

	Suorva	Torpshammar	Trängslet	Vänern	Torsebro
Average A2	14.8	7.0	7.0	5.2	2.5
Average B2	9.8	6.1	6.1	4.3	2.3

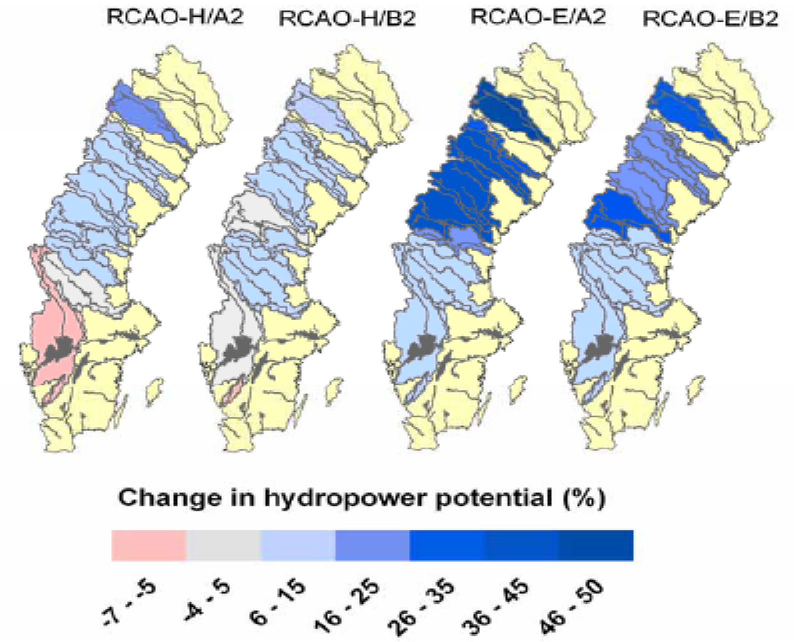
Source: Gode et al, 2007.

Autumn and winter inflows are expected to increase in all areas up to 2071–2100 (Andréasson et al, 2006). The northern parts of the country will also continue to see a pronounced spring flood, even if it occurs earlier and its maximum flows decline due to more regular snow melt, as well as due to precipitation in the form of rain instead of snow. More precipitation and at other times than at present can lead to greater sensitivity if the reservoirs are already well filled. Inflow patterns in the south will undergo drastic change. Today’s spring flood, when a short period of snow melt causes large flows, will be replaced by increased flows over a longer period in the winter, with the maximum inflow exceeding today’s levels in many places. Inflow during the summer months will drop considerably. (Gode et al, 2007).

Increased annual runoff and water flow provide higher power potential. The greatest increase in expected in northern Sweden. Simulations for the river Luleälv's drainage basin 2071–2100 compared to 1961–1990 show an average increase in hydropower potential of about 34 percent, an increased inflow primarily during autumn and winter and the end of the spring flood about a month earlier than in today’s climate (Carlsson et al, 2005). Linear interpolation produces an increase of about 15 percent as early as the period 2011–2040.

Calculations for the four climate scenarios have been made for all of Sweden's major rivers for inflow expressed as energy for the period 2071–2100 compared to 1961–1990 (see figure 4.16). The hydropower potential is expected to increase by 7–22 percent for the B2 scenarios and by 10–32 percent for the A2 scenarios (Andréasson, 2006 b; Gode et al, 2007), an average potential of about 15–20 percent. The largest increases will be seen in the northernmost rivers, where most hydropower production is already found (Fenger, 2007). According to the Hadam model, the potential will fall somewhat in the southwestern/western parts of the country. As runoff will drop in the eastern parts of Götaland and Svealand, production potential can also be expected to drop there. All scenarios point towards a changed inflow cycle with higher inflow during the cold months and lower inflow during the warm months. For the period 2011–2040 this corresponds to an increase in hydropower potential of 3–15 percent (linear interpolation).

Figure 4.16 **Annual increase in hydropower potential 2071–2100 compared to 1961–1990 for four climate scenarios**



Source: Andréasson, 2006; Climate and Energy, 2007.

Calculations using the EMPS model[1] have been made for the B2 scenarios and show inflow values of the same order as those reported above, 8–24 percent, and similar inflow patterns. According to the model, the increase in production is not as large as the increase in inflow, 6–20 percent, which may indicate increased overflow (see table 4.8). (Mo et al, 2006). A recalculation of the production increase, in the same manner as before, to 2011–2040 gives 2–9 percent for the B2 scenarios. This interval is most likely somewhat conservative as the existing hydropower system ought to be able to utilise a greater proportion of a small increase in inflow compared to a larger increase. The relationship between increased inflow and increased production is not quite linear. The relative production increase falls as the inflow increases. In most

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[1] A model for market analysis and operating and investment planning for production and transmission that simulates the operation of a given power system and calculates how much of an increased inflow can be used in production. The model has been used with the expected power system configuration for the year 2010.

cases the utilisation of more water most likely requires an expansion of the power station's capacity. (Gode et al, 2007). A new inflow pattern risks increasing the load on overflow channels, which will most likely be used more frequently during the winter with powerful flows and full reservoirs (Fenger, 2007).

Table 4.8 Changed inflow and production according to calculations using the EMPS model for RCAO-EB2 and RCAO-HB2, 2071–2100 compared to 1961–1990

	1961–1990			2071–2100			2071–2100		
	winter	summer	year	winter	summer	year	winter	summer	year
Inflow	12.5	53.5	66.0	21.5	49.8	71.3	30.4	51.2	81.6
Production	34.2	28.1	62.3	34.8	31.5	66.3	39.4	35.1	74.5

Source: Mo et al (2006); Gode et al (2007).

The energy content of wind, incidences of strong wind and icing, which can cause disruptions and damage, are important factors in wind power. According to several global models, the energy content of wind will increase in the long term in the Baltic Sea region and could therefore provide a further increase in wind power production of about 5–20 percent in 20–30 years, that is, an increase from 10 to about 12 TWh. The climate scenarios indicate that wind speeds of 25 m/s or more at 70 metres height will increase marginally in the period 2030–2040. Icing on wind turbines is difficult to assess, partly due to the existence of different types of icing (Gode et al, 2007).

According to the Nordic project *Climate and Energy*, the ECHAM4 and HadAM3H climate models indicate no dramatic average increases in wind energy content this century. Certain areas exhibit increases, others decreases. The maximum wind speed over the Baltic Sea shows an increase in both models. The risk of icing is assessed as negligible in southern Sweden and around the Baltic Sea, and greatly reduced in northern Sweden, which should permit wind power production in new areas. (Fenger, 2007).

Solar radiation, temperature and the snow pack affect the production of solar energy. Cloud cover is also an important factor. The sunniest places on earth receive about 2,500 kW of solar energy per m^2 annually. Conditions are less favourable in the Nordic region, although it still receives 700–1,100 kWh of solar energy per m^2 annually. Insolation is strongly concentrated to the summer half of the year. Solar radiation is expected to drop somewhat in Norrland in the summer, but increase somewhat in the south. The opposite applies to winter time. Higher temperatures cause a drop in solar cell efficiency and hence reduced energy production. A shorter snow season and a smaller geographic spread of the snow pack can also lead to less favourable conditions for electricity production in solar cells due to reduced reflection of sunlight. Overall, the conditions for solar energy production using current techniques will be impaired by climate change. (Fidje and Martinsson, 2007).

Higher coolant temperatures mean lower efficiency in nuclear power stations. The maximum thermal output at which plants can operate is limited by factors such as sea temperature and condensation pool temperature. Each station is optimised for a specific coolant temperature. At the Forsmark nuclear power plant a water temperature of 20 degrees centigrade can lead to a power loss of about 5 percent compared to normal operation, which is about 50 MW per reactor. Moderate temperature rises of the order of two degrees centigrade are assessed to not demand any special measures at the plants. A temperature rise of four degrees centigrade, which may well be seen by the end of the century, could lead to a slightly greater drop in power. Should the problem reach proportions that demand investments in coolant supply, this is deemed technically possible. Shorter freeze-up times do not affect coolant supply. A higher sea level is assessed to have a positive effect, while greater algae growth will have a negative impact. (Hartman-Persson, 2007). Reinvestments in some plants have already taken into account rising water temperatures. Successive adaptation is possible, though this is expected to entail long lead times (Gode et al, 2007).

The natural gas used in Sweden mainly comes from Danish gas fields in the North Sea. Disruptions to extraction affect Swedish gas-fuelled power production. The platforms are designed to cope with a 100-year storm. The storm of December 1999 with average wind speeds of 38 m/s and squalls of up to 50 m/s reportedly had no effect on these platforms. Natural gas extraction at these platforms is not affected by climate change as the incidence of strong winds over the North Sea will increase only marginally. (Gode et al, 2007).

Heating plants, mainly in the district heating network, will face reduced demand when the average temperature increases. Consequently, according to appendix B 8, the number of district heating networks with combined heat and power plants is expected to increase.

The overall assessment of power potentials in a changed climate is dominated by increases in inflow and hydropower potential. The long-term consequences for the Swedish electricity supply ought to be very positive. However, investments in power plants will be needed to take full advantage of the increased potential.

Consequences of climate change and extreme weather events together with damage costs for transmission and distribution

Increased hydropower production, primarily in the northern parts of the country, places demands on transmission capacity to the south. Increased inflow in the seasons that already have good water availability will place heavier loads on the transmission network.

Somewhat increased extreme wind speeds are expected to have little effect on the national grid based on current design requirements (appendix B 7). On the west coast increased wind gusts combined with southwesterly winds could disperse salt over larger land areas and further inland, which could cause disruptions. This could place heavier demands on washing equipment. (Gode et al, 2007).

The climate scenarios indicate reduced ice formation, which is an advantage for overhead lines and stations. Icing patterns could change character, however. Precipitate icing in the form of wet snow could increase, delivered by strong winds. Rising winter temperatures could cause problems with icing and wet snow in other locations than today. More rain in the winter in northern Sweden could also increase the risk of precipitate icing. Extreme precipitation is also expected to increase, and could lead to faster processes. (Gode et al, 2007).

There is no climate data for thunderstorms. A general line of argument from Svenska Kraftnät presumes thunderstorm intensity continues to be greatest during the summer with increased lightning intensity and lightning strikes per unit area. Increased maintenance and renewal of protective devices for the national grid may be necessary. The recommendation is to conduct these successively, parallel to climate change (appendix B 7).

Flooding along watercourses under calm, slow wind conditions does not damage power line pylons as no dynamic forces act on the pylons. On the other hand, pylons are sensitive to longer periods of waterlogged ground, which leads to subsidence. A change in the weather to strong winds after flooding can cause collapse. In the event of a 100-year water level and flooding in the lakes Mälaren, Hjälmaren and Vänern a number national grid pylons could be affected, mostly around Lake Mälaren. Two coastal stations in the national grid are located near the sea. (Carlshem, 2006; appendix B 7).

In Västra Götaland, a region sensitive to the current climate in terms of landslides, only a few national grid pylons and stations are located on land susceptible to landslide. Landslide risks are expected to increase with climate change (Fallsvik, 2007), which could mean broader consequences (see section 4.3.2 for more). Repair costs for individual incidents amount to SEK 0.5–4 million for breakers in stations and SEK 3–5 million for minor pylon collapses involving 2–3 pylons.

The power industry expects to complete the improvements to all critical power lines before the end of 2010 and foresees no need for further expansion or rebuilding work as a result of climate change (see appendix B 8). According to Elforsk's assessment (Gode et al, 2007) climate change will affect the electricity supply networks negatively, but as much is being done today to reduce network sensitivity to weather it concludes that climate change over the next 20–25 years will only affect the electricity supply networks to a limited extent. On the other hand, it is stated that it would be interesting to see which factors will affect the networks in the longer term.

A new possible consequence of increased underground cable use is cable damage caused by an increased number of uprooted trees due to increased wind speeds and decreased ground frost. As ground water content is expected to increase due to increased precipitation, the risks of corrosion on metal pylons and damaged cables also increase. There is also an increased risk of moisture penetrating the insulation on underground cables and thereby shortening the average cable lifetime and increasing fault frequency. The current rate at which cables are being moved underground could entail risks. (Gode et al, 2007).

A further consequence of moisture penetration is that the cable is made susceptible to thunderstorms. Otherwise, increased use of underground cables ought to entail reduced risks of damage in the event of changed thunderstorm patterns. (Gode et al, 2007).

Increased temperatures will mean faster growth of the vegetation in power line corridors, which increases clearing needs.

Our assessment, based on the climate scenarios, is that the risk of windthrow will increase as a result of changed forest conditions, reduced ground frost and increased extreme wind speeds, which will mostly affect systems with overhead lines (see section 4.4.1). The short time span used in the report covers 2011–2040. Even though the transition to underground cables is increasing considerably and local networks are mostly expected to be converted to underground cables within 20–25 years in southern and central Sweden, overhead lines will remain in these areas for a number of years. The electricity network in the northern parts of the country will continue to mostly comprise overhead lines even in the future, although they will be isolated to a greater extent. Taking into account climate change, as well as changed forest conditions and the ongoing rebuilding of the electricity supply system, it is our opinion that disruptions will most likely continue to affect electricity distribution with consequences for important public functions and the general public. Assessing the extent, however, is difficult.

Adaptive measures and considerations

The increase in inflow, mostly in the northern parts of the country, will be gradual. This creates good conditions for a successive increase in hydropower production with increased income. The above calculations indicate a possible increase in power production of 15–20 percent on average, based on the A2 and B2 scenarios. The relative production increase will, however, decline with increasing inflow if power station capacity is not expanded. In order to avoid increased overflow, power stations and storage reservoirs will have to be rebuilt.

Svenska Kraftnät assesses that existing power station and transmission capacity will allow use of increased inflow in power production at times when transmission capacity is not used to the full. Further improvements in national grid transmission capacity are assessed to be appropriate when production capacity is increased by improvements to existing or the construction of new hydropower plants. (Svenska Kraftnät, 2007b). Any transmission bottlenecks between the northern and southern parts of the country may prevent hydropower from being able to fully regulate the power supply in the south. This needs to be taken into account more.

Hydropower is important for momentary and slow regulation of the electricity supply system and will play an increasingly important role as more renewable energy enters the system in the future. Increased wind power production will place demands on electricity supply network capacity and the availability of greater regulation capacity from hydropower. The prerequisites for hydropower as regulatory power in a future energy system with increasing quantities of intermittent energy sources needs to be further investigated.

We consider it important to analyse how changed inflow dynamics in watercourses and any change in the operation of hydropower systems can affect dam safety and the risk of flooding (see also section 4.2.2). It is also important to analyse how the increasing hydropower potential can be utilised.

We deem it important to increase the robustness of the electricity supply network. Extensive rebuilding work on local electricity supply networks is underway including moving cables underground. However, with consideration for the increasing risk of windthrow in large parts of the country, we believe that the move towards underground cables also ought to be applied in areas where the industry presently does not plan to do so, such as in northern Sweden. This applies primarily to local electricity supply networks.

The Swedish Energy Agency ought to consult with Svenska Kraftnät and then analyse the energy sector's vulnerability to extreme weather events. Disruptions affecting third-parties should be considered.

Different measures are recommended in appendices B 7 and B 8. We would like to emphasise the following:

- Studies to identify installations at risk of land collapse, landslide and flooding.
- Clear and broaden overhead power line corridors in regional and local networks.
- Renew corrosion protection on power line pylons in areas with increased precipitation.

- Identify areas with an increased risk of salt coatings.

For many installations, especially in the national grid, the assessment is that successive adaptation will take place based on the lifetime of each installation component. National grid maintenance costs due to extreme weather and extended growth periods are estimated to increase by SEK 10–20 million a year.

Many installations are in isolated locations. It is our opinion that network and station owners ought to secure the necessary agreements to ensure the accessibility of installations on isolated roads.

We recommend that Swedenergy work to support the industry by preparing background data and spreading knowledge within the industry on how climate change could affect the electricity supply system.

Research and development

It is important to continue climate research on extreme ice and wind conditions, as both separate and combined phenomena. We need to map, for example, icing phenomena as regards return periods, intensity and affected geographic areas. More knowledge is needed of the maximum wind gust speed per month. Thunderstorms are another factor for which data is currently lacking.

Providing support in the planning of initiatives to secure the electricity supply network against wind-felled trees demands increased knowledge of the risk of windthrow in forests in different parts of the country based on local forest conditions, future wind conditions, ground frost conditions and soil moisture levels.

There is a need for studies into the effects of climate change on ecosystems in regulated watercourses. Increased flooding, increased erosion due to higher flows, changed water temperatures and ice conditions can affect, for example, fish populations in regulated watercourses.

Recommendations

- The directives for the Swedish Energy Agency and Svenska Kraftnät respectively must clearly state that the agencies are assigned responsibility for adapting to climate change within their areas of responsibility (see section 5.10.2).
- The Swedish Energy Agency ought to be tasked with consulting Svenska Kraftnät then analysing the energy sector’s vulnerability to future extreme weather events, such as storms, flooding, landslides, and suggesting measures. Disruptions affecting third-parties should be given special attention.
- The Energy Markets Inspectorate ought to be delegated clearer responsibility to ensure that regional and local electricity supply networks are robust against climate change and extreme weather events.

Recommendations are also provided on the following and are described in greater detail in the indicated sections:

- Section 4.2.2: Review of dam safety as regards the Swedish state's role and dam owners' internal inspections.
- Section 4.2.2: Survey of the vulnerability of dams in risk classes I and II.
- Section 4.2.2: Analysis of flows of importance to dams in risk classes I and II.
- Section 4.2.2: Analysis of how changed inflow dynamics in watercourses and the operation of hydropower systems can affect dam safety and the risk of flooding.

4.2.2 Dams

Climate change entails a risk of the flow, for which dams in risk class I are designed, increasing in parts of the country, though there is much uncertainty. The 100-year flow indicates dramatic increases, primarily in western Götaland and western Svealand, with increased risks mainly for dams in risk class II. The 100-year flow is also increasing in mountain regions with the risk that this can spread downstream along the entire watercourse to the outlet. In many areas today's 100-year flow is expected to become more commonplace.

Division of responsibility

The Swedish Environmental Code states that the party responsible for maintenance, generally speaking the owner, is strictly responsible for the consequences of dam failure with the exception of acts of war or the like. In the case of dams classed as installations pursuing hazardous activities the owner must maintain reasonable contingency in compliance with the Swedish Act on the Prevention of Accidents. In accordance with the Swedish Environmental Code's statute on inspection Svenska Kraftnät has ultimate responsibility for providing guidance on inspections in the field of dam safety while the country administrative boards have operative responsibility for such inspections. The local authority inspects dams classed as hazardous operations in accordance with the Swedish Act on the Prevention of Accidents. The same act states that the Swedish National Rescue Services Agency has central responsibility for inspections.

System description and dam classification

Sweden has about 10,000 dams of various sizes, types and ages spread throughout the country. Most of the dams of interest in terms of safety are in Norrland. Most were built before the 1980s and are power plant dams. No major rebuilding is expected in the foreseeable future. Lifetimes are long and extend throughout the time spans covered by the report. Some dams are used by the mining industry to take care of mining waste and new mining dams are built for waste disposal. If mining dams employ water to cover the mining waste as an after treatment then the planned lifetime is essentially perpetual. There are dams without a party responsible for maintenance, such as dams on disused floatways where responsibility for maintenance has not been established.

The consequences of a dam accident depend on many factors, such as flow conditions, reservoir size, dam height, dam type and downstream conditions. Dam safety work in the power and mining industries uses different classification systems. Dams are divided into consequence classes that take into account the possible consequences of dam failure, irrespective of the cause. About 200 power plant dams and a few mining dams have the highest consequence classes 1A and 1B. Failure at one of these dams can have very serious consequences for life, infrastructure and the environment. (Swedenergy, 2002; SveMin, 2007).

Dams are also classified in accordance with the Swedish Flow Committee's Risk Class Guidelines[2] to determine the floods dams can handle (Swedish Flow Committee, 1990). Work is underway with a new edition of the guidelines, with publication expected in the autumn of 2007. It is mostly these risk class classifications that are of interest in this report. The recommendation is that dams in risk class I should be able to handle a very extreme flow sequence without serious damage to the dam, a maximum flow determined by hydrological modelling. At maximum water level it is recommended that risk class II dams are able to handle an inflow with a return period of at least 100 years, which also applies to dams of risk class I. According to the new edition of the guidelines, new dams of risk class II shall also be adapted to a flow determined using cost-benefit analysis, which will also apply to existing dams. See table 4.9 on classification.

Table 4.9 Classification in accordance with the Swedish Flow Committee's guidelines

Risk class	Type of risk in event of dam failure
I	A not insignificant risk to human life or of other personal injury; substantial risk of serious damage to important traffic route, dam structure or comparable installation or to considerable environmental assets; clear risk of major economic losses.
II	A not insignificant risk of damage to traffic route, dam structure or comparable installation, environmental assets or other property not belonging to the dam owner in cases other than those specified in risk class I.

Source: Swedish Flow Committee (1990); appendix B 9.

Maximum flows have been calculated for dams in the major watercourses based on the current climate. About 120 installations owned by the Swedenergy member companies have been classified as risk class I by the dam owners.

In recent years, Swedenergy and Svenska Kraftnät have established a system for classifying criticisms on dam safety, known as standardised assessment classes. The system is intended

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[2] The term "risk class" used in the Swedish Flow Committee's guidelines (Swedish Flow Committee, 1990) is to be replaced by "flow specification class" in the new edition of the guidelines, which are expected in 2007. In our report we use the current term risk class.

for use in the dam owners' internal inspections and for reporting any weaknesses to the authorities. The assessment classes use a five point scale to assess how serious an identified weakness is for the safety of the concerned dam.

Sensitive climate factors and consequences of past extreme events

Extreme flows are by far the most important climate factor for power plant dams. Insufficient discharge capacity can lead to overflow, and embankment dams are particularly sensitive to this. Wind, ground frost and ice are other significant factors, but are not of the same importance. Mining dams are sensitive to prolonged drought.

Two dams higher than 15 metres, the Aitik mining dam and the Noppikoski dam, have failed over the years. The Noppikoski dam collapsed due to overflow at the top of the dam. There were no personal injuries. During the high flows in Norrland in 2000 a few smaller dams collapsed. During the storm Gudrun a number of hydropower stations were shut down due to damage to the transmission network and problems arose in communication between the power stations, field staff and command centres. However, dam disaster protection worked and no dam failures occurred.

Current adaptation work based on today's climate

According to Svenska Kraftnät's 2007 report to the Swedish government, in 2006 fourteen counties submitted annual reports on dam safety to Svenska Kraftnät. The dam owners have reported about 40 identified weaknesses found in some 30 structures. As in 2005 most of the weaknesses concerned problems related to discharge equipment. (Svenska Kraftnät, 2007).

The Flow Conference, a collaboration between Swedenergy (representing the energy industry), Svenska Kraftnät and SMHI, follows up current work to adapt dams of risk class I to handle extreme flows in accordance with the Swedish Flow Committee's guidelines. By March 2006 measures has been taken or initiated at about 60 percent of the installations where the guidelines have led to the conclusion that measures are needed, which was at about two-thirds of the 120 risk class I installations. The installations are adapted to the extreme flows calculated for today's climate. A review of the highest observed flows in relation to those for which the installations are designed is conducted annually for a few sites. These are assessed not to have exhibited any increase in the flow. The costs of adaptation to the Swedish Flow Committee's guidelines are estimated at SEK 2 billion. (Svenska Kraftnät, 2007; appendix B 9)

To further develop dam safety efforts and investigate the possibilities of meeting the need of both the dam owners and society for a special review of the safety of dams where dam failure would involve major consequences, in 2005 Svenska Kraftnät and Swedenergy decided on a joint pilot project, an international review of the Trängslet hydropower station dam. After the pilot project a decision was made to extend the trial and development period to 2008, with another five dams to be reviewed by international experts. The model chosen after discussions between the industry, Svenska Kraftnät and the country administrative boards, the same model as for Trängslet, is to keep the international review a part of the owners' internal inspections, which they finance. The supervisory authorities have insight and influence. The review includes the Höljes dam, Suorva, Håckren, Ajaure and the Hällby dam. Of these, the Höljes dam has now been reviewed.

The foreign expert panel has submitted critical opinions on the two reviewed dams. Regarding Trängslet, previous safety evaluations were considered insufficient. The shortcomings were considered more serious than indicated in the classification system used for internal criticism. The review of the Höljes dam in May 2007 indicated, among other things, that previous safety studies exhibited considerable shortcomings in terms of detail and scope. The experts also concluded that dam failure due to surface erosion on embankment dams is possible with overflows with flows of considerably shorter return periods than the flows for which they are designed. Current monitoring conducted on the dams was also considered to be of an inappropriate nature. (Swedish National Audit Office, 2007).

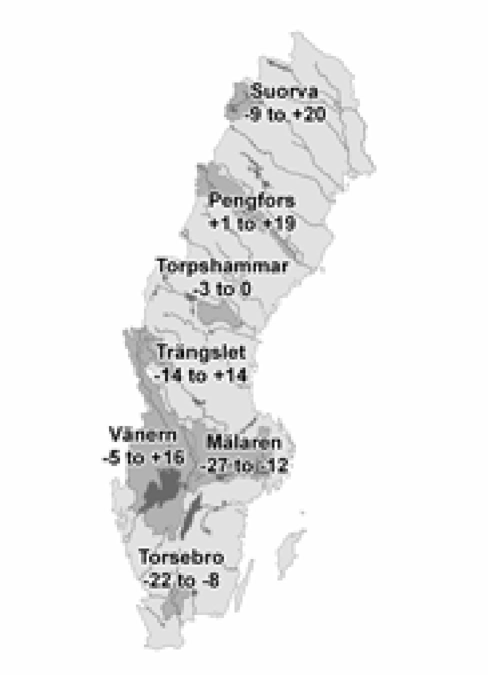
Development is underway to coordinate dam failure contingency planning for the major hydropower rivers. In the case of Ljusnan, joint planning materials have been prepared, including an alarm plan and an information brochure. Similar work has begun for the rivers Luleälv, Ljungan, Dalälv and Göta älv.

The consequences of climate change and extreme weather events

Maximum flows have been calculated for six areas, taking into account climate change. The calculations have been made for four climate scenarios and the time span 2071-2100 (Andréasson et al, 2006). Decisive flows and accumulated 100-year flows in a changed climate have been calculated for the entire regulated length of the river Umeälv upstream of the confluence with the unregulated river Vindelälv. Tapping strategies adapted to a future climate were used in the calculations. (Andréasson, 2007; appendix B 10). The climate scenarios generally indicate increased precipitation, while the maximum snow pack for the spring flood declines. Depending on how these factors interact, the scenarios exhibit both increases and decreases in the maximum flow (see figure 4.17). According to *Climate and Dam Safety in Sweden,* appendix B 9, it is difficult to make general conclusions on how the maximum flows will be affected by climate change. What is clear, however, is that the climate issue adds an extra uncertainty factor that motivates continued studies into the effects on maximum flows and increased safety margins in specification work (Svenska Kraftnät, 2007).

The Swedish Flow Committee's guidelines are currently under review. A new edition of the guidelines is expected in the autumn of 2007. Svenska Kraftnät states that the methods in the new edition of the guidelines have not been revised to take into account climate change, though their application in a changed climate will be reviewed (appendix B 9).

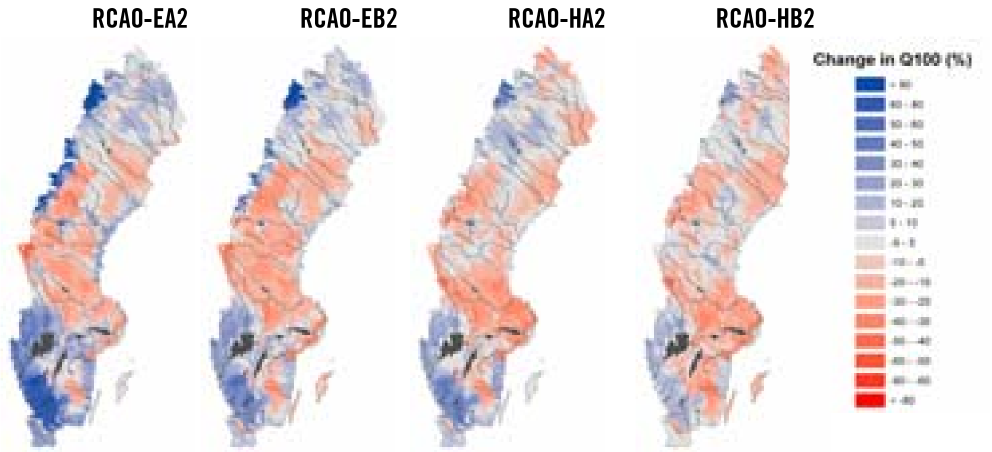
Figure 4.17 Percentage change in maximum flow, 2071–2100 compared to 1961–1990 (RCAO-EA2, RCAO-EB2, RCAO-HA2, RCAO-HB2)



Source: Andréasson et al, 2007.

Calculations of future local 100-year flows show increases mostly in western Götaland and western Svealand, but even in the mountain regions and northeastern Götaland (figure 4.18) (Carlsson et al, 2006). In many parts of the country, today's 100-year flows are expected to drop due to smaller spring floods, but also due to increased evaporation. There is a risk that the increase in today's 100-year flows in the mountains may spread downstream along watercourses to outlets in the future. The situation need not be as problem-free as the maps of the local 100-year flows would make it seem (appendix B 14). The accumulated 100-year flows for the river Umeälv exhibit increases between 0 and 34 percent, and the highest values mostly fall during the autumn rather than in the spring, as is currently the case (Andréasson et al, 2007; appendix B 10). In our assessment the risk of dam failure in smaller dams and retaining dykes may increase.

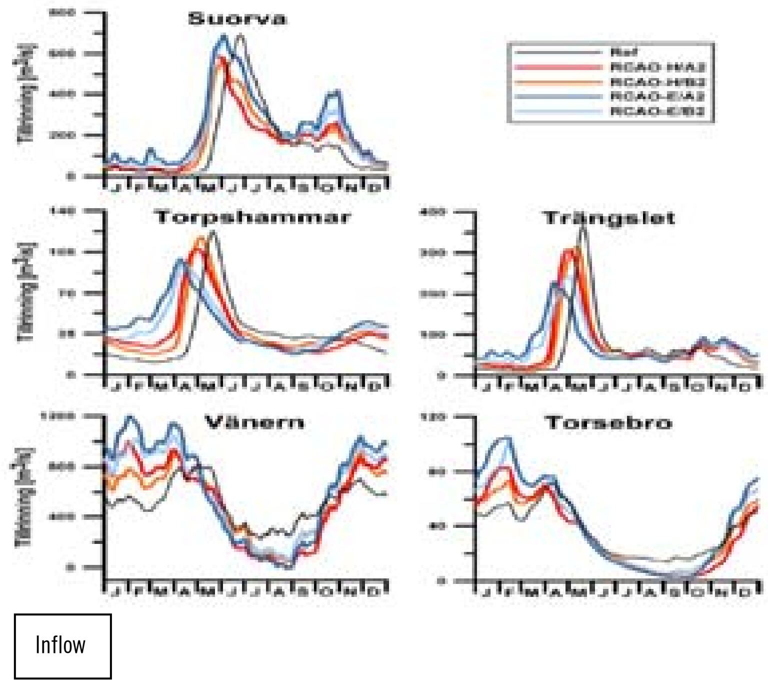
Figure 4.18 Percentage change in local 100-year flows (2071–2100 compared to 1961–1990). The results of 4 different climate scenarios are shown


RCAO-EA2 RCAO-EB2 RCAO-HA2 RCAO-HB2

Source: Carlsson et al, 2006.

The scenarios exhibit a changed inflow cycle with higher inflow during the cold months and lower inflow during the warm months, and an earlier spring flood. This could cause problems, for example, in replenishment periods that run from the spring flood to the autumn. Increased runoff, especially at high reservoir levels, can lead to increased overflow problems for, among other things, buildings, as the watercourse behaves as if unregulated. This can lead to expectations on flow reduction, for which the Swedish hydropower dams are not designed. Flow reduction can increase the risk to which the dam is exposed if the reservoir's reduction capacity is used before the inflow has culminated. Effective and safe flow reduction places heavy demands on, for example, margins and knowledge of the watercourse's hydrology and the dams' ability to withstand and release high flows. The graphs in figure 4.19 show changes in average annual inflow in the four future scenarios compared to today's climate.

Figure 4.19 **Seasonal dynamics of the inflow, 30-year average for the period 2071–2100, reference period 1961–1990. Catchment area, see figure 4.17 (RCAO-EA2, RCAO-EB2, RCAO-HA2, RCAO-HB2).**



Source: Andréasson et al, 2006.

Strong winds can affect dams. According to appendix B 9, the change in extreme winds is not expected to be of such a magnitude as to cause problems for dams. In general, a warmer climate ought not entail increased problems with ice and frost either. On the other hand, access to dams may be made difficult in conjunction with, for example, heavy precipitation affecting roads.

The greatest risk at disused or active mines is dam failure in a sand reservoir or other accidents affecting mining waste. Extended droughts can lay bare waste and increase the leaching of metal pollutants (see also section 4.3.6). Active mining dams for the disposal of mining waste are often built in stages and spillways are moved or rebuilt in conjunction with such modifications. According to appendix B 9, current mining dam structures are sufficiently robust to withstand major climate change, as they have long lifetimes. Problems are not expected to arise during the time spans covered by the report. The assessment is that the structures can be successively adapted to new conditions.

Swedish National Audit Office review of dam safety at hydropower dams

The Swedish National Audit Office has reviewed the state initiatives in the dam safety of hydropower dams (Swedish National Audit Office, 2007). The report was submitted to the Swedish government in May 2007. The Swedish National Audit Office concluded that although the measures taken by the state have strengthened and better clarified the state's responsibility for dam safety, the work exhibits shortcomings and problems. The Swedish National Audit Office has touched upon the following:

- State control of the dam owners' internal inspections as regards the poor possibility of constitutional regulation. The Swedish National Audit Office is of the opinion that this makes it difficult for the state authorities to adapt and refine the requirements on internal inspections to suit changed conditions. One example mentioned is the Swedish Flow Committee’s guidelines, which are not legally binding.
- The changed conditions climate change can bring to dam safety. It is noted that current adaptations to the requirements of the Swedish Flow Committee's guidelines concern extreme flows in today’s climate, without any direct association to the issue of climate change.
- County administrative board supervision. This is considered limited to encompassing the dam owners' annual reports to county administrative boards. It is noted that supervision has not identified any substantial shortcomings, unlike the two international reviews conducted thus far.
- Svenska Kraftnät’s reporting to the government on the development of dam safety. It is noted that there is a lack of reporting on how supervision and supervisory guidance ought to be changed, stemming from the failure to discover the aforementioned shortcomings.
- Responsibility for conducting the international reviews falling under the dam owners' internal inspections. The extent of the

> authorities’ insight is questioned. Moreover, it is felt that Svenska Kraftnät's assessments of which dams should be reviewed need to be further clarified.

The Swedish National Audit Office considers there to be a need to improve and develop the Swedish state's dam safety initiatives and recommends that the government take the initiative in reviewing them. Such a review should examine whether the current system, which to a large extent relies on the dam owners reporting the level and scope of dam safety work, fulfils the safety requirements expected by modern society. It is suggested that the review examine more explicit regulation of the dam owners’ internal inspections, as well as the scope, organisation, competence requirements and financing of the supervisory advice and supervision provided. It is considered valuable to compare matters with state intervention in other areas that run a risk of serious consequences in the event of shortcomings, such as state initiatives in nuclear power, or state intervention in other countries as regards dam safety.

The Swedish National Audit Office recommends the supervisory bodies to decide whether there is reason to believe that similar shortcomings in dam safety also exist in dams where dam failure would result in major consequences other than those that have now been reviewed by international experts.

Adaptation based on climate change together with considerations

We believe, in agreement with the Swedish National Audit Office, that the field of dam safety ought to be examined. The examination ought to focus on whether the current system fulfils the safety requirements expected by modern society. Dam safety ought to be examined in view of both today’s climate and climate change. It is our opinion that the review ought to examine society’s need to better regulate the dam owners' internal inspections, as well as the scope, organisation, competence requirements and financing of the supervisory advice and supervision provided. Further, we find reason to consider more explicitly defined centralised supervisory responsibility with regulatory powers. The review also ought to compare matters with state intervention in other areas where shortcomings in safety risk very serious consequences and state intervention in other countries in this area.

It is important that current work to adapt dams to the Swedish Flow Committee's guidelines continues, as described in appendix B 9. Future climate change and extreme weather events ought to be included as an assumption. Adaptation ought to apply to dams in risk classes I and II.

It is important that the development of high flows and risks in unregulated watercourses are analysed as regards climate change, which entails calculations of, among other things, the maximum flows. This demands method development, as calculation techniques that take into account future regulation strategies are currently lacking. Svenska Kraftnät, in cooperation with SMHI, ought to be assigned responsibility for ensuring this is done. Svenska Kraftnät also ought to be tasked with developing suitable methods for surveying the vulnerability of dams in risk class I and II as regards climate change, as well as conduct such a survey.

Certain climate scenarios show an increase in the maximum flows, whiles others indicate a decrease. Differences across the country are also considerable. We consider it important to see intensified discussions between SMHI, Svenska Kraftnät, county administrative boards and the power industry on how to handle the methods for and results of flow calculations, such as the range of the results. It is also important to follow up and compare future flow situations with the calculated maximum flows.

According to the climate scenarios, the characteristics of inflow dynamics will change over time. Electricity requirements will also change throughout the year. This may mean that the hydropower system can be operated differently to today. It is important to study whether and if so how this will affect dam safety, as well as the risk of flooding. The possibilities of using reservoirs to minimise flooding also ought to be illuminated. Svenska Kraftnät ought to conduct such work in cooperation with the power industry.

This report focuses primarily on hydropower dams, with a briefer study of mining dams and the consequences of dam failure in such dams. We consider it important that these are also analysed in greater depth as regards long-term climate change.

There are dams with no body appointed responsible for maintenance. We consider it important to survey all dams in each county and examine the ownership structures. Such a task ought to be assigned to the county administrative boards (see also section 5.4).

It is important that the subject of climate change and its effects are included in educational programmes on dam construction and dam safety, as well as in the teaching of hydrology. Further, it is important to convey knowledge about climate change to dam owners. We recommend that Swedenergy work to support the industry by preparing background data and spreading knowledge within the industry on how climate change could affect dam safety.

Climate change could entail stronger and more frequent strong winds with the accompanying risk of power failure. We believe that each dam owner should have the necessary reserve power to maintain dam safety.

Dams are often located in isolated locations. Dam owners ought to ensure that the necessary agreements between landowners and access road owners are in place to regulate access to the installations.

According to appendix B 9, the costs of adaptation are estimated to be of the same magnitude as the adaptation work currently underway, that is, about SEK 2 billion.

Research and development

We consider there to be a need for, primarily, more detailed flow analyses in the areas where dramatic increases in runoff can be expected. Through Elforsk, the power industry and Svenska Kraftnät have placed an order with SMHI for a continuation of the sensitivity analysis of how maximum flows are affected by climate change. The project runs from 2007 to 2010. SMHI will also conduct analyses of all locations with access to flow measurements and flow size calculations, as well as develop the methodology.

It is important that expertise is maintained in Sweden, by dam owners and other players alike. The Swedish Hydropower Centre was established in 2005 as a part of this initiative.

Recommendations

- A review also ought to be made of whether the current system fulfils the safety requirements expected by modern society. The review ought to examine society's need to better regulate the dam owners internal inspections, as well as the scope, organisation, competence requirements and financing of the supervisory advice and supervision provided. Dam safety ought to be examined in view of both today's climate and climate change.
- The directive for Svenska Kraftnät must clearly state that the agency is assigned responsibility for adapting to climate change within its area of responsibility (see section 5.10.2).
- Svenska Kraftnät ought to be tasked with developing methods for surveying the vulnerability of dams in risk class I and II as regards climate change, as well as conduct such a survey.
- Svenska Kraftnät, in cooperation with SMHI, ought to be tasked with developing methods for and calculating the significance of climate change for dams in risk classes I and II.
- Svenska Kraftnät, in cooperation with the power industry, ought to be tasked with analysing how changed runoff conditions due to climate change and the operation of the hydropower system can affect dam safety and the risk of flooding.
- Svenska Kraftnät ought to be tasked with cooperating with the mining industry on conducting an analysis of mining dams as regards long-term climate change.

Regarding the survey of dams and dam ownership, see section 5.4 on water permits.

4.2.3 Heating and cooling needs

Climate change will greatly affect heating and cooling needs. Heating needs will fall greatly as a result of rising temperatures while cooling needs will climb. Reduced heating needs will entail great cost-savings through reduced energy use.

This section looks at how climate change will affect the heating and cooling needs of residential and business properties. The report does not cover holiday homes not used as permanent residences as they represent too small a share of energy use and useful statistics are lacking. Industrial premises are only covered in brief as statistics on energy use for heating are lacking (see appendix B 11).

Current heating and cooling needs

The need for heating and cooling depends on both climate-related and non-climate-related factors. In an assessment of future energy use for heating and cooling it is therefore important to assess possible developments as regards both the climate-related and the non-climate-related factors.

Climate factors of significance to heating and cooling needs primarily comprise temperature and solar incident radiation, though cloud cover and wind also play a role.

Examples of non-climate-related factors that affect heating and cooling needs are building characteristics, such as isolation, the types, locations and sizes of windows, ventilation, heating systems, cooling systems, sun shades and more. Other influencing factors are the use of the building, the number of people inside, and the extent to which heat-emitting devices are used.

Current property holdings and energy use for heating houses, flats and business premises, excluding industrial premises, are presented in table 4.10.

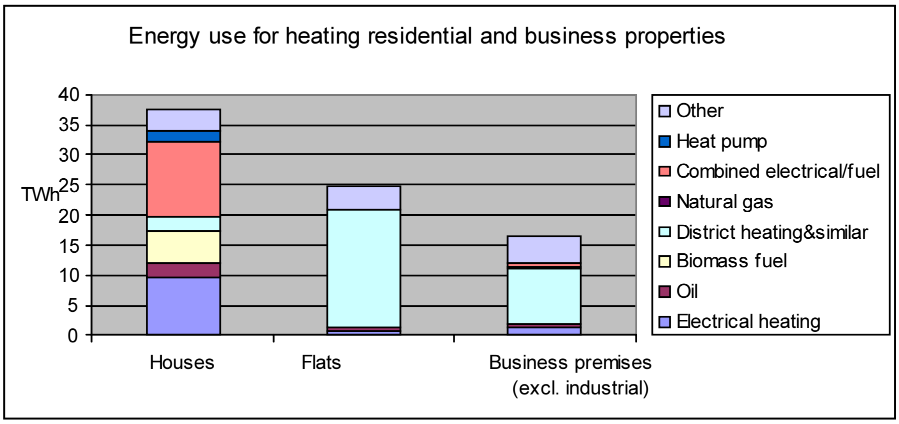
Table 4.10 Property holdings in Sweden (2005) and their energy use for heating

Property type	Floor, space, millions of m^2	Energy use forheating, TWh	Comments
Holiday homes, non-permanent residences	40	3.2	Very rough estimate of floor space, total energy use
Houses incl. permanently occupied holiday homes	260	37.5	
Flats	165	24.8	
Business premises excl. industrial	144	16.4	
Industrial premises	88	?	Floor space refers to heated floor space

Source: Appendix B 11.

Figure 4.20 shows the different types of energy used to heat different types of property. Electricity or combinations of electricity/fuel dominate among houses, while district heating dominates among flats and business premises.

Figure 4.20 Energy use for heating residential and business properties



Source: Statistics Sweden, 2006; Statistics Sweden, 2006b; Statistics Sweden, 2006c.

Reliable statistics for energy use for cooling are currently lacking (appendix B 11; IVL, 2007). A large number of properties are currently cooled, but the exact extent is unknown. According to a study by the Swedish Energy Agency, the STIL Report (Swedish Energy Agency, 2006), 91 of the 123 premises surveyed had access to cooling. Among the properties with access to cooling, electricity use for cooling comprised 12 percent of total electricity use. The total cooling needs of premises based on these figures currently stand at about 2.5 TWh.

At present very few residential properties have access to cooling. In those cases where cooling exists it is mainly air/hot air pumps used for air conditioning during the summer months.

Effects of climate change on heating and cooling needs

The climate factors of the most importance to heating and cooling needs are expected to change as follows in the future.

Temperatures will generally increase by an average of about 4 degrees centigrade throughout the country according to the climate scenarios. The largest increase is expected in Norrland in the winter. In the summer the largest increase is expected in southern Sweden. Increased temperatures are accompanied a reduced number of heating degree days, HDD[3], and an increased number of cooling degree days, CDD[4] (see appendix B 11).

The climate scenarios show a decrease in solar incident radiation in the summer in northern Sweden, but an increase in the winter. In southern Sweden an increase in solar incident radiation is predicted for the summer and a decrease for the winter.

The climate scenarios are more uncertain and difficult to assess as regards the other climate factors, cloud cover and wind, that can affect heating and cooling needs.

Future heating needs

The analysis of the future heating needs of residential and business premises is based on current property holdings and the RCA3-EA2 climate scenario. A sensitivity analysis based on RCA3-EB2 has not, however, been made. The calculations of the effects of climate change on energy needs for heating are based on the assumption that there is a linear relation between the number of heating degree days, HDD, and energy needs (see appendix B 11). The assumed number of degree days of a future climate has been compared with the reference period 1961–1990. Further, the analysis includes a study of the effect of the fulfilment of the EU objective to optimise energy use in the construction and property sector. The objective means there is an optimisation potential for Sweden's housing and property holdings of 30 percent until 2020 (EU Commission, 2006c).

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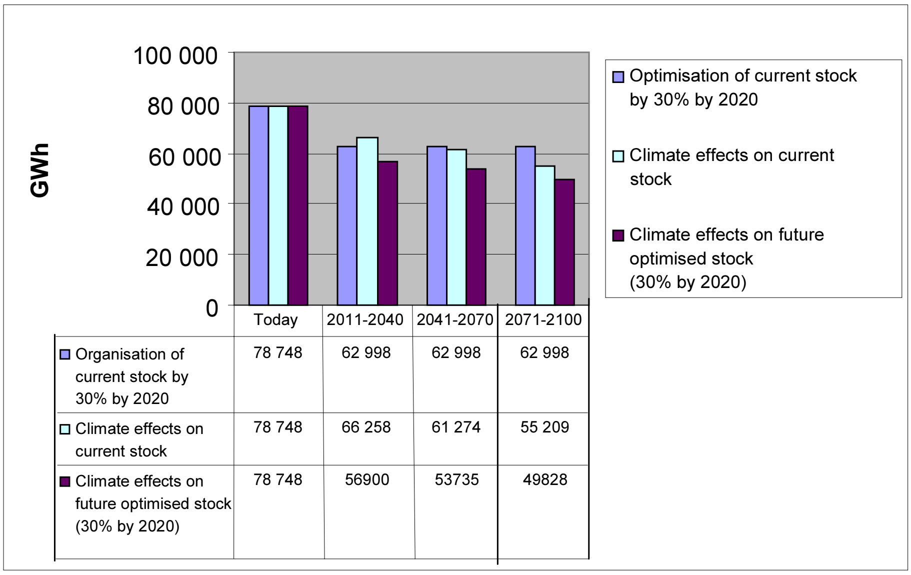
[3] HDD refers to the number of days when the outside temperature drops below 17°C multiplied by the number of degrees drop.

[4] CDD refers to the number of days when the outside temperature exceeds 20°C multiplied by the number of degrees rise.

Figure 4.21 **Changed number of heating degree days and the effect of energy optimisation on heating needs in current residential property holdings 2011–2040, 2041–2070 and 2071–2100 (RCA3-EA2). Industrial premises and holiday homes not included**



	Today	2011-2040	2041-2070	2071-2100
▨ Organisation of current stock by 30% by 2020	78 748	62 998	62 998	62 998
☐ Climate effects on current stock	78 748	66 258	61 274	55 209
■ Climate effects on future optimised stock (30% by 2020)	78 748	56900	53735	49828

Source: IVL, 2007

Figure 4.21 shows the results of the calculations. With the assumption that optimisations corresponding to the EU objective are achieved, the energy need for heating will fall by about 22 TWh (28 percent) by the 2020s, by about 25 TWh (32 percent) by the 2050s and by about 29 TWh (37 percent) by the 2080s.

Climate scenario RCA3-EB2 results in negligible differences compared with the RCA3-EA2 scenario until the 2020s and the 2050s, but by only 25 percent by the 2080s.

If we only consider the effect of climate change without assuming any optimisation, then energy use still falls by about 12 TWh by the 2020s, 17.5 TWh by the 2050s and 23.5 TWh by the 2080s in RCA3-EA2.

When it comes to heating needs in the winter, solar incident radiation can reduce heating needs in northern Sweden. In southern Sweden the drop in solar incident radiation in the winter may mean that the reduction in heating needs due to increased temperatures may not be as large as estimated.

Energy needs will drop in particular in business premises and housing that currently largely rely on district heating.

Changes in cooling needs

It is more difficult to estimate how climate change will affect cooling needs. The following analysis is based on information from the EU's Euroheatcool project, in which the cooling needs of different countries are estimated based on outside temperatures (Ecoheatcool, 2006). A simplified assumption has been applied to the different time spans wherein Sweden has a similar climate to Germany/Sweden until the 2020s, a similar climate to France/Germany until the 2050s and a similar climate to France/Spain until the 2080s. The calculations are based on current residential property holdings and no optimisation is taken into account.

Table 4.11 shows the estimated future cooling needs.

Table 4.11 Estimated cooling needs of residential and business premises in the 2020s, 2050s, 2080s as electricity needs in TWh

Cooling needs Sweden housing	*Electricity needs (TWh)*
2011—2040 (Climate similar to Germany/Sweden)	2.0
2041—2070 (Climate similar to France/Germany)	2.2
2071—2100 (Climate similar to France/Spain)	2.8
Cooling needs Sweden business	*Electricity needs (TWh)*
Current	2.0
2011—2040 (Climate similar to Germany/Sweden)	2.5
2041—2070 (Climate similar to France/Germany)	3.0
2071—2100 (Climate similar to France/Spain)	7.7

Source: IVL, 2007.

According to the estimates, residential and business cooling needs will increase dramatically up to 2100. If the trend of large glazed areas in residential properties continues, cooling needs will most likely increase even more.

Changes in solar incident radiation mean that the results may overestimate the cooling needs of northern Sweden and underestimate those of southern Sweden. As most developed areas are found in southern Sweden, total cooling needs are probably somewhat underestimated.

Cost estimates

Our cost estimates are based on an electricity price of SEK 0.40 per kWh and a district heating price of about SEK 0.45 per kWh. The district heating price is equivalent to the average district heating price for the past 10 years.

With these assumptions, energy costs for heating existing residential property holdings will drop dramatically in a changed climate. The costs for cooling, however, will climb. Overall, energy costs for heating and cooling needs are expected to drop considerably in a future climate. No possible optimisations have been considered in the calculations. In the short term, by the 2020s, costs would drop by about SEK 4.5 billion a year, in the medium term, by the 2050s, by about SEK 6.4 billion a year and in the long term, by the 2080s, by about SEK 6.9 billion a year compared to current costs (see table 4.12) (IVL, 2007; appendix B 11; appendix A 6).

Table 4.12 Estimated energy costs (SEK millions a year) for heating, cooling and in total for existing development

Time span	Cost for heating	Cost for cooling	Total costs
Now (2006)	33,780	991	34,771
2011–2040	28,426	1,791	30,217
2041–2070	26,284	2,077	28,361
2071–2100	23,686	4,216	27,902

Source: IVL, 2007.

4.2.4 District heating

Increased precipitation and higher ground water levels increase the risk of subsidence and flooding, incidents that can seriously damage the district heating network. As gradual adaptation to climate change is assessed to be feasible for district heating systems, climate change is not expected to affect such systems to any larger extent.

District heating production

At present there are about thirty district heating systems in Sweden, mostly in larger and medium-size towns. In terms of volume, district heating is the most common form of heating in Sweden today. The district heating system was established in the 1940s and was originally run by the local authorities. In recent years some district heating companies have been incorporated with both private and international owners. District heating is generally produced in district heating plants, where water is heated by combusting fuels, such as branches, treetops, twigs and bark from the forest. District heating is also produced using the waste heat from industries and sewage systems.

Existing district heating system and current vulnerabilities

The heat is distributed via district heating pipes to housing, offices, hospitals, industries and so on. The district heating system currently encompasses about 16,000 km of pipelines. These are replaced at a rate of about 3 percent a year (about 50 km) at a cost of SEK 250 million.

District heating mains are located in many types of ground and geological conditions, from north to south. Most district heating pipes comprise steel pipes inside concrete conduits. Older concrete conduits are exposed to weathering. The pipes can even rust away and leak if the joints are not tight. Plastic conduits (insulated steel pipes with plastic casings) were used to gradually replace the older concrete conduits in the 1970s and are now standard. Even modern standardised district heating pipes have an Achilles' heel in that every year the joins suffer extensive damage.

Some towns use a tunnel system for their district heating pipes, sewage systems, electricity cables and electronic communication. If such a tunnel system is flooded, the district heating system can fail.

The operation and maintenance of the supply pipes are decisive factors in quality of service and lifetime. There are many different district heating monitoring methods and many companies have localised weak pipe sections.

Ground displacement, due to increased ground water levels or poor drainage, can lead to the loss of a district heating pipe's natural fixation, with severe mechanical strain as a result. Ground displacement can have a direct and disastrous effect on pipes at great economic cost.

In the past 20 years there have been about 20 major leaks, that is, leaks of such a scale that production was threatened due to low system pressure and supply water shortage. Operational, distribution and maintenance systems are very dependent on electricity, trafficable roads and communication systems. District heating pipes risk freezing in the event of a production stop or failure in the winter.

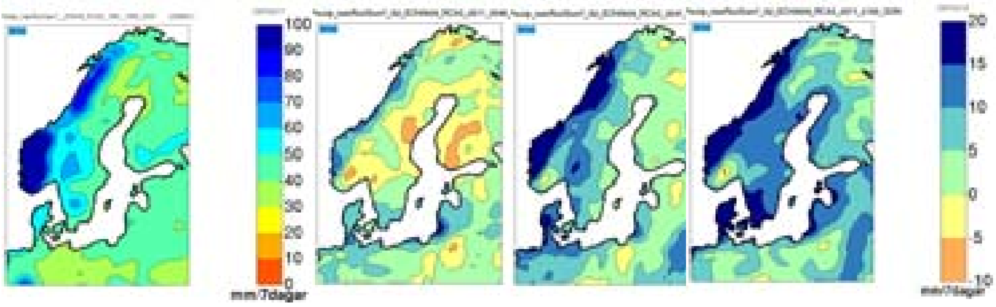
District heating distribution is most sensitive to heavy precipitation, flooding and high ground water levels.

The consequences of climate change and extreme weather events

The district heating analysis *District Heating* is based on climate scenario RCA3-EA2 (see appendix B 12).

Climate change means increased precipitation throughout the country. District heating pipes in dry ground with good drainage have considerably longer lifetimes than pipes in wetter ground. The risk of ground displacement increases as a consequence of increasing precipitation. A higher ground water level and increased precipitation means drainage systems must be improved. Figure 4.22 shows the change in maximum precipitation over seven consecutive days.

Figure 4.22 Changed maximum precipitation over a seven-day period Dec-Feb for the periods 2011–2040, 2041–2070, 2071–2100 compared to 1961–1990 (RCA3-EA2)



Source: SMHI, 2007.

In many places climate change also means an increased risk of flooding, which can lead to serious consequences for district heating pipes located in tunnels near watercourses, such as Slussen in Stockholm. The flooding of production facilities can cause failure and a loss of heating. A total freezing of the network results in the contraction of the pipelines, which weak components may not withstand, and at the worst this can lead to pipe fracture. There is also a risk of district heating distribution being affected by land collapse, landslide or flooding.

Increasing amounts of water and rainfall put the oldest conduits to the test. These are often the largest diameter conduits and those closest to production facilities, which is why the consequences of failure are by far the worst. According to appendix B 12, about 270 km of conduits are assessed to be in particularly exposed locations. Even the rigid and flexible district heating pipes, installed until the end of the 1970s, can suffer increasing problems from increased precipitation when the joins become old.

District heating production relies on fuel supplies, which in turn demand functioning logistics, such as roads, waterways, and loading and unloading. A changed climate with effects on logistics, such as disruptions to road transport as a result of storms or flooding, can have a serious indirect impact on district heating. District heating production is even affected indirectly if fuel beds are flooded.

Adaptive measures and considerations

The Swedish District Heating Association's *Installation Instructions* comprise the standard for new district heating systems. These instructions are regularly updated. By focusing on climate change in the next edition of the instructions, the Swedish District Heating Association says that it will then be possible to build district heating and cooling systems adapted to climate change. We recommend that the Swedish District Heating Association take climate change into consideration in the next update of its Installation Instructions. Further, it is important that the Swedish District Heating Association continue its work to spread knowledge in the industry about how climate change may affect district heating systems.

The Swedish District Heating Association believes that for the most part it is possible to gradually adapt the district heating systems as the climate changes. It is estimated that by 2020 half of the oldest systems will have been renewed and that by 2050 all concrete conduits will most likely be gone.

We believe it is important that the Swedish District Heating Association identify which district heating pipelines are particularly sensitive to climate change. The rate of renewal ought to increase in these particularly sensitive areas as well as of the oldest systems for which the consequences of failure can be major.

The renewal of vulnerable conduits (270 km) is estimated to cost SEK 1,350 million, according to appendix B 12. Operating and maintenance costs will also increase.

4.2.5 Drinking water supply

The consequences for drinking water supply are considerable. The quality of the raw water in water sources will most likely deteriorate with increased humus content and increased microorganism contamination. The risks of disruption to and pollution of the drinking water supply increase parallel to increased risks of flooding and landslide.

A great deal of the data used in this section is taken from the report *Drinking Water Supply and Climate Change* prepared by a working party within the committee (see appendix B 13).

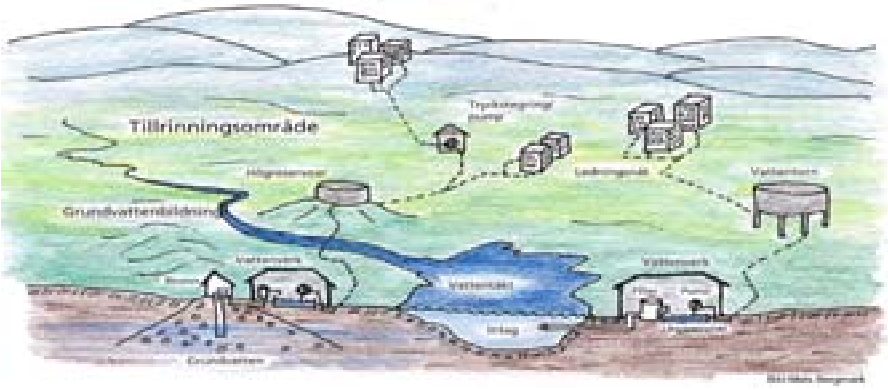
System description and current vulnerability

A public water supply is a prerequisite for life in modern societies. Local authorities are responsible for the roads and public places in most of the country's urban areas, and are also responsible for water and sewage.

Development of the existing water supply and sewage system began about 150 years ago due to continual outbreaks of water-borne diseases in Swedish towns. For a long period it was more common for townsfolk than rural dwellers to die of these water-borne diseases, which were mostly caused by bacteria. First came waterworks, water pipes and sewage pipes, and eventually sewage works.

Sweden has been favoured as regards water supply. It has been relatively easy to find good water sources of sufficient capacity. The water supply comprises a *chain* of functions from catchment areas and water sources through waterworks to a distribution system of water mains, booster stations and water reservoirs (see figure 4.23).

Figure 4.23 Drinking water supply is a "chain" from catchment areas to consumers' taps



Illustrated by Mats Bergmark

Tillrinningsområde	Catchment area
Tryckstegring/pump	Booster pump
Ledningsnät	Water piping
Vattentorn	Water toser
Högreservoar	Elevated reservoir
Grundvattenbildning	Ground water replenishment
Vattenverk	Waterworks
Filter	Filter
Pump	Pump
Lågreservoar	Earth reservoir
Brunn	Well
Grundvatten	Ground water
Vattentäkt	Water source
Intag	Intake

Source: Drinking Water Supply and Climate Change, appendix B 13.

Half of Sweden's local water supplies come from surface water, that is, from lakes and running watercourses. The other half come from ground water, where the infiltration of surface water comprises an important part of ground water replenishment. Good quality raw water from these water sources has made purification techniques in Sweden relatively simple. About 8 million of Sweden's inhabitants are supplied from a public water source while about 1.2 million have a separate/private water supply, with ground water comprising the dominant majority.

Most surface water treatment works in Sweden employ a relatively simple treatment/purification technique, which is adapted to hygienic, good quality raw water. The process generally comprises the following steps:

a) Course filtering or micro filtering of incoming raw water to separate larger particles (fish, zooplankton etc.).
b) If necessary, the water's alkalinity is raised using lime/carbonic acid.
c) Chemical precipitation with an iron or aluminium salt.
d) Separation of precipitate by sedimentation and filtering.
e) Reduction of any substances affecting taste and smell by adsorption using activated carbon or microbiological reduction using a slow sand filter.
f) pH adjustment to minimise the water's corrosive properties.
g) Disinfection using chlorine, chlorine dioxide or UV light.

Waterworks that use ground water as raw water often use simpler treatments than surface water treatment works.

Swedish waterworks are designed to deal with contagions in the form of bacteria. In surface water treatment works, chemical precipitation and filtering as precipitation barriers and chlorine as a disinfectant are most common. In ground water treatment works, chlorine (sometimes UV light) is often used as a disinfectant or contingent disinfectant. In recent years the microbiological threat has begun to change due to increased knowledge and actual change.

Another aspect of today's threats is the risk of various chemical pollutants entering a water source. For example, in the event of extreme precipitation, torrential rain or flooding there is a great risk of pollutants being mobilised and dispersed in different ways.

Sweden’s water and sewage systems are comprised of about 160,000 km of piping, enough to circle the earth 4 times, and about half of this is used to distribute drinking water. In the event of torrential rain causing landslide, parts of the distribution network may be damaged. For example, in a town outside Sundsvall 100 meters of drinking water pipeline was lost in conjunction with high flows in 2001.

Separate (private) water supplies work in a similar manner, but with smaller pipelines, often without water treatment and generally with a pressure tank/hydrophore as a reservoir/pressure equalizer. The most common type of private water supply is a well drilled into the bedrock. The water quality of private wells is analysed considerably less often than that of drinking water from larger facilities. Most take a water sample when the well is drilled, but after this it is common that no new samples are taken to follow up on water quality and variations. The surroundings of the well are decisive to how well it can cope with extreme weather and climate change without drying up or being polluted. Private water sources often have intentional or unintentional sewage infiltration nearby, which increases the risk of microbiological contamination in conjunction with weather that creates high ground water levels. Private water supplies near farming and cattle breeding can also be contaminated by manure.

In conjunction with the floodings of recent years, several Swedish water sources were polluted, even by microbiological contaminants. This has meant that consumers in many places have been forced to boil drinking water. The longest boiling period, which lasted nearly four weeks, was caused by flooding in Alvesta in the summer of 2004. In southern Norrland in the summer of 2000, and even the autumn of 2001, high flows and heavy rain led not only an official proclamation to boil all water, but even landslide in the water supply pipe network. In the autumn of 2004, Bergen in Norway suffered an outbreak of waterborne disease caused by a parasite resistant to chlorine (giardia). The chain of events leading to the outbreak included heavy rain. Despite being confined to a small part of the water supply system, the outbreak cost the community about NOK 46 million and many claims are still pending. The heavy rain in southern Sweden in the summer of 2007 also led to polluted water sources. In conjunction with the storm Gudrun four small water sources were left without electricity and reserve power was needed to maintain drinking water distribution. See also appendix B 13.

The consequences of climate change and extreme weather events

The climate scenarios indicate increased precipitation and runoff throughout the country, with the exception of the southern parts in the summer. The southeastern parts may even experience a drop in annual runoff. The winter increase will be particularly sizable. The risk of major flooding increases notably in the western parts of Götaland and Svealand, as well as in parts of Norrland. SMHI's statistics show that the intensity of heavy downpours has increased in recent years and, according to the scenarios, will continue to increase.

When the climate changes so do the conditions for water supply. Sweden will continue to be favoured as regards water supply. Water resources will increase in many places, with the exception of the southeastern parts of the country where water resources exhibit some risk of shortages. However, to make the most of the advantages offered to a modern society with a functioning water supply, with high quality drinking water, we must manage a few threats. This applies to existing threats, which may be reinforced by climate change, as well as new threats or conditions.

The risk of waterborne contagion by single-cell parasites (such as amoeba) and viruses will most likely increase even more due to successive climate change with increased temperatures and increased risk of heavy precipitation. The chlorine doses used in Sweden are essentially ineffective on parasites and have only a moderate effect on viruses. As such, separation by chemical precipitation/filtering is the only barrier in many surface water treatment works and is not perfect. In the case of ground water, the separation of viruses in the ground is strongly dependent on different climate and ground water conditions, which can quickly change in extreme weather.

There is reason to believe that climate change will increase the risk of chemical pollutants entering water sources. In a survey of Swedish local authorities, those responsible for water supply assess that the risk of serious contamination in conjunction with flooding and/or heavy downpours will increase for 86 percent of the water sources (see appendix B 13). The protection of water sources/drinking water supply will therefore be of increasing importance as the climate changes.

Today’s relatively simple preparation of raw water, whether surface or ground water, as drinking water will in many cases remain sufficient despite climate change. In addition to the microbiological risks, the chemical/biological makeup of many Swedish water sources will successively alter, and we have already seen increasing humus content and algal blooming in many water sources. Higher temperatures, longer periods where lakes and watercourses are free from ice, and increased runoff will lead to increases in eutrophication and humus content (see the section on freshwater environments, 4.5.2).

The distribution of drinking water in the supply pipes may also experience increased loads in a climate with greater variations, such as increased risks of land collapse, landslide and flooding. Rising sea levels increase the risk of saltwater contaminating water sources near the coast.

Private wells are often more exposed to climate change than public water sources.

Damage costs for the water supply and society in general will most likely amount to many billions of Swedish krona if measures are not taken or taken too late.

Adaptive measures and costs

The working group within the committee that produced the drinking water supply data have suggested a number of measures that are essential to securing the supply of good quality water (see appendix B 13). The following measures are recommended.

- Each water supply system ought to be analysed for vulnerabilities due to local conditions. This ought to be done by the local authorities assisted by the Swedish National Food Administration and the county administrative boards as a continuation and consolidation of the Swedish National Food Administration's start-up assistance for local authorities.
- Water sources ought to be protected against increased risks of chemical and microbiological pollutants. Requirements on the establishment of secure water protection areas for important local water sources ought to be examined to see whether they need tightening. The national environmental goals include an intermediate goal that all water sources supporting more than 50 people or producing more than 10 m^3 a day should be declared water protection areas, though there is no mandatory

requirement. Well-considered physical planning in water source catchment areas is also an important and basic aspect of ensuring safe drinking water. For example, developments in farming and forestry ought to be taken into account, and farming and forestry ought to take into account drinking water sources. There is reason to better clarify this and even to provide the opportunity to class important water sources as being of national importance.

- Where necessary, microbiological safety in the preparation of drinking water at waterworks ought to be increased. A review of the regulations covering the microbiological requirements of drinking water is needed, concerning, for example, microbiological barriers in ground water and waterworks, as well as sampling and monitoring routines.
- Measures ought to be taken to cope with the changes arising in the chemical/biological quality and temperature of raw water. There is a great need to clarify what current regulation entails and to formulate guidelines for monitoring the quality of raw water in Swedish water sources. It is also important that these guidelines include microbiological raw water quality.
- Measures ought to be taken to cope with reduced water supplies, mostly in southeastern Sweden. Water saving measures may include replacing parts of the pipe system, mains pipes, valves etc. that leak. Temporary restrictions on water use may also be announced, such as hosepipe bans. However, these measures will most likely be insufficient. Establishing new water sources is one alternative, as is building pipelines from other water sources.
- Distribution systems that can be exposed to heavy burdens ought to be secured. One example of a measure is to double up pipelines. In certain areas, for example, the risk of landslide with consequences for the water supply network is increasing. Doubled up pipelines should not be run in close proximity.
- Contingency plans ought to be expanded to include disruptions due to extreme weather or other consequences of climate change that can affect water sources, waterworks and distribution facilities. Contingency plan issues have been handled in cooperation with state agencies since 2002 within the bounds of

the joint areas of the crisis management system. The Swedish Emergency Management Agency is the state agency responsible for coordinating operations. At present about 30 central agencies collaborate, with both regional and local representatives. It is important that this cooperation is furthered in the area of drinking water due to the increased risks due to climate change.

– There is a need for education and information initiatives on the effects of climate change on the drinking water supply. In the case of local authority water supply there is a need for information and education in order to cope with possible and likely changes/effects of climate change. There is also a great need for education and information for owners of private water sources. The responsible authorities, trade associations (primarily the Swedish Water & Wastewater Association) and others ought to contribute with education, information material and advice to increase both awareness and knowledge of climate change and the need to adapt.

The accumulated costs of successively adapting the Swedish water supply to increased risks and new conditions due to climate change during the period 2011–2100 are very roughly estimated to be at least SEK 5.5 billion for local authority water supplies, but most probably more. A large share of these costs, SEK 4.25 billion, are also expected to arise during the period 2011–2100. As for private water supplies, adaptation costs are estimated at about SEK 2 billion. See table 4.13. Appendix B 13 explains in greater detail how these costs were calculated. The above-mentioned measures will require research, study, and development efforts to secure a favourable outcome. Other costs include operating costs and costs for local measures to reduce the risk of pollution of protected areas for water sources/resources.

In an international comparison, Sweden currently has an inexpensive drinking water supply. Even if costly measures may demand a noticeable increase in water charges for local authority water supplies (an increase of about SEK 1 or more per m^3), the actual cost per user will still be low in an international comparison. As an example, the cost in 2006 was SEK 5.50 per m^3 in major cities in Sweden while the cost in England and Wales was SEK 9.50 per m^3, in Scotland and the Netherlands SEK 11.30 per m^3 and in the USA SEK 8.40 per m^3. A reasonable estimate is that climate change in Sweden will cause an increase in costs of about SEK 2 per m^3. This increases annual costs to SEK 2 billion.

Table 4.13 Summary of estimated cost magnitudes of investment needs. Costs in addition to these include increased operating costs for various treatment plants at waterworks

Measure	**2011–2040**	**2041–2070**	**2071–2100**
Measures against water shortages in water sources (reduced inflow).	500 million	800 million	700 million
Increased need to separate at waterworks due to naturally occurring substances in ground water.	50 million	75 million	?
Increased need to separate at waterworks due to humus substances in surface water.	400 million	300 million	?
Increased need to separate at waterworks due to algae in surface water.	50 million	50 million	?
Increased need to separate/inactivate microorganisms at waterworks. These measures counteract the increased risk of outbreaks of waterborne disease. Further changes to microbiological risks later on are difficult to assess, but will probably lead to lower costs.	1,300 million	?	?
Need to cool water at waterworks (depends in part on consumer acceptance of warmer drinking water and guideline adjustments).	---	?	?
Cost of establishing protected water resource areas.	250 million	---	---
Cost of measures to reduce the increasing risk of pollution in protected water source areas (local conditions must be studied).	?	?	?
Increased need to separate chemical pollutants in waterworks (the cost depends on the substances and content levels, in the event of contamination).	?	?	?
Increased need for redundancy in the distribution of water and other preventative measures and contingencies.	600 million	?	?
Consequences of rising sea level (Gothenburg water sources).	400 million		
Cost of measures for private water supplies.	750 million	750 million	500 million
Total investment cost in SEK billions (current monetary value)	**At least 4.25**	**At least 1.9**	**At least 1.2**

Examples of damage costs	
Cost of waterborne diseases	The cost to society of a waterborne disease outbreak varies from a few million to several hundred million Swedish krona for each incident, depending on the extent of the outbreak and the size of the community.
Cost of replacing a water source polluted beyond decontamination	The cost of replacing smaller water sources varies from a few tens of millions to more than a billion Swedish krona for larger water sources.
Costs in the event of landslide affecting water mains and loss of water supply for several days.	A cost to society of SEK 10 – 50 million per incident (if reserve water mains are lacking). Moreover, there is an increased risk of leakage of polluted and contagious water in depressurised water piping.

Source: Appendix B 13.

Considerations

In our assessment climate change and extreme weather events will cause problems for the water supply in the future. The risk of spreading contagions and pollutants in drinking water sources are serious and measures must be taken. The increased concentration of humus in the water will also mean problems as temperatures and runoff increase. In our assessment the measures recommended above are important to maintaining a good water supply in the future.

Responsibility for Sweden's water supply is currently split between different national, regional and local authorities. Chief responsibility for the implementation of the measures recommended above falls to the local authorities and/or principals tasked with handling the drinking water supply. Trade associations, primarily the Swedish Water & Wastewater Association, have an important role in the requisite future adaptation of the drinking water supply. It is important that the Swedish Water & Wastewater Association can assume responsibility for informing and educating its members.

In light of the changes to drinking water quality that climate change can bring water analyses ought to be broadened. It is our opinion that the Swedish National Food Administration ought to review drinking water quality analyses throughout the production chain.

Private wells do not enjoy the same purification techniques and analyses as public water purification. It is therefore important to provide information about risks and protective measures. The

Swedish National Food Administration has issued, for example, a brochure together with the Geological Survey of Sweden. Together with other responsible authorities, the Swedish National Food Administration ought to be tasked with spreading information about private wells.

In line with the committee's overall recommendations, the county administrative boards ought to be charged with coordinating and lobbying to ensure the implementation of climate adaptations to secure the supply of good quality drinking water. This task also ought to include cooperating with other players to initiate strategic water planning.

Central responsibility is split between agencies. The Swedish Environmental Protection Agency is responsible for water source protection issues. The Geological Survey of Sweden is responsible for ground water as a natural resource and is responsible for environmental goals concerning ground water. The Swedish National Board of Health and Welfare is responsible for private water supplies. The water boards are responsible for preparing management plans and action programmes for Swedish water. The Swedish National Food Administration places demands on the quality of water leaving waterworks and reaching consumers. The Swedish National Food Administration also handles water supply safety and contingency issues. The Swedish National Board of Housing, Building and Planning has recommendations on water pressure in consumer water pipes and, where necessary, requirements on return flow protection to prevent contaminated water forcing its way back from a building and into a water main. The Swedish National Board of Housing, Building and Planning is also responsible for the overall environmental goal for the physical planning and administration of land and water. This division of responsibility is not appropriate with consideration for the pending risks and the measures that ought to be taken. It is our opinion that responsibility should not be so divided and coordination improved. We recommend that chief responsibility for drinking water at national level be assigned to the Swedish National Food Administration. This responsibility would include cooperating with other authorities and following up the measures recommended above.

Research and development

Follow-up studies and research on the effects of climate change on Swedish water supplies ought to be conducted. There is a need to supplement knowledge of water supplies at the local level and a need for research at the national level. For example, it is not possible to directly adopt purification techniques from warmer countries in Europe or the rest of the world due to the high humus content and, even in a warmer climate, relatively cold temperature of Swedish water.

Trade associations, especially the Swedish Water & Wastewater Association, ought to contribute to establishing research and development in the strategic issues of adapting water supply and sewage systems to climate change.

Recommendations

- The Swedish National Food Administration ought to be named responsible for drinking water issues at national level. This includes information initiatives, identifying research and development needs, the need to analyse raw water and so on.
- The Swedish National Food Administration ought to be tasked with:
    - Following up the implementation of adaptations to the drinking water system.
    - Reviewing, together with the appropriate authorities, protecion and water analysis procedures throughout the entire drinking water production chain, from the protection of raw water to purification and distribution.
    - Informing, together with the appropriate authorities, concerned parties of the risks with and protective measures for private wells.
- In our recommendations the county administrative boards are given greater responsibility for climate adaptation within their respective counties. This encompasses strategic planning for the county' water resources and cooperation with local authorities, water boards and other stakeholders (see 5.10.2).

4.3 Developments and buildings

4.3.1 Flooding of waterfront developments

The country's westerns and southwestern parts are expected to experience flooding along watercourses more often or much more often due to climate change. The increasing 100-year flows in the mountain regions may also spread along watercourses with flooding as a consequence, but there is some uncertainty for regulated watercourses. In other areas the risk of flooding will drop or remain at its current level. A higher sea level places increased demands on measures and planning for new development, especially along the country's southern coastline, but even along the central coastlines.

How is flooding defined?

Flooding is defined as water covering land areas above the normal bounds of lakes, watercourses or seas (Swedish National Rescue Services Agency, 2000). Flooding along watercourses and lakes means that more water than they can discharge is fed into them. The flooded land areas cannot absorb or drain the water if they are already saturated. Flooding can also affect developed areas away from watercourses due to heavy precipitation, which is covered in greater detail in section 4.3.4.

Division of responsibility

The Swedish National Rescue Services Agency is tasked with working for a safer society as regards dangers ranging from commonplace accidents through disasters to war. The agency shall create the conditions necessary for different players to cooperate and take preventative measures against natural disasters. General flood maps are prepared for risk areas along watercourses to aid emergency services personnel in planning and local authorities in general physical planning. The Swedish National Rescue Services Agency also follows the development of high flows and continually reports to the Swedish Ministry of Defence, assists with backup resources at major incidents, such as floodings, and establishes river groups.

The Swedish Meteorological and Hydrological Institute, or SMHI, manages and develops information about weather, water and climate for public services, businesses and the general public. SMHI has a permanently staffed forecast department prepared to issue warnings to prevent or limit damages to people, property and the environment, such as in the case of high water flows, extremely heavy rain and high sea levels. In the event of major flood situations, SMHI staff can also be stationed at the affected location to assist the emergency services and county administrative board.

Development size and geographic location

In total, there are 3.1 million buildings in Sweden (2005), a third of which are located in the three main metropolitan areas. Most of the buildings are houses and holiday homes. The coastal zone, defined as all islands and the mainland up to five kilometres from the shoreline, including the coast of Gotland, comprises 6.5 percent of the country's area. This zone is home to more than 30 percent of the country's total number of buildings and is inhabited by about 3.5 million people. The southern part of the coast is developed to a somewhat greater extent than the northern part. About 30 percent of the Swedish coast is developed within 100 metres of the shoreline. Almost 120,000 buildings are located within 100 metres of the shoreline. (Swedish National Board of Housing, Building and Planning, 2006)

Construction in recent years has been considerably lower than in the 1970s and 80s. In the coastal zone, however, the percentage share of construction has increased, especially in southern Sweden. In the years 2000–2003 it amounted to almost half. The percentage of houses built within 100 metres of the shoreline has more than doubled, from 2 percent in the 1970s to more than 5 percent at the end of the 1990s. Intensive building is particularly pronounced along the west coast, the coast of Skåne, the southern coastal area of Blekinge, and along the entire coast and archipelago of the Stockholm region. Another trend is to build in attractive harbour areas. There is also a tendency for holiday homes near larger developments in coastal areas to be used as permanent homes.

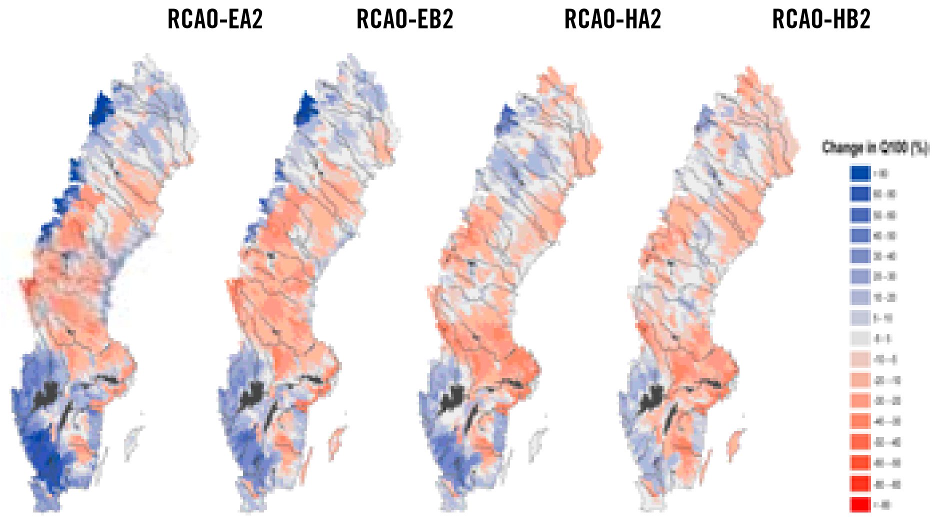
Proximity to water, and perhaps most of all to the sea, and the pleasant natural surroundings it offers makes the coastal landscape attractive for development, tourism and business. According to

Statistics Sweden' forecast for demographic evelopment 2006–2050, a population increased of 1.4 million is expected during this period. If the above trend continues most of this people will settle in the coastal zone.

Climate factors that affect flooding along watercourses and seas

According to the climate scenarios, precipitation and temperature will increase throughout the country, with the exception of precipitation in southern Sweden where the climate will be drier in the summer. The number of days with extreme precipitation is also expected to increase in most parts of the country. Such preciitation causes local extreme flows. Local average runoff, calculated from about 1,000 runoff areas covering 400 km^2, is increasing in western Götaland, western Svealand and large parts of Norrland. If we look at changes in the more extreme flows with a 100-year return period, it is mostly western Götaland and western Svealand that stick out, though even parts of the mountain regions and north-astern Götaland. Other parts of the country can expect unchanged or smaller 100-year flows, mostly due to a more evenly spread snow melt period with lower spring floods, but also increased evaporation (see figure 4.24). A 100-year flow means that each year there is a 1-in-100 probability that the flow will reach this level and a 63 percent risk that this will occur during the 100-year period.

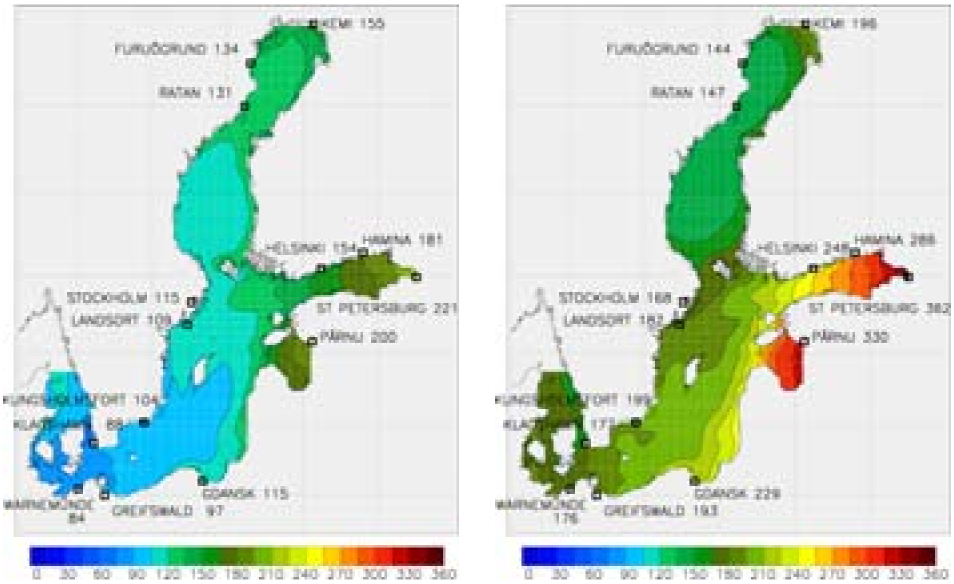
Figure 4.24 **Percentage change in local 100-year flows, 2071–2100 compared to 1961–1990. The results of 4 different climate scenarios are shown (from the left RCAO-EA2, RCAO-EB2, RCAO-HA2, RCAO-HB2)**



Source: Carlsson et al, 2006.

A rise in sea level is expected along large parts of the coast due to a rise in ocean levels. This has consequences for, among other things, developed areas. We have based our findings on SMHI's climate scenarios with rises in sea level of 9 cm, 48 cm and 88 cm, which are based on the IPCC's scenarios from the third assessment report. The scenarios take into account land elevation, which varies between minus 0.5 mm a year in the southernmost part of Sweden to plus 8 mm a year on the coast of Bottenviken. Consequently, in the northern reaches of the country rises in sea levels are essentially compensated by land elevation, even if the rise in sea level is large. The highest water levels will change in a similar manner to the average water levels. The changed low pressure path and changed wind patterns also come into play here. We have studied the highest expected water levels in one hundred years (see figure 4.25).

Figure 4.25 On the left, the 100-year water level 1961–1990, on the right, the 100-year water level 2071–2100 (RCO-EA2) with a global rise in sea level of 88 cm. The levels are stated in cm above the average water level of the period 1903–1998



Source: Meier, 2006, with permission from Springer Science and Business media.

Consequences of flooding along watercourses in today's climate and damage costs

The period from the beginning of the 1960s to the beginning of the 1980s saw relatively little rainfall and high flows were relatively uncomon. As the degree of regulation on regulated watercourses increased, the frequency of high flows decreased, as the reservoirs could generally cope with the snow melt. The reservoirs have also been able to function as buffers during rain seasons and developents have been able to move closer to the watercourses. Since the beginning of the 1990s, on several occasions high flows and flooding have been seen due to long periods of heavy rain outside of the spring flood. These flows have damaged buildings, infratrucure and the environment. Regulated watercourses can act as if unregulated if, for example, persistent rain falls after a heavy spring flood and the reservoirs are already relatively full. The surplus must then be discharged from the reservoir.

Establishing development closer to watercourses and lakes is generally a problem and is seen near both regulated and unregulated watercourses. The committee has ordered an analysis to get a general idea of the proportion of existing developments near watercourses that are in the risk zone for being flooded by current 100-year flows and the costs this would entail (see General Vulnerability Analysis for Flooding, Landslide and Erosion in Developed Areas in a Future Climate, appendix B 14). The calculations are based on the Swedish National Rescue Services Agency's outline flood maps and the National Land Survey of Sweden's GSD ground maps. These maps cover 8,000 km of the 56 watercourses thus far assessed to be of the highest priority. The information this produces is flooded areas according to ground class (low, confined and high development, holiday homes, detached buildings and industrial buildings). The building area calculations are based on models for several urban areas of different sizes and locations and the GSD properties map. Damage cost calculations are based on the insurance industry's information on damage costs for flooded buildings, and are in the interval of SEK 1,000–4,950 per m^2 depending on building type and mainly comprise renovation costs. The analysis does not take into account flooding due to heavy rain. This is covered in section 4.3.4. Table 4.14 shows the flooded area of existing developments at the current 100-year flow and damage costs.

Table 4.14 Flooded existing development (2006) along watercourses at the 100-year flow with today's climate and estimated costs per incident (km^2, SEK millions, appendix B 14)

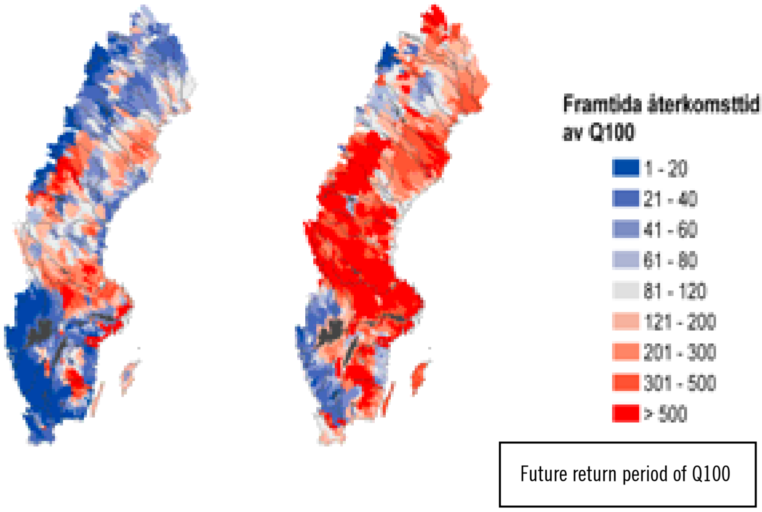
	Low development	Holiday homes	Detached buildings	Confined and high development	Industrial premises	Total
Building areas	1.6	0.1	1.0	0.8	2.7	6.2
Damage costs	7,700	250	5,700	2,150	2,700	18,500

If today’s 100-year flow should occur in all watercourses for which we have general flood maps, the total costs for existing buildings would amount to SEK 18.5 billion for such an incident. This corresponds to about SEK 2.3 million per watercourse km and mostly affects low and detached buildings. This does not include flooding at lower or higher flows, just 100-year flow levels. Climate change has not been considered. The 8,000 km of mapped watercourses correspond to 8 percent of the country's total watercourses.

Consequences of flooding along watercourses in a changed climate

Figure 4.26 shows the return period that today’s local 100-year flows may have in a future climate. Changes in extreme values have been calculated using a model developed to calculate changes in average values, which adds a degree of uncertainty. Much indicates that a changed climate would entail increased variability with greater changes in extremes than in the average climate, which makes it more likely that the results show too long rather than too short return periods (appendix B 14).

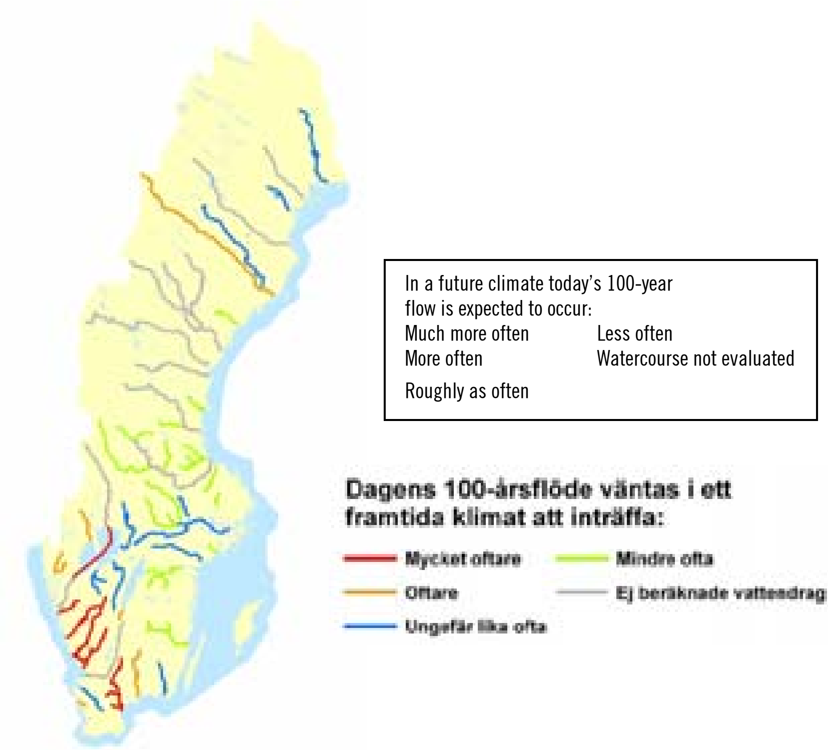
Figure 4.26 Expected return period of today's local 100-year flows 2071–2100, the shortest (on the left) and longest (on the right) return periods respectively, (RCAO-EA2, RCAO-EB2, RCAO-HA2 and RCAO-HB2)



Source: Andréasson et al, 2007b and appendix B 14.

Appendix B 14 presents estimates of the changed frequency of today’s local 100-year flows for unregulated or lightly regulated watercourses in a changed climate (see figure 4.27). For other regulated watercourses the uncertainties surrounding future tapping strategies are too large to make any estimates. There is, however, a risk that the increased local 100-year flows in the mountain regions may spread down the watercourse to its outlet, as runoff from the mountain regions dominates the flow in several of these watercourses. Consequently, the situation need not be as problem-free as the maps of local runoff would indicate. A calculation for the regulated river Umeälv exemplifies this outcome (see appendix B 10). It is, however, difficult to make any general conclusions for other regulated rivers in Norrland from one particular outcome.

Figure 4.27 **Changed frequency of today's 100-year flows in unregulated and lightly regulated watercourses 2071–2100. Heavily regulated watercourses are not included (appendix B 14)**



In a future climate today's 100-year flow is expected to occur:

Much more often
Less often
More often
Watercourse not evaluated
Roughly as often

Parts of the areas that currently have problems with high flows are expected to experience recurrent flooding more often or a lot more often, while other areas will see recurrent high flows less often. Table 4.15 shows flooding of existing development and costs at today's 100-year flow as in appendix B 14 and broken down according to the assessed frequency of the 100-year flow in the future. The assessments show that the building areas at risk of flooding from today's 100-year flows will decline in a future climate, based on the 8 percent of the watercourses surveyed so far.

Table 4.15 Flooded existing development along watercourses at the 100-year flow with today's climate, according to the changed frequency of the 100-year flow 2071–2100 (km^2, SEK millions)

Change in frequency	Less often	Roughly as often	More often	Much more often	Regulated
Building areas	2.9	0.8	0.3	0.8	1.4
Damage costs today	8,300	2,500	1,100	2,100	4,400

Heavily regulated watercourses are not included, which is why it is not possible to form a complete picture of the change in risk.[5] As shown above, there is a risk that the increased 100-year flows in the mountain regions spread down the entire watercourse resulting in flooding. The analysis does not include flooding caused by lower or higher flows than today's 100-year flow. According to figure 4.27, today's 100-year flow in the country's western/southwestern parts will return much more often. This shorter return period means they can occur several times a century. This also means that the 100-year flow in a changed climate in these areas will be considerably higher and cause flooding of a larger area. In the eastern parts of the country, the return period will increase instead.

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[5] The regulated watercourses are the rivers Faxälv, Fjällsjöölv, Göta älv, Nordre älv, Indalälv, Klarälv, Lagan, Ljungan, Ljusnan, Luleälv, Skellefteälv and Ångermanälv.

Consequences of flooding along seas in a changed climate together with damage costs

No flood maps like those for watercourses have been prepared for the sea. In order to obtain an overview of the extent of development in the risk zone for flooding due to increased sea levels, two basic analyses have been conducted (appendix B 14). In the first analysis, developed areas located below the first contour line (5 metres above sea level) have been estimated in the same way as in the area calculations for watercourses (see table 4.16). In the second analysis, existing development flooded by the 100-year water level and a global rise in sea level of 88 cm have been surveyed in three reference communities. The reason for not conducting a more detailed analysis of the entire coast is the lack of more detailed elevation data.

Table 4.16 Existing building area (km^2) between surveyed shoreline and +5 m contour line, 2006 (appendix B 14)

	Confined and high development	Low development	Holiday homes	Detached buildings	Industrial premises	Total
Southern*) Sweden	9.6	18.8	3.2	3.0	14.9	49.5
Northern Sweden	1.1	3.4	0.3	0.4	5.3	10.5

*) In the analysis, southern Sweden encompasses the coastal stretch up to Uppsala County.

The coasts along western, southern and southeastern Sweden and Stockholm County have extensive development below the 5 metre line. These areas comprise about 75 percent of the total area according to the basic analysis. In Skåne, the 5 metre line penetrates far inland due to the flat terrain and developed areas under the 5 metre line comprise almost 30 percent of all development below this level. Development in Stockholm County is relatively dense on islands and along the coast.

Using a model from the insurance industry, the value of building areas under the 5 metre level in southern Sweden totals SEK 164.1 billion. At the same time, none of the climate scenarios used in the report indicates such a large increase in sea level in the next 100 years. Towards the end of the century the 100-year water level of the sea in southern Sweden will be about 0.8 to 2.0 metres above the average water level in 2071–2100, depending on the climate scenario (see section 3.5.4).

Three reference communities, Gothenburg, Ystad and Sundsvall, have mapped existing development that could be flooded by a global rise in sea level of 88 cm. The selection of this *high scenario* (see figure 4.25) is based on the fact that the developed areas comprise a system with a very long lifetime and the sea levels are expected to continue to rise even after this century. The rise in the 100-year water level 2071–2100 compared to today's 100-year water level and taking into account land elevation/subsidence is 0.18 metres in Sundsvall, 0.95 metres in Ystad and 0.90 metres in Gothenburg. The calculations include the effects of low pressure, wind and land elevation.

Problems vary considerably between the towns. The effects of land elevation and the topography of the Sundsvall area result in a small net increase in sea level, the consequences of which are limited. Damage costs are estimated at SEK 18 million using models from the insurance industry. Extrapolating the results to other parts of Norrland's coast is difficult as the high coast differs, for example, from the flatter coastlines of Västerbotten and Norrbotten. The consequences are greater in southern Sweden. The difference between today's average water level and the future 100-year water level approaches 2 metres. In Ystad, an estimated 4.1 km^2 of the town's 352 km^2 will be flooded. A large part of this area is uncultivated land, thought developed areas and infrastructure would also be affected. The damage costs for flooded developed areas are estimated at SEK 172 million. If, on the other hand, we assume that half of the rise in sea level comprises a increased average water level the damage costs rise to SEK 580 million, when the calculations are based on market value. For Gothenburg, a rise in global sea level of 0.9 metres above the highest high tide would entail insurance payouts of SEK 7,500 million. The total flooded developed area is estimated at 2.1 km^2 of the total of 23.0 km^2 in the three zones studied in Gothenburg.

The numbers of flooded buildings in Ystad and Sundsvall and the numbers of buildings under the +5 meter contour line are, in the case of Ystad, 168 and 859 respectively and, in the case of Sundsvall, 50 and 849 respectively. The outline analysis of developed areas under the 5 metre contour line threatened by flooding therefore overestimates the number of threatened buildings in Ystad by a factor of 5 and in Sundsvall by a factor of 17. These results provide a very rough idea of flooding conditions along the coast of a 100-year water level with a global rise in sea level of 88 cm. roughly speaking, this would mean a flood risk for about 20 percent of development under the 5 metre level in the country's southern parts and for about 5 percent on the country's northern parts.

According to the climate maps (see section 3.5.4) the global rise in sea level of 88 cm gives a rise in average water level of about 80 cm in southern Sweden at the end of the century, taking into account subsidence. In northern Sweden, land elevation and any rise in sea levels essentially counter each other. In the southern parts of the country, the rise entails not just flooding but even permanently submerged areas. This means higher damage costs and, naturally, costs for preventative measures. The Falsterbo peninsula is an example of a very exposed area.

Possible technical measures to reduce flood damage

Different technical measures are available to reduce the risk of damage to, primarily, existing development. Possible measures include:

- Reduction in flows by changing regulation methods or by using alternative discharging to other areas.
- Increase discharge capacity by increasing watercourse cross-section, remodelling dams, or furrows.
- Damming.
- Landfill/raise buildings.
- Adapt buildings and their use.

All measures can be used for flooding in watercourses, while options for increased sea levels are limited to the last three. The first two measures are generally used in larger contexts, while land filling, adaptation and, to some extent, damming can be implemented by individuals. Time is also an important aspect. Warnings of high flows are generally given at short notice, placing heavy demands on preventative and preferably permanent measures. If permanent measures have not been taken, then damming and pumping are the main options. But even these measures need planning. Demands are placed on the availability of materials, personnel and knowledge of storm water system locations and geotechnics.

Adaptive measures against the flooding of waterfront development and considerations

A reliable way to reduce the risk of flood damage is to avoid building in flood risk areas. As the climate gradually changes and as buildings have very long lifetimes, it is especially important to early on consider and take into account expected increased flood risks resulting from increased precipitation, changed flows and rising sea levels, as well as the uncertainties surrounding the extent of the increases in risk (see also section 5.5). In *The First Step Towards Simpler Planning and Building Legislation* bill (2006/07:122) the government has made clear in the key regulations that development shall be localised to land suited to the purpose with consideration for the health of the inhabitants and others, personal safety, and the risk of accidents, flooding and erosion.

Local authorities need to take flood risks into account to a greater extent in general and detailed town planning. Increased consideration for climate change is also needed when planning infrastructure. The county administrative boards have an important role here (see section 5.10). Flood risks will increase along watercourses, mostly in western and southwestern Sweden, but also in other areas, and along the coast. In other parts of the country the risk may decrease.

In many communities there is a need to improve knowledge about flood risks. In our opinion, this ought to be achieved by the Swedish Association of Local Authorities spreading information to local authorities about climate change and its effects as a basis for the safe localisation of development.

SMHI ought to be given greater responsibility for spreading knowledge about climate change and establishing a broader information base for various groups, in particular local authorities, government agencies for different sectors and county administrative boards (see also section 5.10).

The local authorities have a key role in identifying, analysing and prioritising areas at risk from different natural disasters, such as floods. Local authorities and property owners ought to take measures to adapt developed land in prioritised areas to avoid damage and establish contingency plans and resources to reduce the consequences of any disasters. The above permanent technical measures are solutions which, with concrete requirements and the right formulation, can protect existing and new buildings.

The Swedish National Rescue Services Agency is currently responsible for flood surveys along watercourses. In our opinion it is important that these surveys are continued and broadened to even include climate change. The Swedish National Rescue Services Agency also ought to examine the possible need to review the areas already surveyed as regards climate change (see also section 5.1). This work demands good quality topographic information. Subsequently, there is a need for a national elevation database of greater precision than the current GSD elevation data (see section 5.2). Completed surveys may also need reviewing once a new elevation database is available.

Reliable data on precipitation and flows is an important prerequisite for safe community planning. SMHI currently provides forecasts and warnings for, among other things, high flows, and has a network of precipitation and flow monitoring stations that cover the country (see also sections 5.2 and 5.3).

River groups exist for most major watercourses. Regional cooperation on issues concerning flows, flow control and preventative measures and the like against floods for specific watercourses will be of increasing importance in the future. It is our opinion that the county administrative board ought to be the party that takes the initiative to establish river groups (see also section 5.10).

Research and development

Issues surrounding extreme weather and climate change and its consequences concern many sectors of society, bringing to the fore close cooperation between various agencies, such as the Swedish National Rescue Services Agency, the Swedish National Board of Housing, Building and Planning, the Geological Survey of Sweden, the Swedish Geotechnical Institute, the Swedish Meteorological and Hydrological Institute and the Swedish National Environmental Protection Agency. There is a need for research programmes on issues focused on consequences for the community and measures concerning land, the environment and property development. The formulation of such a research programme could be coordinated with the Swedish National Rescue Services Agency's work on a national platform for dealing with natural disasters. Important tasks include:

- Increasing knowledge of the interplay between developed areas and the land.
- Adapting existing developments and infrastructure to large water flows and high water levels.
- Adapting community development and designing new building structures for the climate conditions expected over the next 50–100 years.

Recommendations

We submit recommendations for several areas. The recommendations concern the following and are described in greater detail in the indicated sections:

- Section 5.1: Flood maps.
- Section 5.2: Elevation database, observation data.
- Section 5.5: Physical planning, agency support in physical planning.
- Section 5.10: Division of responsibility.
- Section 5.10: River groups.

4.3.2 Landslide and erosion

Climate change with heavier and harder precipitation, as well as changed ground water levels, increases susceptibility to land collapse, landslide and erosion. The southwestern/western parts of the country and stretches of the east coast are particularly exposed. Low developments in areas susceptible to landslide are most at risk. In other areas the risk is falling as the snow melt season is becoming longer and the spring flood and high flows are decreasing in magnitude.

A changing landscape

The landscape is changing continually. Geological processes build up and break down landscape formations in a very large geological cycle. These processes affect the land's characteristics and its suitability as a foundation for infrastructure, property development and ecosystems. An understanding of how the geological processes arise and act is essential to the correct interpretation of how climate change will affect different types of soil movements and the consequences of these on the suitability of the land to development.

A particular soil's firmness and its susceptibility to different types of mass movement are highly dependent on its internal composition, that is, the relative proportions of solid particles, water and pore gas. In coarse soils friction acts as a cohesive force and its size depends on the water pressure in the soil. Soil movements in frictional soils take place, for example, as slow settling or rapid collapse if the angle is steep. Molecular attraction, cohesion, is also at work between the smallest particles in fine soils, such as clay and silt. Soil movements, aside from slow settling and creeping movements, can be rapid landslides with large soil masses slipping out. In the Göta älv valley and other parts of western Sweden, for example, areas susceptible to landslide are comprised of quick clay. Quick clay loses its firmness and becomes fluid when disturbed, which can lead to landslides affecting large areas with accompanying consequences for the community. The soils most susceptible to erosion have a grain size between fine and medium sand. In Sweden water erosion is most significant to developed areas. Susceptibility to erosion is limited in soils with mixed size grains.

Current division of responsibility

As the Swedish state's expert body in landslide, erosion issues, the Swedish Geotechnical Institute, or SGI, works to reduce risks in the area of geotechnology based on the principle that people should be able to live on safe land, so that lives and property are not lost in natural disasters in the form of landslide, and erosion. The SGI has special responsibility for monitoring stability in the Göta älv valley and assists the county administrative board and local authorities in Västra Götaland County. The agency also provides technical support to the Swedish National Rescue Services Agency when administrating subsidies for preventative measures against natural disasters. In emergencies, when a landslide has occurred or is anticipated, the SGI assists, for example, the local emergency services. The SGI is also affiliated with a committee for landslide issues, a liaison agency for contact and cooperation with agencies involved in landslide issues.

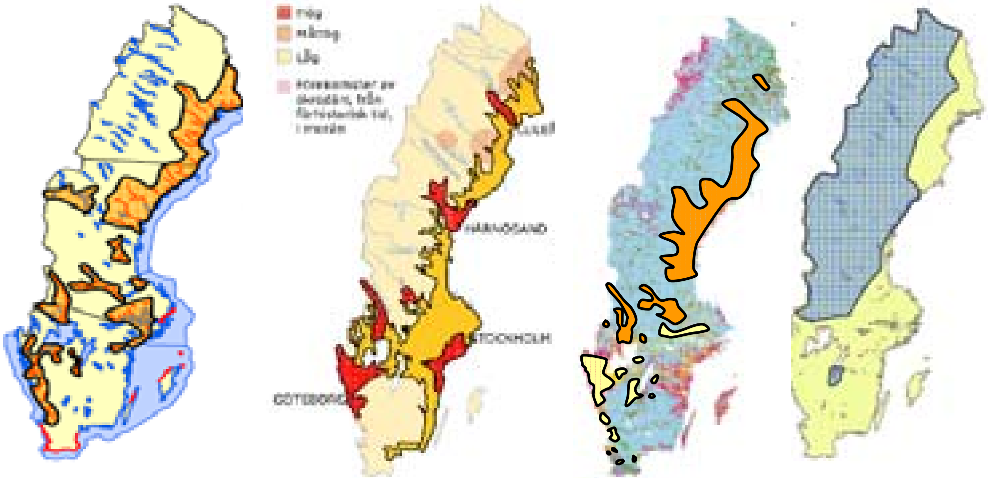
The Geological Survey of Sweden, or SGU, is responsible for issues concerning the country's geological composition and mineral management and is tasked with providing geological information regarding the environment, health, physical panning and more. The SGU's bedrock and soil type data provides fundamental geological information for construction planning and land surveys. The SGU also produces ground water maps and documentation. The SGU participates in, for example, landslide investigations and the committee for landslide issues.

Areas currently exposed to landslide and erosion in water

Major landslides with extensive consequences for human life and developed property have mostly occurred along the Göta älv valley – the Surte, Göta and Tuve landslides. Vagnhärad also suffered a major landslide in 1997. The direct costs for the landslide in Vagnhärad have been calculated at SEK 120–130 million. During the period 1996–2005, 64 local authorities conducted 131 actions due to landslide or land collapse, and by 2006 73 local authorities had applied for state grants for preventative measures on some 400 occasions. There is clearly already a problem with landslide risk today.

General Vulnerability Analysis for Flooding, Landslide, and Erosion in Developed Areas in a Future Climate, appendix B 14, presents an analysis of how the conditions for landslide and erosion in water may change due to climate change. To this end, general maps have been prepared over the conditions for *erosion, landslide, ravine formation in slopes of clay, silt and sand, and boulder clay landslides and mud flows, including ravine formation in boulder clay slopes* in today's climate (see figure 4.28). The maps are based primarily on data from the Geological Survey of Sweden, the Swedish Geotechnical Institute and the Swedish National Rescue Services Agency. Erosion along the coast is presented separately in section 4.3.3.

Figure 4.28 **Different risk areas today. From the left, soils susceptible to erosion; landslide risks in clay and silt; ravine risks in clay, silt and sand; risk of boulder clay landslide, mud flows and ravines in boulder clay slopes**



High
Moderate
Low
Presence of (prehistoric) landslide scars in boulder clay
Gothenburg

Source: Fallsvik et al, 2007.

Climate factors affecting soil stability

The climate scenarios generally indicate increased and heavier precipitation in large parts of the country. Local runoff will increase in most of the country, while the local 100-year flows will mainly increase in the southwestern/western parts and in mountain regions.

Increases in precipitation have a negative impact on soil stability, affecting susceptibility to landslide. Increased water pressure in ground pores reduces firmness. Ground water changes affect pore pressure. Increased precipitation can also lead to increased runoff and erosion, which affect slope stability. High flows, which are extreme and more frequent, increase erosion along watercourses and in lakes. Long periods of high precipitation saturate the ground and heavy rain with surface runoff resulting in erosion contributes to ravine formation. Heavy rain and saturated soil stratum also increase susceptibility to mud flows and even landslide in boulder clay soils.

The climate scenarios indicate the greatest increase in precipitation in the winter half of the year when evaporation is low, leading to high water levels. In the summer conditions are drier, especially in southern Sweden. Water levels drop when summer arrives and counter forces decrease. This results in increased landslide risk as water pressure in the ground can remain high.

Changed susceptibility to land collapse, landslide and erosion in a future climate

Appendix B 14 prevents assessments of changed susceptibility to:

- Erosion in watercourses and lakes.
- Landslide.
- Ravine formation.
- Boulder clay landslide and mud flows.

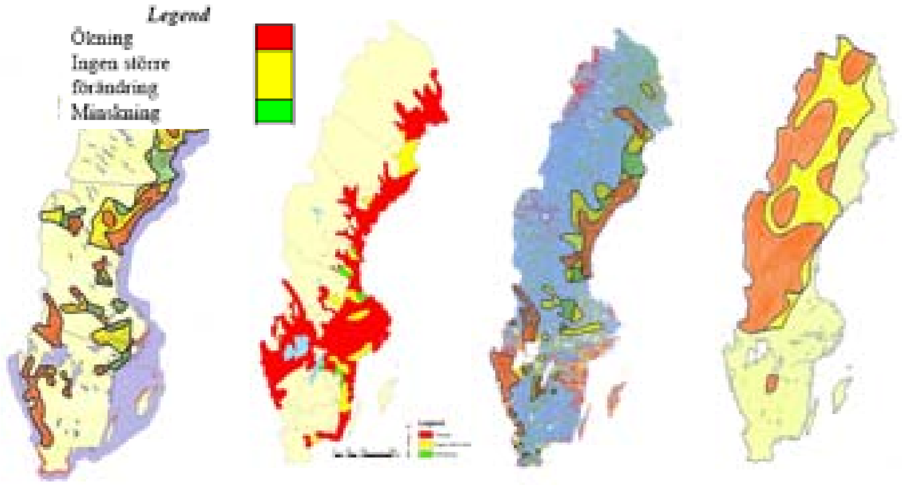
A general assessment of the consequences for developed areas. The assessments of soil movements have been prepared by a working group coupled to the committee in cooperation with the Swedish Geotechnical Institute (SGI), the Geological Survey of Sweden (SGU), the Swedish National Rescue Services Agency, SMHI and Swedish Road Administration Consulting (Fallsvik et al, 2007).

The assessments of soil movements have been divided into three classes: no major change, an increase or a decrease in the frequency of the soil movement. The assessments are limited to the areas currently known to be problem areas and shown on the maps above (figure 4.28). Current soil stability risks have been considered together with the climate factors judged to be most significant to each soil movement. The climate index used is heavy rain > 25 mm a day, local 100-year flows, local runoff and seasonal precipitation during the summer. All included values, maps and climate indices have been weighted as equal with the exception of boulder clay landslide and mud flows, where the increase in heavy precipitation has been assigned three times the weight of the change in average precipitation. Ravine formation is also seen in steeper slopes where the soil stratum mostly comprise boulder clay. The development of these ravines is included in the assessments for boulder clay slopes.

The analysis is based on EA2. The assessments of the changed susceptibility to different soil movements due to climate change are shown in figure 4.29.

The chosen model is based on certain simplifications, such as a simple correlation between runoff, ground water replenishment and pore pressure. Topography is not considered. The natural environment in Sweden is marked by large variations in short distances. As such, the results can only be used for a general assessment of the consequences for the entire country or regions, not for local assessments. An analysis of such detail has not been possible within the scope of this report.

Figure 4.29 **Changed susceptibility to erosion, landslide, ravine formation and mud flows, 2071–2100 compared to 1961–1990 (RCAO/RCA3-EA2). From the left, erosion; landslide risks in clay and silt; ravine formation in clay, silt and sand; boulder clay landslide, mud flows and ravines in boulder clay slopes**



Key
Increase
No major change
Decrease

Source: Fallsvik et al, 2007.

Erosion is expected to increase mostly in southwestern and western Sweden and parts of central Norrland due to increased precipitation and increased high flows. Erosion is expected to remain unchanged in eastern central Sweden and parts of Norrland due to an extended and evenly distributed snow melt season, reduced spring flood and reduced high flows. L*andslide risk* is expected to increase in large parts of the country due to increased erosion and increased local flows with increased ground water levels and pore pressure. In some areas of eastern and northern Sweden the situation will be more or less unchanged. The reason is reduced erosion. Increased susceptibility to *ravine formation* is expected in parts of Svealand, western and southern Götaland and parts of central and northern Norrland due to increased precipitation and increased high flows. This leads to saturated soil stratum and erosion, as well as increased ground water formation and underground erosion. In parts of Norrland's coastal areas and Svealand the extent of problems will decrease or remain unchanged due to a reduced frequency of high flows. In the northern mountain regions, most of southern Norrland and northern Svealand susceptibility to *boulder clay landslide, mud flows and ravine formation in boulder clay slopes* will increase due to an increased frequency of heavy rain and increased precipitation during summer. The situation in Norrland's inland is expected to remain essentially unchanged. Overall, the maps show that certain areas risk being more exposed than others. The west coast, the river Klarälv and the central coast of Norrland are such areas.

Consequences and damage costs of climate change in developed areas

Changes in ground characteristics affect, for example, land development. The degree of vulnerability depends on how well society adapts to different changes, the extent to which they are considered in the physical planning and design of infrastructure and buildings.

Erosion along watercourses and lakes affects the natural environment and developed land. Erosion in watercourses also transports sediment, with the additional consequences of this action. Many landslides and land collapses begin with erosion. Ravines can form slowly due to underground water erosion or rapidly due to surface erosion and are often initiated by landslide. Ravines seldom threaten developed areas to any greater extent. Areas with high susceptibility to boulder clay landslide and mud flows are less populated. However, the sites where the soil masses accumulate often make interesting locations for development, at the base of slopes, near water and on firm ground. The risk of consequences of new flows is considerable in such places.

Landslides are the soil movements that can affect developed areas with the greatest consequences. Human lives are also at risk. However, we have not been able to calculate the extent of the danger to human life due to an increased risk of landslide. In order to get a general idea of how large a proportion of existing developments and which assets are threatened in the areas where susceptibility to landslide is expected to increase, a rough calculation has been made of the number of buildings and their value (see tables 4.17 and 4.18, appendix B 14). As the problem with landslide mostly occurs near water the calculations have been limited to a 100-metre wide zone adjacent to lakes, watercourses and seas. This still probably entails an overestimate of the problem as not all development within these areas will be threatened. Ground types are broken down as low, high and confined development, holiday homes and industrial premises respectively. Farmland and forestland are also included. The ground type survey is based on the National Land Survey of Sweden's GSD ground maps. The number of buildings per ground type is based on statistics from Statistics Sweden (Statistics Database, Statistics Sweden).

Table 4.17 Increased susceptibility to landslide 2071–2100 compared to 1961–1990, number of existing buildings within 100 metres of water (appendix B 14)

	Low development	Holiday homes	Low and confined development	Detached buildings	Industrial premises
Buildings (number)	36,800	25,000	1,900	151,600	3,600

Mostly low buildings, holiday homes and detached houses are found in the areas with increased susceptibility to landslide. Almost 40 percent are found in the counties of Stockholm and Västra Götaland. Forestlands and farmland etc. assessed to be exposed account for 6,910 and 759 km^2 respectively, mostly in Västra Götaland, Värmland and Västernorrland.

A rough calculation has been made of the values at threat. The cost estimate is based on the average plot size per local authority and building type and the average price per building type and local authority (Statistics Sweden, Statistics Database). Farmland has been valued at an average price per hectare and county. Forestland valuation is based on the taxable value with adjustments for market value and proximity to watercourses.

Table 4.18 Total value of existing development with increased susceptibility to landslide within 100 metres of water, 2071–2100 compared to 1961–1990, 2005 monetary values (SEK millions, appendix B 14)

Low and detached development	Holiday homes	Low and confined development	Industrial premises	Total
233,000	30,300	37,300	15,600	316,200

There is no data available to estimate the costs of increased susceptibility to erosion and ravine formation. Both phenomena can, however, be considered a landslide problem and can therefore be considered included in the cost of increased susceptibility to landslide in developed areas. No cost estimate has been made for boulder clay landslide due to a lack of data.

Threatened forestland and farmland values in 2005 monetary value comprise about SEK 14 billion and SEK 1.5 billion respectively. The cost of damages to water supply and sewage systems is estimated at about SEK 16 billion.

The calculations can be interpreted as a very rough estimate of the threatened capital. Not all of these values will be destroyed. Some areas will most likely be completely unaffected. Nor will entire buildings always be affected, but rather parts. Gradual adaptation will also take place through preventative measures and more. Threatened values within areas away from water are not included in the calculations. There may even be some overlap as regards threatened values in coastal areas due to beach erosion.

According to the Swedish Geotechnical Institute's statistics for the river Göta älv, at least 2 percent of the stretches susceptible to landslide (clay-rich areas) will suffer landslides in a 50-year time span (Swedish Geotechnical Institute, 2007). If this scenario should apply to the entire country, then 4 percent of the areas susceptible to landslide would suffer landslides during the next 100 years. According to the above calculations, this corresponds to property values of about SEK 12 billion plus water supply and sewage systems, forestland and farmland at a value in excess of SEK 1 billion.

Landslides comprised of polluted masses along watercourses affect the environment. Knowledge about the effects of different soil movements in a changed climate is currently insufficient and we lack a concise picture of how developed areas will be affected in different parts of the country (see also section 4.3.6).

Possible reinforcement measures in fine and coarse grained soils

There are different types of reinforcement methods to counter landslide a in fine grained soils. The methods and associated rough costs are as follows:

- Erosion protection along the sides of watercourses (SEK 400–450 per m^3).
- Ballast, excavation, levelling (SEK 200–500 per m^3).
- Reinforcement with lime cement supports (for example, SEK 25,000 per m for blocks about 2.0 m deep, 10 m wide and 15 m high).
- Lowering or limiting of ground water pressure (SEK 40,000 per well).
- Soil nailing (for example, SEK 1.3 million for an area of 1,300 m^2).

Developments on and at the base of long, steep slopes of coarse grained soil are protected using methods that take into account the terrain and local precipitation characteristics. Drainage systems to drain wet slope sections and lower the ground water table over time. Vegetation can be established to reduce the risk of landslide and mud flows. Dams can also be built. Methods to prevent ravine formation in coarse grained soils are:

- Erosion terraces (for example, SEK 1.35 million for six erosion terraces and protection of intermediate stretches, a total of 45 metres).

- Sedimentation dams (for example, SEK 5.3 million for a dam with a volume of 10,000 m^3).
- Watercourse channelling.

The different soil movements are natural processes in the geological cycle. When they threaten developed areas the consequences can lead to major costs and suffering. Table 4.19 shows the estimated damage costs and the costs of preventative measures from a study of three example areas. For each area landslides of three different magnitudes have been assessed, based on geotechnical surveys. The results show that the costs of strengthening are very low compared to the possible damage costs (Swedish National Rescue Services Agency, 1996).

Table 4.19 Calculated examples of damage costs and costs of reinforcement measures, 1996 monetary value (SEK millions, appendix B 14)

Area	Small extent	Most probable extent	Large extent	Reinforcement measures
Lilla Edet	34	209	1,401	9
Lidköping	66	616	489	4
Umeå	5	13	80	6

Adaptive measures against landslide and erosion together with considerations

According to the Swedish Planning and Building Act, the physical planning conducted by local authorities is the most important instrument in avoiding new development in areas under threat either today or in the future (see also section 5.5). A changed climate means changed geotechnical conditions, which means, for example, a need for safety margins to increase protection against ground fracture. Measures must be taken in relation to local geological conditions. It is important that the choice of reinforcement measure aims to counter the cause of the unsatisfactory stability, in other words, counter the problem and not the symptoms. New areas will fall under the threat of landslide in a changed climate. Subsequently, there is a need to increase knowledge about these phenomena in many local authorities. So it is important that the Swedish Association of Local Authorities spreads information about climate change and its effects as a basis for the safe localisation of development.

At present, the Swedish Geotechnical Institute is responsible for assisting the county administrative board and local authorities of Västra Götaland in their community planning process. The increased risks that changed soil stability entail for developed areas gives, in our opinion, good reason to expand the Swedish Geotechnical Institute's responsibility to encompass assisting county administrative boards and local authorities in other regions that are susceptible as regards soil stability in conjunction with the local authorities' general and detailed town planning. This also means cost increases of SEK 4.7–6.3 million a year (see also section 5.5). The Swedish Geotechnical Institute also ought to encourage the review of issues concerning environmental geotechnics in the plans, as the risks are expected to increase due to climate change. The costs are estimated at SEK 1.3–2.4 million a year. The costs are sourced from the Swedish Geotechnical Institute's action plan and are calculated for a period of three years. (Swedish Geotechnical Institute, 2006)

The Swedish National Rescue Services Agency is currently responsible for preparing stability surveys of developed areas exhibiting the prerequisites for landslide. Based on the described analysis of changed soil stability, we consider it important that these surveys are continued and broadened to even take into account climate change. The Swedish National Rescue Services Agency also examines the possible need to review the surveys already conducted with consideration for climate change (see also section 5.1).

It is important to conduct a more detailed analysis of geographic areas exhibiting the prerequisites for landslide in light of climate change. Such an analysis is valuable in the physical planning of developments and in potential development areas. The analysis ought to be continuation of the general maps of changed soil stability prepared for the report under the responsibility of the Swedish Geotechnical Institute (Fallsvik et al, 2007). This more detailed geographical information can initially be a part of the recommended national landslide database (see section 5.2) to limit and focus the scope of the map database.

The Swedish Geotechnical Institute, in cooperation with the Geological Survey of Sweden, the National Land Survey of Sweden and the Swedish National Rescue Services Agency, has previously presented a model of a general national map database of landslide conditions in clay and silt soils, as an aid to general planning. We consider it important that this general national map database of developed and undeveloped areas is created, and that it also take into account climate change (see also section 5.2).

Today, the Swedish Geotechnical Institute assists, for example, the local emergency services when a landslide has occurred or is anticipated. This type of action has increased in recent years and is expected to increase in the future due, for example, to erosion. We recommend that this work is intensified.

Knowledge of how geotechnical conditions are affected by climate change is very important and is of fundamental importance to many different infrastructure systems. The subject of climate change ought to be included in technical university and college education.

Research and development

The ground comprises a complex system of solid matter, gases and water. Its response to changed precipitation and temperatures are difficult to predict in detail. Considerations and assessments of risks and measures are needed concerning the interaction between developed areas and the ground. Greater knowledge of the changed conditions for erosion and landslide in a changed climate is fundamental. An important future task is to adapt existing development. Another is to adapt community development and design new structures.

Refined geotechnical and environmental geotechnical knowledge will be necessary as an aid to planning and construction. This concerns, for example, models of the dispersion of pollutants in the ground, knowledge about methods for mapping and preventing boulder clay landslide, studies of ravine formation, methods for surface mapping areas of quick clay, the evaluation of reinforcement methods and the development of risk-based models to aid decision-making.

It is important that existing and new knowledge is implemented, which requires close cooperation between parties. In interdisciplinary research coupling this directly to infrastructure projects proves effective.

Recommendations

- The directive for the Swedish Geotechnical Institute and the Geological Survey of Sweden must clearly state that each agency is assigned responsibility for adapting to climate change within its area of responsibility (see section 5.10.2).

Recommendations are also provided concerning a number of tasks, which are described in greater detail in the indicated sections:

- Section 5.1: Survey of risks of landslide in developed areas.
- Section 5.2: Map database of landslide conditions.
- Section 5.3: Emergency operations for landslide and erosion.
- Section 5.5: Physical planning and agency support in community planning.

4.3.3 Coastal erosion

Increased sea levels and stronger winds will entail considerably increased problems with beach erosion along the coast with consequences for developed areas and infrastructure. This can entail major losses of value. The country's southernmost coasts are most exposed.

Beach erosion

Many different coast formations are found along Sweden's 11,500 km of coastline. These can be divided into coasts with sand beaches, cliffs, river deltas and land elevation. Bedrock erosion is a very slow process. Subsequently, our analysis focuses on the erosion of soil overburden along the coastline, and mostly the erosion of sand beaches where changes involve faster processes.

Beach erosion is the process that leads to the loss of material, such as sand and gravel, from the beach and the seafloor in the beach area. Erosion and sedimentation are continual and natural landscape processes. Balance can be reached along and perpendicular to a beach through alternating erosion and accumulation. The natural balance can be disturbed by human activities, such as offshore constructions, shipping traffic, waterfront deforestation and more. Under certain circumstances more extensive erosion can take place, especially during storms.

Division of responsibility today

The Swedish Geotechnical Institute is tasked with participating in reducing geotechnical risks with a strong focus on people being able to live on safe ground. The Swedish Geotechnical Institute is tasked with coordinating beach erosion issues between different agencies, acting as liaison agency for agencies in the EU and the referral agency for county administrative boards and local authorities in preventative measures against beach erosion in physical planning and assisting environmental courts in permit issues.

The Geological Survey of Sweden's area of responsibility includes issues concerning the country's geological makeup. The Geological Survey of Sweden surveys and documents ground water conditions, and conducts marine geological surveys, which are important to mapping seabed matter dynamics, which in turn affect coastal erosion.

Coastal areas currently exposed to beach erosion

There are many places along Sweden's coastline with soils susceptible to erosion. This is especially prominent along large parts of the coasts of Skåne, Halland, Öland and Gotland. Beach erosion is most frequent along the south coast of Skåne, in particular in the town of Ystad where erosion was first documented at beginning of the 1800s. The most severe damage arises at high water with southwesterly winds when the shoreline has moved several dozen metres. The shoreline at Löderup has moved 150 metres inland over the past 30 years. According to the Swedish Geotechnical Institute's general survey, the necessary conditions for beach erosion exist along about 15 percent (about 1,800 km) of Sweden's coastline (Rydell et al, 2006). Values that may be in the risk zone are developments, infrastructure such as roads, railways, water supply and sewage systems, tourist facilities, valuable land, valuable natural environments and recreational areas (Rankka et al, 2005).

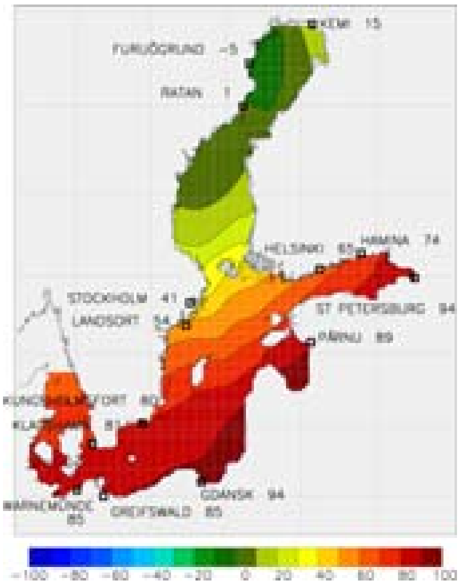
Factor affecting coastal erosion

Coastal erosion is most affected by the following conditions:

- Sea level relative to land elevation.
- Wave conditions – height, frequency, direction, extreme conditions.
- Wind and current conditions – direction, intensity.
- Geology/soil types on land and seabed.
- Topography and morphology – heights of dunes and areas behind the beach as well as the form of the shoreline.
- Bathymetry – seabed depth and gradient.

The first three items are directly related to climate and affect the latter items. According to the climate scenarios sea levels will increase as sea levels rise globally and thereby reach previously unaffected beach areas. The average sea level is expected to be the dominant factor, with a slow but continual effect throughout the year. Locally, very powerful waves combined with high water levels can have great impact. Whether current conditions promoting erosion will be reinforced by winds and storms due to climate change has not yet been fully resolved, however. According to the ECHAM, model the average wind will increase somewhat, as will squalls, while the Hadam model shows insignificant increases in the average wind. More powerful winds can lead to higher waves and hence greater erosive forces. Figure 4.30 shows the average sea level along Sweden's coast at the end of the century with a global rise in sea level of 88 cm, the high scenario described in section 3.5.4.

Figure 4.30 Average sea level 2071–2100 compared to 1903–1990 with a global rise in sea level of 88 cm (RCO-EA2)



Source: Meier et al, 2004, with permission from Inter Research.

Consequences of beach erosion along the coast in a changed climate together with damage costs

General Vulnerability Analysis for Flooding, Landslide and Erosion in Developed Areas in a Future Climate, appendix B 14, presents a very rough analysis of how large a proportion of coastal development may be exposed to erosion 2071–2100. The analysis is based on the Swedish Geotechnical Institute's general survey of coastal areas susceptible to erosion based on geological conditions (Rydell et al, 2006). The stretches presented in the survey cover the areas where the coast is mostly comprised of sand and silt. Based on a global rise in sea level of 88 cm, the country has been divided into three zones, with a rise in sea level of 80 cm in southern Sweden (up to Östergötland), 50 cm in the central region (up to Uppland) and 20 cm in the northern region.

Height information of sufficient precision is lacking for most of the Swedish coastline. Subsequently, the assessment of which seafront areas may be affected has been made using a model based on the correlation between the rise in sea level and the effect on beaches (Bruun, 1988). According to the model, a general estimate is that a 1 cm rise in sea level has an effect 1 metre inland. An addition has been made of about 25 percent to the width of the coastal strip assumed to be affected to allow for local effects such as storms. The zones that are assessed to be affected have widths of 100, 65 and 30 metres respectively moving from south to north. The global rise of 88 cm (the high scenario) has been chosen with consideration for the fact that developed areas comprise a system with a long lifetime, and that sea levels are expected to continue to rise even after this century (see section 3.5.4).

The affected area of each ground type and coastal town has been calculated using the National Land Survey of Sweden's GSD ground maps. Ground types are broken down as low and high development, holiday homes and industries, and farmland. The number of buildings per ground type is based on statistics from Statistics Sweden (Statistics Database, Statistics Sweden).

In total, more than 1,135 km^2 could be affected, of which low development comprises 222 km^2, holiday homes 84 km^2, high development 0.5 km^2, industry 62 km^2 and farmland etc. 767 km^2. Sixty percent of all land susceptible to erosion is found in Skåne. Forestland and other land are included in the land types, but have not been calculated or valued.

Table 4.20 presents the number of existing buildings which, according to the rough calculations, are threatened by erosion along the coast 2071–2100. Table 4.21 presents the total value of the threatened developed areas and farmlands. The cost calculation of the value of threatened development is based on the average plot size and price of each type of building in each town (Statistics Sweden, Statistics Database). Farmland has been valued at an average price per hectare and county. The calculations are for the period 2071–2100.

Table 4.20 Increased risk of beach erosion along the coast with a global rise in sea level of 88 cm 2071–2100, number of threatened existing buildings (appendix B 14)

Low development	Holiday homes	High development	Industrial premises	Total
116,900	32,400	100	3,500	152,900

Table 4.21 Total value of threatened existing development 2071–2100 and farmland, 2005 monetary value (SEK millions, appendix B 14)

Low development	Holiday homes	High development	Industrial premises	Farmland	Total
168,400	33,900	1,200	16,900	4,000	224,400

The value of development threatened by coastal erosion in Skåne, Halland, Blekinge and Stockholm counties represents about 75 percent of the total value at threat, with Skåne alone representing about 40 percent. Low development is most exposed. Threatened houses are estimated to comprise little more than 4 percent of total house holdings, corresponding to about 10 percent of its value. As well as damage to affected buildings, local infrastructure, such as roads, water supply and sewage systems, electricity cables and telephone lines, can also suffer damage. Appendix B 14 estimates damage costs for water supply and sewage system connections to buildings due to beach erosion at roughly SEK 10.7 billion.

In all likelihood, not all of these values will be destroyed. The lack of elevation data of sufficient precision has meant that a simplified model has been used to calculate the breadth of effected beach. This means that the calculations of the number of exposed buildings and the total value of these buildings are uncertain. Some areas will most likely be completely unthreatened. Nor will entire buildings always be affected, but rather parts. Gradual adaptation will also take place through preventative measures etc. to reduce the risk of erosion.

An analysis from Ystad town shows the consequences and the values that may be lost due to beach erosion with a rise in sea level of 0.5 metre within 100 years if no measures are taken. This would entail the shoreline moving an average of 100 metres inland, with 415,000 m^2 of the beach zone being lost. The total loss is estimated at SEK 488 million in 2005 monetary value. The calculations do not include tourism, which would be greatly affected, as it would be possible to build a new beach area further inland.

In addition to bathing beaches, camp sites could also be affected along sections of the coast, with lost income and costs as a result, and a risk of the loss of valuable natural environments. Many nature areas, such as waterfront meadows, have limited breadths and border on roads and development. If such areas are eroded away, the developed areas risk erosion and flooding.

Possible measures to protect coastal areas and the costs of such measures

There are different measures to limit and prevent erosion and possible flooding of coastal areas. The purpose of coast/erosion protection is to:

- Provide a barrier between the water and the beach matter susceptible to erosion.
- Reduce the energy of waves and currents.
- Control watercourses and sediment flows to achieve the desired transport and sedimentation.
- Prevent water from flooding developed and other areas.

Different types of coast protection exist. The type of protection chosen depends on technical and environmental factors, local conditions such as topography, water depth and wave climate, and economic factors. Several types are often combined. The effectiveness of different types of protection has not yet been established. Examples of protection and costs follow:

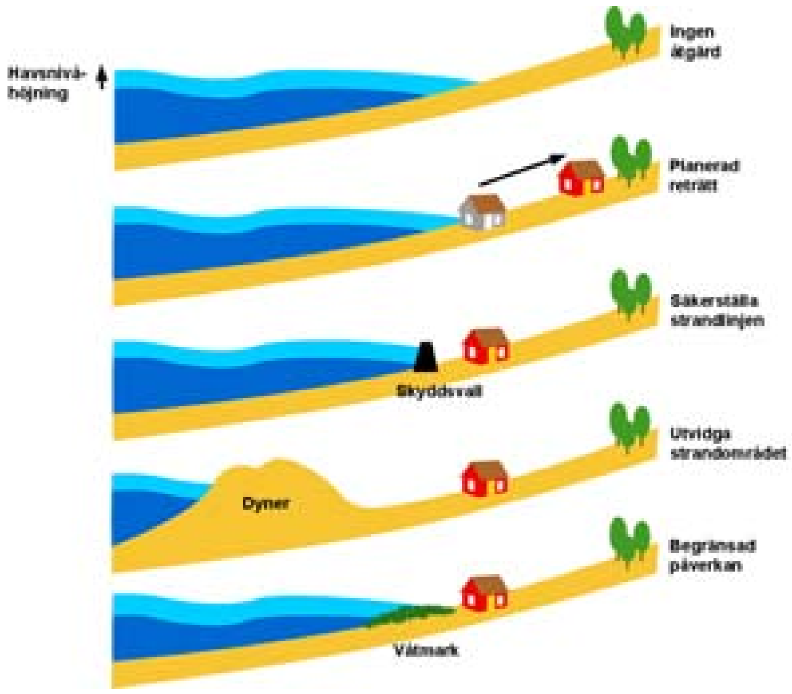
- Revetment, sheet piling, quay structures (SEK 800–1,200 per m^2).
- Sand ballast (SEK 40–100 per m^3).
- Breakwaters (example from Ystad SEK 1.25 million, length 50 metres, height 3 metres).
- Groins (simple SEK 10,000–20,000 per metre, jetty SEK 30,000–40,000 per metre).
- Reinforcement of natural coast protection, dunes or bays between headlands (depends on local conditions).
- Vegetation (reinforced dykes with plants, SEK 200 per m^2).
- Beach drainage (200 metres plus pumping station SEK 1.5 millions).
- Fins on seabed (not yet fully developed).

The Swedish Geotechnical Institute has made a rough estimate of the length of coast that needs protection against erosion (Rydell, 2007). This calculation assumes coast protection comprises sand ballast combined with revetment and stone slope protection. According to the National Land Survey of Sweden's land register index map, about 220 km of the coastline susceptible to erosion is developed, corresponding to about 12 percent of the total stretch susceptible to erosion. This is in good agreement with a comparison with known erosion areas in Ystad, where about 15 percent of the parts of the town susceptible to erosion are developed. The installation costs for sand ballast and revetment have been estimated at about SEK 15,000–20,000 per metre of coastline in the calculations. Sand ballast requires maintenance about every five years and revetment every 30 years. The investment cost for protection along a stretch of 180–270 km, corresponding to 10–15 percent of the stretches susceptible to erosion, are estimated at SEK 2,700–5,400 million, assuming the conditions described above. This ought to be considered in relation to the rough estimates of the threatened values, which amount to SEK 224 billion according to the above.

Adaptive measures against coastal beach erosion together with considerations

Coastal erosion must be viewed in a wider perspective based on the interests of society. The point of departure ought to be that nature has its way in areas where there are no private or public interests or values at threat. Through planning processes the local authority is responsible for localising development to land suited to the purpose. If values of importance are threatened, such as development, infrastructure and other areas worthy of protection, measures may be appropriate (see also section 5.6). Figure 4.31 presents the different strategies for protecting beaches against erosion.

Figure 4.31 Strategies for protecting coastal areas



↑Rise in sea level
No measure
Planned retreat
Secure shoreline
Expand beach area
Limited impact
Safety dyke
Dunes
Wetland

Source: Appendix B 14.

Physical planning must take into account climate change. Local authority physical planning is one of the most important instruments for avoiding new developments in areas at risk from, among other things, coastal erosion. According to the Swedish Planning and Building Act, development shall be localised to land suited to the purpose. A sustainable society requires land use with a long-term perspective. Development – buildings and infrastructure – has a long lifetime, which means erosion risks must be assessed with a very long-term view. When planning new structures in the sea, it is equally important to take into account any possible consequences they may have on areas susceptible to erosion. Local authority planning work must therefore consider the risk of future coastal erosion to a greater extent than at present. See also section 5.5.

In order to aid physical planning, the county administrative board's responsibility to provide data to local authorities for their planning ought to be broadened and clarified (see also section 5.5). The Swedish Geotechnical Institute ought to be tasked with assisting county administrative boards and local authorities in their community planning process.

The Swedish Geotechnical Institute has conducted a general national survey of coastal areas susceptible to beach erosion, which provided the basis for the above analysis. It is our opinion that this ought to be followed by a survey of the risks of beach erosion in developed areas and can provide a basis for more detailed studies and the need for reinforcement measures (see also section 5.1). Climate change must be taken into account. Areas of great natural or recreational value can also be important to protect, but are of secondary importance.

Surveys require elevation information of adequate precision. Such data is currently lacking for the Swedish coastline. There is a need for a national elevation database with more accurate elevation data of greater density than the current elevation database. The National Land Survey of Sweden ought to be tasked with developing such a database (see section 5.2). There is also a lack of general bathymetric data and data on changes to the seabed as a result of erosion and accumulation of significance to coastal processes. The Swedish Maritime Administration ought to be tasked with collating and making available bathymetric map data of the Swedish seacoast (see also section 5.2).

It is our opinion that the compensation system for preventative measures in the event of natural disasters should also include beach erosion. Erosion has thus far been interpreted as a natural disaster with a slow course of events, even though it can eventually lead to rapid events with major losses of land or development. Climate change with rising sea levels, higher winds and possibly changed currents can lead to the risk of threatened values increasing (see also section 5.6).

Research and development

There is a continual need for increased knowledge about and experience of coastal erosion and the effects of protective measures. The MESSINA project, in which the Swedish Geotechnical Institute and the Erosion Damage Centre have participated, aims to gather and share experiences of how beaches can be protected. The work has been done in cooperation with government agencies, local authorities, universities and those putting theory into practice at local and regional levels in different European countries. We consider it important that this type of knowledge sharing and feedback between different players and countries is encouraged.

It is uncertain how different offshore structures affect the incidence and development of currents and accompanying erosion and accumulation, as regards both erosion protection and other offshore structures. It is our opinion that continued research is needed to increase knowledge of the effects of different measures on current formation, sediment movement etc.

Recommendations

Recommendations are submitted concerning a number of tasks and are described in greater detail in the indicated sections:

- Section 5.1: Survey of risk of erosion in developed areas.
- Section 5.2: Elevation database.
- Section 5.2: Bathymetric map data.
- Section 5.5: Physical planning.
- Section 5.5: Agency support in community planning processes.
- Section 5.6: Compensation system for preventative measures.

4.3.4 Storm water systems and waste water overflow

The waste water systems will be heavily burdened in a changed climate due to increased rainfall and a redistribution of rain to autumn, winter and spring when evaporation rates are low and the ground saturated. Extreme heavy downpours will overload conduits.

The risk of backflows with flooded basements as a result will increase, as will overflowing waste water and the accompanying health risks.

Division of responsibility

Responsibility for public sewage systems falls to the local water supply and sewage system principal and encompasses conduits in a delimited area of operations up to the point of connection to consumers. Responsibility after the connection point falls to the property owner. The local authority is required by the Swedish Planning and Building Act to use its general community planning as a means to prevent flooding. The principal responsible for water supply and sewage systems may be liable for flood damage in the case of penetration via public sewage pipes depending on the particular circumstances. The new law on public water services extended liability to even encompass flooding from surface water running from open storm water facilities that are part of the public water supply and sewage system. The law requires that the flood damage arises in a relation between the principal responsible for the water supply and sewage system and the consumer/fee-paying party.

The sewage network today

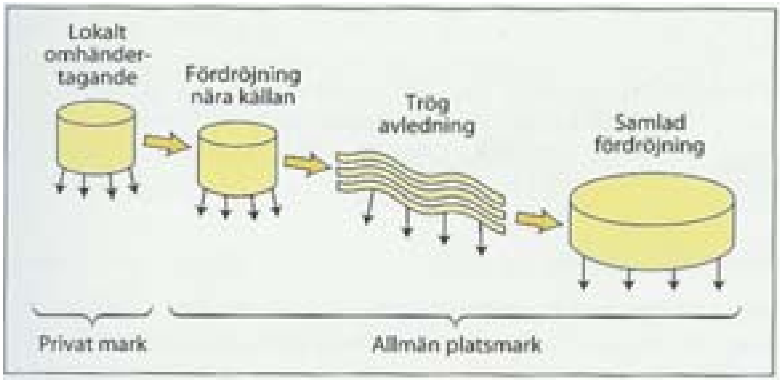
The sewage network comprises waste water pipes and storm water pipes. In principle there are three types of sewage network system. A combined system that discharges waste, storm and drainage water in a single pipe. This system includes spillways to protect low-lying development during heavy rainfall. Duplicate systems discharge waste and storm water in separate pipes. Drainage water can be discharged to either of these. A separate system discharges waste water in a separate pipe. Storm water is handled locally or by ditches and drainage water is discharged in a separate pipe or together with other water. The separate system can be considered a precursor to that which is now known as *long-term sustainable storm water management* and was first used in residential areas at the beginning of the 1900s.

The expansion of the sewage system started in larger towns at the end of the 1800s. This expansion increased dramatically from the 1950s onwards along with other community development, but also due to a transition from a combined to a duplicate system. The network has a pipe length in excess of 100,000 km, of which 90 percent stems from after the 1950s, with half being installed in the 1970s. The storm water pipes comprise 35 percent, the waste water pipes 57 percent and the combined pipes 8 percent. A third of local authorities have sewage networks partly comprised of combined systems, most often located in the central and older parts of towns. Then there are the service pipes, which total about 20–30,000 km. The average degree of dilution of waste water in sewage works due to other water is currently 200 percent, that is, the proportion of other water is equal to the proportion of waste water.

Pipeline lifetimes vary. If defects arise, even newer pipes may require measures while other sewage pipes can work ceaselessly for more than 100 years, all depending on ground conditions, installation methods and quality. This is why in many cases parts of a sewage system and not the entire system are replaced. The rate of renewal of waste water and storm water pipes is currently lower than one percent per year.

Over the past 10–20 years a change of system has been underway as regards storm water management. The aim is to reduce the discharged water flows, retain the ground water balance in developed areas, make areas durable against heavy precipitation and reduce the pollutant load on the receiving body of water (see figure 4.32).

Figure 4.32 Long-term sustainable storm water management



Local management
Retardation near source
Slow discharge
Collective retardation
Private land Public land

Source: The Effects of Climate Change on Public Sewage Systems – Problem Description, Costs and Recommended Measures, appendix B 16.

Vulnerabilities of current system and past extreme events

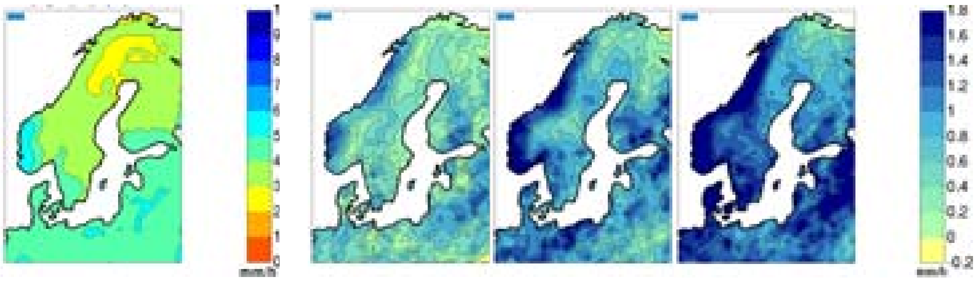
Combined systems entail a flood risk for low-lying basements with a risk of backflow in the event of an overburdened system. A combined system has spillways to protect low-lying buildings. In the event of very heavy precipitation, drainage from garage ramps to waste or combined water pipes can cause basement flooding, due to the flows being directed down towards the ramp but not being discharged to a sufficient extent. The situation can be made worse if the sewage pipe is overburdened and a backflow occurs. Low-lying drainage systems connected to the storm water systems of buildings with basements can also be burdened by backflowing storm water, which places demands on basement walls able to withstand temporary backwaters. Of all flood damage reported to insurance companies about 75–80 percent concerns flooding in conjunction with the backflow of water via the waste water system.

Extreme heavy downpours can cause damage of at least the same scale as flooding in conjunction with high water levels in watercourses and lakes. Major flooding due to heavy downpours occurred in 2002 and 2003 on the island of Orust and in Kalmar resulting in costs of SEK 123 million and SEK 63 million respectively. The number of basement floods 2003–2005 reported to the Swedish Water & Wastewater Association and extrapolated to apply to the entire country amount to a combined total of 5,700 for this period, one of which, an extreme event, the heavy downpour in Kalmar in 2003, was responsible for 600 of these reports. (Swedish Water & Wastewater Association VASS; appendix B 16).

Consequences of heavy precipitation and high water levels together with damage costs

Transient precipitation is of great significance to the sewage system as heavy rain showers mean increased volumes to discharge with flood and overflow risks. The models used in the climate scenarios have grids representing 2,500 km^2 each. The time interval for the calculations is 30 minutes. Flooding of the sewage system can, however, occur as a result of more local downpours and in shorter times. The assessments in appendix B 16 are therefore based on current precipitation patterns and take into account the changes in precipitation predicted by the climate scenarios. These show that precipitation amounts, frequencies and intensities will increase, meaning worse flooding. Figure 4.33 shows the annual change in precipitation intensity in a changed climate.

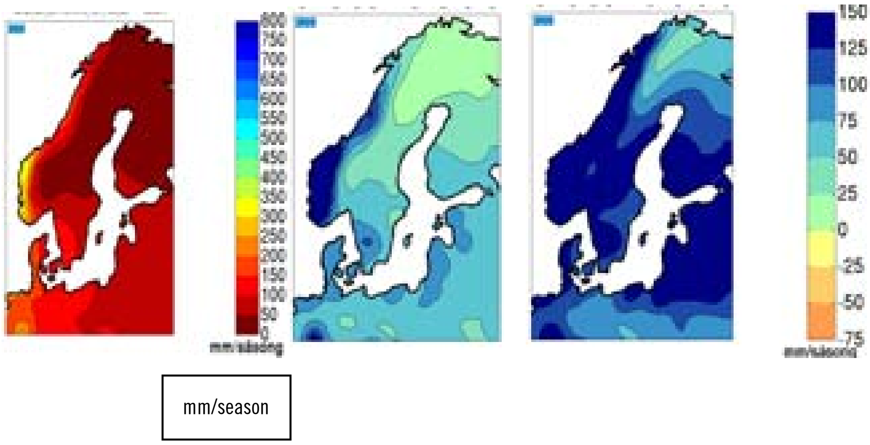
Figure 4.33 **Intensity of the heaviest rainfall, mm/h and year, for the periods 2011–2040, 2041–2070, 2071–2100 compared to 1961–1990 (RCA3- EA2)**



Source: SMHI, 2007.

Total annual precipitation will increase while summer precipitation will fall in the southern and central parts of the country. This redistribution of rain to autumn, winter and spring with low evaporation and saturated ground means increased flows of other water into the sewage systems, which will place increasing demands on the entire system. Figure 4.34 shows the change in winter precipitation in the form of rain.

Figure 4.34 Change in rainfall, Dec-Jan, 2011–2040 and 2071–2100 compared to 1961–1990 (RCA3-EA2)

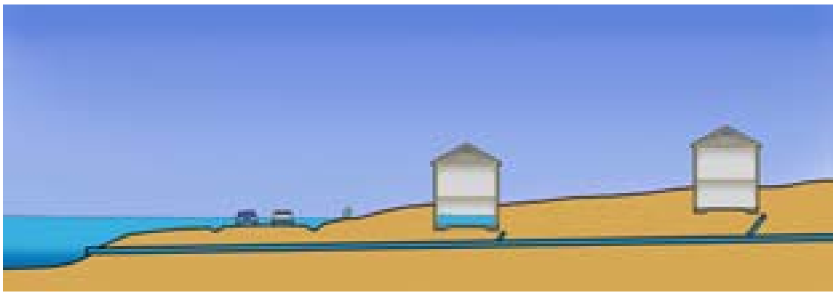


Source: SMHI, 2007.

Emissions scenario B 2 exhibits the same pattern, but with slightly less rainfall. The areas currently with critical status will continue to be so and the spread of flooding will increase. New critical areas may arise.

Even high water levels at sea, in watercourses and in lakes can increase the volume of other water due to increased drainage. Average runoff is expected to increase in most of the country and the 100-year flow will increase mostly in western Götaland and western Svealand, but also in some mountain regions and in northeastern Götaland. Increased sea levels mostly affect the southern parts of the country, where land elevation is non-existent or low. The discharge of storm water is complicated if the receiving body of water is backed up further down the system. Storm water pipes with outlets under the water table are exposed to an increase in water level through the risk of backflow. There is also a risk of backflow in spillways and emergency overflows. Figure 4.35 shows high levels in the receiving body of water and the accompanying backwater. Appendix B 16 presents examples from the towns of Malmö and Gothenburg as regards physical planning with consideration for water supply and sewage systems and flood risks.

Figure 4.35 **Very high water levels with backed up service pipes and flooded basements**



Source: Appendix B 16.

It is difficult to estimate future damage costs resulting from heavier transient precipitation as the climate scenarios do not have the resolution for the runoff from paved surfaces that is decisive in this matter. In order to get an idea of the magnitude of the damage costs the estimate is based on the current situation. The damage costs are based on previous floods in Malmö and Gothenburg in the years 2003–2005 with a cost interval of SEK 15,000–50,000 per building (see table 4.22). The figures are probably somewhat overestimated, as even flooding due to blockages in sewage pipes are included, which need not be related to heavy precipitation.

Table 4.22 **Estimated annual cost of basement floods, 2003–2005 (SEK millions; appendix B 16)**

Year	Estimated number of floods	Total cost (SEK 15,000/building)	Total cost (SEK 50,000/building)
2005	1,600	24	80
2004	1,700	26	85
2003	2,400	36	120

Sewage system overflow

High flows in conjunction with heavy precipitation can occasionally lead to conduit capacity being exceeded in combined systems with the excess flow, diluted with rainwater but untreated, discharging into the receiving body of water via spillways. Sewage works can also suffer overflows when inflows exceed capacity. In such cases, the water is usually discharged to the receiving body of water after the primary treatment step. The principle for overflow, in piping as well as at sewage works, is to discharge the sewage to the receiving body of water via a waste weir.

Emergency discharging, such as in conjunction with pump failure in pumping stations, involves the discharge of untreated waste water. Such discharges spread microbiological content in higher concentrations than in the event of overflows from combined systems, where the sewage is diluted with storm water. In Sweden there are currently no microbiological requirements on the waste water reaching a receiving body of water, even if there are certain requirements on registering, for example, the volume at overflow points.

Local authority sewage works are often low-lying, as the aim is to take advantage of gravity in water flows as far as possible. As a result, facilities are often susceptible to flooding.

Increased precipitation in a changed climate, and mostly increased frequency of heavy downpours, can lead to more frequent and more widespread overflow discharges. This can lead to increased microbiological burdens with accompanying health risks from raw water (see section 4.3.6). Various studies have shown a correlation between heavy precipitation and waterborne disease outbreaks. Outbreak statistics from the USA for the period 1948 to 1994 show that 51 percent of waterborne disease outbreaks were preceded by incidences of heavy rain (see also section 4.6). (Åström et al, 2007).

Adaptive measures against increased water levels and heavy precipitation, costs and considerations

Requirements on elevations and restrictions on water and sewage levels are not always given the necessary attention to ensure safe constructions. In a climate with increased and heavier precipitation and higher water levels, sewage management must be established to a greater extent than at present in the local authority planning process. The planning process must be seen as a whole and safety issues must be emphasised early to illuminate their interaction with other possible measures outside the Swedish Planning and Building Act. There is also a need for a clearer division of responsibility for different types of flooding.

The surest way to avoid problems in future developed areas near watercourses, lakes and the sea is to apply far-sighted planning to ensure safe elevations in relation to surrounding bodies of water. This planning must take into account climate change in a long-term perspective and with the uncertainty that applies (see section 4.3.1 and section 5.5 on the flooding of waterfront development and physical planning). In *The First Step Towards Simpler Planning and Building Legislation* bill (2006/07:122) the government has made clear in the key regulations that development shall be localised to land suited to the purpose with consideration for the health of the inhabitants and others, personal safety, and the risk of accidents, flooding and erosion.

The Swedish National Board of Housing, Building and Planning ought to prepare general guidelines for planning, localising and determining the elevation of buildings including water supply and sewage systems with consideration for flooding, land collapse, landslide and erosion as an aid for local authorities and county administrative boards. The Swedish National Board of Housing, Building and Planning also ought to prepare general guidelines for planning and ensuring measures to protect existing development against the above-mentioned natural disasters as well as water penetration from sewage systems (see also section 5.5).

Existing storm water conduits are designed to cope with today's *normal* rain. Precipitation in a changed climate is expected to increase, in frequency and intensity as well as quantity. Extreme heavy downpours can temporarily overload conduits. There will be a need to secure the storm water systems, so that existing development is not flooded by backflows from receiving bodies of water under, for example, erected flood banks. By fitting conduits with non-return valves or pumps, buildings can be protected against backflow from storm water conduits.

A reasonable aim is to reduce, as far as possible, the amount of storm water that needs to be discharged through the sewage system. Local storm water management with elements of open solutions and well-considered elevations throughout the developed area minimises the risk of flooding. If conduits are overloaded, the flows must be directed to non-sensitive areas or discharged above ground in a safe manner, such as to a compensation basin, complementary canals, ditches etc. Other technical measures are the construction of alternative storm water conduits for peak flows and increased conduit capacity. Technical measures will also need to be taken against high water, such as damming and storm and drainage water pumping. (Swedish Water & Wastewater Association, 2004)

We assess the risk as large that flooding will increase in existing sewage systems due to increased heavy precipitation if no measures are taken. The current rate of piping renewal is about 0.4 percent a year and this is expected to gradually increase during the next few decades, levelling out in 25–50 years. Appendix B 16 includes an estimate of current renewal costs, the expected gradually increasing renewal over 25 years and additional investments in *hydraulically critical areas* corresponding to 10–15 percent of the sewage system. The costs also take into account overlap in renewal (see table 4.23).

Table 4.23 Adaptation cost for the sewage system over the next 25 years, current monetary value (SEK millions, appendix B 16)

Normal renewal	Gradually increasing renewal	Critical areas (some overlap with renewal)	Critical areas (no overlap with renewal)
25	25	24–36	10–20

According to table 4.23, the cost of adapting the public sewage system to climate change with consideration for greatly increased precipitation means an increase of SEK 10-20 billion in addition to the *normal and gradually increasing renewal* of SEK 50 billion. We deem it important that the rate of renewal be increased.

Adaptation to a future climate must be based on a holistic perspective that encompasses private as well as public piping if the measures taken are to prove as effective as possible. There is no assessment of how private water supply and sewage installations will be affected by the future climate. There is a great need to examine how renewal of private water supply and sewage piping should be implemented to take into account climate change. A rough estimate, according to appendix B 16, is that the cost of renewal of private water supply and sewage installations (service pipes) ought to total about 40 percent of the public costs, making an additional renewal cost of SEK 4–8 billion over a 25–year period. The issues that need to be addressed are how to coordinate adaptation of the public and private systems and which party is to be the driving force for climate adaptation on private land.

We recommend that the Swedish Water & Wastewater Association continues its work to support the industry with recommendations and knowledge on flood-safe constructions in today's and tomorrow's climate.

The subject of climate change and its effects should be included in education on technical infrastructure. Important areas include the physical planning of development and infrastructure and the design of water supply and sewage systems.

Research and development

There is a need for high-resolution rain series for different urban areas in Sweden for the design of water supply and sewage systems, such as with a duration of ten minutes to two hours and a range of about one km^2. See also sections 5.2 and 5.9. The water supply and sewage industry conducts a number of different projects on precipitation and runoff in urban areas and the consequences for system design. It is important that these projects are run in close cooperation with and with more involvement from SMHI.

There is also a need for research on how to plan renewal work to make the renewal of the water supply and sewage system as cost-effective as possible, with consideration for climate change. This research ought to be conducted in close cooperation with the trade association (Swedish Water & Wastewater Association), its members and technical universities.

Recommendations

Recommendations are provided concerning the following, which are described in greater detail in the indicated sections:

- Section 5.5: Physical planning.
- Section 5.10: Division of responsibility.

4.3.5 Building structures

Climate change can seriously impact existing and future building structures. Increased precipitation means increased risk of damage due to damp and mould, overflowing sewage systems and flooded basements. Outdoor maintenance needs will increase. The increased temperature will lead to reduced heating needs, but increased cooling needs.

Division of responsibility

The Swedish National Board of Housing, Building and Planning is the state agency responsible for issues concerning community planning, town and land development, building and administration, as well as housing issues. The Swedish National Board of Housing, Building and Planning prepares, for example, regulations for new buildings and monitors the development of physical planning and suggests changes to planning legislation.

A description of property holdings and current vulnerabilities

There are about 3.1 million buildings in Sweden of different types and various ages. One way of classifying buildings is to break them down into flats and business premises, houses and holiday homes and industrial premises. For background material to this section, see *Buildings in a Changed Climate*, appendix B 17.

In the period 1996–2005, Sweden's population increased by 169,000 citizens. Parallel to this, 97 percent of new residential buildings were built in the coastal zone, the strip reaching 5 kilometres inland from the seashore (Swedish National Board of Housing, Building and Planning, 2006). Almost 1 million of the country's 3.1 million buildings are located in the coastal zone. Development localisation is presented in section 4.3.1.

Flats and business premises: Sweden has about 125,000 buildings housing rented flats and other commercial premises (Statistics Sweden, 2005). In addition to this, there are about another 87,000 specialised buildings for purposes such as distribution, healthcare, education, swimming, sports and athletics, culture, communications and public services. The total area of flats is about 157 million m^2 and of business premises about 166 million m^2. Flats are often made from concrete structures with plaster or brick facades. Other common facade materials are wood, mostly on buildings from the 1980s and 90s, and sheet-metal, on buildings from the 1960s and 70s. Sand-lime brick and asbestos cement are less common. Modern buildings increasingly incorporate large glazed areas. The most common roofing material is clay tiles or concrete shingles. Sheet metal and felt materials are used to a lesser extent.

Houses and holiday homes: The number of houses including farm buildings and holiday homes is about 2.6 million. These buildings often have wooden structures. The facades are also often made from wood. Bricks were used mostly in the 1960s and 70s and plaster in the 1940s and 50s. Sand-lime brick is also seen. The most common roofing solution is concrete shingles, followed by, in order, clay tiles, felt, sheet steel, sheet aluminium and asbestos cement. Foundations most commonly comprise basements (60 percent), followed by crawl space (20 percent) or concrete slab (20 percent). Concrete slabs have increased since the 1970s.

Industrial buildings: About 150,000 industrial properties, of which some 50,000 plus are developed. Industrial buildings are often steel or concrete pillared structures. Load-bearing walls are also common in buildings erected before the 1960s. Roofing materials are dominated by felt, though corrugated metal is also common. Brick facades are common in buildings erected before the 1960s. From 1980 onwards a number of facade constructions were used, such as light element or steel stud framed walls.

The consequences of climate change and extreme weather events

The analysis in appendix B 17 is based mainly on the RCA3-EA2 climate scenario and the 2071–2100 time span. It focuses on how different climate factors may affect the climate shells (outer walls, windows, doors, roofs and foundations) of buildings. The differences between the scenarios have been taken into account. Table 4.24 presents the climate factors of most importance to building structures and a brief description of their effects.

Table 4.24 Different climate factors and their general effect on buildings (appendix B 17)

Climate change	Effect
Snow load	Maximum snow load measured as water content will generally decrease. The climate scenarios present isolated high extreme values in southern Sweden. This indicates a need for further research on that particular factor.*
Precipitation	Increased precipitation increases the risk of flooding in sewage systems and basements, the risk of landslide (see sections 4.3.1, 4.3.2, 4.3.3) and wear on exteriors.
Driving rain (horizontal precipitation)	Increased frequency of heavy rain and driving rain increase the risk of damage due to damp and rot and possibly frost erosion of building materials.
Temperature increase	Increased temperature cuts heating needs by 10-40 percent, depending on the part of the country, and increases cooling needs (see section 4.2.3). A temperature increase can lead to serious health consequences if measures are not taken (see section 4.6).
Zero crossings	The number of zero crossings will increase in northern Sweden December-February and decrease in the rest of the country. Overall, this means less wear, as most buildings are in southern Sweden.
Higher humidity	Humidity will increase in the north all year round, while it will drop in the south during summer. This means an increased risk of damage due to moisture and corrosion, increased frost erosion in plastered facades in the north and faster degradation of exterior materials.
Higher humidity and higher temperatures	This combination increases the risk of mould, rot (rot impairs the strength of wood) and insect attacks.
Extreme wind loads	A possible increase in extreme winds means increased incidences of storm damage**. Air movements inside buildings are affected, which increases heating needs.

Source: Appendix 17.

*The maximum snow load is used to determine building design requirements. Greater certainty is required as regards future changes to the climate factors snowfall and snow water content as a basis for revising building requirements. An increase in maximum snow load would require reinforced roof beams and maintenance.

**According to information from insurance company Länsförsäkringar, the company's costs for storm damage to buildings amounted to almost SEK 1.3 billion in the period 1999—2006.

Consequences for roofs, facades, windows and foundations

Roofing material: Shallow-angled, flat felted roofs are common on houses, business premises and industrial buildings. The durability of felt is temperature-dependent and strong sunlight and cold and ice increase wear. Higher temperatures can shorten its lifetime by 10 percent (from 20 to 18 years). Increased wind loads can be expected to increase damage to sheet metal and roofing tiles. Metal shingles are sensitive to temperature fluctuations.

Facade material: Wear on the paint of a wooden facade depends on exposure to the sun's ultraviolet radiation and high temperatures. Clear differences in maintenance intervals can be seen between north and south-facing facades. Increased solar radiation and precipitation may mean maintenance (repainting), on average, every nine years and not, as is currently the case, ten years. Undamaged brick facades are very durable and are not normally affected by temperature fluctuations. However, runoff from roofs must be effective if the tiles are to last as intended. Plaster cannot withstand constant damp so good roof drainage is important. An increase in the frequency of extreme rain and direct driving rain can lead to an increased incidence of frost erosion. If facade plaster cracks, it loses its function with a risk of damage to underlying structures.

Windows: Wood-framed windows may need more regular maintenance. A possible increase in condensation may mean faster degradation with repainting every six years instead of every seven.

Foundations: If periods of increased humidity are extended, the risk of damage related to crawlspace foundations will increase. There is also a risk of an increased number of flooded basements due to higher water levels at sea, in lakes and in watercourses, as well as increased extreme precipitation (see sections 4.3.1 and 4.3.4).

Consequences of climate change on buildings of cultural interest

Buildings of cultural interest can also suffer the same problems as other buildings due to climate change. A warmer, more humid climate can entail more widespread problems with mould and rot than at present. Even indoors, not least in buildings that are completely, or partially, unheated, such as churches and castles, and their contents can be affected. The fact that many older buildings have survived thus far shows some robustness to climate change. A changed climate can, however, lead to faster degradation of buildings of cultural interest, unless maintenance measures are put into place in time. Maintenance costs, which are already high for these buildings, will most likely increase in a changed climate. Even different types of adaptive and protective measures, such as retaining dykes, can have tangible effects on environments of cultural interest.

Adaptive measures, costs and considerations

The analysis shows that buildings' climate shells will be affected by climate change, mostly in the negative. Appendix B 17 provides a number of suggestions for adaptive measures, which need to be carried out in order to minimise damage costs. We consider it important to take such measures. We consider it important that the Swedish National Board of Housing, Building and Planning be tasked with reviewing its building regulations and alterations advice and adapting them to climate change.

Generally speaking, in a future climate it will be important that structural engineers use building materials that require a minimum of maintenance. It may even be necessary to use new materials. Maintenance measures are generally expected to increase.

Drainage and sewage systems are designed for an certain amount of precipitation. Existing storm water conduits are designed to cope with today’s “normal” rain. Precipitation is generally expected to increase, in frequency and intensity, as well as quantity. Extreme heavy downpours can temporarily overload conduits. By fitting conduits with non-return valves or pumps, buildings can be protected against backflow from storm water conduits, which can cause damage. Drainage and sewage systems must also be regularly cleaned and inspected to avoid blockages in the event of high water flows (see also section 4.3.4).

In order to reduce damage due to damp, vapour barriers ought to be better prioritised in new buildings, renovation work and extensions. The moisture ratio ought to be checked more regularly than at present during building work.

There is a risk of increased damage due to mould. This can be countered by heating building foundations with indoor air or fan heaters.

To counter a general increase in cooling needs in a warmer climate, sun blinds should be used to a greater extent.

A possible rise in the maximum wind gust and wind load may require some preventative reinforcement, such as more secure rafters, roofing tiles, sheet metal and ridges in building work.

In general, snow water content and snow pack extent will decrease. Snowfall will decrease in southern Sweden, but increase somewhat in northern Sweden in the short term and later decline. The climate scenarios exhibit isolated extreme values of maximum water content of snow within limited geographic areas of southern

Sweden. Roof structures are designed for a maximum snow load and heavier loads may require reinforced roof beams or active systems. We consider there to be a need for additional research on these snow factors to establish the possible need for changes to maximum snow load requirements for new buildings. Active systems for snow loads include, for example, warning systems for sagging roof beams. Advice and information on how the degree of compaction and warning signals should be interpreted are other measures.

Maintenance costs for roofs and facades are expected to increase in southern Sweden and decrease in the north. Table 4.25 below shows the present value of increased maintenance costs caused by climate change in different future time spans.

Table 4.25 Present value of increased maintenance costs for roofs and facades for the time spans 2011–2040, 2041–2070, 2071–2100, SEK millions (appendix B 17)

Time span	Felt roofs	Brick and plaster facades	Wood facades	Repainting windows	Total
2011-2040	0	0	1,000	1,000	2,000
2041-2070	4,000	1,000	4,000	6,000	15,000
2071-2100	7,000	2,000	8,000	8,000	25,000

Source: Appendix 17.

Knowledge about climate change and its effects on building structures and heating and cooling needs must be increased. We consider it important that the subject of climate change is included in basic technical university and college education.

Research and development

There is a need for continued research on extreme snow loads and their water content and changes in solar incident radiation in a changed climate.

Recommendations

- The directive for the Swedish National Board of Housing, Building and Planning and the Swedish National Heritage Board must clearly state that each agency is assigned responsibility for adapting to climate change within its area of responsibility (see section 5.10.2).
- The Swedish National Board of Housing, Building and Planning ought to be tasked with reviewing its building regulations and alterations advice and adapting them to climate change.

4.3.6 Pollutant dispersion in flooding and landslide

The increased risk of flooding, and especially of landslide, means that chemical substances and contagions can be spread from contaminated land and disused depositories. Subsequently, there is an increased risk of the pollution of, primarily, local water sources and pastures.

Climate change increases the risk of pollutant dispersion

The scenarios we have worked with indicate increased precipitation in most of Sweden. There will be more precipitation days and heavier rain. Precipitation will increase in the autumn, winter and spring. During these seasons, downpours will be heavier, but not more so than can be expected due to the average change in precipitation. During the summer, on the other hand, precipitation is expected to be heavier despite average precipitation decreasing in the southern parts of the country. The highest flows, the 100-year flows, will mostly increase in the western parts of Götaland and Svealand as well as in Norrland, especially in the mountain regions. In other parts of the country a reduced spring flood may lead to reduced 100-year flows. The rise in sea level and the changes in precipitation and snow melt will affect water flows and ground water levels.

One effect of flooding, high and powerful flows and downpours is the increased risk of pollutants being dispersed in the environment. These pollutants can be metals or organic substances, and the risk of spreading contagions also increases. Most substances, whether dissolved or bound to particles, are washed away with surface water into lakes and watercourses. Extreme rain leads to faster transport of water, which in turn can lead to bursts of pollutants into surface and ground water. A rise in surface and ground water levels also lead to an increased risk of pollutants leaching as new areas are exposed to flowing water.

Fluctuating ground water levels have a strong effect on chemical conditions in the ground and most ground pollutants become considerably more mobile. Sulphide minerals, for example, are oxidised at low ground water levels during dry periods. Metal compounds that are more soluble than the original sulphides can then be dispersed over large areas. This applies to naturally occurring substances and mining waste.

Changed precipitation conditions and surface and ground water levels increase the risk of erosion and landslide, which can release chemical substances and contagions. Ground pollutants currently found in relatively immobile ground can, as a result of land collapse, landslide and erosion, come up to the surface, where they can pose a threat to people and animals directly or further down the direction of flow. The dispersion of pollutants poses a risk to the ecosystem, drinking water quality, farmlands, fishing and more.

Of particular interest is an increased dispersion of bacteria and other microorganisms. Under certain conditions the flooding of polluted ground with high levels of easily leached substances can also pollute wells, affecting water quality.

Agricultural land, farmland and pasturelands can be affected by pollutants that are dispersed and come into circulation in conjunction with floods. Increased dispersion of microorganisms and other pollutants presents a risk to animals feeding on pastureland. On cultivated land, metals and bioaccumulable substances, together with toxic microorganisms, are of the greatest interest as regards health effects on humans.

The areas and activities that can contribute to the spread of pollutants in conjunction with flooding or land collapse, landslide and erosion include polluted ground, depositories, industries and industrial land, sewage treatment, petrol stations, depots with environmentally hazardous substances and more. Polluted ground can comprise areas with rubbish dumps, depositories, mining waste, disused petrol stations, impregnation plants, pollutants deposited in sediment in lakes and watercourses and more. (Andersson-Sköld et al, 2007).

Pollutant dispersion from different business activities

On behalf of the committee, the Swedish Geotechnical Institute (SGI) has calculated the risk of flooding or landslide for a number of cases (Andersson-Sköld et al, 2007b). The business activities and areas studied are as follows:

- Chloralkali factory.
- Impregnation plant.
- Glassworks site and ground pollutants near metal works.

The conclusion drawn from the calculations is that in these cases a landslide or similar event would lead to a temporary rise in concentrations that affect drinking water quality in all studied areas. Flooding causes no direct and immediate effect on concentrations in nearby watercourses. Drinking water in nearby wells were also found to be unaffected by isolated flooding events impacting any of the studied activities due to dilution effects. If several businesses are closely located and jointly impact a receiving body of water, individual wells can be considerably more affected.

Mines and mining waste contain large quantities of metals that if dispersed into the environment would greatly impact the environment and possibly pollute water sources and suchlike. In general, mines are not considered to pose a risk of pollution in the event of flooding. The greatest risk at disused or active mines is dam failure in a sand reservoir or other accidents affecting mining waste (see section 4.2.2). Greater evaporation and occasionally reduced precipitation during the summer could expose waste containing sulphides in water-covered depositories and exposure to air can increase the leaching of metal pollutants.

A study of the consequences of a possible failure in a sand reservoir has been conducted by a consultancy (Golder Associates AB, 2004). One of the reservoirs contains a total of 12.9 million m^3 of water that can be released and, in addition to this, about 3.5 million m^3 of sand. A dam failure under these conditions would have major consequences and result in a flood wave. The maximum height of the flood wave is estimated at 5.5 metres. Nearby wells would be flooded. According to calculations, after about one-and-a-half hours the water would reach the nearby river, which is a surface water source. The total concentrations of cyanide, lead and arsenic in the river would most probably exceed drinking water limits. Subsequently, to reduce the consequences for drinking water the intake of raw water ought to be temporarily suspended in waterworks located downstream.

The probability of dam failure is low (see section 4.2.2). Dam failure has, however, occurred previously. After a dam failure in Aitik on 8 September 2000, a limited rise in the copper content of the water was observed for a limited period. In this particular case, the copper discharge did not exceed the permitted limit. No biological effects were observed, aside from a tendency towards degradation of riverbed fauna. It was not established, however, whether this was related to the dam failure. (Benckert and Göransson, 2001)

Today, the county administrative boards have registers of depositories and polluted land within their borders. There may be shortcomings in the data and it is not yet complete. Among other things, there are the graves of animals which died of anthrax (splenic fever). The risk of infection remains for many decades and can present a risk in the event of flooding or landslide.

Increased precipitation increases river Göta älv pollutant levels

Preliminary results of measurements taken in the rivers Mölndalsån, Säveån and Göta älv show higher concentrations of environmental toxins in 2006 than in 2005. The most probable explanation is that concentrations have increased due to higher precipitation and flows in the watercourses in 2006 than the previous year. Increased precipitation leads to, among other things, oil residues being washed from road surfaces and various pollutants leaching to a greater extent from polluted ground.

The county administrative board of Västra Götaland has had as assessment made of the overall impact of increased precipitation on the entire length of the river Göta älv. Previous case-by-case calculations had only considered the impact of individual business activities or land areas in the event of isolated floodings.

The report shows that an increase in precipitation of 30 percent leads to an increase in pollutant levels of 23 percent. Table 4.26 presents the results for metals, though the trend is assessed to be the same for suspended matter and organic matter.

Table 4.26 Estimated annual flow of metals in the river Göta älv via storm water with a presumed annual increase in precipitation of 30 percent

		800 mm/year	+30% precipitation
Pb	kg/year	625	769
Cu	kg/year	1,064	1,309
Cd	kg/year	12	15
Cr	kg/year	172	212
Ni	kg/year	219	269
Hg	kg/year	2.4	3
Zn	kg/year	4,089	5,029

Source: County Council of Västra Götaland, Publication 2003:57.

Survey of business activities and polluted ground that can contribute to increased pollutant dispersion in conjunction with flooding

On behalf of the committee, the Swedish Geotechnical Institute, together with the Swedish National Rescue Services Agency, has surveyed business activities and polluted ground in areas at risk of flooding at today's 100-year flows (Andersson-Sköld et al, 2007b). The survey is based on the Swedish National Rescue Services Agency's general flood map and the MIFO and EMIR databases. MIFO contains data on possibly polluted areas. EMIR contains information on business activities considered hazardous to the environment under the Swedish Environmental Code, referred to as A and B activities. Figure 4.36 shows the geographic distribution of polluted areas and business activities considered hazardous to the environment in the flood risk zone.

Further, areas at risk of possible impact have been surveyed. Well archive data has been used to determine the number of wells in the potential flood zone. Figure 4.37 shows the geographic distribution.

The results of the study show the following:

There is currently a total of 376 A and B business activities (EMIR) in the flood risk zone of today's 100-year flows. The risk zone also contains 932 land areas that may be polluted. The breadth and variety of the potentially environmentally-hazardous business activities and the polluted areas are great. Depending on the type of incident, these potential sources of pollution can contribute to increased pollutant dispersion in conjunction with flooding. The pollutant burden can affect watercourses and lakes, as well as the final outlet areas, the Baltic Sea and the North Sea.

The flood map watercourses are lined with a large number of private wells and even other water sources. According to the Geological Survey of Sweden's well archive, the flood risk zone (100-year flows) contains about 3,300 wells. Of these, 2,500 are in Svealand. Västra Götaland has considerably fewer wells. The river Göta älv is, however, the water source of the Gothenburg region.

The flood map risk zone along the watercourses comprises 82,000 hectares of open ground, 38,000 hectares of which are fields. The potential pollution sources as well as the wells and open ground are quite spread out along the entire watercourses.

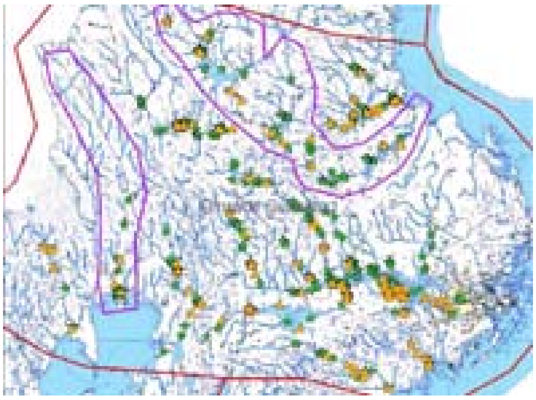
For more detailed information about the above surveys, refer to the underlying reports from the Swedish Geotechnical Institute (Andersson-Sköld et al, 2007 and 2007b).

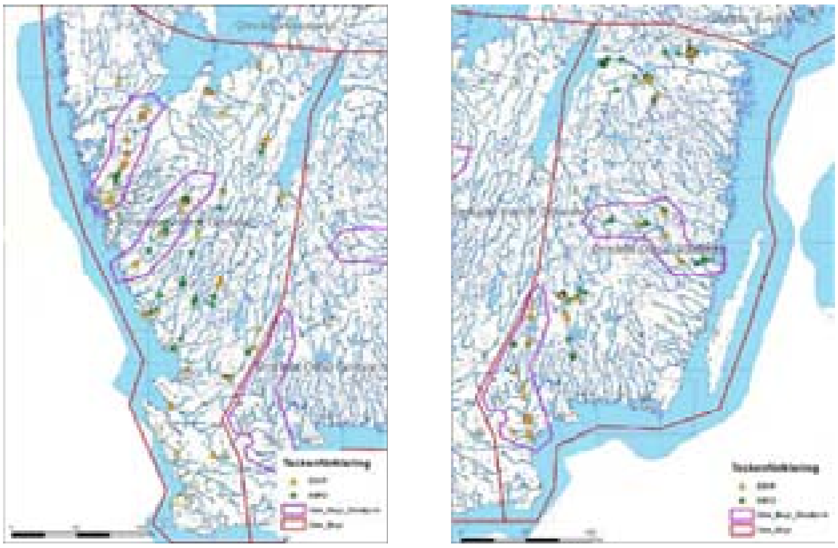
Figure 4.36 Current environmentally-hazardous business activities (EMIR) and polluted land areas (MIFO) in the flood risk zone of today's 100-year flows

Norrland

Key
Area_Lim_Detail_ar
Area_Lim

Svealand



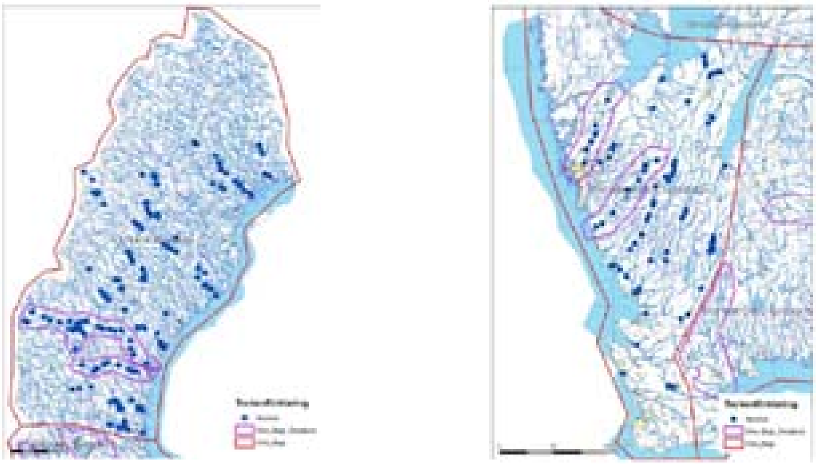


Västra Götaland **Östra Götaland**

Key
Area_Lim_Detail_ar
Area_Lim

Source: Pollutant Dispersion in Floods. Phase II, Swedish Geotechnical Institute, 2007.

Figure 4.37 Wells in the flood risk zone, today's 100-year flows



Norrland **Västra Götaland**

Svealand **Östra Götaland**

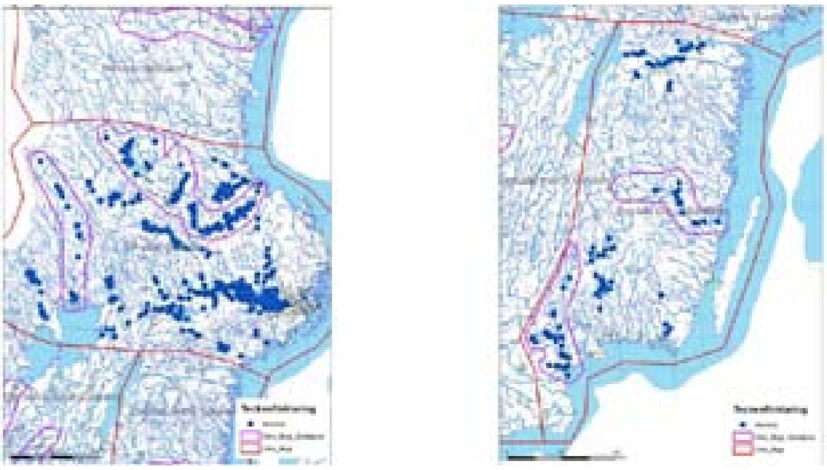
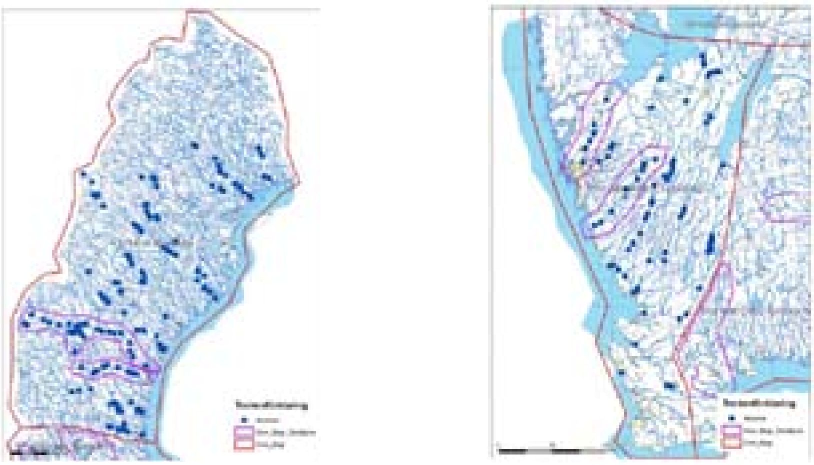
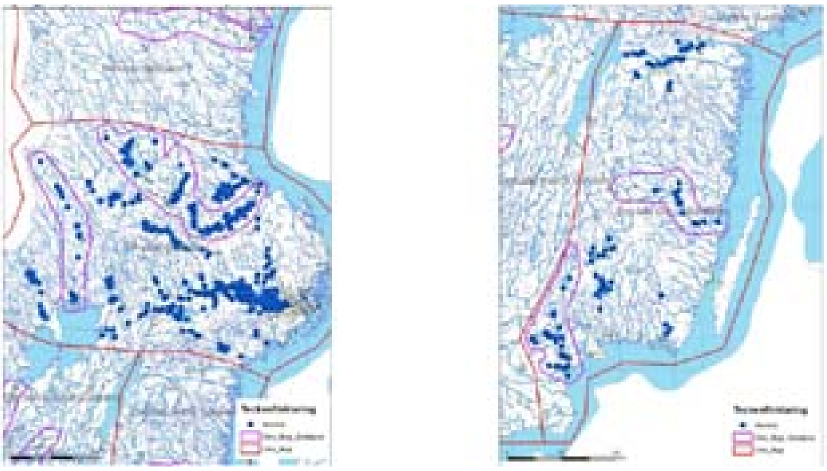


Figure 4.38 Wells in the flood risk zone, today's 100-year flows

Norrland **Västra Götaland**





Svealand **Östra Götaland**

Key
Area_Lim_Detail_ar
Area_Lim

Source: Pollutant Dispersion in Floods. Phase II, Swedish Geotechnical Institute, 2007.

Adaptive measures and considerations

The changed climate will increase the risk of flooding in some parts of the country. Areas that are particularly exposed include Västra Götaland and parts of Norrland. The intensity of rain showers will also increase in most places, increasing the risk of local flooding.

Surveys show that a large number of sources of pollution and drinking water are in areas at risk of flooding. Data in the form of updated flood maps is therefore important for assessing pollutant dispersion (see section 5.1).

Within the bounds of the wider responsibility for climate adaptation that we recommend be assigned to the county administrative boards, they ought to survey known depositories, industrial land, anthrax graves and so on in light of the increased flood risks. Special attention should be given to the pollution risks affecting drinking water sources and pastureland.

Recommendations

Recommendations are provided in the following areas.

- 4.2.5: Recommendation concerning a review of the protection of drinking water sources.
- 5.10: Recommendation concerning wider responsibility for climate adaptation for county administrative boards.

4.4 Rural businesses and tourism

4.4.1 Forestry

The consequences for Sweden's forests and forestry will be significant. Increased growth will result in greater timber production, although increased frequency and extent of damage primarily from insects, fungi and storms, as well as wetter forest land, can entail considerable costs.

Forestry and the forest industry – preconditions for one another

Sweden's forests and forestry are the foundation for the Swedish forest industry, one of the most important businesses in the country. In 2003, the forest industry's production value amounted to SEK 181 billion, which constituted 13 percent of the manufacturing sector's total processing value. The forest industry's and forestry's combined processing value constituted 3 percent of GNP (Statistics Sweden, 2006). Paper and cardboard production are the most important in terms of overall processing value, although the production of timber for wooden goods is responsible for 2/3 of the timber's value (SOU 2006:81). Pine and spruce are the most important tree species in Swedish forestry and the forest industry. In recent decades, biofuels from the forest have once again become important, along with timber for wooden goods, paper and packaging.

Out of Sweden's total land area of 41 million hectares, 23 million hectares are productive forest land. Out of a growing stock of approximately 3 billion cubic metres standing volume, 42 percent comprises spruce, 39 percent pine, 11 percent birch and approximately 6 percent other deciduous trees. There were approximately

354,000 forest owners in 2000, many of whom are private owners with small forest holdings.

Within forestry, the normal final felling age varies from around 45 years to over 100 years. There will therefore probably be time for the climate to change tangibly for the forest being created today. Forest growth varies considerably according to the climate, other conditions and tree species in the habitat, from more than 10 cubic metres standing volume per hectare per year on good land in southern Sweden, down to the lower limit of what is deemed productive forest land, 1 cubic metre per hectare per year on poor, wet or semi-mountainous land. The growth in volume is small at the nursery stage, but increases rapidly as the tree grows. The most common form of management in Sweden is cutting by compartments. When the stand is old enough, final felling of the majority of the trees takes place, after which reforestation measures are required through natural regeneration or planting.

During the 17th and 18th centuries, the growing stock declined in more densely populated parts of Sweden due for example to burn-beating, pasture, and the harvesting of wood and timber. During the sawmill boom in the 19th and early 20th centuries, Norrland's forests were largely cleared of sawing timber, without measures being taken to ensure reforestation. Largely as a consequence of this development, legal requirements for regeneration were introduced in 1902.

Since the 1920s there has been a significant increase in growth and the growing stock in Sweden's forests. In addition, forest fires have been combated relatively effectively for more than fifty years. These would otherwise have a significant impact on the forest landscape.

The forest's growth takes place through the conversion, via photosynthesis, of the air's carbon dioxide and carbohydrates. Access to water and nutrients, particularly nitrogen, as well as the length of the growing season, are also factors that affect growth. In south-eastern Sweden it is not unusual for access to water to limit the growth of trees during parts of the summer.

Damage that affects forests and forestry

Damage to forests is primarily caused by insects, fungi, grazing animals, storm winds and heavy wet snow. Forestry can also be affected by weather-related limitations in other ways. Heavy precipitation and little freezing of the soil impede the potential for logging, i.e. felling and transport from forest to forest road. Floods can cause similar problems, although they seldom damage standing forest to any great extent. Thawing of frozen soil can make it difficult to transport the timber on from the stacking point via the forest road and public road network.

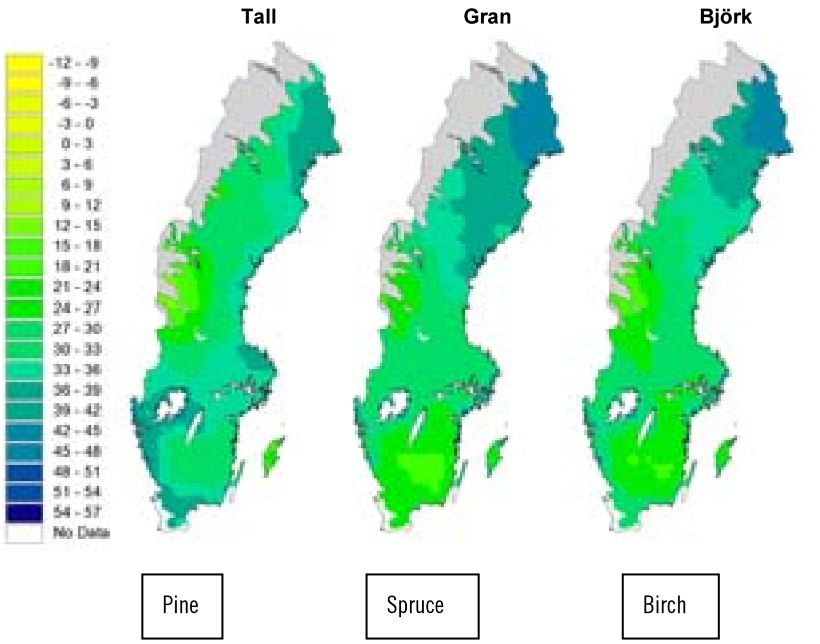
In historic terms, storms have been responsible for the greatest economic damage in forestry. Hurricane Gudrun in 2005 brought down or damaged around 75 million cubic metres standing volume, which is equivalent to almost a year's felling in Sweden. The total cost to forestry was estimated at between SEK 11–12 billion (Swedish Forest Agency, 2006). Hurricane Per in January 2007 is estimated to have brought down around 16 million cubic metres. Previous storms have also been responsible for major damage. More hidden causes of damage, such as root rot in spruce trees, is estimated to cost around SEK 500–1,000 million annually in reduced timber value. Pine weevil attacks in plantations and damage caused by game are also significant from a financial perspective. Grazing pressure, primarily from elks, is now very serious. In its most recent evaluation, the Swedish Forest Agency has established that "*The level of damage in young forests is very significant. At present, 46 percent of the pine stands are damaged. Tree growth of aspen and mountain ash in young forest has declined since the turn of the century*" (Swedish Forest Agency, 2007). This is one of the reasons why spruce is now chosen on up to 38 percent of the land in Götaland where pine would otherwise have been the most suitable tree species (SOU 2006:81). The profitability of selected valuable deciduous forests is greatly restricted by the costly fencing that is required.

Increased growth and more tree species in a warmer climate

The generally warmer climate, a longer growing season and increased carbon dioxide levels in the atmosphere are expected to entail increased forest growth. Standing, existing forest, however, will not be as well adapted to the new climate, and will therefore be unable to make full use of a longer growing season. In certain cases, new tree species and trees with different origins (provenances) will be able to deliver even higher production, provided they can survive the critical nursery stage in the current climate. Without active forestry, significant changes would occur in the forests in the long run, in line with climate change. Valuable deciduous forests would migrate increasingly to the north, and the spruce would be forced back (see Appendix B 23).

In a study conducted for the investigation, the future growth of some of our most common forest trees on the most common type of land, medium-dry ground, has been calculated using a forest production model adapted for boreal forests (see Appendix B 19). The results are based on studies of scenarios EA2 and EB2, and show that the growth of pine, spruce and birch will gradually increase, achieving a level of around 20–40 percent greater than at present by the end of the century. This increase is expected to be greatest in the north, relatively speaking, and generally greater in EA2 than in EB2. Spruce and birch will become more competitive compared to pine in Norrland, while the reverse is true in Svealand and Götaland. In the south, drier summers will mean that an increase in growth as regards spruce will change to a decrease during the latter part of the century. Beech and Sitka spruce have also been studied with the model. Beech growth is increasing to more or less the same extent as pine. The growth of the Sitka spruce is developing on a par with or slightly below that of spruce. With an assumed average net timber value of SEK 230 per cubic metre (solid volume excluding bark), the increase in growth would provide forest owners with increase earnings totalling SEK 5–9 billion annually. The industry's processing value would also increase, provided the timber can be processed within Sweden.

Figure 4.39 **Relative production changes according to the EA2 scenario for pine, spruce and birch for the period 2071–2100, compared with the period 1961–1990**



Source: Appendix B 19.

With higher growth, the rotation periods from seedling to fully-grown tree can be shortened. A warmer climate also provides the potential to cultivate new tree species for timber production whose northerly limit currently runs through either the most southerly parts of our country or even further south.

Among the valuable broadleaved trees, it is considered that oak and beech could expand northwards. Elm has been in strong decline for many years as a result of Dutch elm disease, which is spread by the elm bark beetle. Since 2005, ash trees have been affected by a new disease known as ash disease. Fast-growing broadleaved trees such as hybrid aspen and poplar could become important, with growing demand for biofuels.

Generally speaking, however, broadleaved trees are heavily grazed by cloven hoofed game, which in practice often requires costly fencing around plantations. In our judgement, numbers of grazing game will increase further in a warmer climate, with unchanged pressures as regards hunting and predators. In this case, the potential to spread risks and adapt forestry via the choice of tree species is tangibly restricted. In addition, the potential to protect the biodiversity associated with those tree species that are heavily grazed is also impaired (see Appendix B 18).

Non-native conifers that are already cultivated on a limited scale include the hybrid larch, the Sitka spruce and the Douglas fir. The conditions for cultivating these will improve in much of the country in the future climate, although probably no more than for some of our native tree species. In addition, the non-native conifers will affect the natural and cultural environment, the landscape and biodiversity, often detrimentally.

Risk of poorer quality conifers in a warmer climate – better for some broadleaved trees

High quality saw logs often refer to straight, knot-free timber with no damage or discolouration. Relatively thick dimensions and a high density are also sought after. With more rapid growth, the density of conifers decreases while the frequency of knots increases. Bends can also become more common. For existing, slightly older forest, a warmer climate may be reflected primarily in a more rapid volume growth. The quality of a tree is established primarily while it is young, and the quality of standing forest may therefore increase in the shorter term. A changed climate can consequently result in poorer quality in the traditional sense of the term for coniferous saw logs. At the same time, we can anticipate larger dimensions, a quality factor that is changing for the better. For pulpwood and energy wood, a reduction in density is detrimental, as the volumes that have to be handled and transported increase with no corresponding increase in the fibre yield.

For broadleaved trees with bands of pores, such as oak, ash and elm, a warmer climate and faster growth are also positive from a density and quality perspective (see Appendix B 18).

Effects on the forest of changed precipitation conditions

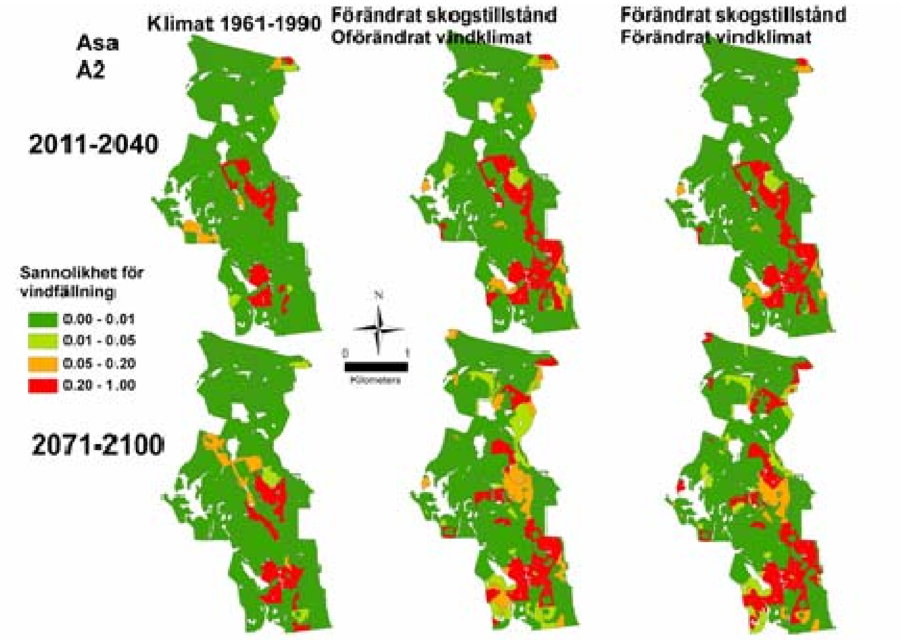
The climate scenarios are pointing to reduced summer precipitation, above all in Götaland and Svealand. On dry land, this will mean that tree species that are sensitive to dry conditions, such as spruce and birch, will be disadvantaged, while those that are more resistant to a dry environment will benefit, such as pine and oak. On land that has better access to water, medium-dry and moist land, spruce and birch may hold their own well in large parts of the country, at least up until the middle of the century. In south-eastern Götaland, however, drought may become a significant problem, particularly towards the end of the century. Extended field trials can provide answers regarding the development of various tree species in a drier climate. We consider that the risk of waterlogging, leading to reduced growth in the areas where precipitation is increasing, will be relatively limited, as evaporation will also increase. There may possibly be some increase in Norrland and in areas where the breaking down of peaty soil is leading to a sinking ground level. Waterlogged ground is often valuable from a biodiversity perspective.

Increased risk of wind damage in a changed climate

Spruce are most sensitive to storms, followed by pine. Deciduous trees generally cope better, as they have usually lost their leaves during the windy autumn and winter months. Wind-felled trees have historically given rise to extensive and costly damage. The climate scenarios do not point unambiguously to an increase in the frequency of strong winds. According to HadAM3H, the occurrence of strong winds will not increase in Sweden, except in the winter in the southernmost part of the country. According to Echam4, however, there will be a more pronounced increase in strong winds (above 21 m/s), above all in southern Sweden.

At the request of the investigation, the Swedish University of Agricultural Sciences in Alnarp has studied the risk of wind damage in a future climate with the aid of various wind and forest production models in two case studies (see Appendix B 19). The results show that increasing growth and the associated change in the state of the forest, including the presence of taller trees, will in itself result in an increased risk of wind damage. Similarly, a change in the distribution of tree species may have the same outcome. The anchoring of the trees is also affected detrimentally by reduced frost, particularly in southern Sweden. The way in which the occurrence of frost will change in the north is less certain. Wetter conditions in the winter will also contribute to an increased risk of wind damage. If the frequency of strong winds increases, this will contribute to a further increase in the risk of wind damage. This increase will already be noticeable by the 2020s (see figure 4.40).

Figure 4.40 **Probability of wind damage in a forest area in Asa test park (southern Småland) during the periods 2011–2040 and 2071–2100 in today's climate, in a future forest state, as well as in a changed climate and forest state**



Source: Appendix B 19.

The risk of snow-breakage will probably decrease in southern Sweden in the future climate, but may increase in Svealand and Norrland, where heavy wet snow may become more common (see Appendix B 18).

Risk of more damage caused by fires, fungi, insects and game in a changed climate

During the 20th century, forest fires in Sweden have rarely resulted in particularly extensive losses of timber. The cost of fire-fighting during the 1990s and early 2000s amounted to an average of SEK 7–8 million, based on *paid remuneration* in accordance with § 37 of the Rescue Services Act. The total cost of fire-fighting is greater than this, however, and lost timber value has to be added to this figure. According to one study for the investigation by the Swedish Meteorological and Hydrological Institute (SMHI), the Swedish University of Agricultural Sciences and the Swedish Rescue Services Agency, the frequency of forest fires may increase tangibly in a changed climate according to the climate scenarios we have studied. This increase is anticipated to be greatest in southern Sweden. Fire-fighting costs alone may reach SEK 200–300 million annually in the fairly near future (see also Appendix B 21).

Root rot, which is caused by the bracket fungus and primarily affects spruce trees, currently causes damage in the order of SEK 500–1,000 million annually (see Appendix B 18). Bracket fungus spreads in conjunction with felling or other exposure of wood and roots at air temperatures above around 5°C. It penetrates the spruces' root system and spreads between trees. Biological countermeasures exist and are in use, primarily during thinning. In a warmer climate, root rot, which is currently mainly restricted to southern Sweden and along the coast of Norrland, will become more common in a larger part of the country.

Insects such as the pine weevil and the spruce bark beetle cause extensive damage in the forest. The chemical treatment methods that are widely used at present to counteract pine weevil damage in plantations will be phased out by 2009 according to the current timetable (Swedish Chemicals Agency, 2005). The cost to forestry of pine weevil damage where there is no functioning plant protection has been estimated at SEK 0.5–1.0 billion annually, whereas the cost of treating plants can be estimated at around SEK 100 million annually (see Appendix B 18). Trials are currently under way in several different areas to find sufficiently effective alternative methods. In a warmer climate, there is a risk of an increase in pine weevil damage.

The spruce bark beetle benefits from the presence of large volumes of spruce wood that has recently died, followed by a warm, dry summer. After Hurricane Gudrun in 2005 and the warm summer of 2006, the extent of damage has increased dramatically. Countermeasures include removing all timber from the forest before swarming in the spring/early summer and the setting of special traps. In a warmer climate, the spruce bark beetle will regularly be able to swarm several times in a single year. In combination with the risk of increased wind damage, the climate scenarios entail a significant risk of serious, costly attacks by spruce bark beetles in standing spruce forest in the future.

Insects that cause major damage elsewhere in the world could spread into our country in a warmer climate. A couple of species that could cause problems in the future are the pine processionary moth and the pine wood nematode. The latter has caused very extensive damage in countries such as Japan. The pine wood nematode is currently found in Portugal, probably introduced by ship in packaging timber.

Diffuse damage, including increased resin flows and reduced vitality in spruce trees was observed at the beginning of the 1990s in Denmark and Sweden. The damage in Sweden has been limited so far, however, and the stands have often recovered. The causes of this type of damage have not been established, although there is a risk that such damage, which primarily affects spruce trees on the edge of or outside their natural area of distribution, may increase in a warmer climate. In Danish soil with a very high clay content (>20 percent), spruce trees often die at the age of around 45–50 years, although they can grow very well until this time (see Appendix B 18).

A warmer climate entails increased net primary production of plant material. With shorter rotation times, the proportion of young forest will also increase, providing larger amounts of forage. This will probably create the conditions for increased numbers of game animals. Significantly increased temperatures may disadvantage the elk, whereas other cloven hoofed animals are not as sensitive to temperature. On the whole, a warmer climate will probably result in denser stocks of and higher grazing pressure from herbivorous game. Pressure from predators and hunting are decisive as regards the size of the game stocks, however. The extent of the damage is also probably dependent on forest management. With more investment in broadleaved tree regeneration, grazing pressure on individual stands could decrease. In other cases, the damage may increase if there is no increase in the numbers of predators or pressure from hunting.

More difficult logging conditions

The forest industry is dependent on a continual flow of timber. A reduction in the occurrence of stable frost in the winter and increased precipitation during the winter months will probably make logging, i.e. felling and transporting timber to a main road, more difficult at this time of the year. Driving over moist ground also causes damage and increases the leaching out of organic substances, sediment and mercury. This can result in damage to biodiversity in runoff water (see Appendix B 18).

Repeated, prolonged thawing periods also risk exacerbating accessibility problems on forest roads and public roads in the winter. These problems will probably be greatest in southern Sweden initially, although they may gradually extend northwards as the century progresses.

Adaptation measures for utilising climate change and minimising damage, as well as other considerations

A future climate may entail increased growth potential for our most important tree species, although also an increasing risk of damage. The spruce is the species for which there are probably the greatest apprehensions. The spruce is threatened for example by increased storm damage, increased numbers of bark beetles and, along with several broadleaved trees, by extreme droughts in some years, particularly in southern Sweden. At the same time, the spruce currently has the highest value production on Sweden's medium and good quality forest land. It is not impossible that, despite increasing damage, it will retain a leading position in a large part of the country, at least over the next few decades.

The increased risk of wind damage can, to some extent, be countered by shorter rotation periods. It is possible to thin hard and early, and thereby achieve a more storm-resistant forest in stands that are exposed to the wind. Furthermore, it should be possible to identify systems that improve the potential for small forest owners to adapt their felling planning to that of their neighbours, in order to reduce the occurrence of cutover edges that are very exposed to the wind (Appendix B 18).

It is not certain how successful the methods for combating spruce bark beetles can be in practice, i.e. the removal of dead spruce wood from the forest and the setting of traps. A future climate will probably increase the risk of extensive bark beetle attacks and stipulate demands for more refined methods for dealing with damaged forest, at the same time as taking into consideration the benefits entailed by the presence of dead wood from a biodiversity perspective.

The risk of drought damage and reduced growth can be countered through an increased focus on pine, mixed stands and oak, for example, above all on those areas in southern Sweden where the ground is already drier.

There is considerable uncertainty surrounding exactly how the climate will change and future demand for different tree species. Land owners must however be prepared for the fact that the risks will increase over time, particularly in traditional forestry targeted at maximum production. For many, the increased production will make up for the damage, although individual land owners may be seriously affected.

From a social perspective, we should also take into account the negative effects that wind damage to forests in particular has on many other social functions, such as electricity, telecommunications, roads and railways, and the businesses that are dependent on these. It can be justified to take specific measures in stands that are particularly exposed to wind. Means of control for achieving such measures should be considered. It is also clear in other respects that changes to the climate justify an increase variation and spreading of risks in forestry throughout the country, particularly in southern Sweden, where the risk of storm damage and other climate-related damage will probably be greatest.

The insurance sector offers insurance against forest fires and wind damage, but these policies hardly provide comprehensive protection. The terms seldom give full compensation for damage in timber-rich stands, while as a rule no compensation at all is paid for damage that only affects small areas, even though this may amount to several stands. A follow-up should be conducted looking at how damage and applicable insurance terms affect the finances of individual forest owners.

Increased variation in forestry can be achieved in several different ways, including through the use of more tree species. Birch can be cultivated more actively, ideally in mixed stands with conifers. It allows in more light than spruce and is consequently positive for biodiversity. Pine should be considered on drier land. Oak and beech have long rotation periods. Oak trees in particular are more resistant to drought than spruce. Both oak and beech are currently less profitable than spruce and are perhaps selected primarily by individuals who want to spread their risks, who believe in a favourable development of demand for these tree species in the long term, who value the landscape highly and/or who want to promote biodiversity. Other valuable broadleaved hardwoods may also be suitable. New, fast-growing tree species such as hybrid aspen, poplar, Sikta spruce and hybrid larch are other alternatives, although these do have disadvantages to varying extents from a natural environment perspective as they are non-native tree species. Compared with pure spruce stands, these can entail increased variation and, in most cases, more light reaching the ground. There is insufficient knowledge about optimum management of mixed stands and species other than spruce and pine, however, and this needs to be developed in order to achieve good-quality, wider-ranging advice.

Additional ways of spreading risk include the use of different although sufficiently hardy provenances, increased variation as regards thinning regimes and type of felling, e.g. continuity forestry on certain markets.

There is consequently a need for an overhaul of the rules and recommendations as regards the choice of tree species, provenance choice, clearing, thinning and final felling, as well as for fertilising, the use of non-native tree species, rotation periods and rules aimed at minimising pests. This overhaul should be targeted at strengthening the potential to achieve the forest policy's two objectives of a good yield and the protection of biodiversity in sustainable forestry in a changed climate.

Game cause considerable damage to the forest, and there is a risk of this damage increasing in an altered climate. The elk stock (or other game) is not currently managed primarily on the basis of information regarding forage conditions or the level of damage. Without costly fencing, we do not have the conditions for cultivating most broadleaved hardwoods in many places, bearing in mind the existing game populations. In some areas, broadleaved trees could become a complement to the dominant conifer forestry to a greater extent that at present, as well as an important element in strengthening biodiversity in a changed climate. However, this would require new, cost-effective protection methods for seedlings and young forest or an adaptation of game management. It is probable that greater access to grazing in the forest, by means of the forestry sector allowing or investing in broadleaved trees to a greater extent, will result in less damage to young forest. With unchanged access to grazing, more extensive hunting may be required instead to facilitate the use of valuable broadleaved hardwoods, for example. On the whole, the management of game should be developed to a greater extent towards balancing various social benefits and costs. The aim should be to keep the game stocks at a level where good (valuable) broadleaved regeneration can be achieved at the same time as conducting meaningful hunting. In order to facilitate such a change, better knowledge is required about e.g. the game's choice of forage, population dynamics and the effects of a changed climate and forest state.

Preventive action against root rot through stump treatment at the time of felling is a relatively cheap measure that could be even more profitable when climate changes are incorporated in the cost/benefit analysis. Chemical countermeasures against the pine weevil exist, but their negative environmental effects and the planned ban on the pesticides that are currently in use mean that new methods need to be developed.

As far as we can judge, forest fires are set to increase. Preventive measures will become increasingly important. These include both communicating restrictions regarding the lighting of fires and ensuring that these restrictions are complied with. It may also be necessary to refrain from certain forestry measures during extremely dry periods. Fire monitoring is a central task for which resources should be guaranteed in the future as well, as the early discovery of fires is decisive as regards the speed with which they can be put out and the level of resources required. Moreover, Sweden and other countries in northern Europe should draw benefit from experiences in southern Europe, and develop operational preparedness and capacity by planning, participating in and contributing resources to international co-operation to a greater extent. Collaboration with eastern European countries should also be strengthened, as their climate and forest conditions in many cases resemble those found in Sweden.

In general, the systems for reporting, following up and evaluating damage in the forest as a consequence of storms, insects, fungi, game grazing, damage caused by driving and damage to biodiversity should be developed. The financial effects of damage suffered by individual forest owners should also be followed up. This is required for several reasons. In addition to generally providing data for future adaptation measures, such reporting, following up and evaluation can be used to distinguish trends in damage patterns, provide data for research into the importance of climate factors for various types of damage, as well as the potential to implement rapid preventive measures during and after extensive wind damage. It may also be appropriate to establish more trial areas in various parts of the country, where different management methods and tree species selections can be tested. Attempts should be made to co-operate with interested forest owners in order to keep down costs.

The climate scenarios clearly indicate significantly milder winters with more precipitation in the form of rain. This means that there will be a deterioration in bearing capacity, both in forests and on land, as well as on public roads and forest roads. There is a risk of the conditions experienced during late autumn and winter 2006–2007 in Central Sweden becoming increasing common and even more severe. The cost of closing the public road network currently corresponds to an annual cost of between SEK 750 million and SEK 900 million annually, or SEK 13–15 per cubic metre (solid volume excluding bark). In order to counteract these problems, the stocks held by the players in the forest industry can be increased. The additional cost for increasing the stock by 50–100 percent compared with present levels could be in the region SEK 9–19 per cubic metre in today's values (see Appendix B 20).

The cost of various technical aids during felling, which could reduce the problems during logging, is considered to be a modest SEK 2 per cubic metre (solid volume excluding bark). Such aids could also tangibly counteract the risk of damage to biodiversity in runoff water. Rules consequently need to be developed that entail the employment of such aids where the need exists or arises. These methods and aids may also need to be improved.

New forest roads across marshy areas may in future be a precondition for felling in areas that can currently be reached over frozen ground. However, a careful evaluation of the biological values in the affected wetland areas should be undertaken before such measures are allowed. The rules and recommendations concerning logging and constructing forest roads in damp areas and beside watercourses should be reviewed. Otherwise there is a risk of a negative impact on the environmental objectives *Flourishing lakes and streams* and *Thriving wetlands.* It may possibly be necessary to introduce a separate test procedure when constructing new forest roads.

Increased clearing of ditches within forestry is another measure that could contribute to reduced problems during logging, although it often impairs biodiversity. There is now a general ban on the construction of new ditches. The environmental aspects and the risk of a negative impact, primarily on the environmental objectives mentioned above, should be taken into consideration here.

An improvement to the standard of existing forest roads and public roads is vital in a more unstable winter climate. Improving 70 percent of the forest roads to a higher standard that permits transport during the majority of the year, and equipping an equally large proportion of the lorries with variable air pressure, would cost around SEK 2 and SEK 1.5 per cubic metre (solid volume excluding bark) respectively (see Appendix B 20). Improvements to the public road network would probably cost a similar amount. Measures for raising the standard of the road networks, both forest roads and public roads, as well as improvements to lorries can consequently be justified from a socioeconomic perspective. This should be taken into consideration by the Swedish Road Administration when developing future maintenance plans for the public road network, although in the first instance it should be a matter of informing forest owners about the benefits of a higher standard of forest roads.

Clearer inclusion of issues surrounding climate change in all basic forest-related training and further education is an important element in raising knowledge about how climate changes may affect the forest and the forestry sector. In addition, sustainable and comprehensive measures are required for conveying knowledge about climate changes and their effects on the forest to the many individual forest owners. The deregulated forestry policy means that, to a large extent, it is the forest owners' own decisions now and over the next few decades that will govern the state of the forest this century, which is extremely important for one of our most important business sectors as well as for other social functions. The numerous private forest owners own a large proportion of Sweden's forest land. They constitute a heterogeneous group, and many have forestry as a side-line. In general, private forest owners have limited opportunities to acquire new knowledge. An important channel for the distribution of information is the Swedish Forest Agency's regional organisation. The Agency, its regional organisation and forest sector's organisations should work together on an information campaign in order to convey knowledge about climate change and forestry, primarily to private forest owners. Separate resources should be allocated to the Swedish Forest Agency for implementing this work.

Build-up of knowledge, research and development

Knowledge about how climate changes affect the forest and forest ecosystems is still limited. Knowledge concerning the management of broadleaved trees, mixed stands and new tree species is generally weak. In addition, increased knowledge is required as regards genetic variations in forest trees and how we can benefit from these. Damage to forests often follows complex connections, where many different factors play a role. Our understanding of the dynamics behind the extent and distribution of wind damage needs to increase, as well as the link to various climate variables. Similarly, research regarding forest fires needs to be strengthened. The population dynamics of various pests, their sensitivity to climate factors and their ability to spread is extremely important as regards the effects that arise. More monitoring and following up of damage as well as long-term trials are an important foundation for the increased research that has to be conducted in order for the forestry sector to be able to draw benefit from the potentially larger growth in a warmer climate.

In summary, we can see a need for increased research, development and compilation of knowledge regarding:

- Climate scenarios, climate indices and local variations.
- Methods for spreading risk, including mapping land and geographic areas and their suitability for different tree species/provenances/processed material in a changed climate.
- Build-up of knowledge surrounding optimum management of mixed stands, broadleaved stands and land where there has been

forest continually for at least 300 years, including set-aside options, for example through long-term trials.
- Developed/adapted general consideration measures for practical forestry, which can balance the negative effects of climate change on biodiversity in the forest.
- Pests (spruce bark beetle, pine weevil, and other broadleaved tree diseases) and countermeasures.
- Game's choice of forage, population dynamics, effects of a changed climate and state of the forest.
- Developed tools for stand planning and felling planning, including modelling and minimising wind damage.
- Development of new tools to facilitate the harvesting of timber and minimise damage in conjunction with logging on damp, unfrozen ground.
- Consequences regarding the intensity of forest fires, their spread, extent and course in a changed climate with a changed forest situation, including the linking of climate scenarios to fire risk models.
- Consequences for the environment and biodiversity of adaptation measures in forestry.

Proposals

- The instruction for the Swedish Forest Agency should be amended so that responsibility for adaptation to a changed climate is clarified (see section 5.10.2).

- The Swedish Forest Agency should be commissioned:
  - in consultation with affected authorities and organisations, to carry out an review of the Forestry Act and the Swedish Forest Agency's associated directives and general advice, against the background of the fact that the climate changes will entail a gradual change to the conditions.
  - in consultation with the Swedish University of Agricultural Sciences, to develop a system for reporting, following up and evaluating damage caused by game, storms, insects, etc., including the economic effects of the damage, as to establish trial areas for various management methods and tree species selections.
  - to evaluate and assess whether the potential to achieve the environmental objective *Healthy forests* is affected by the

climate changes, both within the time periods to which the objective relates and in the longer term, as well as whether the environmental objective and the sub-objectives are relevant in a changing climate. The Swedish Forest Agency should, if necessary, propose changes to the formulation of the objective and the action programme.
  - to implement a wide-ranging information campaign in relation to forest owners in co-operation with the Federation of Swedish Farmers, forest owners associations and other players in the forestry sector, with regard to climate change and the effects of a changed climate on forestry. The Swedish Forest Agency is being allocated SEK 10 million over three years for the implementation of this campaign.

- Continued state financing of fire monitoring and airborne monitoring in conjunction with extensive damage.

4.4.2 Agriculture

On the whole, the climate changes are improving the conditions for agriculture. Longer growing seasons are producing increased harvests and providing the potential for new crops. At the same time, more pests and weeds are emerging, and new requirements for watering and drainage may arise due to the altered precipitation patterns.

Agriculture in Sweden

Agriculture is one of the sectors where the climate and the weather are decisive for production and profitability. The arable land in Sweden covers approximately 2.7 million hectares, or approximately 6.5 percent of the total land area. Pasture, hayfields, watercourses and cultural environments have considerable aesthetic value and are valuable elements of the Swedish countryside. Many of these are also valuable when it comes to biodiversity.

The economic value of agricultural production, including direct support, amounted to approximately SEK 44 billion in 2003. Plant production represented a value of SEK 19.3 billion, while livestock production represented SEK 21.1 billion. A large proportion of the food industry is dependent on raw materials from Swedish agriculture. The change in the structure of Sweden's agriculture in recent decades has resulted in fewer, larger companies and, above all, a reduction in the number of dairy cows. The majority of the agricultural companies that were shut down were in Götaland's forested districts and in northern Sweden. The proportion of people employed within agriculture is falling, with around 175,000 people now working in the sector (SOU 2007:36).

The structure of and production from agriculture differs greatly in different parts of the country. In Norrland, livestock companies are dominant and there is a large proportion of small farms. In Svealand and northern Götaland, there are many large arable farms and few small farms. In Götaland's forested counties, livestock companies working with cattle are dominant, while arable companies dominate agriculture in Skåne. Plant cultivation is dominated by the growing of grain, in particular barley, wheat and oats, as well as by the cultivation of grassland. Grain cultivation covers approximately 42 percent of the arable land. The varying climate conditions affect the distribution of the crops across the country. The length of the growing season and the temperature are limiting factors for many crops. In the north, plant cultivation focuses primarily on grassland, green fodder and fodder grain. The production of cereal grain is concentrated in the flatter areas in Götaland and Svealand. Grain has declined since 1990, while grassland and fallow land have increased (see table 4.27).

Table 4.27 Distribution of crops on arable land, thousands of hectares

Year	1990	2006
Grain, total	1,336	978
Legumes	33	36
Oil-yielding plants	168	48
Grassland (including silage plants)	970	1,113
Potatoes	36	28
Sugar beet	50	44
Completely fallow	176	307
Total	2,769	2,572

Source: Swedish Board of Agriculture (2006); SOU 2007:36.

Energy crops are now harvested on almost 3 percent of Sweden's total arable land of approximately 2.7 million hectares. This relates both to residual products from plant cultivation, hay and haulm, as well as to cultivated energy crops. Increased demand for biofuels can be anticipated over the next few decades as a result of political decisions regarding reduced carbon dioxide emissions and increased investment in renewable fuels. Whether this demand will make a breakthrough as regards agricultural energy crops and how their cultivation will develop are dependent on a number of factors, such as the price of oil, energy taxes and attitudes towards growing energy crops. Salix is considered to have the greatest potential, although other crops such as corn, poplar, hybrid aspen and hemp may also become important. (SOU 2007:36)

Agricultural policy

The EU's Common Agricultural Policy (CAP) is extremely important for the scope, focus and profitability of agriculture. Competition within agriculture is restricted by means of duties on imports and the market regulations entailed by CAP, although changes are taking place that are reducing duties on imports. Since 2005, CAP's direct support for crops has largely been transferred to general farming support that is paid irrespective of the crop. In addition, funds for the programme for rural development have increased. It is estimated that, in the long-term, the reform of the direct support that has been implemented will result in around 20–50 percent of existing agricultural companies in Sweden becoming unprofitable. This applies mainly to dairy companies (Swedish Board of Agriculture, 2006). The Swedish Board of Agriculture administers the EU's agricultural policy, as well as having central responsibility within the agricultural sector. The National Veterinary Institute specialises in animal diseases, as well as working with issues relating to fodder, for example.

Sensitivity of plant cultivation to climate factors

Optimum growth and quality requires a favourable combination of many weather parameters. In broad terms, we require just the right amount of sunshine, just the right amount of rain and the absence of extreme weather.

In dry years, it is necessary to water crops that are sensitive to dry conditions, in particular vegetables and potatoes. In total, around 100,000 hectares of agricultural land are watered in dry years, although this figure is smaller in other years. Irrigation dams are used for around 20 percent of the watered land, watercourses or lakes are used for around 65 percent, and groundwater for around 15 percent (see Appendix B 24). In the event of prolonged drought, there is often significant loss of crops on land that is not watered.

Soil drainage is now required on a large proportion of Sweden's agricultural land. Existing drainage systems are often not sufficient to cope with the highest flows. Crops losses occur in particular in conjunction with continuous rain and flooding. Banking up occurs primarily around Lake Vänern and Lake Hjälmaren, and as well as protecting agricultural land it also guards other land, buildings and infrastructure. The embankments are not always in the best condition, and during the floods in 2000/2001 around Lake Vänern, large areas were under water for a considerable amount of time. This resulted in crop losses, in particular those crops sown in the autumn.

Heavy rain and hail for short periods can also result in significant crop losses. Continuous rain and very damp conditions can seriously impair the quality of crops.

The conditions during the winter are important for crops sown in the autumn. Sowing should not take place too early as the crops can become too large and be damaged by the harsh winter climate.

Chemical control measures are used in Sweden primarily to combat pests, diseases and weeds (see table 4.28). Their use per hectare is significant less than further south in Europe, in part because many pests cannot survive the winter in Sweden.

Table 4.28 Value of control measures sold within Swedish agriculture

Type of control measure	SEK millions
Seed disinfectants	62.8
Fungicides	173.4
Herbicides	413.5
Insecticides	45.4
Others	2.0
Total	697.1

Source: Appendix B 24.

Livestock production and sensitivity to climate factors

In financial terms, livestock production is approximately as important to agriculture as plant cultivation. Grazing animals are a precondition for preserving biodiversity in the agricultural landscape. In 2004 there were around 1.6 million head of cattle in Sweden, of which around 400,000 were dairy cows. Over the past ten years, the number of dairy cows has fallen by around 15 percent, although the average yield per cow has increased dramatically in the same period. This trend is expected to continue in the future. Chickens for slaughter have increased, as have sheep and lambs to a certain extent, while the number of animals of other species has remained more or less unchanged (Swedish Board of Agriculture, 2006). There are also around 300,000 horses in Sweden at present, which is a high ratio of horses per inhabitant in international terms. This number has increased dramatically over the past 30 years. Horses achieve a turnover of around SEK 20 billion annually, and are now the fifth largest source of income within Swedish agriculture.

In general terms, the health situation among Swedish animals is very good compared to the rest of the world. Serious diseases, such as swine fever and foot and mouth disease, have not been discovered in the country for several decades. Swedish meat and dairy producing animals are basically free from salmonella, unlike large parts of the rest of the world.

Current meat and dairy production takes place predominantly and increasingly in large, specialised stocks. These are highly dependent on a secure supply of power for ventilation, feeding, milking, etc., but are also sensitive to disruptions in the transport of fodder and animals for slaughter.

Access to sufficient amounts of fodder and good quality water are decisive for meat and dairy production. For large-scale livestock management in particular, secure access to good quality water is decisive, not least for milk production. In conjunction with extreme weather conditions such as floods or prolonged droughts, lack of pasture can become a problem. Lack of pasture can cause the animals to start grazing on toxic plants or expose them to parasitic infection, for example because they graze closer to the ground. Supplementary feeding may then be necessary. Fodder can also be damaged, for example in damp weather conditions.

Organic production with livestock kept outdoors is increasing. This requires organic plant cultivation to provide the animals with fodder, which usually entails home-grown fodder. Extreme weather that damages crops can be very serious for this type of production.

Demand for agricultural land in a changed climate and as a consequence of changes to other outside factors

Many factors influence the future use of Swedish agricultural land. In the short term, deregulation is leading to increased international competition within agriculture, both in Sweden and in the rest of Europe. In the longer term, developments in the outside world are difficult to assess, but are extremely important for the future development of agriculture in Sweden.

The Swedish University of Agricultural Sciences has evaluated two land usage models on behalf of the investigation, called ATEAM and ACCELERATES, as well as their results as regards Sweden and the EU. The models describe the development of agricultural land as a result of the global socioeconomic trend and climate changes based on some of the IPCC's emissions scenarios, including A2 and B2, through until the end of the century. The historically rapid development in productivity is expected to continue, but varies from scenario to scenario. The three factors that are expected to determine the productivity trend are technical development, increased carbon dioxide concentration in the atmosphere, and climate change. By 2050, it is assumed that the increase in productivity will deliver greatly increased harvests per hectare, in the region of 85–160 percent. In the longer term, the increase will be even greater. The need for agricultural land will therefore reduce, despite the increase in the population. In the B2 scenario, which indicates minor climate changes but expensive input goods such as fertiliser, energy, etc., the ACCELERATES model suggests that basically all agricultural land will be discontinued, except in southern Götaland. With the major climate change indicated in the A2 scenario, the amount of cultivated land in Sweden may instead increase according to the ACCELERATES model. The ATEAM model consistently shows significant reductions in agricultural land, both in Europe and in Sweden. The models do not include the production of biofuels on arable land.

Table 4.29 Change in the amount of agricultural land for food raw materials in Sweden and Europe according to two models (see also Appendix B 24)

	Area	A2	B2
Model			
ATEAM, year 2080	Sweden	-48%	-33%
	Europe	-45%	-28%
ACCELERATES, year 2050	Sweden	-21%	-72%
	EU	-1%	+5%
ACCELERATES. year 2050, Climate only	Sweden	+21%	+21%
	EU	+16%	+15%

If we look at the effects of climate change in isolation with current socioeconomic conditions, Swedish arable land's competitiveness as regards food and fodder production would increase according to the ACCELERATES model, which would result in increased agricultural land in both the A2 and the B2 scenarios. There is considerable uncertainty in the models, however (see also Appendix B 24).

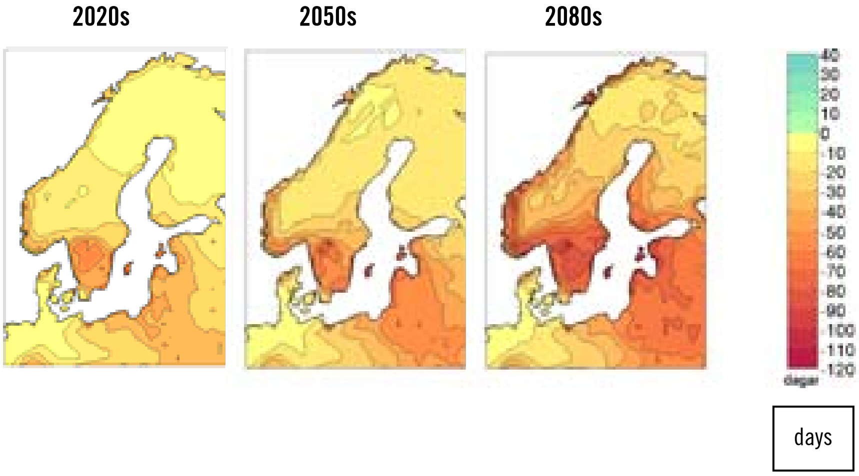
Agriculture's heavy investment in a changed climate

The technical service life of agricultural machinery, buildings and equipment is relatively short. On the whole, a rate of turnover for agricultural machinery of around 15 years can be assumed. This rate is slightly slower for animal housing, at approximately 20 years. A gradual adaptation to a warmer climate should therefore be possible in most cases in conjunction with new investment. One exception is systems for drainage and banking up. The lifetime of pipe draining in light clay can reach 50–80 years (Swedish Board of Agriculture, 2006). With the dramatic increases in precipitation indicated in the climate scenarios, particularly in the winter, there is a tangible risk that the capacity of installations for drainage will regularly be insufficient. Insufficient drainage may significantly delay the sowing of crops in the spring in future, with an increase risk of pest attacks and problems with weeds, but can also entail a risk of damage to crops sown in the autumn, infrastructure and buildings, as can insufficient banking up. It is probable that significantly increased problems will arise as early as the 2020s, possibly in Western Götaland in particular.

Development and quality of crops in a changed climate

The growing season and the cultivation period will be significantly extended according to the climate scenarios (see figure 4.41). Increased temperatures will lead to increased growth, particularly in the spring, when growth is currently severely restricted by temperature.

Figure 4.41 **Number of days by which the start of the growing season is brought forward compared with the period 1961–1990 (RCA3-EA2)**



Source: SMHI, 2007.

Precipitation is expected to increase between October and March and remain unchanged in April. Less precipitation is expected between May and September, at least in southern Sweden. The land will not dry out until significantly later than the start of the growing season, and this will therefore restrict when in the spring farming operations and crop sowing can take place. The harvesting of crops sown in the spring is still anticipated to be around three weeks earlier than at present. According to the climate scenarios, the growing season will be extended by more than a month in the autumn, and autumn sowing will therefore be able to be delayed to a corresponding extent. In the case of winter wheat, for example, flowering and ripening will be brought forward by around three weeks compared to the current situation. Higher temperatures and reduced precipitation in the summer are expected to increase the need for watering, at the same time as access to water will reduce. However, calculations indicate that the growth of e.g. fertilised grasslands will not be impeded by the 2080s, and will still be at the current level in July-August. Autumn crops that are harvested early, before the drought has had time to become a problem, will benefit in comparison with crops sown in the spring (see Appendix B 24).

Increased carbon dioxide levels in the atmosphere mean that the plants will be more economical with the water. The need for watering is also governed by when the precipitation occurs, the water-holding capacity of different soil types, choice of crop, etc. This makes it difficult to quantify the increased watering requirement.

Anticipated changes in cultivation conditions can be exemplified with two areas in Sweden: the Mälar Valley and Västerbotten. In the Mälar Valley, which will have a climate similar to that currently experienced in Skåne, winter wheat could be grown on a large proportion of the land currently used for oats. In Västerbotten, a large proportion of the grassland could be replaced by grain cultivation, primarily winter wheat. The harvests are expected to increase for all crops in both areas (see table 4.30). The relative increases will be significantly higher for Västerbotten than for the Mälar Valley, and will vary from crop to crop.

Table 4.30 Relative changes in the combined regional harvest for six crops in the event of climate changes corresponding to current differences between the regions

	Year 2000		Change in regional harvest in event of climate change	
	Total area (10^3 ha)	Total regional harvest (10^3 tonnes/ year)	No change in acreage distribution	Acreage distribution according to the more southerly region
Västerbotten	59	257	- 56%	+ 26%
Mälar Valley	280	1,527	+ 19%	+ 27%
Skåne	307	2,128		

Source: Appendix B 24.

The aim of plant cultivation is to achieve a product with a certain quality, where each product is defined by several different quality parameters. The hygienic quality will probably be affected negatively, as instances of plant damage are expected to increase, partly as a consequence of increasing temperatures. Crops sown in the spring will be affected more than those sown in the autumn, and southern Sweden will be affected more than the north of the country. The nutritional quality is determined by the protein content of the plant and is proportional to the nitrogen content. The purpose for which the crop is to be used is reflected in the desired protein content. High temperatures during grain filling can impair the introduction of protein and the protein composition. These factors also argue in favour of an increase in crops sown in the autumn. The dynamics of crop growth and protein build-up in a changed climate are complex, with the fertilisation regime also playing a role. When it comes to other quality parameters, there are currently no methods for predicting the effects on quality of given changes in the climate (see Appendix B 24).

Weeds and pests in a changed climate

Problems associated with pests such as insects, fungi and viruses will increase in a warmer climate. With a temperature increase of 3–4°C in the winter towards the middle of this century, a number of aphid species will probably also be able to survive the winter on various crops and weeds in Sweden. Negative effects can then arise, both in the form of direct damage, as well as indirect damage through the spread of various viral diseases, such as barley yellow dwarf virus and several diseases that affect potatoes and sugar beet. These aphids will probably also be favoured more than spring-sown crops as they will develop earlier than now in relation to the crop's development. This situation can also benefit the frit fly, which causes damage to cereals. The greatest problems can be anticipated in dry areas, particularly in the south-east of Sweden. The problems may also be significant in northern Sweden, for example when growing seed potatoes.

Rust fungi and powdery mildew that affect cereals, as well as fungal diseases that affect oil-producing plants, will probably benefit from higher temperatures as they are not as dependent on a moist climate. Other, more moisture-demanding fungal diseases, such as leaf spot fungi, will probably become less common, at least in southern Sweden.

One of the insects that may establish itself in southern Sweden is the Colorado beetle, which damages potatoes. Other species may spread northwards, such as the cabbage stem flea beetle.

The number of species of weed flora is expected to increase, although it is not necessarily only competitive weeds that will increase. A more drawn-out appearance of crops in relation to the start of the growing season in itself means an increased and repeated need for control (mechanical and/or chemical). More cultivation of crops that do not compete well, such as maize, is having the same impact. However, the extent to which the need to combat weeds may change is not certain. If the use of control measures were to increase to the Danish level, it would have to almost double. The cost of this would be around SEK 600 million annually.

Effects on livestock management in a changed climate

A warmer climate with a longer growing season will result in more, larger grass harvests and increased potential for pasture for a longer period of the year. Dry periods in the summer mean that supplementary feeding may be required to a greater extent, however.

The increased temperatures in the summer can cause problems, particularly for pigs and poultry breeding. Young pigs like a temperature of around 30°C, whereas adult pigs prefer a temperature of 15–20°C. Large poultry stocks require a high ventilation capacity. A power failure can quickly result in high mortality. Hens prefer a temperature of around 20°C. A higher frequency of e.g. sudden cardiac death occurs when the temperature is too high.

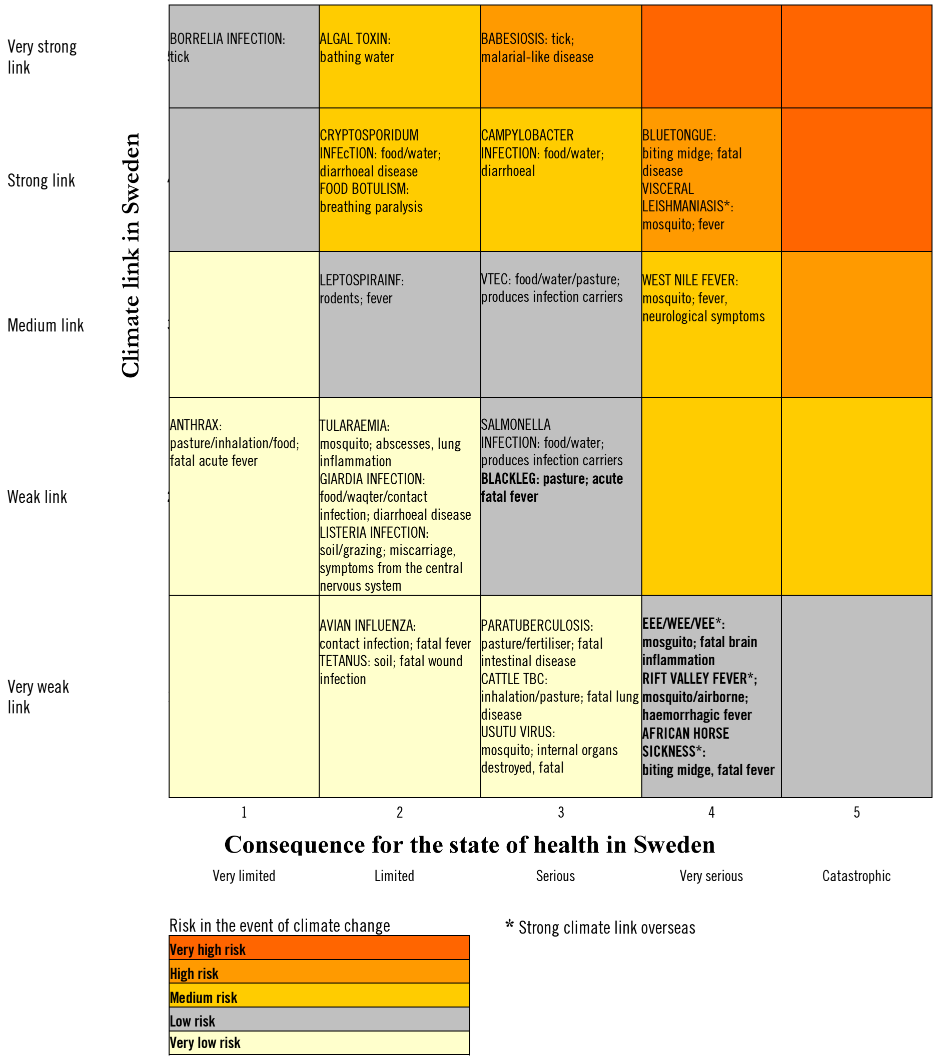
Floods and the overflowing of sewage water can result in animals consuming contaminated drinking water and in pasture being contaminated. Increasing problems associated with attacks by micro-organisms in growing crops, as well as growth in harvested fodder, can be a consequence of higher temperatures and increased relative humidity during the storage period in winter. More mycotoxins in fodder and salmonella in industrial fodder production are another consequence, which can e.g. disrupt the reproduction and growth of pigs.

A northwards spread as regards the transmission of infection has already been observed for a number of vector-borne infections (*Bluetongue, West Nile fever, Borreliosis*). It is not certain how the first outbreaks of disease will occur and how they will become established in Sweden (see more in Appendix B 34). If this happens, new problems can arise for Sweden's livestock industry. The main new diseases that can affect animals are zoonoses, which are spread for example by ticks and rodents, as well as viral diseases.

See table 4.31 *Erlichiosis*, which occurs in sheep, cattle and horses.

Babesiosis is a disease that is transmitted by ticks and that resembles malaria. It is now common among cattle and sheep in southern Sweden, and may become more common in a warmer climate. Around 3,000 cattle are currently affected every year. Viral diseases that may become established in Sweden include *Bluetongue*, which is spread by biting midges and causes a serious disease, primarily in sheep. During 2006, the disease spread to more than 2,000 stocks in countries such as the Netherlands, Belgium and Germany.

Table 4.31 **Summary climate risk – assessment of consequences for infectious disease in Sweden affecting animals. The risk assessment is based both on the strength of the link between the increase in the risk of disease and climate change in Sweden, as well as on how important the disease is, i.e. its consequences for the health situation in Sweden (see more in Appendix B 34)**



Climate link in Sweden	1 Very limited	2 Limited	3 Serious	4 Very serious	5 Catastrophic
Very strong link	BORRELIA INFECTION: tick	ALGAL TOXIN: bathing water	BABESIOSIS: tick; malarial-like disease		
Strong link		CRYPTOSPORIDUM INFEcTION: food/water; diarrhoeal disease FOOD BOTULISM: breathing paralysis	CAMPYLOBACTER INFECTION: food/water; diarrhoeal	BLUETONGUE: biting midge; fatal disease VISCERAL LEISHMANIASIS*: mosquito; fever	
Medium link		LEPTOSPIRAINF: rodents; fever	VTEC: food/water/pasture; produces infection carriers	WEST NILE FEVER: mosquito; fever, neurological symptoms	
Weak link	ANTHRAX: pasture/inhalation/food; fatal acute fever	TULARAEMIA: mosquito; abscesses, lung inflammation GIARDIA INFECTION: food/waqter/contact infection; diarrhoeal disease LISTERIA INFECTION: soil/grazing; miscarriage, symptoms from the central nervous system	SALMONELLA INFECTION: food/water; produces infection carriers **BLACKLEG: pasture; acute fatal fever**		
Very weak link		AVIAN INFLUENZA: contact infection; fatal fever TETANUS: soil; fatal wound infection	PARATUBERCULOSIS: pasture/fertiliser; fatal intestinal disease CATTLE TBC: inhalation/pasture; fatal lung disease USUTU VIRUS: mosquito; internal organs destroyed, fatal	**EEE/WEE/VEE*: mosguito; fatal brain inflammation** **RIFT VALLEY FEVER*; mosquito/airborne; haemorrhagic fever** **AFRICAN HORSE SICKNESS*: biting midge, fatal fever**	

Consequence for the state of health in Sweden

Risk in the event of climate change

Very high risk

High risk

Medium risk

Low risk

Very low risk

* Strong climate link overseas

Source: Appendix B 34.

Plant nutrient leaching in a changed climate

Several factors are pointing towards an increase in nitrogen leaching from Swedish agricultural land. Higher temperatures and raised production levels, which are increasing the volume of harvest residues, are increasing nitrogen mineralisation. Greater precipitation and a larger share of rain in the winter are resulting in more extensive leaching. Increased summer drought is having a similar effect, delaying the breakdown of fresh organic material until the autumn. The need for nitrogenous fertiliser increases at certain times, particularly for certain crops such as fodder maize, and with that the risk of nitrogen leaching. An expected reduction in grassland will mean that a larger area is worked and ploughed each year, which will increase nitrogen leaching. At the same time, a longer growing season and taller growth will provide the potential to remove a larger proportion of nitrogen through harvesting. Similarly, an increased acreage of autumn-sown land can act as "catch crops" during mild autumn/winter periods. However, the effects of these factors are not certain. Several studies that have been carried out also point to the likelihood of a significant increase in nitrogen leaching (see Appendix B 24).

There is also a risk that the leaching of phosphorus may increase from agricultural land, although we consider this situation to be less certain. With increased precipitation during the winter and an increased frequency of intensive precipitation, the risk of particle erosion and hence the loss of particle-bound phosphorus from agricultural land will increase. More frequent periods with alternating freezing/thawing can increase the leaching out of phosphorus from autumn-sown crops and grassland. Higher production levels also demand increased application of phosphoric fertiliser if larger areas of fodder maize and less grass are cultivated. However, a reduction in the area of grassland will lead to a reduction in phosphorus leaching from frozen plant material. In the event of reduced snow cover and less frost, surface runoff associated with the melting of snow will decrease, which in turn can reduce phosphorus losses. It is probable that at least some of the increased leaching of nitrogen and phosphorus will be captured through increased take-up in watercourses on route to the sea (see also section 4.5.3).

Measures for utilising opportunities and avoiding risks in a changed climate, as well as considerations

We consider that there is a great deal to indicate that Sweden's agriculture will benefit from a longer growing season, the potential for increased and in certain cases more harvests, as well as new crops. There are a number of worrying factors, however, and a planned adaptation of agriculture to the new conditions may strengthen to potential for a positive development.

Access to water in the future climate will differ from the current situation. More precipitation in the winter, but less in the summer, will place new demands as regards both drainage and watering. In order to cope with the watering requirements, new reservoirs may need to be created, while ditches and pipe drains may need to be widened or redimensioned, particularly in western Götaland.

Embankments may also need to be reinforced. The status of the various systems within different geographic areas, the need for action and costs both for new watering systems and reservoirs and for drainage work will need to be investigated in greater detail. The effects of possible work on the environment and on e.g. buildings and infrastructure should also be taken into consideration.

Measures for draining land, changes to embankments or water outlets will require altered permits or, occasionally, new water court rulings. Amending permits and water court rulings can often be a complicated process. In a changed climate, the function that a permit or water court ruling was originally intended to safeguard will, in many cases, be unachievable. The legislation in this area should therefore be reviewed on the basis of the anticipated climate changes, with the aim of enabling the drainage companies and embankments to retain their function without an extensive legal process (see also section 5.4). In the review of the legislation, the importance of giving consideration to other social functions, biodiversity and the capture of nutrients should be taken into account, as an alternative might be to create wetlands in some low-lying areas.

Wetlands in an agricultural landscape can serve several purposes. In addition to regulating flows, they can also act as traps for nutrients. The form and location of wetlands is extremely important for how well nutrients can be captured, and their efficiency can vary by a factor of 10 (Svensson et al, 2002). Current support systems for creating and managing wetlands on agricultural land should be developed so as to prioritise those areas and types of wetland where the benefit of the measures for capturing nutrients is greatest. The potential to combine measures that have several purposes, such as reservoirs for watering and benefiting biodiversity, should also be a starting point for the prioritisation work.

In order to reduce the leaching out of nutrients in a future climate, cultivation systems and crop rotation should also be developed. For example, larger areas should be sown with crops that capture nutrients during the autumn and winter, and the tilling of soil in the autumn should be minimised. Information efforts can be important in this respect. In addition, knowledge about variations in nitrogen and phosphorus leaching locally and regionally should be increased. When it comes to leaching, the importance of the choice of crop, soils, fertilisation and tilling measures should be studied on the basis of anticipated changes in the climate, including the climate's variability.

The conditions for keeping livestock will generally improve as a result of a warmer climate. However, there will be a tangible increase in the risk of extremely high temperatures, and housing for pigs and poultry in particular should be adapted to provide greater potential for good ventilation. Building standards and advice regarding the construction of animal housing should be reviewed. With an increased risk of flooding, above all in western Götaland, the risk of spreading infection from pasture at water outlets for animals and people should be charted and countermeasures planned, for example in the form of restrictions on grazing close to watercourses or warning systems when there is a risk of flooding. There is also a tangible risk of new animal diseases reaching Sweden. It is therefore necessary to follow developments closely and take measures if required.

New crops, changed cultivation methods and systems, sowing and harvesting times as well as adapted fertilisation and control measures will be required in order for agriculture to be able to draw full benefit from the fundamentally improved cultivation conditions that a changed climate will entail. Several factors, such as wetter winters, drier summers and changes in the occurrence of pests also argue for an increase in the share of autumn crops. More knowledge about the interplay between crop growth, pests, weeds and quality in a changed climate is required, however. Continued plant refinement and the development of non-crop-specific growth models, which also include pests and quality aspects and which are adapted to changes in the climate, are examples of important areas. New, ecologically adapted cultivation methods and systems need to be developed with the aid of experiments and field trials. Efforts aimed at increased knowledge about growth-adapted fertilisation and ecologically sustainable ways of minimising pests should also be prioritised. Biotechnology and genetic engineering can also offer the potential to develop new, tailored varieties, although negative environmental effects and poor customer acceptance constitute obstacles. It is therefore vital to conduct more research within the area of agriculture and climate change.

Despite the fact that the conditions for agriculture in Sweden will generally improve, the risk of extensive crop damage as a consequence of extreme weather events, such as drought, intensive rain and flooding, will probably increase. A number of countries now have developed, state-financed or subsidised crop damage protection. Such national systems are permitted according to the EU's regulations, under certain conditions. On the other hand, as far as we can judge, no European country has a comprehensive insurance system without state subsidisation. In most cases, single farm payments under the EU's Common Agricultural Policy provide a basic income, regardless of the result of the harvest. We consider that, in the current situation, it is not appropriate to introduce a specific system based on state subsidisation for crop damage. This situation may change, however, if it should become evident that crop damage is becoming more extensive than we can currently predict, and if the basic support entailed by single farm payments is reduced or phased out. In order to create a foundation for future decisions, a more detailed analysis of crop damage linked to meteorological and climatological data should take place. During this analysis, the financial significance of the damage for individual farmers should also be documented.

Many agricultural operations are small companies or one-man companies, often with limited potential and resources to obtain information. Climate changes will have a significant impact on Swedish agriculture. There is therefore a great need to develop effective methods for conveying information about climate change and the effects of a changed climate on agriculture. Issues that should be looked at include the choice of crops, the split between autumn/spring sowing, drainage systems, watering, pests, fertilisers/leaching of nutrients including effective catch crops, developed cultivation systems and the used of control measures, as well as the impact of measures on the environment and biodiversity. Advice regarding long-term investments is particularly important.

Research and development

There is a considerable need for research in order to achieve effective adaptation of agriculture. Increased co-ordination of the research in this area is also desirable. We primarily see a need for:

- dynamics regarding climate change and the growth of crops, the impact on populations of pests, weeds and quality.
- developed, regionalised climate scenarios, modelling at a local/farm level.
- the impact of the climate on growth, quality, pests and weeds, as well as how developed cultivation systems, plant refinement and biological control measures can reduce pest problems and the need for control measures. This should include both modelling and field trials.
- research regarding nutrient leaching in a changed climate dependent on soil type, crop, fertilisation regime, tilling measures, altered growth and regarding the impact of nutrient cycling on other environmental goals, such as biodiversity, as well as methods for minimising negative effects.
- Research regarding animal health, fodder production and methods for managing the keeping of livestock for the greatest environmental benefit.
- Consequences of various adaptation measures in agriculture as regards the environment and biodiversity.

Proposals

- The instructions for the Swedish Board of Agriculture and the National Veterinary Institute should be amended so that responsibility for adaptation to a changed climate is clarified (see section 5.10.2).

- The Swedish Board of Agriculture should be commissioned:

  - in consultation with affected authorities and organisations, to chart the need for future watering and land drainage, as well as the status of existing drainage systems and embankments and the need for action. This charting process should be followed by proposed measures, including an assessment of costs and the need for any support systems.
  - in consultation with the Swedish Environmental Protection Agency, to propose a developed support system for wetlands where a premium is placed on their effectiveness as regards catching nutrients and their function for combined purposes such as biodiversity and the creation of watering reservoirs.
  - to review livestock protection regulations, including building standards and recommendations regarding housing primarily for pigs and poultry, with consideration for the risk of increased thermal stress and free-range operations outdoors.
  - in consultation with SMHI, the Swedish University of Agricultural Sciences and affected organisations, to develop a system for following up crop damage where the weather conditions at the time the damage occurred and the financial damage are documented.
  - in co-operation with agricultural organisations, to conduct extended information efforts for farmers regarding climate change and its effects on agriculture and the environment.

- The National Veterinary Institute should be commissioned, in co-operation with the Swedish Institute for Infectious Disease Control:
  - to monitor the development of the epidemiology of new and known infections as a consequence of climate change, and if necessary to take the initiative for measures aimed at maintaining a high level of disease control.
  - to take the initiative for research and to develop supporting information for continued training regarding infectious diseases for veterinarians.

4.4.3 The fishing industry

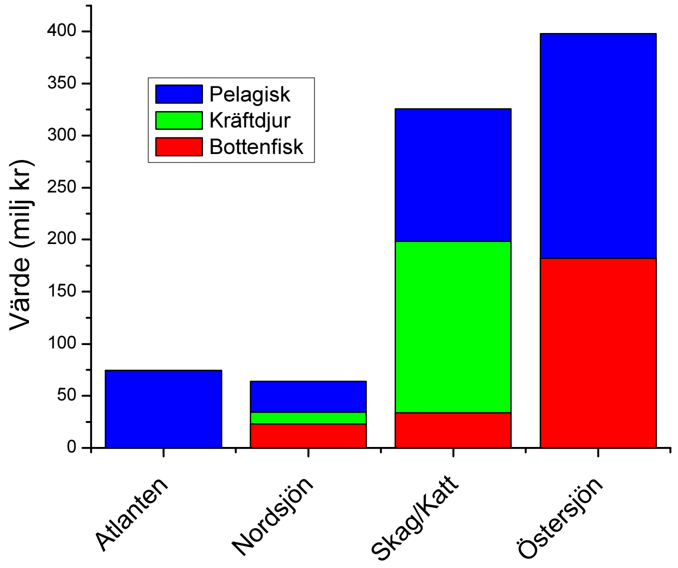
Major changes to ecosystems and to fishing can be anticipated in a warmer climate. Cod may be entirely wiped out in the Baltic Sea, and instead be replaced with freshwater species. Warm-water species will *replace cold-water species in lakes. Fishing in the North Sea and in certain lakes may benefit.*

The fishing industry – a hard-pressed sector

The Swedish fishing, aquaculture and production industry employs a total of around 5,000 people and has an annual turnover of around SEK 5 billion. Fishing is entirely dependent on the biological resources that the sea and waterways produce. In addition to the Baltic Sea (including the Gulf of Bothnia) and the North Sea, commercial fishing also takes place in the large lakes and in a number of small, fish-rich lakes.

Fishing quotas laid down by the EU restrict fishing for many species. Of our nine most common species, only the eel and the Torbay sole do not have quotas. Despite the restrictions, many fish stocks have declined in recent years. Swedish saltwater fishing has experienced a dramatic decline as regards income and profitability in recent years. Between 2002 and 2004, the landing value fell from SEK 1,174 million to SEK 830 million, or almost 30 percent. The distribution into different species groups and fishing areas can be seen from figure 4.42. Lake fishing has a total turnover of around SEK 50 million.

Figure 4.42 **Geographic distribution of total catch value in Swedish marine commercial fishing (average landing prices in 2004)**



Value (SEK millions)

Pelagic
Crustaceans
Bottom fish

Atlantic
North Sea
Skagerrak
Kattegat
Baltic Sea

Source: Appendix B 26.

The total number of licensed anglers fell from 2,900 to 1,900 between 1995 and 2002. During the same period, the number of vessels in the sea fishing fleet fell in total from 2,540 to 1,597 boats, primarily due to a decline in coastal fishing. Among large vessels targeting pelagic species, the overall gross tonnage increased by 19 percent.

Fishing’s focus in different areas

Fishing using passive tools (nets, fish traps, cages and long lines) is primarily conducted close to the home port. This also applies to vessels based along the south and east coasts that fish with active implements (trawls, dragnets). Larger west coast vessels, which fish for pelagic species such as herring/Baltic herring, mackerel and cod, operate in all waters that are available to Swedish fishing (Atlantic Ocean, North Sea, Skagerrak, Kattegat and the Baltic Sea). The largest quantity of caught fish, around 60 percent, comprises fish for reduction.

Coastal fishing in the Gulf of Bothnia is conducted primarily using small ships and boats. The most important species are vendace, salmon, common whitefish and Baltic herring. Leisure fishing is significant and is targeted mainly at perch, pike, burbot and brown trout.

Coastal fishing in the Baltic Proper is dominated by net fishing for cod and eel, often combined with fishing for flounder, turbot, herring/Baltic herring, pike, common whitefish and zander. Leisure coastal fishing in the Baltic is approximately as large as commercial fishing, if we ignore eel fishing.

In the saltier water in the Skagerrak and Kattegat, there are significantly more commercial fish species and a rich stock of shellfish. Eel, Norway lobster, crab, lobster and mussels are important species. Commercial fishing for mackerel is not very extensive, although for leisure fishing the mackerel is one of the most important species.

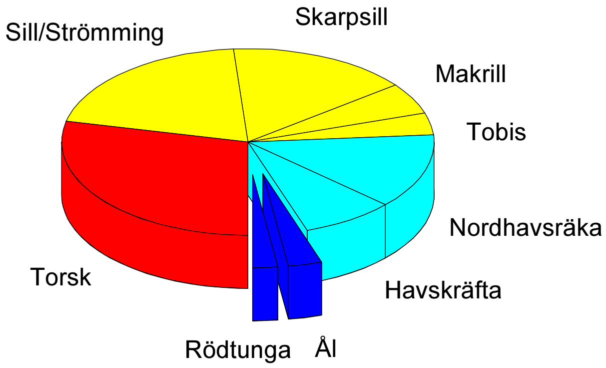
In Lake Vänern, zander and vendace are the most important species from an economic perspective. In Lake Vättern, crayfish fishing is most important. In Lakes Mälaren and Hjälmaren, fishing for zander is currently most important, although fishing for crayfish is also important in Lake Hjälmaren. In the lakes in Norrland, the yield is dominated by common whitefish and charr. In the nutrient-rich, small, southerly lakes, fishing is dominated by eel and zander.

Cod and the pelagic species are responsible for ¾ of the total catch value of Swedish fishing. Figure 4.43 shows the proportions by species for the nine dominant species (in terms of value), which in 2004 were responsible for more than 90 percent of the catch value. The remaining 10 percent is distributed between 56 different species.

Figure 4.43 **Distribution of catch value for the nine most important species in sea and coastal fishing in 2004. The total catch value was approximately SEK 870 million**

/medurs fr. Skarpsill/

European sprat
Mackerel
Sand eels
Northern shrimp
Crayfish
Eel
Torbay sole
Cod
Herring/Baltic herring



Source: Appendix B 26.

The Swedish production industry offers a broad product range, including everything from filleted herring, Baltic herring and cod to ready-made dishes and smoked products. The majority of the value comes from various types of herring product. The production industry and the specialised trade has a turnover of around SEK 4 billion annually and employs around 1,700 people.

Aquaculture including fish farming is relatively unimportant in Sweden, and the breeding of edible fish has declined in recent decades. There are a total of around 200 fish farms mainly producing salmon, around a hundred crayfish farms and some 20 oyster and blue mussel farms (Appendix B 34). Many companies have switched their operations so that they now focus on breeding in order to release their produce into its natural habitat. Aquaculture has an annual turnover of around SEK 220 million and employs around 200 people.

Temperature increases, salinity decreases and other climate factors changing the conditions for fish stocks

The temperature is one of the most fundamental factors for a fish's survival and growth. As the temperature rises, the metabolism increases up to an optimum temperature for each species, before declining at higher temperatures. For cold-water species such as common whitefish, herring/Baltic herring, European bullhead and cod, the optimum temperature is often around 15°C, while for warm-water species (e.g. perch, pike, carp, eel and shore crab) the optimum temperature is between 20–25°C. The flatfish flounder and turbot are examples of species that adopt an intermediate position.

An increase in temperature of 2.5–4.5°C, which is predicted in the scenarios towards the end of the century, will have various effects on fish communities depending on the depth conditions in the environment in question. The thermocline will be displaced away from the coastline, moving to a deeper level. This means that the warm-water species will have more space in which to live, at the expense of the cold-water species. The extent of the change will depend on the depth conditions in the environment in question. Living space for marine species in the Baltic Sea is expected to decrease due to the reduction in salinity that is predicted in most climate scenarios (see also section 4.5.3). The extent of the changes will depend on the extent of the reduction in salinity.

The flow situation in freshwater sources entering the Baltic will change, with less seasonal variation but a greater overall outflow, primarily from the rivers in Norrland. The anticipated reduced seasonal variations in the flow, primarily in Norrland's larger watercourses, can alter the conditions for the fish species that undertake annual migrations, as spawning and fry growth are adapted to peaks in plankton production in conjunction with spring and early summer peaks in the flows.

During the early stages of life, the fry's survival is heavily influenced by variations in access to food in the form of zooplankton. Changes in zooplankton levels will probably occur as a consequence of a changed climate. Plankton production can be affected by several climate-dependent factors. For example, the increased runoff with more transport of humus into the sea can result in a decrease in plankton production. Reduced uplift and sedimentation can favour plankton production, however. It is therefore uncertain what effects climate changes will have on the plankton stocks, as well as what the secondary effects on fish stocks will be.

Climate changes could wipe out cod fishing in the Baltic Sea

The extent of the decline of marine species in Baltic Sea is dependent on the extent of the reduction in salinity. Reduced salinity displaces the reproduction areas of the marine species to the south. With the considerable reductions in salinity that are outlined according to Echam4's scenarios, the changes will be more dramatic. The cod, which is so important for commercial fishing, will probably be completely wiped out in the Baltic Sea due to the disappearance of reproduction areas with sufficient salinity and oxygenation.

Cod fishing currently represents 25 percent of the total value of Swedish fishing, around SEK 200 million annually. The total loss of cod fishing in the Baltic Sea would have a very serious impact on a large proportion of the Swedish fishing industry, as the leading value-creating species in the Baltic would be lost. This would probably also have significant consequences for both employment and the cultural environment in smaller towns and fishing villages, primarily in south-eastern Sweden.

Major changes for other species in the Baltic Sea and the North Sea

Flatfish such as turbot, flounder, European plaice and common dab will decline. The most important pelagic species among the marine fish that are important for coastal fishing are the herring/Baltic herring and the European sprat. The latter will probably benefit from the increased water temperature relative to the herring, a trend that is already being observed today. However, the reduced salinity will entail increased physiological stress for the sprat as well. New species may also seriously disrupt the ecosystems. The American comb jelly, which has previously contributed to major changes to the ecosystems in the Black Sea, may now be on the way to establishing itself in the Baltic Sea (Swedish Board of Fisheries, 2007).

With a temperature increase of 2.5–4.5°C, warm-water species such as perch, pike and zander and their prey fish such as carp will establish themselves much more strongly towards the north. For perch and zander, there are clear links between generation strength and long, warm summers. Pike are probably affected in the same way. Commercial fishing for zander, perch and pike ought to be able to increase from today's low levels, provided the poor replenishment that is currently occurring in the Baltic Sea can be overcome (see table 4.32).

Table 4.32 **Catches of certain species by Swedish commercial and leisure fishing in the Baltic Sea, including the Gulf of Bothnia (tonnes/year)**

	Perch	Pike	Zander	Common whitefish	Vendace	Brown trout	Cod	Herring/Baltic herring	European sprat	Flatfish
Commercial fishing	105	47	35	200	800–900	30	10,000	70,000	100,000	500
Leisure fishing	1,000	1,300	75	400–600	little	>30	little	little	little	little

Source: Appendix B 26.

The conditions for the eels that come to our coastal waters will also improve, although the supply of incoming leptocephalus (transparent eel larva) are decisive for stock levels. Cold-water species such as common whitefish, vendace and brown trout are disadvantaged by higher temperatures, with poorer conditions for roe development and hatching. The spread of whitefish and vendace to the south will be favoured by the anticipated reduction in salinity, however. The coastal brown trout will be disadvantaged, particularly in the most southerly parts of the country.

In the marine environment on the west coast, there will probably be more fish and shellfish species that currently have a more southerly range. During the summer of 2007, large numbers of the Pacific oyster *(Crassostrea Gigas)* have been discovered along the west coast, which may be a result of higher water temperatures (Dagens Nyheter, 2007). Coastal stocks of warm-water species with freshwater origins can be expected to result in increased production, which will provide the conditions for an increased yield. An increased yield of marine warm-water species can be anticipated as a result of the inward migration from the south of species such as mullet and European sea bass. Increased bottom water temperatures also entail higher growth for lobsters, crabs and Norway lobster. Catches of Norway lobster have increased by 30 percent over the past two warm years, for example (see Appendix B 26).

Shift from cold-water species to warm-water species in freshwater

A mean temperature increase of 2.5–4.5°C will radically change the distribution pattern for various freshwater species and migrating species. Lakes in Gävleborg will have the same temperature regimes as currently experienced in lakes in Skåne, which in climate terms are in the lowlands of central France. Several of the species adapted to cold water, i.e. charr, burbot, European smelt, vendace, common whitefish, grayling, salmon and brown trout are economically important, and some of the non-commercial species such as the European smelt are key species and important prey fish. In southern Sweden, many stocks of vendace have already become weaker, probably as a result of shorter winters and reduced ice-cover. In Lake Vättern, there are indications that the recruitment of common whitefish and charr is following the same pattern. With higher summer temperatures, the thermal stratification in the summer is becoming more robust and more long-lasting. In combination with an increased supply of nutrients and increased production, there is an increased risk of oxygen deficiency and hydrogen sulphide formation in the bottom water. There is a risk of this resulting in unique charr stocks in southern Sweden being wiped out. Further warmer winters will also have a negative impact on the recruitment of salmon, despite a certain, gradual adaptation to the changed conditions. Despite this, total fish production will probably increase in fresh water, as the warm-water species, including commercially important species such as pike, zander and perch, will be able to spread further across the country due to higher temperatures and an increased supply of nutrients to watercourses as a result of increased runoff. The distribution of crayfish should also increase in northern Sweden.

Increased frequency of extreme high flows means that river channels will be changed, and the transport of sediment will change within the channels. Generally speaking, all major watercourses have now been actively cleaned and channelled to some extent, and for many species, such as salmon and lampreys, important spawning substrates such as gravel have disappeared. Increased runoff can further contribute to the impoverishment of fish fauna, in particular salmon production. Warmer summers will entail longer periods with a low water supply. Summer droughts are already resulting in the deaths of up to around 10 percent of the natural production of smolt (juvenile fish leaving the rivers) in south-western Sweden.

Increased catches in the major lakes in a warmer climate

Common whitefish and vendace are expected to decrease in *Lake Vänern* (see Appendix B 26). Vendace that spawn early in the autumn have already disappeared, while common whitefish have not yet been affected. Vendace currently (2006) command a value of SEK 6.4 million, while common whitefish generate SEK 2.5 million. Other species that spawn in lakes, including pike, zander and perch, will all benefit. The zander is already the most important species in Lake Vänern in financial terms, worth SEK 5.5 million in 2006. The yield of zander may double in less than 100 years.

In *Lake Vättern*, the typical cold-water species of common whitefish and charr will probably decline further. It will probably become impossible to conduct any commercial fishing of these species. The warm-water species, which are mostly found in the archipelago areas, will be able to spread out. None of these species currently has any particular economic value. Catches of signal crayfish, currently the most important species, should be able to increase significantly, perhaps by around 50 percent, provided mortality and stress factors are kept down. The current level equates to around SEK 11 million.

Pike, perch and zander will increase in *Lake Mälaren*. An increase in yield for zander in the order of at least 50 percent from today's SEK 8.2 million is possible.

Lake Hjälmaren is dominated by warm-water species, burbot and European smelt. As the lake is shallow and circulates fully, the entire water mass has the same temperature in the summer. Catches of zander have increased from 167 tonnes to 288 tonnes (equivalent to SEK 13.7 million) over the past two years, thanks to warm summers and autumns, considerate fishing and an increased minimum fish size. A further increase of around 25 percent should be possible in the future.

In total, the yield of crayfish and zander in the large lakes should be able to increase by SEK 15–20 million annually.

More perch and pike in Norrland's lakes – fewer brown trout and charr

Significant changes can also be anticipated in smaller lakes. On the basis of yield and climate data from Swedish lakes during the period 1920–1960, the Swedish Board of Fisheries has simulated how the yield from lakes measuring between 1,000–10,000 hectares may change in a changed climate in four Swedish regions (see Appendix B 26). Based on anticipated changes in species structure and yield at an annual mean temperature increase of 3°C, there will be considerable biological effects. The economic effects will vary between different regions in Sweden, but in total the yield is predicted to increase by 10–20 percent or by SEK 1–2 million annually. This is largely because the price per kilo for zander, which are benefiting, is higher than for other species, with the exception of charr. In inland parts of Norrland, a decrease in yield of around 10 percent is predicted, as the loss of brown trout and charr will not be compensated by a corresponding increase in perch and pike. If these fish were to have the opportunity to spread freely and colonise new water systems, the average economic yield would increase by around 20–40 percent.

Salmon threatened in southern Sweden's watercourses

A warmer climate will result in salmon production ceasing in southerly watercourses such as Mörrumsån. On the other hand, production of young salmon, known as smolt, should increase significantly in Norrland's rivers. The development of access to prey fish in these watercourses is decisive, however, as is the extent to which higher temperatures result in better smolt production. Whether increased salmon production in Norrland's rivers can be utilised by the fishing industry depends for example on relatively complex links between temperatures and ice conditions in various parts of the Baltic Sea and the Gulf of Bothnia, as well as the change in the runoff conditions in Norrland's rivers.

Reduced number of fishing days in a changed climate

The most tangible effect of climate change on the fishing sector's potential to conduct fishing is the effect on wind conditions. Net fishing and trawling using smaller boats is extremely weather dependent, for example. For net fishing, the restricting factor in many cases is that the bottom currents increase at high wind speeds, and loose material such as red algae is driven into the net. This is a major problem in the southern Baltic Sea, which in practice sets and upper limit for fishing at a wind speed of around 10 m/s. Bottom trawling for Norway lobster on the west coast takes place to a large extent using small, one-man boats. Here, the potential to work is greatly restricted at wind speeds above 12–14 m/s. Cage fishing for crayfish and lobsters also experiences problems at such wind speeds.

Table 4.33 presents an estimate of the number of days that the most weather-sensitive fishing activities are expected to lose as a result of excessive winds, according to the climate scenarios studied by the investigation. All the scenarios entail an increase in the number of lost fishing days, and hence an overall reduction in the catch. It should be noted that a reduction in the number of fishing days does not necessarily entail reduced catches in total. The difference between Echam4's and HadAM3H's climate models is greater than the differences between scenarios A2 and B2 (see also Appendix B 26).

Table 4.33 Effects of increased frequency of high wind speeds on various types of fishing. The number of vessels and fishing day relates to data for 2005 and to vessels with total fishing of more than two times the basic amount.

Fish category	Active vessels	Fishing days	Weather limit	Increase in days above the weather limit		Percentage increase		Reduction in fishing, SEK millions	
	Number	Number	m/s	EC A2	EC B2	EC A2	EC B2	EC A2	EC B2
Cod nets, Baltic Sea	171	123	10	15	10	8%	5%	7.3	4.9
Trawlers < 24 m, Baltic Sea	49	148	14	20	15	13%	10%	12.3	9.2
Cage fishing, crayfish	45	113	10	15	10	8%	6%	1.4	0.9
Crayfish trawling	67	120	14	25	20	21%	17%	14.1	11.3
Prawn trawling	46	161	14	25	20	19%	15%	19.0	15.2
Total								54	41

Source: Appendix B 26.

Other types of fishing take place using large vessels and are less weather sensitive, although an increase in the number of storms will limit the fishing potential for this category as well. Some adaptation of the equipment is expected to take place over time to cope with the more difficult climate conditions.

Adaptation measures and considerations

Changes to the climate will entail significant changes to the preconditions for fishing. The biogeochemical processes in the sea, and the affect that climate changes have on them, are still poorly understood. The same applies to the effects of climate change on the leaching of nutrients and the extent of the changes to the salinity of the Baltic Sea (see also section 4.5.3). Despite a relatively good understanding of the temperature changes that will result from the changes to climate, it is therefore difficult to draw more far-reaching conclusions on how fish stocks and the conditions for fishing may alter in a changed climate, particularly in the Baltic Sea's complex brackish water system. It is consequently also difficult to identify suitable adaptation measures and how the fishing sector may be affected. As a basis for future decisions, it would however be appropriate to study in greater detail the consequences of the most important species, cod, stopping reproducing in the Baltic.

In the short term, continued work on restricting fish catches is probably the main effect of climate change. Research into the changes in the longer term, for example as regards decreased salinity and the supply of nutrients, as well as regarding the biogeochemical processes in the sea and plankton production, is needed in order to chart the effect that decisions on restricting fishing may have on different species (see also section 4.5.3).

In freshwater and in the North Sea, there is a clearer trend towards greater numbers of warm-water species and a greater spread of these northwards. To make it easier for species to spread to new lake systems and thereby to facilitate the preservation of a particular fish, even when cold-water species are declining due to climate change, it is essential for migration opportunities between and within water systems to be maintained or increased. Alternatively, the artificial distribution of fish can be considered.

Research and development

There is a considerable need for research when it comes to understanding the complicated conditions and ecosystems in the Baltic Sea, and we consider that further measures will be necessary in order to improve the basic understanding of the system and how it is affected by climate change (see also section 4.5.3). More specific research efforts aimed at describing fish populations and changes include the development of species-specific models regarding bioenergetics and growth, recruitment and energy allocation. In addition, population and community models need to be developed. The models also need to be tested and verified against existing and newly collated material regarding effects in and of e.g. natural yearly variations in temperature, for example can the 1980s be compared with the 1990s, north/south temperature gradients and effects in cooling water recipients.

Proposals

- The instruction for the Swedish Board of Fisheries should be amended so that responsibility for adaptation to a changed climate is clarified, see section 5.10.2.

- The Swedish Board of Fisheries should be commissioned, in consultation with the Swedish Environmental Protection Agency, to identify prioritised measures for the spreading of fish, such as removing migration barriers in order to maintain/create new fish stocks and freshwater fishing in a changed climate.

- The Swedish Board of Fisheries should be commissioned to examine the effects on the Swedish fishing industry should the cod stop reproducing in the Baltic Sea.

4.4.4 Reindeer herding

The conditions for conducting reindeer herding in Sweden will be seriously affected by climate change. The growing season could be extended and plant production during the summer grazing is expected to increase. Insect plagues could become worse and the snow conditions in the winter will become more difficult. The bare mountain areas above the tree line are expected to decrease, which could lead to more frequent conflicts of interest with other sectors.

The right to conduct reindeer husbandry in Sweden is reserved for the Sami and is founded on ancient tradition. This right is decisive for the preservation of the Sami culture and identity. There are around 3,500 reindeer-owning Sami and just over 900 reindeer herding companies in Sweden. In addition there are around 1,000 reindeer owners of non-Sami origin, for whom the Sami undertake reindeer husbandry in concession Sami villages. There are a total of around 230,000 reindeer in Sweden, although the number varies considerably from year to year (Moen & Danell, 2003). The economic scope of reindeer herding is small in relation to Sweden's overall economy. However, it is important for the local economy in sparsely populated areas in Norrland's inland and mountainous regions. Recent research has also shown that reindeer grazing is extremely important for maintaining open countryside in the mountains and for preserving biodiversity (see section 4.5.1).

Reindeer's seasonal migrations and search for food, and reindeer husbandry's vulnerability to extreme weather

Reindeer live naturally in herds. The calves are born in the spring/early summer. During the summer, the reindeer build up body reserves of fat and protein. At this time, they live mostly on grass and herbs that can be found in the mountains. In the summer months, reindeer prefer to keep to high terrain (on the bare mountain region above the tree line) or on patches of snow in order to keep cool and obtain protection against insects. In the winter, reindeer graze mainly on lichen, primarily ground-growing reindeer lichen, which grows in the forest areas inland and down towards the coast. In difficult grazing conditions, access to hanging lichens forms an important supplement. Supplementary feeding may also be required. The reindeer herds migrate between summer and winter pastures. This migration generally takes place along the river valleys. Extended infrastructure, altered land usage, dense, uncleared young forest and difficult snow and ice conditions can constitute problems during these migrations. While the reindeer are grazing, they move across large areas to find the plants that are most suitable as food. The reindeer strain found in Sweden are domesticated, although much of their original way of life remains.

Reindeer herding is regulated in the Reindeer Husbandry Act dating from 1971 (SFS 1971:437), as well as certain other laws and ordinances. According to this Act, reindeer husbandry may be carried out by people who are members of Sami villages. Sami villages are both legal entities and a specific grazing area covering land with various owners.

Reindeer herding is carried out according to the needs of the reindeer at different times of the year: land that is situated inland may be used all year round; land down towards the Swedish coast may only be used for reindeer grazing in the winter, i.e. 1 October–30 April (see §3 of the Reindeer Husbandry Act). The Sami villages that move reindeer husbandry from mountainous areas down to the forests and coastal regions are generally known as mountain Sami villages, while forest Sami villages tend to follow the same pattern although covering less extensive areas.

In Sweden, reindeer herding is conducted in just about all of Norrbotten, Västerbotten and Jämtland counties, as well as in parts of Dalarna and Västernorrland. The reindeer husbandry areas makes up around a third of Sweden's land area (Boundaries Delimitation Committee, 2006). The right to conduct reindeer herding is a constitutional civil right, in a corresponding way to proprietary rights. Different types of business and operations can be conducted on the same land. The land is consequently subject to different layers of entitlements. As the reindeer husbandry entitlement is such a special right as regards real property, the Reindeer Husbandry Act is structured in such a way that it deviates at times from usual classifications within the legal system. Its structure means that application difficulties can arise in certain respects. One such difficulty is that, with regard to the winter pasture, it is only specified that it covers land where there are ancient claims. The area is consequently not geographically determined. In several cases, this lack of clarity has given rise to disputes that are taken to the courts by land owners, who have applied for a ruling to establish that there are no grazing rights on their property. In those cases where the courts have adjudicated on the matter, this has been preceded by an extremely protracted hearing, and the parties have incurred significant investigative and legal costs in the cases. The Härjedal case alone cost the Sami villages around SEK 15 million. In some cases, however, a court decision has come about without the court examining the matter, due in every such case to the Sami side considering that it did not have the financial strength to submit a defence (Boundaries Delimitation Committee, 2006; National Association of Swedish Sami, 2007).

Consequences of climate change and extreme weather events

Two positive effects of the climate changes demonstrated in the scenarios are that plant production when there is no snow on the ground (summer grazing) can increase by 20–40 percent and that the growing season can be extended by around a month (Danell, 2007). Towards the end of the century, the growing season may be extended by up to 2–3 months. The lengthening of the time with no snow on the ground and the shorter winters are positive for reindeer. Snow-free grazing is more nutritious than winter grazing, and it is during this season that the reindeer build up their reserves of fat and protein to see them through the winter. The presence of small trees, herbs and grass in the mountains is expected to increase, which is positive for the reindeer as it means increased access to food. The quality of pasture is important for the reindeer's growth and wellbeing. However, it is not certain how this will be affected in a changed climate (Arvidsjaur, 2007; Danell, 2007; Moen, 2006). On the whole, mountain flora are relatively robust against environmental changes and have a considerable buffer capacity. If this buffer capacity is exceeded, however, there is a risk of abrupt and extensive changes to the mountain flora (Moen, 2006). However, climate changes can result in plants that were previously unable to survive in mountain environments, but that are more competitive than mountain flora in a milder climate, spreading into the mountain environment. There are already indications of major changes in the mountain flora.

The negative effects include the expectation that the bare mountain areas above the tree line will shrink, which will increase grazing pressure in the mountains, particularly in the long term, if the current reindeer numbers are maintained. The southern parts of the mountain chain are likely to be particularly susceptible. The anticipated higher temperatures in the summer can entail problems for the reindeer, as they do not like heat. A changed climate with higher temperatures and increased precipitation can result in much worse insect plagues, such as the reindeer nose bot fly *(Cephenemyia trompe)* and the warble fly *(Hypoderma tarandi)* (Danell, 2007; Moen, 2006). The worst insect situations arise in warm, damp conditions, which are likely to become increasingly common according to the climate scenarios. It may also become more difficult for the reindeer to avoid insect plagues due to the shrinking bare mountain environments and fewer patches of snow. The occurrence of parasites, including tissue worms and meningeal worms, can increase as a consequence of a higher temperature. There is also a risk of new parasites and diseases spreading.

According to the climate scenarios, the winters will become warmer and wetter (see Appendix B 27). There appears to be an increasing risk of difficult snow conditions, with ice and frozen crusts on snow that are very difficult for the reindeer to penetrate when looking for food, as the amount of rain in the winter will increase according to the scenarios. At the same time, the temperature will alternate more frequently above and below freezing point. Norrland's coastal areas may become snow-free for long periods, however, even in the depths of winter. An increase in the occurrence of ice and frozen crusts can result in the reindeer having poorer winter grazing, causing them to have to utilise the body fat reserves built up during summer grazing to a greater extent, with reduced fitness as a consequence (Moen, 2006). In other words, there is a risk that the problematic conditions that prevailed in large parts of the reindeer grazing area during the 2006/2007 winter could become more common. There is a link between winters with difficult snow conditions and significant reductions in the size of the reindeer population (Callaghan et al, 2004). Difficult snow, frozen crust and ice conditions mean that it will be necessary to provide supplementary food for the reindeer to an increased extent. Supplementary feeding is expensive. It can cost around SEK 4 per day per reindeer, or SEK 2,000 per day for a herd of 500 reindeer. For the owner of a herd of 500 reindeer, with an annual turnover of perhaps SEK 400,000–500,000 (National Association of Swedish Sami, 2005), finances are soon put under strain in the event of prolonged periods of supplementary feeding. The national budget contains a grant (45:1 Promotion of reindeer herding etc.) of SEK 46.7 million (2007) for support to promote reindeer herding, which should cover price support at slaughter and expenses in the event of supplementary feeding, etc. The difficult snow conditions in the 2006/2007 winter meant that SEK 37 million had to be added to the grant as a consequence of extensive supplementary feeding. A potential increase in the number of pine trees in areas where spruce have traditionally grown, combined with denser forest, can also cause problems for winter grazing.

Increased precipitation can have negative consequences, as the potential to move the reindeer is impaired when there are high water flows (Arvidsjaur, 2007). The reindeer's potential to migrate from their summer pasture to their winter pasture may be impaired in particular. Reindeer migration routes often cross ice-covered watercourses. Milder winters, with thinner ice and shorter periods when the watercourses are ice-covered, can result in these routes no longer being passable.

Forestry is probably the industry that most affects the conditions for conducting reindeer husbandry. A dialogue should now take place between forest owners, primarily forestry companies, and reindeer owners within the year-round areas according to § 20 of the Forestry Act. Certain other rules giving consideration to reindeer herding can also be found in the Forestry Act. In a future climate, the opportunities for conducting forestry will probably move northwards and higher up in the mountains, while forest growth will also increase throughout the reindeer herding region. This ought to promote more intensive forestry and a desire to expand forestry into areas where it is not currently possible to carry out such operations. At the same time, climate changes may encourage an increased concentration of reindeer in certain areas, particularly near to the coast, during difficult grazing years. As a result, there will be an increased risk of conflicts of interest between forestry and reindeer herding.

It is very likely that climate changes, alongside socioeconomic developments including a probable future intensification of forestry, development of infrastructure, increased tourism, etc., will increase the risk of conflicts of interest between reindeer herding and other interests as regards land usage. Some forms of tourism are already in conflict with reindeer herding. For example, dog teams and snowmobiles disturb the reindeer herds. With a reduction in bare mountain areas above the tree line, tourism and reindeer herding will probably both be concentrated on the remaining mountain areas, with a potential increase in the risk of conflicts of interest.

There is also a risk of conflicts regarding land use between reindeer herding infrastructure, mining, wind power, space operations and military exercises.

A warmer climate that favours agriculture in northern Sweden may also become a source of increased land usage conflicts. New competition for summer pasture may also arise, for example with roe deer, which are spreading northwards. An increase in the roe deer population and other prey animals can in turn increase the presence of predators. More forest-clad mountains can also result in such an increase (Arvidsjaur, 2007).

Adaptation measures and considerations

Reindeer herding is not particularly important from a national economic perspective, but it is very important for the local economy in sparsely populated areas and for the preservation of mountain environments. The Sami as an indigenous people and reindeer husbandry deliver culture and environmental values that are difficult to translate into economic terms. The reindeer herding policy should be formulated so that it creates the conditions for sustainable and robust reindeer herding in a changed climate.

As far as we can tell, there are a number of measures that can be taken at a low cost or that are profitable. Examples of such measures include increased clearing, replanting with pine (not spruce), more considerate ground preparation and greater consideration when felling in dry pine areas with a large proportion of reindeer lichen in the ground vegetation. In addition, increased extraction of biofuel should also improve accessibility for reindeer during their migrations. The Swedish Forest Agency should be commissioned, alongside the Sami Parliament, to identify essential winter grazing areas where e.g. more considerate ground preparation should be used. The starting point should be the material produced by the county administrative boards regarding the grazing quality of various areas. The Swedish Forest Agency and the Sami Parliament should also analyse and submit proposals for other measures that facilitate the avoidance of conflicts of interest between forestry and reindeer herding. In addition, the demands for consultation in accordance with § 20 of the Forestry Act should be extended to cover all reindeer grazing land.

Tourism is already having a disruptive impact on reindeer herding in some cases. In a future climate, reindeer herding and tourism will be competing for shrinking mountain areas. It should be possible for conditions to exist for reindeer herding to be conducted side-by-side with the tourism industry, as long as there is mutual consideration. Reindeer herding contributes to maintaining open mountain expanses, the landscape on which tourism in the area is largely based. Some regulation of tourism in areas that are sensitive for reindeer herding may be necessary, and the Sami may need to be given more opportunities to influence how tourism is shaped in these areas. There is also a need to review which areas are of most importance for each sector and to identify where co-operation is possible. One possible route is to appoint areas of national interest (see also section 4.4.5). It is also necessary to develop and formalise forms of consultation between reindeer herding and the tourism sector.

Consideration should also be given to whether Sami villages should be given the opportunity to conduct other businesses that are compatible with reindeer husbandry and Sami culture. Examples of such businesses include tourism and nature management. *A* *new reindeer herding policy – open Sami villages and co-operation with other land users* (SOU 2001:101) proposes lifting the ban on Sami villages conducting operations other than reindeer herding. The proposal is currently being prepared in the Swedish Government Offices. This study supports the proposal of Sami villages being given the opportunity to conduct other businesses that are compatible with reindeer husbandry and Sami culture.

When planning infrastructure and other facilities, consideration should be given to the fact that reindeer herding may need to find alternative migration routes in a changed climate. In some cases, this relates to areas where it has not previously been necessary to give consideration to reindeer herding. Future infrastructure solutions should be designed in such a way as to guarantee accessibility for the reindeer. In conjunction with the application of the Environmental Impact Assessment and the Strategic Environmental Assessment when investing in infrastructure, greater consideration should be given to the effects of climate change on reindeer herding.

The altered conditions for reindeer herding in a future climate will stipulate increased demands for flexibility. The period of time when land situated down near the Swedish coast may be used for winter grazing, currently 1 October to 30 April, may in future need to be adapted to a shorter winter season. Such an adaptation could potentially make land-owners better disposed to other proposed adaptation measures.

The Reindeer Husbandry Act in its existing form results in extensive, costly court processes in the event of land conflicts. The legislation appears in many respects to be obsolete. On this basis, the Boundaries Delimitation Committee concluded that conflicts regard the Sami's land rights should primarily be resolved through agreements between the parties to the case. In a future climate, in which we can expect more difficult snow conditions corresponding to those experienced in the 2006/2007 winter, it is probable that winter grazing areas other than those used at present will be of interest to reindeer herding. In years when it is evident that the most suitable winter pastures wholly or partially comprise areas with no established reindeer grazing entitlement, reindeer grazing agreements could be entered into where the private land owner receives compensation. It should be possible for the grant supporting for the promotion of reindeer herding to be used to finance such contractual solutions with land owners. By entering into contractual solutions on an ad hoc basis, where suitable winter pasture is identified with regard to the particular circumstances in the year in question, the need for costly supplementary feeding limited, as are the number of very costly court processes. In future, Government grant 45:1 Promotion of reindeer herding etc. will be burdened by expenditure arising as a consequence of agreements entered into with land owners regarding winter grazing, and as a result the grant in question should be extended. The grant should be increased from the current level of SEK 46.7 million (2007) to SEK 60 million per year. An increase of SEK 13.3 million per year to cover costs arising as a result of agreements entered into regarding winter grazing is justified, as it can limit costs for both supplementary feeding and court proceedings. These costs, added together as well as individually, greatly exceed the proposed figure of SEK 13.3 million per annum. The outcome and the effects of Government grant 45:1 being increased to SEK 60 million annually, and subsequently also being burdened with expenditure arising as a result of agreements entered into with land owners regarding winter grazing, should be evaluated after ten years.

Research and development

There is a need to investigate how reindeer herding and conditions for the Sami will be affected by the climate changes.

The development of analysis methods and modelling of grazing biotopes in order better to estimate future access to pasture in summer and winter are examples of research that could make things easier for reindeer herding in a changed climate.

Proposals

- The Swedish Forest Agency should be commissioned, in consultation with the Sami Parliament, to propose further measures, including changes to current regulations, to ensure that forestry shows greater consideration in the reindeer husbandry area, as well as to identify essential winter grazing areas where e.g. considerate land preparation should be employed.

- It should also be possible in future for Government grant 45:1 Promotion of reindeer herding etc. to be used for expenditure arising as a consequence of agreements entered into with land owners regarding winter grazing.
- Government grant 45:1 Promotion of reindeer herding etc. should be increased to SEK 60 million per year as a result of the fact that it should be possible in future to use the grant for expenditure arising as a consequence of agreements entered into with land owners regarding winter grazing.
- § 20 of the Forestry Act (1979:429) should be amended so that liability for consultation ahead of felling is extended to the entire reindeer grazing area (see chapter 1).
- The County Administrative Boards in Dalarna, Jämtland, Norrbotten, Västerbotten and Västernorrland should, in consultation with Nutek (Swedish Agency for Economic and Regional Growth) and the Sami Parliament, be commissioned to develop forms of dialogue between reindeer herding and tourism as well as other businesses in the reindeer grazing area.
- Nutek, the Swedish Environmental Protection Agency and the Sami Parliament should be commissioned, within their respective areas of responsibility and in consultation with each other, to highlight mountainous areas of national interest for tourism, outdoor activities and reindeer herding (see also section 4.5.1).
- The Swedish Environmental Protection Agency, the National Board of Housing, Building and Planning, and the Sami Parliament, should be commissioned to propose how the effects of climate change on reindeer herding can be taken into account in Environmental Impact Assessments and Strategic Environmental Assessments.

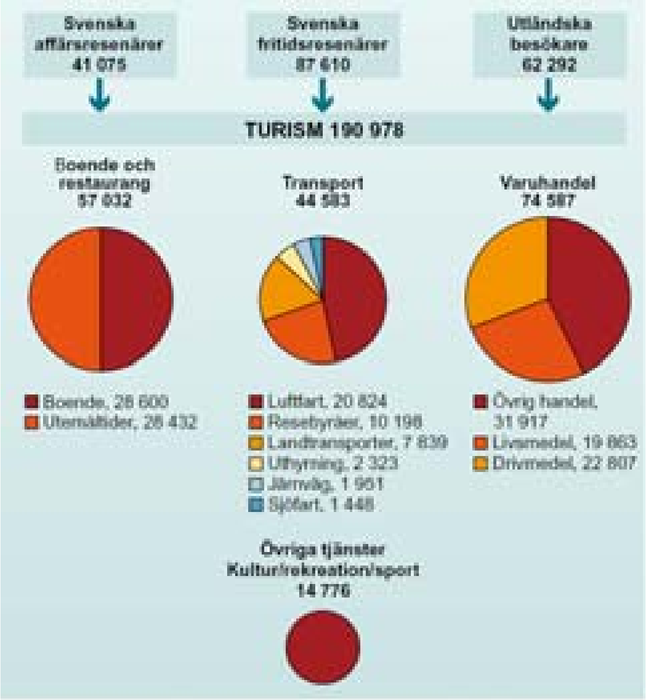
4.4.5 Tourism and outdoor activities

The rapidly growing tourism industry can achieve even greater potential in a changed climate, with warmer summers and higher bathing temperatures. Water resources and quality will be key issues, however. Winter tourism and outdoor activities will be confronted with gradually less snowy winters, particularly in the southern *mountains. With forward-looking adaptation, competitiveness can probably be maintained, at least over the next few decades.*

The tourism industry – a growing sector

The tourism industry is an important and growing sector in Sweden. In 2006, the combined turnover was around SEK 215 billion, almost 3 percent of GNP in total sales. This was almost 11 percent more than the year before and 90 percent more than in 1995 at current prices. This strong growth is largely following the international trend of strongly expanding tourism. Income in the tourism sector arises primarily within the sale of goods, accommodation and restaurant visits (see figure 4.44).

Figure 4.44 Distribution of the tourism industry's total turnover in 2005, SEK thousands



Swedish business travellers
Swedish leisure travellers
Foreign visitors

Tourism

Accommodation and restaurants
Accommodation
Meals out

Transport
Air travel
Travel agencies
Land transport
Hire
Railway
Shipping

Goods shopping
Other shopping
Food
Fuel

Other services
Culture/recreation/sport

Source: Nutek/Statistics Sweden.

The sector is also important in terms of employment. In 2005 almost 140,000 people were employed in tourism, calculated in man-years. Tourism is particularly important regionally in some sparsely populated parts of the country. The counties of Jämtland, Dalarna and Gotland head the list when looking at the proportion of accommodation income per inhabitant (Nutek, 2007).

Many Swedes devote a considerable part of their free time to outdoor activities. The Swedish Association for Outdoor Life channels some of this interest, with approximately 10,000 leaders and 100,000 members (Swedish Association for Outdoor Life, 2007).

Both tourism and outdoor activities, as well as the tourism industry, are very complex phenomena, and there are hardly any simple methods for either defining or describing them in an unambiguous way. By studying the primary reasons behind the choice of destination, however, it is possible to gain a good overview. The reasons for travel frequently include visiting friends and acquaintances, attending conferences and similar activities, and in this respect climate factors generally play a subordinate role in the choice of destination. Another common reason for travelling is to participate in an activity, such as skiing.

If we look at the regional distribution of tourism based on participation in an activity, the ‘skiing counties’ are at the top of the list. In 2003, Dalarna had more than 3 million visitors, with Jämtland in second place (Swedish Tourist Authority, 2005). The number of days spent by visitors at ski-lift centres makes up around 7 percent of all visitor days at the approx. 2,000 most popular visitor destinations in Sweden (see table 4.34). In the 2004–2005 season, the Swedish alpine industry’s total turnover was approximately SEK 900 million (Moen et al, 2007).

Table 4.34 Number of visitors who primarily chose a destination for a specific activity (statistics from the approx. 2,000 most popular destinations in Sweden)

Principal category	Sub-category	Number of visitor destinations	Total 1998	Total 2003
Activity	Bathing	60	8,740,536	10,867,768
Golf	Golf	131	905,719	1,039,283
Ski lift centre	Ski lift centre	66	5,428,917	6,914,313
	Other indoor	20	959,868	1,442,995
	Other outdoor	103	1,226,716	1,361,836
Total activity		380	17,261,756	21,626,195
Total (also other travel reasons)		2,123	103,744,916	110,260,370

Source: Swedish Tourist Authority, 2005.

Visits to holiday cottages are another common reason for travelling. The attraction and hence the existence of holiday cottages will be affected in the longer term by a location's climatic conditions.

Climate change – one of many governing external factors

Many external factors affect our choices when it comes to tourism and outdoor activities. The general socioeconomic trend, such as the population's age structure, economic growth and transport costs, are some of the factors that govern travel. Climate factors are also important, however, and interact with the above socioeconomic factors. The tourism industry and outdoor activities are weather and climate dependent to varying degrees.

Climate changes will affect tourists' choice of travel destination, and this can result in altered profitability and, in the long run, the elimination of companies associated with certain destinations; at the same time, others may benefit and new ones may develop.

Tourism linked to outdoor activities is particularly weather and climate dependent. Bathing and skiing tourism have been identified as important by other investigations (e.g. Sievänen et al, 2005), and these are also responsible for a significant volume in Sweden. Furthermore, climate change may directly influence the conditions for certain types of outdoor activity, such as cross-country skiing. Indirect effects such as a changed forest landscape, more ticks or other unpleasant animals may also affect outdoor activities. It has already been shown that the population's preferences for recreation and outdoor activities change with the climate. For example, the proportion of the population participating in cross-country skiing declines when there is a reduction in access to snow close to where people live (Sievänen et al, 2005).

Climate changes also affect the investment strategies of companies engaged in the tourism industry. The fact that tourism is a relatively fragmented industry with many small players means that few of these have succeeded so far in building up knowledge and acting strategically ahead of future climate changes. Small and locally-based companies also have limited opportunities to steer their investments towards other areas. Larger companies generally have different opportunities to take changes in the climate into account when making investment decisions, and can allocate investments to areas and activities that they believe will benefit from climate change. Such considerations are already being employed. One example of this is Holiday Club (Östersund, 2007).

Effects of climate change on summer tourism

A warmer climate will entail a lengthening of the summer season. The conditions for summer activities such as bathing, camping, hiking and golf will be improved as a result of the longer season. Towards the end of the century, September may have roughly the same monthly average temperature as August enjoys today, and the average temperature in May could start to approach that which we currently experience in June. Bathing temperatures will become more pleasant during the summer along our coasts and in our lakes. Towards the end of the century, the water temperature in the Baltic Sea in the summer (June–August) will be 2–4°C higher than at present (see section 3.5.4). In the summer, both the amount of precipitation and the number of days on which precipitation occurs will fall in southern Sweden, while the number of hours of sunshine is expected to increase somewhat. This should benefit bathing-related tourism and outdoor activities linked to the sea and lakes. One area of worry is the increasing risk of erosion, primarily along the coasts of southern Sweden, which can result in the destruction of beaches that are currently popular.

There is a great deal to indicate that summer tourism in the Mediterranean will be severely affected, since the temperatures there are expected to rise significantly more than the global average. At the same time, access to fresh water is expected to decline (Viner, 2007). Every year there are more than a billion overnight stays in the four Mediterranean countries of France, Italy, Spain and Greece. This is equivalent to roughly half of all overnight stays in the EU25. Spain, France and Italy alone are responsible for more than 1/3 of all tourist trips within the EU lasting at least 4 nights (Eurostat, 2007). The flow of tourists to the Mediterranean will probably decrease during the warmest summer months, to the benefit of the Baltic region (Appendix B 28). If just a small proportion of those people who currently travel to Mediterranean countries come to Scandinavia instead, this will entail a significant increase in visitor pressure in Sweden. In a sample calculation in which 1 percent of Mediterranean tourism shifts to Sweden, the number of overnight stays increases by 10 million, equivalent to approximately a doubling of the total number of overnight stays throughout the year in the whole of Sweden. Calculated on today's income level for accommodation, this would be equivalent to almost SEK 30 billion/year in today's monetary value, excluding everything apart from accommodation

The water quality in our lakes and sea and the occurrence of algal blooms will probably become a key issue for the development of summer tourism. Some tourist locations may suffer impaired water quality, while other, more 'fortunate' destinations may see overcrowding, queues and traffic congestion (Sievänen et al, 2005). A series of interviews carried out by the study (presented in Appendix B 29) showed that algal blooms play a limited role in the choice of destination of tourists travelling to Öland. Only a relatively small number of people were interviewed, however, and these were primarily people with links to Öland.

Other effects may also arise through increased flows of tourists to our country in the summer. One trend that has continued for several years is the increase in close-to-nature tourism activities such as white-water rafting, canyoning, mountain-biking, paragliding, etc. At the same time, traditional fell and hiking tourism are still important. In the long term, the bare mountain area above the tree line may retreat significantly upwards and to the north (see figure 4.45). With a continued expansion of various forms of activity-based tourism linked to the mountain environment, there is an increased risk of conflicts of interest over land, for example with reindeer herding.

Figure 4.45 **Example of how the bare mountain area could diminish in a warmer climate**

Source: Swedish Environmental Protection Agency & SMHI, 2003.

Effects of climate change on winter tourism

The significant increase in winter temperature that is predicted in the climate scenarios will entail major changes in winter dynamics, including in the mountains. By 2020, the average temperature will have risen by around 2–3°C throughout basically the whole of the winter season (November–March). In a normal year, the temperature in November and March will consequently be approaching 0°C in the Dalafjällen mountains. If we assume the same deviation as during the 20th century, the average temperature in a very warm year will climb above 0°C in January in several places; in fact, only the Lapland mountains and the highest parts of southern Norrland's mountainous regions will avoid this.

By the 2050s, the temperature will increase by between 2.5–4°C during November–March. In mid-winter (December–February), the average temperature will still be a few degrees below freezing in a normal year. In a warm year, however, the average temperature may be above zero except in the very far north. In March, the average temperature in a warm year will be several degrees above zero except in the very far north.

By the end of the century, the average temperature will still be slightly below 0°C in mid-winter (December–February) at most points along the mountain chain. However, there will probably be long periods of plus temperatures, even during normal years. Occasionally, the average temperature may even be several degrees above zero during January and February along much of the mountain chain. In the B2 scenario, the changes (primarily towards the end of the century) will be slightly smaller, although there will still be a radically milder winter climate and a shorter snow season.

In a normal year, the duration of the snow cover in the mountain chain will fall from today's 6–8 months to 3–6 months by the end of the century. The maximum snow depth will decrease from 80–130 cm during the period 1961–90 to 20–80 cm in the 2080s. For the skiing areas in Svealand and southern Norrland outside of the mountainous regions, the snow depth in a normal year will be less than 10 cm for more than half of the total number of days with snow cover by as early as the 2020s. The minimum limit for cross-country skiing is usually estimated at around 10 cm, while the corresponding figure for alpine skiing is around 30 cm.

According to one study within the framework of Fjällmistra (Sustainable management in the mountain region, Moen et al, 2007), the number of skiing days in Sälen will fall by 60 percent by the end of the century according to scenario A2, and the season will be entirely eliminated up until New Year and after the middle of March.

Other parts of Europe, such as the Alps, may be even harder hit (see Appendix B 28). A reduction in skiing areas in Central Europe will change the conditions for Alpine winter tourism across the entire continent. In a study into the conditions for alpine skiing in Åre up until the 2030s (Edberg, 2006), it is indeed pointed out that the skiing season in Åre up until 2039 may decrease by up to 5 weeks, but this is not expected to entail any major changes for Åre as a tourist destination. Instead it is asserted that, in a 30 year perspective, Åre may be a winner, when other destinations in Europe are affected more by climate change.

The climate changes up to the 2020s will probably first affect cross-country skiing and snowmobiling, as adaptation measures in the form of artificial snow production etc. are not possible for these activities to the same extent as for alpine skiing. People who participate in alpine skiing are more prepared to pay and hence are able to pay increased costs for artificial snow. They are also used to travelling longer distances to partake in their activity compared the majority of cross-country skiers and snowmobilers (Sievänen et al, 2005). Relatively speaking, the changes at Sweden's alpine destinations are smaller compared to many other places in Europe, and this will probably contribute to maintaining the competitiveness of most Swedish alpine skiing destinations.

Towards the end of the century, however, it is likely that the problems will be on the increase. According to the study for Fjällmistra (Moen et al, 2007), the shortened skiing seasons at the end of the century will entail significantly reduced earnings for the Swedish skiing industry. Using linear trends as regards turnover in the skiing industry, the loss by the end of the century would amount to between SEK 0.9 billion and SEK 1.8 billion annually, which is more that today's combined turnover within alpine skiing tourism in Sweden. This study does not take the possibility of producing artificial snow into consideration, however. All in all, we do not believe that the climate changes up until the 2020s will single-handedly and decisively change the prevailing structure within Swedish alpine winter tourism, although certain locations in the southern mountains and outside of the mountain chain may experience problems.

Adaptation measures and considerations

Summer tourism in Sweden may benefit greatly from the climate changes, under certain conditions. A scenario with increasing tourist streams to Scandinavia at the expense of the Mediterranean region in the height of summer is not unlikely. This naturally entails considerable opportunities for expansion of the tourism industry and considerable social income. At the same time, there is a risk of an increase in both congestion and in the load on the environment. Increasing strain on water resources could become a major problem, particularly as increased watering may be required for agriculture (see chapter 4.4.2). Society should step up its plans without delay to deal with increased competition for scarce water resources etc., particularly in southern Sweden. The situation should therefore be reviewed and possibly new areas appointed as being of national interest (including for tourism), primarily along the coasts of southern Sweden.

There is a great deal to indicate that clean water free of algal blooms will be an important competitive advantage in the battle for international tourists. This represents yet another reason for intensifying efforts in order to reduce the supply of nutrients to our watercourses and the sea (see section 4.4.2). In addition, it is important to continue to conduct research aimed at achieving a better understanding of the links surrounding the biogeochemical processes that, together with climate factors, affect water quality and the occurrence of algal blooms.

Towards the end of the century, large, continuous areas of bare mountain above the tree line will probably only be found in the northern Lapland mountains. This could increase competition for land usage in the mountainous regions of northern Norrland, and increase the risk of wear and tear on environment and cultural heritage assets, as well as lead to conflicts between different players and sectors. In many cases, the risk of such conflicts can be reduced through better planning and dialogue. Types of collaboration and prioritisation as regards tourism, outdoor activities and reindeer herding should therefore be reviewed now as a basis for future social planning. The areas that could be utilised for various tourism purposes and for other purposes should be carefully analysed and charted. Here, too, the National interests instrument could be used.

In order for Sweden's skiing centres in the mountains to survive and develop in a changed climate, a great many adaptation measures will probably be required. Potential technical measures that have been suggested in other contexts include excavation and felling work on ski slopes, as well as the relocation of pistes to north-facing locations and higher altitudes. However, several of these measures would have a negative impact on summer tourism by making the natural environment uglier. The risk of erosion would also increase and biodiversity would be affected detrimentally, as would the risk of conflicts with other social interests. Further restrictions to the potential to utilise such measures include tourists' preference for sunny, south-facing pistes, high costs for establishing new pistes at high altitude, the increased risk of avalanches and poor weather.

The most important single adaptation measure is perhaps the production of artificial snow. However, the production of artificial snow also has an impact on the environment and is restricted by costs for energy and water usage. Costs increase rapidly as the temperature rises towards 0°C, even though snow cannon systems have gradually developed in such a way that they are now many times more energy efficient than in their infancy in the 1970s. As the climate scenarios are pointing towards a significant increase in the risk of such temperatures, measures for continued rationalisation of artificial snow production are important. One possibility is the use of high-altitude reservoirs. These generally have a lower water temperature and this, together with the fact that pumping of water can be avoided, can reduce both energy consumption and costs.

We judge that adaptation measures carried out to date at alpine skiing locations, along with continued measures, should be sufficient to retain a considerable portion of the winter season at most mountain destinations through until at least the 2020s. In addition to adaptation measures in the form of increased production of artificial snow, increased diversification of operations at the mountain destinations can be an important adaptation method.

Several destinations have already expanded their summer activities, for example with cycling and riding, and hence achieved a more even load throughout the year. It is not certain whether an extension of the summer season, combined with adaptation measures within winter tourism, will outweigh in financial terms the disadvantages of a shortened skiing season. It should be emphasised here that there are significant location-specific differences, and the need for locally established management and adaptation strategies cannot be emphasised enough. In order to facilitate the development of such strategies, increased knowledge about climate change is required among all players in the sector. Within the framework of its sectoral responsibility, Nutek should be able to formulate a strategy for distributing information and transferring knowledge relating to climate change and adaptation.

After the year 2040, the situation for winter tourism looks more serious. The high season weeks around Christmas and New Year, as well as Easter, will be 'green' to an increasing extent. As far as we can judge, this trend will increase towards the end of the century. A structural shift of winter tourism towards areas that are more assured of having snow in the northernmost parts of the country may then become necessary.

Research and development

There is a considerable lack of systematised knowledge about how existing adaptation measures will be able to handle extreme seasons. Knowledge about snow processes etc. is also limited. Similarly, we do not know much about the interplay between climate changes and socioeconomic changes and their impact on tourist streams.

Furthermore, knowledge about the vulnerability of various outdoor activities to a changed climate is limited. Greater knowledge is also needed about how tourists evaluate and select tourist destinations. This requires increased knowledge about the role that the destination's support for measures aimed at reducing climate change can play, as well as how tourists' perception of climate changes steers their choice of destination. In order to provide supporting data for adequate measures to protect the environment and for future social planning, there is a considerable need to build up knowledge and for research regarding reasons for travel and future tourist streams.

The development of new technical, financial and organisational solutions, as well as knowledge about local product development and new management strategies are also areas that should be prioritised.

Proposals

- The directive for Nutek should be changed so that the authority is given clear responsibility for climate adaptation within the field of tourism (see section 5.10.2).

- Nutek should be commissioned to formulate a strategy for the spread of information and the transfer of knowledge regarding climate change and adaptation opportunities to players within winter-based tourism.

- Nutek, the Swedish Environmental Protection Agency, the Swedish Board of Agriculture, the Geological Survey of Sweden and affected county administrative boards should be commissioned to highlight areas where increased competition for e.g. water resources can arise, primarily along southern Sweden's coasts, as well as to highlight areas of national interest for tourism, nature conservation and outdoor activities within their operational areas.

- Nutek, the Swedish Environmental Protection Agency, the Sami Parliament and county administrative boards should be commissioned to highlight areas where increased competition for land in the mountains can arise, as well as to highlight areas of national interest for nature conservation, tourism, reindeer herding and outdoor activities within their operational areas.

4.5 The natural environment and environmental goals

4.5.1 Terrestrial ecosystems, biodiversity and other environmental goals

Terrestrial ecosystems in Sweden are facing major upheavals, and the loss of biodiversity may increase due to climate changes. Measures for adaptation to a changed climate also risks leading to a negative impact on biodiversity, but the negative effects can be limited.

Functioning ecosystems – the foundation for a sustainable and functioning society

Biodiversity builds up the earth's ecosystems, and the effects of climate change on the services these ecosystems offer will influence people and communities. For example, the UN's climate panel predicts major migrations of people as a consequence of ecosystems becoming unusable for those communities that currently utilise and inhabit them.

A significant part of society's future vulnerability in the face of climate changes will also depend on reduced and less certain access to ecosystem services (see Appendix B 31). Access to biodiversity and robust ecosystems is also an important resource for handling and surviving climate-related crises. For example, wetlands can provide a buffer against flooding and coastal vegetation can offer protection against erosion. By preserving ecosystems' ability to handle stress and shocks – their resilience – we are consequently helping them to protect us.

The term 'biodiversity'

It is clear from the Convention on Biological Diversity's definitions that biodiversity includes diversity within species, between species and of ecosystems. In a nature conservation perspective, we often prioritise *species worthy of protection*, *key species*, *signal species*, etc., on the basis of threat scenarios and consequences for other species of a particular species' disappearance. The term 'high biodiversity' normally entails that an area or biotope type functions ecologically and has all species linked to the living environments. As the number of species per unit of area, per biotope type, etc., is increasing in southern Sweden and Europe, an increased number of species in certain biotopes can be expected in a warmer climate. One interpretation of this could be that climate change can be positive for biodiversity in Sweden. In a nature conservation context, however, an increase in the total number of species is no compensation for the possible loss of northern species and species from northern biotopes, as these, due to the absence of large land masses to the north of Scandinavia, often have nowhere to go.

Climate changes and other factors that affect terrestrial ecosystems

Changes in the climate over the past century have already left their mark. The observed changes, with an increased concentration of greenhouse gases, increased land and sea temperatures, changes to precipitation and sea level, have had an impact on the reproduction of plants and animals, on the length of the growing season, on the distribution and size of populations and on outbreaks and the occurrence of pests and diseases all over the world. The IPCC believes that climate changes will be the most common cause of species extinction by the end of this century (IPCC, 2007). The climatic conditions determine to a large extent whether a species can live in an area, both through direct effects on the species and through effects on the ecosystems in which they live. Several modelling studies have shown that relatively small changes, even less than 1°C in global mean temperature, have clear effects in particularly species-rich areas, known as ecological hotspots. If warming exceeds 2°C, significant effects can be anticipated in many locations and regions around the world. The Arctic region is also extremely vulnerable.

However, our utilisation of natural resources has had the greatest impact on biodiversity to date. This means that it is often difficult to detect and predict the effects of climate changes, as the effects of land usage have normally been, or are, so much more powerful. Changes in the utilisation of resources which are implemented with the aim of adapting society to climate changes can also have a major effect on biodiversity.

Changes in terrestrial ecosystems as a result of a changed climate will also affect the potential to achieve several other environmental objectives, and in some cases will also affect the relevance of their current formulation. The environmental objectives that will probably be affected most are *A magnificent mountain landscape*, *Thriving wetlands* and *Zero eutrophication*.

General effects of climate changes on biodiversity, considerations and actions

Effects of climate changes on biodiversity must be assessed in relation to the effects of other surrounding factors, above all man's utilisation of nature and natural resources. This includes land usage by rural businesses, regulation of lakes and water courses, utilisation of the sea's resources, discharges and emissions into water and air, etc.

In the current situation, biodiversity in the agricultural landscape declines primarily through overgrowing of abandoned hayfields and pastures, incorrect management of land that is still maintained, and through the fragmentation that is caused by overgrowing and by earlier rationalisation of agricultural land. Biodiversity in forest biotopes is declining as a result of the area of natural forest continuing to diminish through felling, and because few forest species can maintain robust populations in the production forest that is being created. Biodiversity in lakes and watercourses has already been dramatically altered by eutrophication, regulation and the introduction of non-native species. Biodiversity in wetlands, primarily in southern Sweden, has been greatly altered by the regulation of watercourses, the watering of land and the cessation of traditional management.

A considerable proportion of Sweden's biotopes and geographic areas are affected by man, and continued utilisation will have a great impact on what the effects of a changed climate will be.

Particularly species-rich areas are even more sensitive to climate change, as there are many demanding and specialised species utilising a specific living environment. As a rule, such areas have long continuity, i.e. they have been able to develop undisturbed for a long period of time. In areas that have undergone significant changes in land usage, the specialised species have already been eliminated; only the generalists are left, and these locations are therefore less sensitive to climate change (see Appendix B 30).

Species that are at risk of being greatly affected include those that have few or no routes of retreat, such as Arctic Ocean survivors in the Baltic Sea and in cold, deep inland lakes, species dependent on the land-uplift coast and species tied to the middle and high alpine region in the mountains.

Increased competition can be anticipated between species that have adapted *on site* and species that are moving in. The risk of a rapid spread of non-native species increases when the climate stress to which they were previously subjected ceases or decreases.

The current system of *red listing* threatened species is one of the most important planning instruments for the protection of biodiversity. The red listing system is based on agreements within the IUCN (World Conservation Union) and is founded primarily on retrospective studies of changes in the species' numerical strength and distribution.

We consider that the red listing system needs to be supplemented in order to strengthen the conditions for assessing the effects of a future changed climate on biodiversity. This is needed in order to reinforce the potential to protect those environments that have the best conditions for promoting biodiversity, as well as to provide a basis for a division of responsibility between different parts of the country and between countries as regards the preservation of species, ecosystems and genetic resources. Extremely climate-dependent ecosystems/species should be identified, for example by classifying different biotopes in different climate zones and seeking to differentiate the importance of the climate factor on the survival of the ecosystem/species from other factors that affect the ecosystem/species, such as land usage. A charting process should therefore be conducted, ideally dividing the ecosystems into the following categories (see also Appendix B 30):

- affected greatly irrespective of land use,
- affected relatively little by climate changes compared to land use,
- the climate impact is reinforced by anticipated changes in land use,
- the climate impact is counteracted by anticipated changes in land use,
- the climate impact can be counteracted through the choice of land use,
- climate changes provide the potential, with correct management/land use, to improve the situation as regards biodiversity.

A warmer climate can provide incentives for intensified land use or competition for land resources, for example for forestry, food production and the production of biofuels. This can reduce the space for biodiversity, unless measures are taken to reinforce it. Such measures can include developed forms of administration at ecosystem and province level. For example, the system of provincial strategies should be developed and scaled up to national and international scale.

The changes to ecosystems' and species' living conditions that climate changes entail will greatly affect the potential in the longer term to achieve the same level of ambition as is expressed in the principal environmental objective, *A rich diversity of plant and animal life*, and its associated sub-objectives. We therefore feel that a thorough review of current strategies in this field is required, as well as an analysis of whether the formulation of the environmental objectives and the sub-objectives is relevant in a changing climate. In addition, an endeavour to give consideration to the effects of climate change on biodiversity should be integrated into social planning and the construction of facilities and infrastructure, particularly when drawing up Environmental Impact Assessments and Strategic Environmental Assessments.

The EU's nature conservation policy should be reviewed in order to reflect the fact that natural areas of distribution for biotopes and species will change in a changed climate. The policy should increasingly focus on the creation of corridors and routes of retreat for species that are retreating to the north. During this review, the need for changes to the EU's Habitats Directive (92/43/EEC) should be considered.

The effects of climate changes on mountain ecosystems, considerations and actions

Mountain ecosystems are affected to a great extent by the snow conditions in the winter in combination with wind, cold, etc. The occurrence of open, windy areas, leeward sides and snow patches greatly affects the vegetation in an intricate interplay, which also includes grazing. Higher temperatures and the reduced occurrence of snow patches have already had an impact on downy birch forest, which is affected locally by drought stress (Kullman, 2007). More knowledge about these interactions, including the impact of extremes, is necessary in order to assess in greater detail the future effects on ecosystems.

The tree line in the Swedish mountains has risen around 100–150 metres during the 20th century. This is probably mainly an effect of a changed climate, although delayed effects of earlier mountain grazing also play a role. It is probable that the tree line will rise by several hundred metres more over the next century. This forestation process is a threat to many groups of species. The importance of reindeer grazing as regards the *leeward side/snow patches/windy areas mosaic* is still poorly understood and needs to be studied in greater detail. Slightly more extensive reindeer grazing would probably be able to counteract the overgrowing of the bare mountain above the tree line, however (see Appendix B 30). Remaining bare mountain environments will also change, and it is probably unavoidable that several alpine species that are not particularly competitive will be eliminated over large areas in a warmer climate.

Species that are dependent on the now rapidly retiring areas of palsa bog (permafrost) will also disappear. Other marsh areas, particularly lime-rich ones, are home to many species at present. It is vital to study in greater detail and model effects on these in a changed climate. The interplay with altered land use and the effects on different ecosystems and biodiversity, such as increased tourism and construction of infrastructure, are also poorly understood and need to be studied to a greater extent.

In other words, climate changes will have an impact on biodiversity in the mountains. As a result, they will also affect the potential to achieve the environmental quality objectives *A rich diversity of plant and animal life* and *A magnificent mountain landscape.* Sub-goals for the objective *A magnificent mountain landscape* do not cover maintaining the bare mountain areas and preventing these areas from becoming overgrown (including with bushes) as a consequence of climate changes and reduced reindeer grazing. In future reviews, we should consider supplementing the environmental objectives regarding the magnificent mountain landscape with an sub-goal that clearly values the bare mountain areas.

The effects of climate changes on forest ecosystems, considerations and actions

More than 90 percent of forest land is now used for forest production. The area of non-utilised natural forest, in the broad sense, is still decreasing. The fragmentation of natural forest as well as the lack of disturbance regimes such as fires are having a detrimental effect on biodiversity. Many southern and middle boreal ecosystems and species are dependent on the various forms of protection that exist, including nature reserves. In such biotopes, we can anticipate a movement of certain species in the semi-mountainous zone, a relatively large proportion of which is currently protected in reserves. We need to evaluate which species and ecosystems could cope with such a move and could perhaps even benefit.

The rapid shift of vegetation zones as a consequence of the warmer climate may also lead to the extinction of many species due to changed ecosystems. This applies primarily to species that cannot adapt, that are not competitive, that find it difficult to spread in light of the current land usage, or that have no areas to move to.

The effect on biodiversity of the factors that are currently taken into consideration when carrying out felling is poorly known. There are indications that these considerations are not sufficient to accommodate robust populations of certain species unless there are relatively large areas of non-production forest in the vicinity (see Appendix B 30). In a changing climate, there will be a greater need for dispersal corridors and routes of retreat to the north. In order to achieve this, a comprehensive system of natural forest corridors will probably need to be built up. In order to be effective, corridors must also be created in pure production forest, which means that it will take a long time before they are of such a quality that natural forest species can live in them. The corridors and the existing natural forest fragments must then be saved for a sufficient length of time for the desired colonisation and dispersal to be able to take place. Current protection and management strategies therefore need to be reviewed.

A reasonably narrow focus on the preservation of existing living environments for individual species, which has often led the way in work on biodiversity, needs to be altered so that we move increasingly towards creating conditions for the establishment of desired species at a local level. The potential to create areas with greater consideration within production forestry compared with the current general considerations should be investigated. One possibility is to further develop the system of nature conservation agreements offering temporary protection with some potential for timber extraction. Bearing in mind the length of time that is required to build up forest ecosystems and their biodiversity, protection for longer periods than at present may be required. It is possible that the general consideration that must be given in the form of compensation according to § 14 of the Forestry Act could be reduced for certain areas of land that are uninteresting as regards biodiversity and other ecosystem services, such outdoor activities, hunting, etc. How this would take place in practice, and how disadvantaged forest owners would be compensated, should be investigated in greater detail.

It can be assumed that the prevailing trend, with increased extraction of biofuel from forest land, will continue. The forms of biofuel harvesting play a major role in the potential to create conditions for rich biodiversity. Alternative methods such as coppice forestry and the management of overgrown pasture are probably considerably more positive from a biodiversity perspective than e.g. stump extraction and the removal of branches and tops followed by fertilisation. Such alternative forms of biofuel harvesting should be studied with regard to profitability and the impact on biodiversity, and measures for support and information regarding such alternatives should be investigated.

Shorter rotation periods, increased fertilisation and increased use of new tree species that are negative for natural biodiversity, such as the Sitka spruce, are probable adaptation measures for a warmer climate that produce an increased risk of wind damage. In-depth studies of the effects of such measures on biodiversity should be conducted, and regulations regarding these should be reviewed in conjunction with a general overhaul of forestry policy in a changed climate (see section 4.4.1).

The effects of climate changes in the agricultural landscape, considerations and actions

Fragmentation, overgrowing of abandoned hayfields and pastures, lack of managed land, management of such land and the shortage of wetlands are factors that are reducing biodiversity. The EU's agricultural policy and its application through the rural development programme's various support forms are extremely important for the development of agriculture. Agriculture in Scandinavia will benefit to some extent from the changes in climate, and this can partially favour biodiversity in the agricultural landscape, provided an increased number of agricultural companies contribute to looking after biologically valuable land.

As far as we can tell, the need for pesticides will increase, as will the use of fertilisers. The way in which agriculture meets this development will influence biodiversity. The development of cultivation systems, fertilisation regimes, growth sequence, etc., can reduce nutrient leaching and the need for pesticides (see section 4.4.2).

Some pastures are among the most important ecosystems in the agricultural landscape from a biodiversity perspective. The climate scenarios point towards increased summer drought in southern Sweden, which may benefit certain plants in south-eastern Sweden, an area relatively rich in natural pasture. The overall need for grazers to maintain good management of such natural pastures will then decrease, which can favour high biodiversity. Support for natural pasture and other land that is valuable from a biodiversity perspective should be prioritised in future reviews of the EU's agricultural policy, and the effects of climate change should be taken into account.

The changing climate will probably affect the potential to achieve the environmental objectives *A varied agricultural landscape*, *Thriving wetlands* and *A rich diversity of plant and animal life*. However, there is a risk that the adaptation measures being implemented within agriculture, such as crops that require more fertilisation, will influence the environmental objectives to an even greater extent. Such a development would seriously impair the potential to achieve the environmental objectives *Zero eutrophication* and *A balanced marine environment.* Information measures concerning these issues should be established (see section 4.4.2). Increased winter precipitation can make low-lying areas more difficult to cultivate. Improved drainage of these areas can facilitate continued cultivation, but at the same time risks increasing the removal of nutrients. The recreation of wetlands in the agricultural landscape can have extremely positive effects on biodiversity, at the same time as potentially reducing the leaching of nutrients into watercourses, lakes and the sea. The system for supporting the creation of wetlands should therefore be further developed (see section 4.4.2).

The effects of climate changes on coastal and freshwater beaches, considerations and actions

There is a general lack of compiled information on the way ice conditions and the frequency of storms in the Baltic Sea and our lakes affect beach ecosystems. With reducing spring floods and higher winter flows, the spread of wetlands close to beaches will probably decrease. The potential for ice lift will also decrease, which could reduce the mechanical impact on reeds. More reeds hinder biodiversity in the beach ecosystems of many lakes and increase the need for control measures.

There is only limited knowledge about the role that the timing of water supplies plays for various ecosystems. In regulated watercourses, a greater annual variation could possibly compensate for the absence of ice lift. These issues should be studied further, however. An increased sea level can be expected to have little impact on biodiversity in areas where subsidence is already taking place. In areas with significant uplift, major effects on biodiversity can be anticipated if the uplift and hence the formation of new coastal meadows and other coastal ecosystems should cease. Coastal meadows, primarily in southern Sweden, will be trapped between increased sea levels and the use of the land situated directly inland. Extended maintenance measures may be necessary in the long term in order to maintain living space for certain species.

Water shortages, either direct or through the increased need for watering, can result in the impoverishment of ecosystems in watercourses, above all in southern Sweden. The areas where there is a risk of water resources becoming particularly strained should be charted, and the risk of negative effects on the environment, including on biodiversity, should be taken into consideration (see sections 4.4.2 and 4.4.4).

Need for increased knowledge, research and development

Despite a growing realisation that ecosystems will change in a changed climate, there is generally speaking a considerable lack of understanding about how different ecosystems will change and the role played by land usage. With our current level of knowledge, it is difficult to lay down overall guidelines for how to adjust the protection of the natural environment and biodiversity with regard to climate changes.

A compilation based on current knowledge about the effects of climate changes on various ecosystems should be created (see above), and would also constitute a good foundation for identifying additional research needs. However, we can already see additional areas where efforts aimed at increasing knowledge are required. These cover research that includes modelling, field trials and long-term trials, environmental monitoring and compilations of existing knowledge. This applies to e.g.:

- Scaling down of climate models to ecosystem level based on conditions and processes that are of decisive importance for biodiversity.
- The tendency of species to spread, access to dispersal routes and the species' ability to establish themselves.
- The importance of climate changes and extremes as regards population changes and key species versus, and in interaction with, the role of man/land usage.
- New species' degree of 'invasivity' in various ecosystems and the susceptibility of existing species
- Extended environmental monitoring, including in the mountains, as well as support for a relevant research infrastructure, e.g. mountain research stations.
- Knowledge about changes in the patterns of migrating species.
- The importance of uplift and ice as regards beach ecosystems, as well as the extent to which increased management can contribute to maintaining the ecosystems' values.
- Effects of biofuel production, including regional impact and the importance of alternative production methods as regards biodiversity, as well as their economic conditions.
- Effects of altered land use, such as intensified tourism, the building of infrastructure, altered intensity of reindeer grazing.
- Risks associated with and need for strategies for active relocation of species.
- Field studies, e.g. areas with low-lying forest or agricultural land, with the aim of describing which types of wetland forest/wetland may be formed in the event of unrestricted development in a wetter climate, and as a basis for planning measures within forestry and agriculture.

Several of the research efforts mentioned in section 4.4.1 are also of interest here.

Proposals

- The Swedish Environmental Protection Agency should be commissioned, in consultation with the Swedish University of Agricultural Sciences, to chart the sensitivity of various ecosystems/species to a changed climate, taking land use into consideration. It should also highlight extremely climate-dependent species, species with particular requirements as regards living environment, key species, species that are threatened regionally in Sweden and responsibility species for Sweden, and should proposed measures for the protection of these, including any amendments to the Habitats Directive.
- The Swedish Environmental Protection Agency and the Swedish Forest Agency should be commissioned, on the basis of various ecosystems'/species' climate sensitivity, to evaluate the effectiveness of current protection systems regarding the creation of dispersal corridors for ecosystems/species in a changed climate, to propose changes to regulations, guidelines and support systems, e.g. the potential to introduce greater protection in production forest, developed forestry agreements, scaling up of operations relating to landscape strategies to a regional, national or cross-border scale.
- The Swedish Environmental Protection Agency should be commissioned to evaluate and assess whether the potential to achieve the environmental objectives for which the Agency is responsible is affected by the climate changes, both within the time periods to which the objectives relate and in the longer term, as well as whether the environmental objectives and the sub-objectives are relevant in a changing climate. The Swedish Environmental Protection Agency should, if necessary, propose changes to the formulation of the objective and the action programme.
- The Swedish Forest Agency should be commissioned, in consultation with the Swedish Board of Agriculture, to develop maintenance instructions and support forms for combining biofuel production and nature protection.

4.5.2 The freshwater environment

Increased temperatures in lakes and watercourses, earlier clearing of ice and increased runoff will add to the leaching out of nutrient salts and humus. The outcome in the form of discoloured water, increased eutrophication and probably increased presence of algae and cyanobacteria will entail poorer water quality and make it very difficult to achieve the environmental objectives.

System description and the environmental objectives

Lakes and watercourses are an important feature in the Swedish landscape and an important resource for the whole society. The use of lakes and watercourses is important for a number of different sectors and areas, the provision of drinking water, fishing, agriculture, industry, shipping, hydroelectric power, recreation and the preservation of species and natural environments. The various activities affect the environment around the lakes and watercourses.

According to the decision by the Swedish Parliament regarding the environmental objectives, the *Environmental Objectives Bill*, 2004/05:150, sustainable use of land and water entails that biodiversity is protected at the same time as not impairing the conditions for production, that environmental and natural resources as well as the cultural environment and historical sites are safeguarded as assets in social development, and that damage that cannot be avoided is rectified. In the long term, sustainable use is a precondition for sound economic development.

The environmental objective *Flourishing lakes and streams* entails that lakes and watercourses must be ecologically sustainable, and their living environments, which are rich in variation, must be preserved. Natural production capacity, biodiversity, cultural environmental assets and the landscape's ecological and water management function must be preserved, at the same time as safeguarding the conditions for outdoor activities. The aim is for the environmental quality objective to be achieved within a generation.

The conditions for achieving the objective *Flourishing lakes and streams* are dependent on fulfilling the environmental objectives

Zero eutrophication, *Natural acidification only* and *A non-toxic environment.*

The environmental objective *Zero eutrophication* entails that the levels of fertilising substances in the land and water must not have a negative effect on human health, the conditions for biodiversity or the potential for versatile use of land and water. The aim is for the environmental quality objective to be achieved within a generation.

Water quality is decisive for achieving the environmental objective *Flourishing lakes and streams*. Eutrophication is clearly linked to climate change. The changes to temperature and runoff will probably entail increased levels of nitrogen and phosphorus in our watercourses, which will result in increased algal growth and excessive plant growth. Increases to temperature and runoff will probably also have a negative impact on acidification, although the extent of this impact is uncertain. The cycling of environmental toxins in the environment will also be affected (see section 4.3.6).

Environmental quality standards

The environmental quality standards are a guide for implementing certain EU directives and for being able to achieve the national environmental quality objectives. The environmental quality standards must be based on what people and nature can cope with, and are binding. For water, environmental quality standards currently only exist for fishing and mussel waters.

The Water Directive is an EU directive that is aimed at achieving coherent and comprehensive legislation that is based on the drainage basins. The goal is preserved and improved water quality. One important principle is that no water may deteriorate. In addition to water quality, it relates to looking after the aquatic environment as a whole, access to clean water, water planning, etc. The administration must be built up by watercourse, which stipulates demands for co-operation for all parties in the area. Five water authorities have been established in Sweden in different county administrative boards.

Impact on water quality of changes that have occurred to date

Appendix B 32 describes the impact of climate change on surface water quality. This appendix has been used as a foundation for the analysis set out below.

In Sweden, the mean annual temperature has risen on average by almost 1.5°C during the period 1984–2004, i.e. by approximately 0.07°C per year.

Changes in water chemistry take place primarily due to alterations in deposits and climate change. A comparison over time shows that, of all tested chemical variables, water discolouration demonstrates the strongest link to climate change. Water discolouration is also the chemical variable that has increased most rapidly during the period 1984–2004, with an increase of more than 10 percent in southern Sweden and more than 1 percent in the north. The increase in water discolouration is caused predominantly by increased humus content. There are many consequences of an increased humus content. For example, it affects the energy balance in the ecosystems, the transportation of environmental toxins, the water's light climate and hence the presence of algae. The humus content also affects the quality of drinking water. Raw water containing humus is difficult to purify in water treatment works and can also result in microbiological growth in the drinking water network (see section 4.2.5).

Apart from water discolouration, most other water quality variables are also probably affected, e.g. the total nitrogen content increases despite the reduction in atmospheric nitrogen deposits.

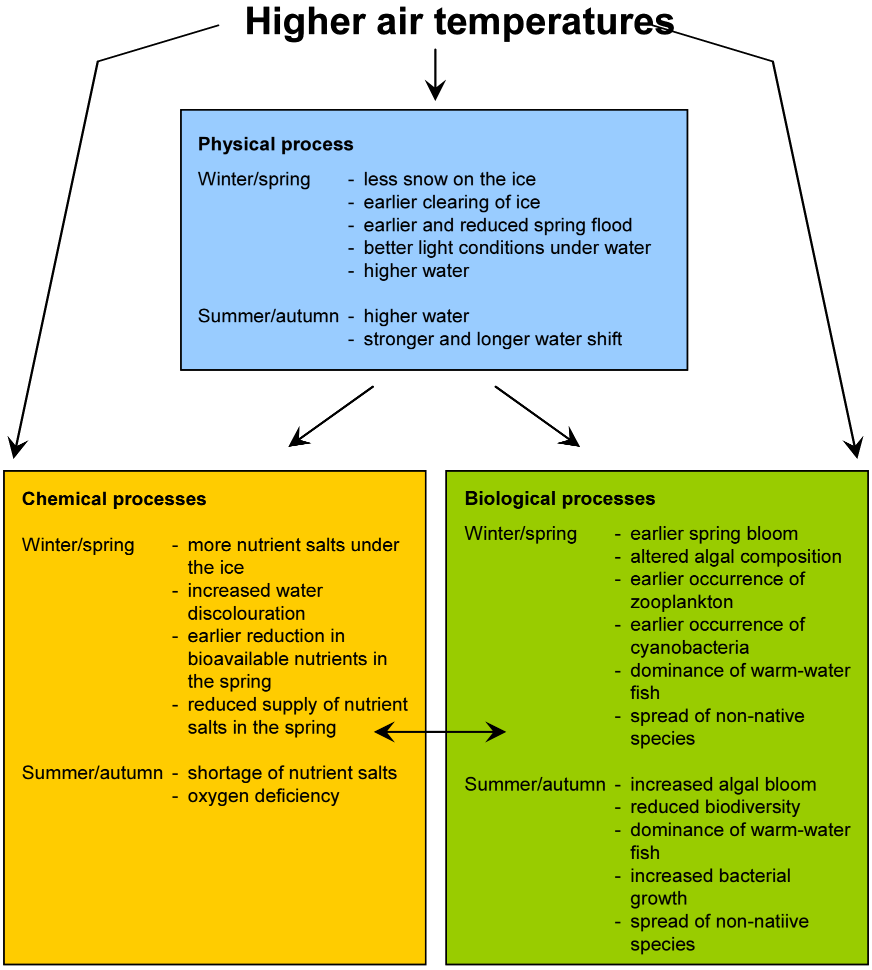
The biological processes are more complicated, and it is therefore more difficult to draw a clear link to climate change. However, it has been shown that the biomass of golden algae increases in line with climate change. There are also indications that biodiversity is declining and that the composition of species in the fish stock is changing. A previous development of cyanobacteria in line with higher summer temperatures has been observed.

Consequences of future climate changes

According to the scenarios we have studied, the air temperatures will rise, particularly in the winter, and the amount of precipitation will also increase. Cloudbursts with a large volume of rain in a short space of time will become more intensive, and heatwaves will become hotter and more common.

The two figures below illustrate how water quality may change when the air temperature (figure 4.46) and runoff (figure 4.47) increase. The figures are based on international studies.

Figure 4.46 **Consequences for water quality of a gradual increase in air temperature**

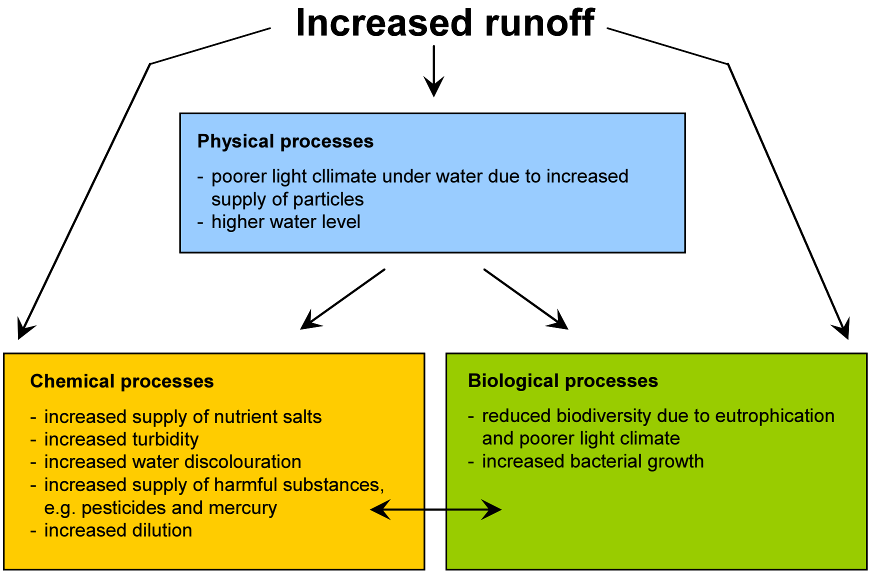


Source: Appendix B 32.

Higher air temperatures in the winter will lead to the earlier clearing of ice, which will result in better light conditions under water. This in turn will lead to an earlier spring algal bloom and an earlier occurrence of zooplankton. In conjunction with the earlier development of biological life, nutrient sales will also be consumed earlier. Warmer winters can also lead to increased water discolouration due to an increase in microbial activity. The composition of fish and their lifecycles will change (see section 4.4.3). In conjunction with increased summer temperatures, there will primarily be a change in thermal stratification in the water, which can result in oxygen deficiency in the bottom water and a lack of nutrient salts in the surface water. An increase in harmful algal blooms due to more intensive thermal stratification has already been observed. This will probably result in more beaches needing to be closed during extremely warm periods in the summer due to increased bacterial growth.

Warming will also result in the spread of non-native species. For example, simulations have shown that 6 new macrophyte species may have arrived by 2100.

Figure 4.47 Consequences for water quality of increased runoff



Source: Appendix B 32.

The consequences of increased runoff are generally an increase in particle quantity, water discolouration and nutrient salt content. A consistent increase in eutrophication and a poorer light climate will probably reduce biodiversity. It is also known that flooding can lead to the increased release of harmful substances such as mercury. In Canada, high mercury levels were measured in both fish and people when the construction of the large hydropower station in James Bay led to major flooding.

Within the VASTRA project (Water strategic research programme), Sweden's water quality in a future climate is described as follows:

> On average, nitrogen leaching from arable land was predicted to increase by 15–4 percent depending on which climate scenario was used. The increase was due primarily to the increased runoff and increased mineralisation during the winter when nitrogen is not absorbed by crops. Even if the growing season was extended and the timing of e.g. soil tilling, harvesting and maintenance was adapted to the new climate, this did not compensate for the increase in leaching. (Jöborn et al, 2006)

The increased ground leaching leads to raises in nitrogen concentrations in watercourses of 7–20 percent, depending on the scenario, and to an increase of 20–50 in the annual nitrogen transport, which that also affects sea water. These results correspond with the increase in total nitrogen concentrations observed between 1984 and 2004, despite the reduction in nitrogen deposits. However, the nitrate nitrogen contents appear to be falling over time, so the forecasts should be treated with caution when it comes to drawing conclusions about biological life. A study that was carried out on our behalf (see Appendix B 24) arrived at a similar conclusion regarding leaching from agricultural land.

Conclusions about water quality

All future simulations show very clearly that leaching will increase in a warmer, wetter climate. As a result, robust measures are required to achieve the environmental objectives and environmental quality standards. Many lakes are already in need of action in order to achieve good ecological status, particularly in southern Sweden.

The situation is worst as regards water discolouration, where up to 90 percent of all lakes in the southern parts of the country require some form of action. There is a risk that the situation will continue to deteriorate in line with the change in climate.

The total nitrogen levels are also far too high for a good ecological status to be achieved, but as the atmospheric fallout will probably continue to decline, no dramatic deterioration of the current situation is anticipated.

The situation regarding total phosphorus levels is slightly better than for nitrogen levels, although many lakes in southern Sweden require reduced total phosphorus levels in order to achieve good ecological status. If the phosphorus levels increase by 50 percent, many lakes will experience problems with phytoplankton, and measures will need to be taken in 20–100 percent of the lakes in southern Sweden.

The reduced nitrogen fallout will probably entail that the phosphorus levels will increase more rapidly than the nitrogen levels, which will lead to an increased risk of harmful algal blooms.

Adaptation measures and considerations

In summary, climate change will make it much more difficult, although not impossible, to achieve the environmental objectives regarding eutrophication and flourishing lakes and streams.

In order to achieve the objectives, the need for action will increase compared to the current situation. We would particularly like to point out the importance of measures to reduce emissions of nitrogen and phosphorus. This entails for example the need to intensify measures aimed at reducing nitrogen and phosphorus waste from agriculture, airborne fallout and point sources.

An analysis of the future environmental work needs to be carried out against the background of the climate changes, particularly in the long term. Action strategies and interim goals may need to be revised. This applies to a large proportion of the interim goals and action strategies. A review should also be carried out by each authority with environmental responsibility.

Research and development

Knowledge about climate change's impact on eutrophication, acidification, the cycling of environmental toxins and biodiversity is to a large extent deficient. An intensification and an increased focus on the climate aspect are essential in ongoing research.

Research about processes surrounding and consequences of the increase in water discolouration and the increased humus levels is important.

Research and development regarding measures for counteracting or adapting to the changes that will accompany a changed climate should be initiated. This applies for example to the increased discolouration of the surface water due to increased humus levels.

Proposals

Proposals concerning the review of the environmental objectives are given in section 4.5.1.

4.5.3 The Baltic Sea and the marine environment

The temperature in the Baltic Sea will increase by several degrees and the extent of the ice cover will reduce dramatically. This, alongside changes in the supply of nutrients, will probably result in large-scale consequences and an increased load on an already polluted sea. If we experience stronger westerly winds and a considerable increase in precipitation, the salinity will be more or less halved. This will lead to dramatic changes, with almost all marine species disappearing, including the cod.

The Baltic Sea today

The Baltic is a unique inland sea with brackish water and special ecosystems. The conditions are largely governed by factors that have the potential to change if the climate changes. The sea water temperature is affected directly by a rising air temperature. Salinity and oxygen content are affected by the turnover of water, which in turn is controlled by precipitation and wind conditions. The supply of nitrogen, phosphorus and organic material, as well as the turnover in the Baltic Sea, are controlled in part by climate parameters and have a major impact on ecosystems and on e.g. algal blooms.

The Baltic Sea is now greatly influenced by human activities. Eutrophication has entailed major changes to the ecosystems. The water has become more cloudy due to an increase in the amount of phytoplankton, and the spread of bladder wrack in the Baltic Proper and the southern Gulf of Bothnia declined through until the beginning of the 1990s. On the Baltic's shallow, soft bottoms, the reed belt has increased in extent instead. The composition of species of zooplankton has changed and algal blooms have become more common. We have become used to recurring, major, annual blooms of cyanobacteria (blue-green algae) during the summer in the Baltic Proper. The bloom in 2006 was the most extensive to have been registered over the past decade. Since the 1990s, blooms of cyanobacteria have also become common in the Gulf of Bothnia. Eutrophication is also causing oxygen deficiency on the bottoms and the elimination of bottom fauna in large parts of the Baltic. Temporary improvements have occurred in conjunction with the saltwater from the Kattegat entering the Baltic. In a long-term perspective, however, there is an unequivocal trend towards increasingly low oxygen levels across all major areas. Oxygen deficiency also occurs in large parts of the Kattegat during the late summer and early autumn.

Emissions of nitrogen and phosphorus, primarily from agriculture and sewage treatment, have fallen in recent years, however. The effects in the environment of this reduction are slow, though, and the improvements witnessed to date are small. The potential exists to reduce emissions significantly from the former Eastern European states in future, although the extent of this and when it can be achieved is uncertain.

The levels of many organic environmental toxins in the Swedish countryside have fallen since the 1970s. For example, the PCB content has decreased tangibly in the eggs of the common guillemot in the Baltic Sea. The damage to fauna is also decreasing, and both the sea eagle and the seal, which were severely affected by DDT and PCB, have now recovered. The picture is not solely positive, however. The levels of dioxin in Baltic fish is more or less unchanged since the 1990s. At the same time, the use of chemicals is continuing to increase, substances that are found in various products and that eventually risk ending up in the countryside.

The situation for several commercially important fish stocks, in particular bottom-living species, has been critical for several years. In particular, the stocks of cod in the Baltic Sea, the Kattegat and the North Sea are threatened with collapse. The high pressure from fishing has resulted in a reduction in the average size of the fish, and adult fish now constitute a smaller proportion of the total biomass (see section 4.4.3).

The over-fishing of cod in the Baltic, along with the good recruitment of European sprat during the warm winters in recent years, are the most probable reasons for the pelagic ecosystem in the Baltic Sea having changed from being cod-dominated to being dominated by sprat. The reduction in cod can also be linked to changes further down in the chain in the Baltic Sea's eastern basins, where the amount of zooplankton in the spring and early summer has decreased, which correlates with grazing by the large stock of sprats. There is also a link between the amount of phytoplankton and the low densities of zooplankton. There is a great deal to indicate that the reduced importance of cod in the ecosystem has produced consequences at several stages, which has resulted in a regime shift taking place in the Baltic Sea. The grazing of sprat on zooplankton, which are also food for cod larvae and young cod, also risks consolidating this situation. All in all, this means that the rebuilding plans for the Baltic's cod stock are extremely uncertain (see Appendix B 33).

The regime shift in the Baltic Sea may also be linked to the recruitment problems for the coastal fish stocks of e.g. perch and pike, which are significantly weakened in the outer archipelago areas in the Baltic Proper. Field studies and experiments indicate that access to suitable food (zooplankton) during the fish's early stages of life can be the cause of the recruitment problems.

Taken together, it will be difficult to achieve the environmental quality objectives *A balanced marine environment* and *Flourishing coastal areas and archipelagos* by 2020. It is possible that we will be able to satisfy the conditions for a good marine environment by 2020. The marine ecosystems' ability to recover and future changes in the load, as well as the climate changes, are decisive as regards when the environmental quality objective can be achieved in its entirety.

Climate changes in the Baltic region

Global warming has occurred at approximately 0.05°C per decade between 1861 and 2000, although in the Baltic region the rate has been 0.08°C per decade. This can be seen for example in the fact that the number of cold days has decreased. The scenarios for the future climate show that the atmosphere will continue to warm up in all parts of the Baltic region. Regional models show a warming of approximately 3–5°C for the area as a whole during this century. The greatest warming is anticipated to the north and east of the Baltic Sea during the winter months and to the south of the Baltic Sea during the summer. (See section 3.5.4.)

There is also a trend towards a reduction in the presence of sea ice. The largest change has occurred as a result of the ice season becoming shorter – it has decreased by 14–44 days over the past century. Most of this change took place during the second half of the century, and on average the past 10 years have all been mild or extremely mild.

The average surface water temperature of the Baltic Sea is expected to increase by between 2–4°C according to the scenarios we have used. This will lead for example to a dramatic reduction in the extent of the sea ice. By the end of this century, the Gulf of Bothnia, large parts of the Gulf of Finland, the Gulf of Riga and the outer parts of Finland's south-western archipelago will be ice-free even in the depths of winter in an average year.

According to the regional climate models, the warmer climate in the Baltic region will result in changed precipitation patterns; there will be a general increase in annual precipitation in the northern part of the drainage basin, and the increase is expected to be greater in the winter than in the summer. The southern parts of the region may become drier, particularly during the summer. These precipitation changes will increase the amount of water running into the Baltic Sea annually from the northern parts, will the amount from the most southerly parts will decrease. (Helsinki Commission, 2007).

The investigation, alongside the Swedish Environmental Protection Agency, arranged a seminar on the effects of climate change on the Baltic Sea. The results of the seminar are summarised in Appendix B 33. The presentation below is based on this seminar and on the Helsinki Commission's summary (Helsinki Commission, 2007).

Salinity and temperature changes

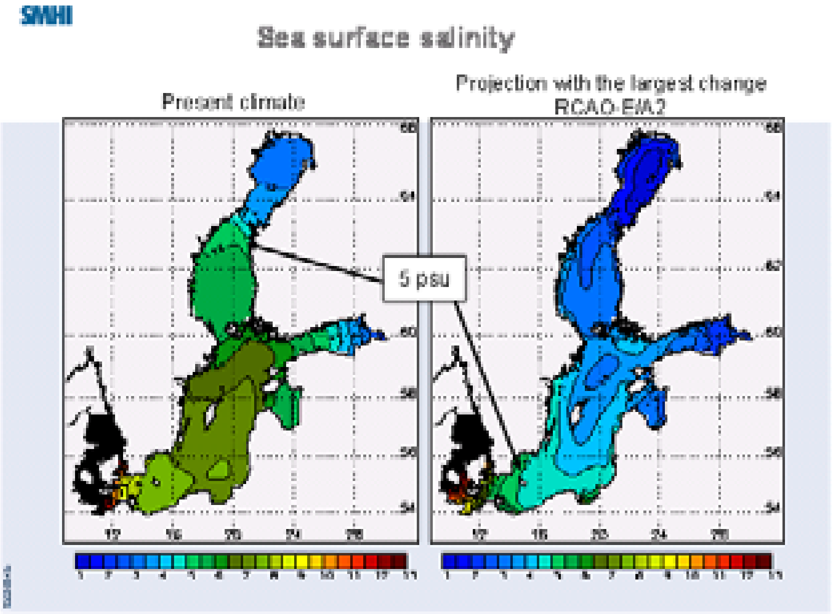
The Baltic Sea comprises brackish water, where the biological life originates either from salt water environments or from freshwater environments. Many species live on the outer edge of their range and are exposed to stress, making them sensitive to change. There is a gradual change from a low salinity level in the Gulf of Bothnia with a relatively low abundance of species, to a significantly higher salinity level in the southwest, west of Bornholm.

The results of the RCAO-EA2 scenario show that, by the end of the century, the salinity of the surface water will decrease dramatically. The halocline, the stratification between salty deep water and the fresher surface water, will be at least 20 m deeper than at present, which will have major effects on biological life. The effects of the RCAO-HB2 scenario are significantly smaller.

Such a change in the salinity of the Baltic Sea will produce major changes in biological life. Species with marine origins that are dependent on a certain salt content will largely disappear from the Baltic Sea north and east of Bornholm (see figure 4.48). It is very likely that the cod will disappear. The majority of the Baltic Sea will be dominated by ecosystems that are more reminiscent of inland lake conditions, and the level of biodiversity will decrease.

However, this development is based on a global scenario, Echam4, that is relatively extreme as regards precipitation and wind. If today's wind conditions remain unchanged and the increase in precipitation is smaller, in accordance with the scenarios based on the other global model we have used in the investigation, HadAM3H, the changes will be less dramatic. However, we do not have any model results that can present the salinity level according to this scenario.

Figure 4.48 **The salinity of the surface water in today's climate and between 2071–2100 according to scenario RCAO-EA2**



Source: Meier et al, 2006 with the permission of Springer Science and Business Media.

All the scenarios we have used point to a warming of the Baltic Sea. The warming of the surface water is anticipated to be between 2–4°C on average over the year for different scenarios in different parts of the Baltic. This will result in a change in the composition of species and a shift from cold-water species to warm-water species. It can also be expected to result in an invasion of non-native species.

Changes in cycling and the supply of nutrients

The emissions of nitrogen and phosphorus, which are large in historical terms, have created problems with eutrophication in the Baltic Sea as described above. The way in which climate change affects the cycling of nitrogen and phosphorus in the Baltic is complicated and involves several difficult processes, some of which counteract each other.

The amount of water running into the sea is predicted to increase by up to 15 percent in total for the entire Baltic region, mostly in the central and northern parts. As there is a covariance between increased flows and increased supply of nutrients, this indicates an increase in the supply of nutrients from these parts. However, new model results from the Swedish University of Agricultural Sciences (see Appendix B 33) show that the level of retention, i.e. the taking up of nutrients in lakes and watercourses, will increase at a higher temperature. Relatively little of the increased leaching from agricultural land would therefore reach the Baltic Sea, instead resulting in increased eutrophication of lakes and watercourses.

In addition to the size of the emissions, a series of other factors affect the supply of nitrogen and phosphorus to the Baltic Sea. For example, the timing and extent of the freeze, the snow cover, the spring floods, the growing season, etc., determine the amount of nitrogen and phosphorus reaching the Baltic Sea. Climate change can also be expected to influence the cycling and distribution of nutrients in the Baltic Sea through changes in the depth of the halocline, oxygen levels, changes in mix, etc. A climate change that results in a lowering of the halocline should result in an increase in nitrogen levels and a decrease in phosphorus levels.

It is difficult to calculate the changes in the overall balance, and there is currently no overall scientific consensus on the impact of climate change on the total nutrient supply to the Baltic Sea.

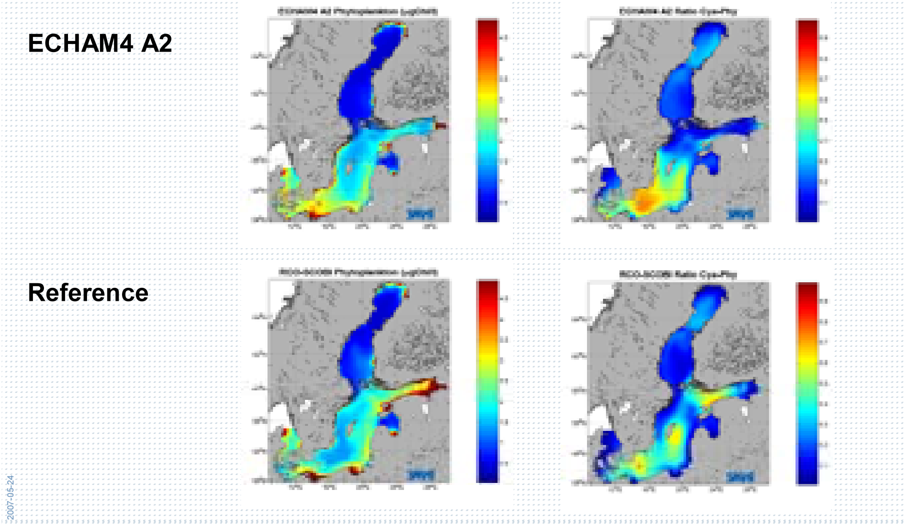
Biogeochemical modelling

Oxygen levels, nitrogen and phosphorus levels as well as the occurrence of plankton in a changed climate have been modelled by SMHI. The results of the modelling using RCAO-EA2 show that, towards the end of the century, the oxygen levels in the surface layer will reduce as a consequence of lower oxygen saturation levels. The oxygen conditions will improve in the northern Baltic Proper due to the halocline being deeper. The oxygen levels will decline in the southern Baltic Proper and in the deeper parts of the Baltic Proper. The results also show that the phosphorus level will diminish somewhat in the Baltic Proper, while the nitrogen level will increase.

The results from the modelling of phytoplankton and cyanobacteria according to the same scenario show that the biomass in the summer will decline in the northern Baltic Proper, whereas it will increase in the southern part. The proportion of cyanobacteria will decrease in the northern Baltic Sea, whereas it will increase in the southern part of the region. See figure 4.49.

Figure 4.49 **Phytoplankton (to the left) and the proportion of cyanobacteria (to the right) according to RCAO-EA2 towards the end of the century compared to current levels, seasonal mean for June–September. According to SMHI's SCOBI model, current nitrogen and phosphorus loads from the atmosphere and current concentrations in lakes and watercourses have been used in the model**

Phytoplankton – Seasonal mean (0–10 m) June-September 1969–1998



Source: Kari Eilola, 2007.

Adaptation measures and considerations

The problems in the Baltic Sea are considerable and have existed for a long time. The change in climate will probably entail major changes that will affect the biology of the Baltic Sea, possibly dramatically. It is clear that if the salinity decreases by 45 percent, as suggested in one of our scenarios, the changes will be dramatic.

In this case, the Baltic Sea will resemble the Gulf of Bothnia and be dominated by freshwater species.

The developments according to the second of the scenarios we are using will not entail such a dramatic change in salinity. However, the temperature will rise by 2–4°C and the ice cover will decrease significantly. This will also lead to major changes in the biology, although it is difficult to specify these in more detail. The algal bloom could both increase and decrease. The way in which the supply and cycling of nutrient salts will be affected is complicated, and it does not appear possible to draw any definite conclusions with our current level of knowledge.

It is difficult to achieve the environmental objectives in the current situation, and it will probably become more difficult against the background of the climate change. This is increasing the pressure to implement the measures that were drawn up within the framework of the Helsinki Com (Helcom). Particularly pressing against the background of climate change is the need to reduce emissions of nutrients and to reduce over-fishing.

Research and development

The potential effects in the Baltic Sea are very extensive, with major consequences for sectors such as fishing, tourism and outdoor activities. It is therefore vital to increase our level of knowledge. In our opinion, it is necessary to carry out more research on the climate changes and their effects on the Baltic's biogeochemistry. We also consider that the research should be co-ordinated to a greater extent. Due to the complicated links within and between different processes, the focus should be on creating models that can interact. This demands an increased investment, as well as a focus that can deliver greater co-operation.

4.6 Human health

This section is largely based on the report *Health effects of climate change in Sweden* Appendix B 34.

Some diseases and population groups are of particular interest when talking about the health consequences of climate change. The most important of these diseases and groups, and their links to climate change, are described in greater detail in Appendix B 34.

Current health situation in Sweden

Fewer and fewer people are falling ill with and dying from cardiovascular diseases. However, this group of diseases is responsible for most cases of premature death, as well as often entailing long-term health problems and reductions in function.

Allergies are continuing to increase. More than 30 percent of men and 40 percent of women in Sweden are reported to suffer from asthma, allergies or some other hypersensitivity. These complaints have more than doubled over the past 20–30 years.

Health has improved for the elderly, although this does not apply to the very oldest people in society. Diseases suffered by the elderly will place ever greater demands on society and on healthcare and medical treatment.

Infectious diseases are still a significant social problem. These were previously a dominant cause of death, although they have declined dramatically during the 20th century. In recent times, however, resistance to antibiotics has made it more difficult to treat certain infectious diseases. Reliable data about the occurrence of infectious diseases exists primarily for those diseases that are covered by the reporting obligation set out in the Communicable Diseases Act.

Responsibility

The National Board of Health and Welfare is responsible for issues relating to healthcare and medical treatment, health protection, infectious disease control and epidemiology. The Swedish Institute for Infectious Disease Control is tasked with monitoring the epidemiological situation as regards infectious diseases in humans, and with promoting protection against such diseases. In addition to these authorities, the Swedish National Institute of Public Health has duties relating to public health. Medical treatment is naturally provided in the first instance by the county councils, although it is also provided privately. The municipalities are responsible for nursing, including home help.

4.6.1 Extreme temperatures

Periods of high temperatures are becoming more common and the highest temperatures are becoming higher than those experienced at present, which is resulting in increased mortality, particularly among vulnerable groups. Future heatwaves may become a significant problem that will require countermeasures.

Sensitivity of various groups to high temperatures

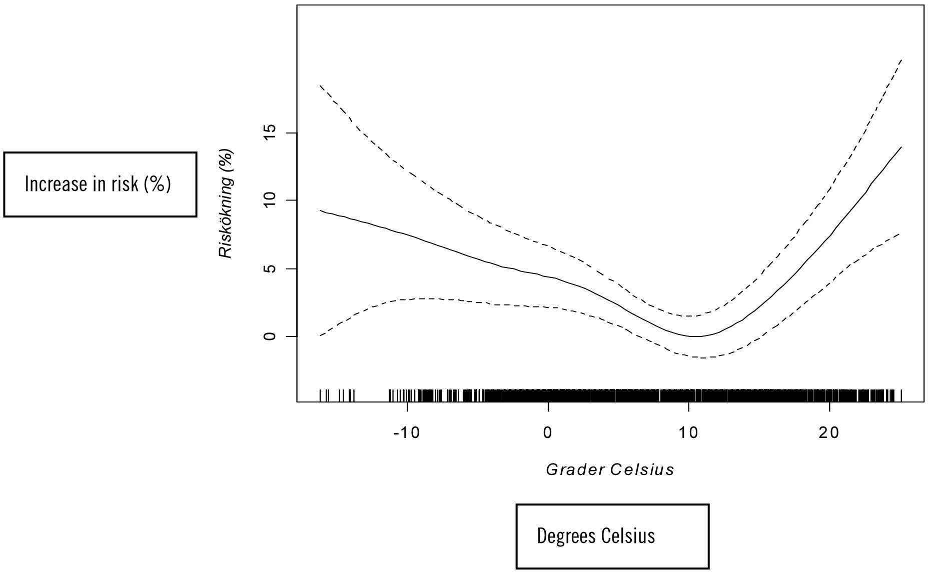
Extreme heat entails various major risks for different individuals, depending on the state of their health. It is above all the elderly who run a large risk. This group reports the largest number of fatalities in conjunction with heatwaves. Diseases that entail particularly sensitivity to heat primarily include cardiovascular diseases, pulmonary diseases and impaired kidney function. Some medications can also alter heat regulation, circulation and fluid balance, particularly beta blockers (heart medicine) and diuretic medicines. Mental disabilities, including dementia, can result in patients not perceiving the risks associated with the heat.

Depending on the current climate and on local adaptation, the optimum temperature from a health perspective, i.e. in this case the lowest number of deaths, is different in different parts of the world. In Finland, the optimum temperature has been calculated at 14°C, in London around 20°C and in Athens around 25°C.

The first Swedish study into how temperature and heatwaves affect mortality has recently been conducted, focusing on 41 communities within Greater Stockholm with some 1.1 million inhabitants between 1998–2003 (Rocklöv and Forsberg, 2007).

The study shows that mortality that is dependent on daily average temperature, viewed over the whole year, has a V-shaped appearance (see figure 4.50). Mortality is adjusted for other factors such as influenza, season, time-trend and day of the week. The *optimum temperature* corresponds with the lowest relative risk according to the figure, and is the temperature at which mortality is lowest. For Stockholm this figure is 11–12°C. It can be seen from the figure that the average percentage increase in mortality is around 15 percent at 25°C and around 10 percent at -15°C. It can also be seen that mortality increases much more dramatically at high temperatures than at low temperatures.

Figure 4.50 Effect of daily average temperature on daily number of deaths, adjusted for season, time-trend, day of the week and influenza



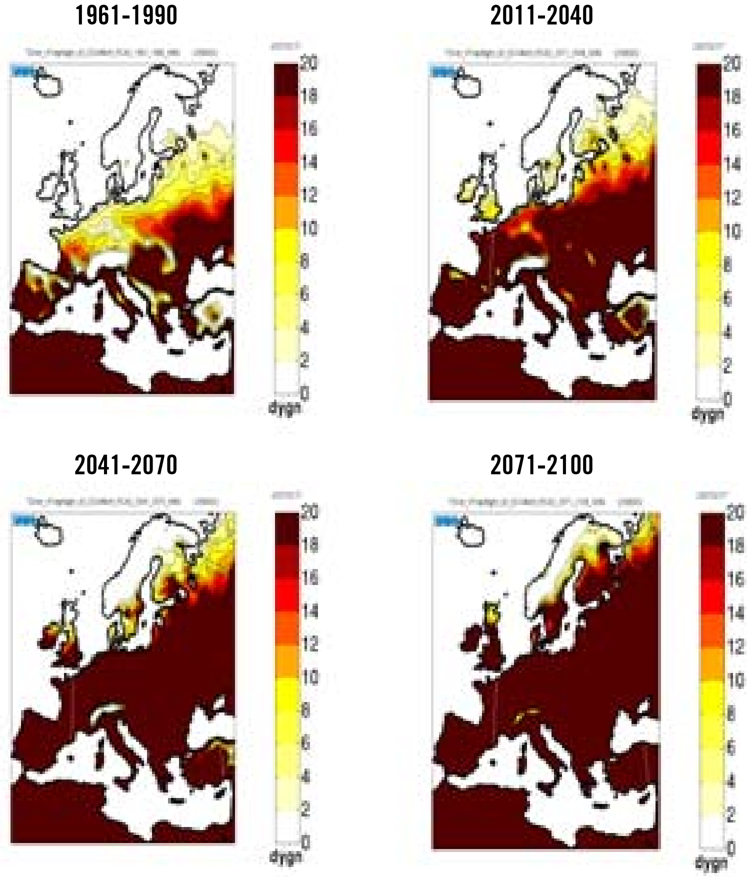
Source: Rocklöv and Forsberg, 2007.

Consequences of high temperatures

When Europe was affected by a severe heatwave in August 2003, it is estimated that more than 33,000 people died as a direct consequence of the heat, a number that could not be predicted from normal data. In the event of future heatwaves with temperatures higher than those we have been used to up until now, the effects may be more dramatic than that predicted from existing data.

A clear increase in mortality has been observed after just 2 days of sustained heat. Periods of high temperatures are expected to become more common in Sweden, with the highest temperatures higher than those experienced today. In the most southerly parts of the country, the temperature on the warmest days will increase proportionally more than the mean temperature. The number of tropical nights, i.e. 24 hour periods when the temperature never falls below 20°C, will increase dramatically in southern and central parts of the country and along the coast of Norrland, and during the period 2071–2100 may be equivalent to the number currently experienced in southern Europe (see figure 4.51). The scenario that is illustrated in the figure is based on the model and the emissions scenario that give the greatest temperature increase, RCA3-EA2.

Figure 4.51 **Number of tropical nights per year. The upper left map shows the period 1961–1990, and is followed by models for the periods 2011–2040, 2041–2070 and 2071–2100 (RCA3-EA2)**



1961-1990

2011-2040

2041-2070

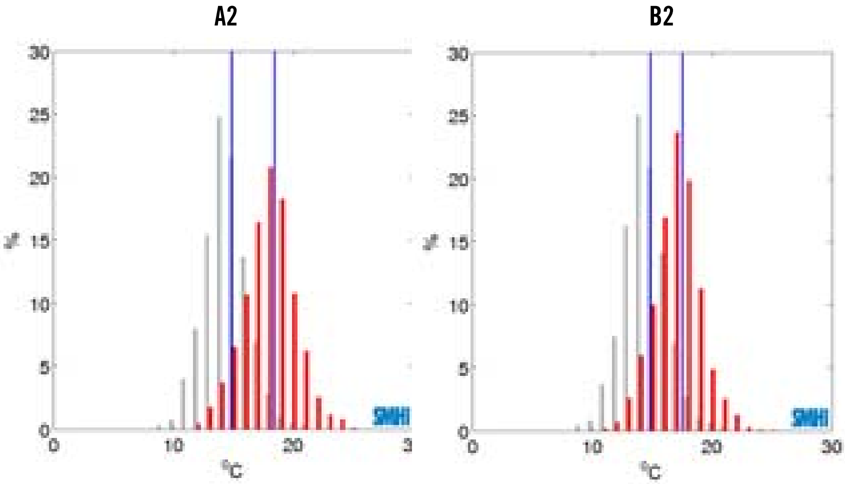
2071-2100

days

Source: SMHI, 2007.

The effect of a warmer climate on mortality in the Stockholm region has been studied by Rocklöv and Forsberg, 2007 (see figure 4.52).

Figure 4.52 **Distribution of summer temperatures in Stockholm 1961–1990 (grey) and 2071–2100 (red). The figure to the left is based on the IPCC's emissions scenario A2, and the figure to the right on emissions scenario B2. Blue medians 1961–1990 and 2071–2100**



Source: Rocklöv and Forsberg, 2007.

On the basis of temperatures for the years 1998–2003 taken from the data, the summer temperatures in the Stockholm region could increase by a further 3–4°C in scenario A2 and by 2–3°C in scenario B2 by 2100. The increased mortality is presented in table 4.35.

Table 4.35 **Increased mortality in Greater Stockholm from increased summer temperatures, compared to 1998–2003, and the year in which this temperature will be reached according to A2 and B2**

Temperature increase	Increase in mortality		Time A2	Time B2
Degrees Celsius	**Number**	**%**	**Year**	**Year**
1	29	1.2	2025–2040	2025–2040
2	60	2.4	2060–2070	2080–2090
3	94	3.8	2090	2100
4	131	5.3	2100	-

Source: Rocklöv and Forsberg, 2007.

An important area of uncertainty in the estimate is the assumption that people's sensitivity will be the same in the future, without taking the age distribution of the population or acclimatisation into consideration. This may mean that the effects are being overestimated. On the other hand, we can anticipate a significant underestimation of the effects of temperatures that exceed those used when producing the model, in particular in the event of long, continuous periods of high temperatures. Similarly, the number of cases could be underestimated, bearing in mind the increase in the average age. Neither can we be sure that the distribution of summer temperatures that have been measured in the data is representative for the future. It is probable that the temperature will increase more on the hottest days that it does on average.

Few cold snaps produce positive health effects

Cold is also associated with deaths and health effects. A milder winter climate in Sweden, with fewer cold snaps, will therefore entail positive effects with a reduction in the number of directly cold-related deaths and instances of frostbite. Milder winters will also contribute to reducing the number of episodes whereby people suffering from vascular spasms, chronic heart and lung disease, as well as rheumatic problems, experience a deterioration in their health. Fewer really cold winter days can, on the other hand, can result in increased occurrence of ticks and parasites.

Adaptation measures and considerations

The high number of deaths that occurred on the Continent in conjunction with the heatwave in 2003 indicates a need for rapid adaptation. This applies even if the temperatures we can anticipate here in Sweden are not as high, as we will be more sensitive to high temperatures. As early as the following year, France introduced a warning system in which meteorological forecasts were linked directly to healthcare and medical treatment resources. In the USA, a significantly lower number of deaths has been noted in areas that have effective air conditioning.

It is vital to have the potential for air-conditioning at hospitals, nursing homes and other premises where ill or elderly people are staying, so that the indoor temperature can be kept within reasonable levels, even in the event of a heatwave. This can be achieved by planning new premises in such a way as to prevent high temperatures, for example through technical construction measures or through air-conditioning. Air-conditioning may need to be installed in existing premises. Sun screening, awnings and trees that provide shade are other alternatives.

When carrying out town planning, the increasing temperatures during the summer should also be taken into consideration when designing buildings. This may require a new approach, as the future climate will probably entail extreme heatwaves, of which we have no experience in our country. Buildings have a very long lifetime, and a change-over should therefore be initiated early in order that the adaptation can be carried out when building new properties and when carrying out renovation and conversion work (see section 4.3.5).

The potential for cooling in emergency, intensive care and cardiac departments should be introduced as standard across the whole country. The need for cooling should be inventoried for premises other than those mentioned above. We should aim to achieve energy-efficient solutions such as district cooling.

Preparedness for heatwaves should be reviewed and vulnerable groups should be identified. For example, action plans should be drawn up for how e.g. home-help services can assist exposed groups in the event of a heatwave.

An early warning system for heatwaves corresponding to the one introduced in France in June 2004, but tailored to Swedish conditions, could be developed by SMHI in co-operation with municipalities and county councils. Such a warning system should be co-ordinated with the established warning systems that have been developed by SMHI and the Swedish Rescue Services Agency (see section 5.3.1).

Research and development

More research is required regarding high temperatures and health effects, in part in order to specify the temperature variables that best express the change in risk in various parts of the country.

Proposals

- In the instruction to the National Board of Health and Welfare, it should be evident that the authority is responsible for adaptation to a changed climate within its area of responsibility (see section 5.10.2).

- The National Board of Health and Welfare should be commissioned to develop supporting information for municipalities' and county councils' preparedness for heatwaves. This information should include proposed measures for cooling premises and for identifying and contacting susceptible groups.

- SMHI should be commissioned to investigate the potential for warning systems (see section 5.3.1).

4.6.2 Altered air quality

Air pollution can be expected to increase slightly due to climate change, although other factors will cause bigger changes.

The concentration of air pollutants and the depositing of acidifying and eutrophying substances will differ in future compared with today. A series of international agreements, most recently the 'Göteborg Protocol', indicate significant reductions in Europe's emissions in the future. Changes in emissions in North American and Asia will also affect air pollution levels and deposits in Europe.

Climate change will affect wind directions and precipitation patterns, as well as many other weather-dependent processes in the atmosphere, such as chemical and physical conversion that control the level of air pollutants. A future climate change will probably also result in changes to human and natural emissions.

Health effects of air pollution are now a major problem in Europe. These emissions will be affected by many factors in the future. In the following section, we have only taken into account the effects of a future climate change on the basis of today's emissions level.

The impact of climate change on ground-level ozone

Raised ozone levels impair the health of asthmatics and other susceptible groups. The ozone level can interact with high temperatures, which constitute a risk to elderly and weak individuals, and so influence the daily number of deaths.

Emissions of nitrogen oxides and hydrocarbons (volatile organic substances) that form ground-level ozone are expected to decrease in Sweden and in the rest of Europe in the future. Model simulations of the effects on the air environment of a changed climate suggest a possible increase in the ozone level of 1–2 percent per decade through until 2050 in central and southern Europe, particularly during the summer, in the event of unchanged emissions and background levels. The maximum levels will increase more than the average levels. Ozone concentrations are only expected to alter a little in Scandinavia. Southern Sweden may possibly experience a slight increase in ozone levels in the spring, summer and autumn, while northern Scandinavia can expect reduced ozone levels. See figure 4.53. (Engardt and Foltescu, 2007).

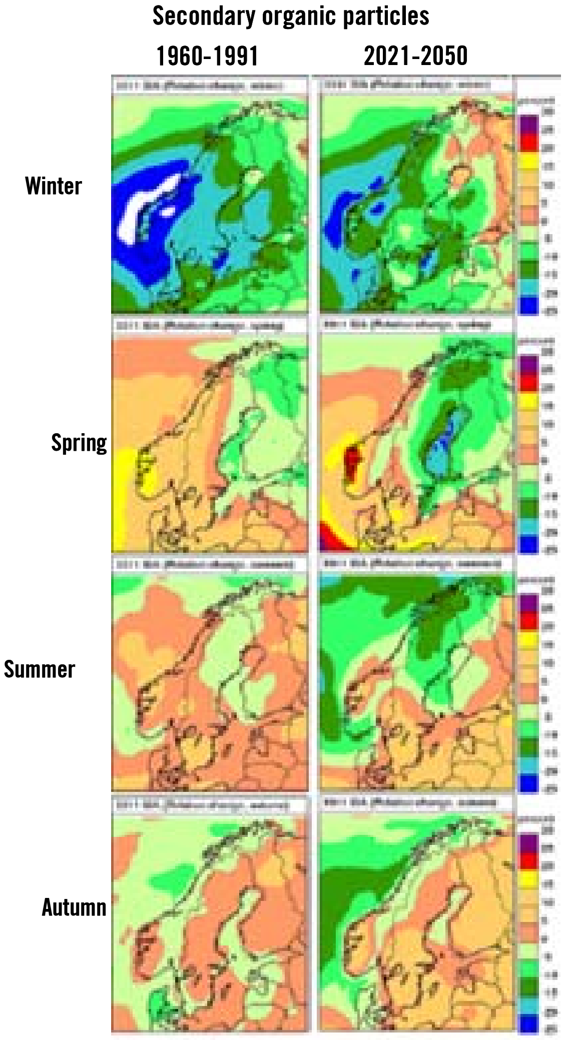
The impact of climate change on particles

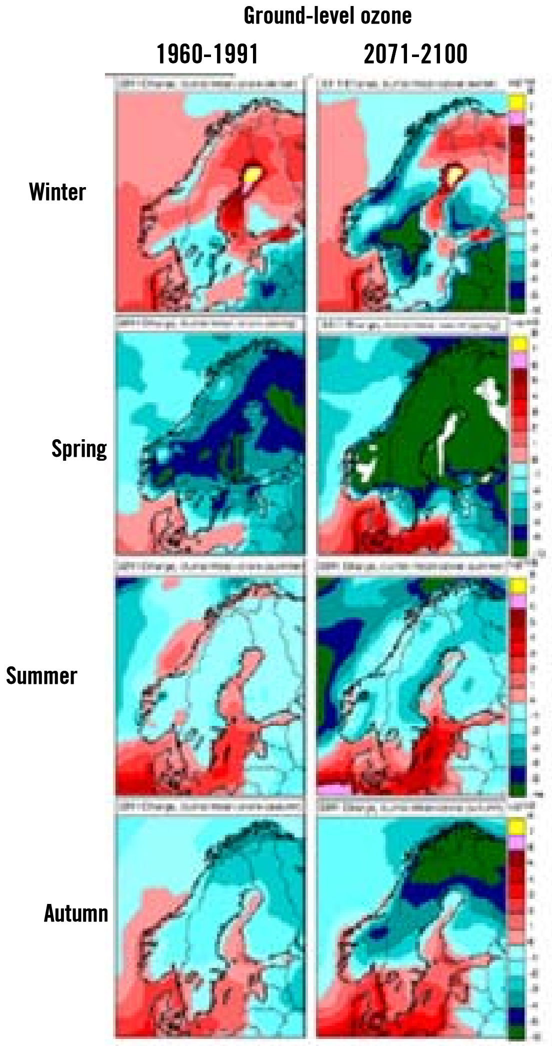
The link between the particle content and mortality, like the link with pulmonary and cardiac problems, is better documented than the equivalent link for ozone levels. Even moderate raises in particle levels increase the number of cases of acute cardiac disease.

Model simulations that only demonstrate the effect of changes in the climate (see figure 4.53) show that the content of secondary inorganic aerosols (SIA), comprising sulphate, nitrate and ammonium, may increase significantly, by 3–5 percent per decade, through until 2050. This applies to the whole of continental Europe during all seasons apart from winter. Southern Scandinavia will probably experience a moderate increase in SIA of up to 2 percent per decade, primarily during the spring and summer, while northern parts of Scandinavia will report reducing SIA levels during all seasons, according to the scenarios. The total amount of particles in the atmosphere may be influenced even more greatly by the climate changes, however, as dust that is whipped up from desiccated land in southern and central Europe is expected to increase in line with the predicted decrease in precipitation in these areas. (Engardt and Foltescu 2007; Kjellström et al., 2005)

Figure 4.53 Modelled change in secondary inorganic aerosols (SIA) and ground-level ozone

The left-hand map sequence shows relative percentage change in the daily average concentration of secondary inorganic aerosols (SIA) across the Nordic region between the current and future climate in different seasons. The right-hand map sequence shows the modelled 3-month average content (day + night) change in ground-level ozone. The rows of maps from top to bottom show the following periods: Winter (Dec.-Feb.), spring (Mar.–May), summer (Jun.–Aug.), autumn (Sep.–Nov.). Within the map sequences, the left-hand map row shows the change between 1960–1991 and 2021–2050, and the right-hand row show the change between 1960–1991 and 2071–2100.





Source: Engardt and Foltescu, 2007.

Pollen allergies

Approximately 15–20 percent of young adults in Sweden are allergic to pollen. In total, pollen allergies account for approximately 40 percent of all allergies in Sweden. Birch, alder and hazel are responsible for most allergies caused by deciduous trees. Many different grass species can give rise to allergies, even though the amount of produced pollen varies considerably between different species. Birch, grass and mugwort are now the most common individual allergenic plants in Sweden.

A number of reports from Europe and North America have shown that the pollen season has been starting earlier and earlier in recent years (IPCC, 2007; Menzel et al, 2006).

Laboratory trials have shown that an increased level of carbon dioxide in the air increases the amount of pollen from species of ambrosia, primarily ragweed, which in the USA is one of the most allergenic of the pollen-producing plants (Wayne et al, 2002). Ragweed has arrived in Europe through contaminated seed and, starting in Hungary and the Rhône Valley in France, has spread dramatically, above all in Eastern and Central Europe. Wherever it has gained a foothold, it contributes to sensitisation, i.e. increased tendency to suffer allergies. Ragweed is now also found in many locations in southern Sweden and up along the Norrland coast.

Changed seasons and a longer growing season may result in changes to the spread of pollen-producing species and to the start, length and intensity of the pollen season. In southern and above all central parts of the country, deciduous trees are becoming increasingly competitive in relation to conifers. This can result in a greater occurrence of deciduous trees (see section 4.4.1) and lead to an increase in pollen allergies.

Indoor air

Sweden, along with the other Nordic countries and Canada, has the most airtight housing in the world. An increase in the outdoor temperature will mean an increased moisture load indoors, which can entail a greater microbial load and more house dust mites. This, along with the effects of increased precipitation and more frequent floods, increases the risk of mould and mite allergies.

Adaptation measures and considerations

The climate changes will alter the conditions for the work on reducing air pollution. It is important for scenarios for climate change to be integrated in models and action plans, primarily for ground-level ozone and particles. For example, effects of climate change should be taken into consideration when working on the environmental objective *Clean air*, for which the Swedish Environmental Protection Agency is responsible.

Increased window ventilation in the summer months, or other forms of ventilation, can counteract increased moisture content and consequently mould and mite problems. The National Board of Health and Welfare should monitor the problem and, in the event it should get worse, provide information on the issue.

When formulating regulations and recommendations, the National Board of Housing, Building and Planning should take into account the need to use different materials in housing and workplaces in areas where moisture problems can arise. (See section 4.3.5 and Appendix B 17.)

Research and development

More research is required on the combined effect of altered emissions and a changed climate on air quality in Sweden in the future. A critical factor in the calculations is the forecasting of regional precipitation in Europe. Southern Scandinavia is at the boundary between increased and decreased precipitation in northern and central Europe respectively. There are significant north-south gradients in the pollution whose occurrence is largely governed by precipitation. This means that southern Scandinavia in particular is sensitive to change. If the boundary for droughts should move slightly to the north, southern Sweden at least may experience significantly higher levels of both ground-level ozone and secondary formed particles. The simulations of atmospheric chemistry should be repeated with input data from several different global climate scenarios and/or climate models on a global and regional scale, in order to conduct an analysis that takes into account the uncertainty as regards the occurrence of precipitation in the gradient area.

Research regarding e.g. causes for the occurrence of allergies, the spread of pollen and possible countermeasures is important against the background of the increase in allergies that can be anticipated with the change in climate.

4.6.3 Health effects of floods, storms and landslides

The increased risk of flooding and landslides produces a risk of personal injury and increased problems for e.g. medical treatment and home-help services.

Consequences of climate change

Extreme weather events such as storms, floods and landslides can create problems ranging from personal accidents to disruptions to electricity and water supplies (see also sections 4.3.1 and 4.3.2). This can cause problems for healthcare and medical treatment in terms of e.g. ambulance transport and home-help services being paralysed.

The risk of infectious diseases increases following a flood, for example through insufficient refrigeration of food due to power failures or due to the contamination of drinking and bathing water with infectious agents. The risk of waterborne exposure to chemical substances can also occur due to leaks from industrial land, old landfill sites and service installations. Vulnerable groups such as the elderly, disabled and ill are particularly exposed. Psychological effects are also common after major disasters.

On a local level, there is a risk that floods and landslides can expose old toxic chemical dumps as well as buried animal cadavers infected with anthrax. The latter primarily generates a risk of infection for animals living outdoors in the area, although people can also be exposed.

Adaptation measures and considerations

Society should be prepared for a greater number of and more intensive extreme weather events and natural disasters. In crisis situations, the focus should be on vulnerable groups. Elderly people living alone, as well as people with physical and mental disabilities, should be actively contacted.

The county administrative boards should chart known dumps, industrial land and animal graves infected with anthrax, etc., in order to obtain a comprehensive map of risk areas in the event of floods, landslides and erosion (see section 4.3.6).

4.6.4 Spread of infection

A warmer climate with increased precipitation produces an increased risk of the spread of infection. Dispersion patterns for infectious diseases will probably change, and entirely new diseases and disease carriers may enter the country. The uncertainties and the risk of surprises are considerable, however.

The spread of viruses, bacteria and parasites causes many types of disease. Spreading through water, food and various vectors, i.e. animals, insects, arachnids, etc., will probably increase in a warmer climate.

Health effects of the climate impact on water flows and water quality

Altered water flows, both increases and decreases, can give rise to negative health effects. In the event of floods and landslides, the spread of infectious agents and toxic chemical substances that are present in soil and land can contaminate water supplies, pasture, bathing water in outdoor pools and water for irrigation and watering. Sewage can leak into drinking water sources and into pipelines. This results in an increase in the risk of outbreaks of waterborne diseases. The infectious agents that are of most concern for people are Cryptospiridium, Giardia, Campylobacter, Norovirus and VTEC (EHEC), of which the latter normally causes the most serious disease symptoms (see Appendix B 34).

The size of the outbreak will depend not only on the extent of e.g. floods in various areas, but also on other conditions, such as the presence of infectious agents and disparities in the design of the local water and sewage systems. A single outbreak can cover anything from a few tens to several tens of thousands of cases.

Increased water flows can contribute to the leakage of infectious agents from drains and contaminated pasture to bathing resorts. With an altered climate, the bathing season will also be extended and more people with bathe more often. This, combined with higher water temperatures, can increase the risk of the spread of certain gastrointestinal bacteria, skin infections such as swimmer's itch (cercarial dermatitis) and systemic infections.

Vibriosis vibrios are a new, serious problem for Sweden. These infectious agents are present in Swedish waters, but do not grow until the water temperature exceeds 20°C. The optimum salinity for these vibrios is 0.4–1.7 percent, i.e. the same as the Baltic Sea in the summer, but they are also found in freshwater. The risk of an outbreak of vibriosis will increase during the century in the Baltic Sea, all the way up to the Umeå region.

Toxic algal blooms (cyanobacteria) occur in both fresh and brackish water. They benefit from higher water temperatures, and in nutrient-rich water they can give rise to harmful concentrations. Algal blooms will probably increase in lakes and watercourses. For the Baltic Sea there is some uncertainty as regards the development (see sections 4.5.2 and 4.5.3). Small children and animals are the groups most at risk of falling ill if they bathe in or drink water where there is an ongoing, harmful algal bloom,

Health effects of climate impact on food

A warmer climate during the summer months is expected to increase the number of cases of food poisoning, as a result of an increased risk of food being exposed to high temperatures due to the refrigeration chain for food being broken or because the food is not handled adequately during preparation and storage by consumers. Micro-organisms such as Staphylococcus aureus, Clostridium perfringens and Salmonella grow rapidly in many food products if they are not refrigerated.

The spread of infection through watering with contaminated water during food production may increase as a result of an increased risk of floods.

Swedish food production may need to adapt to a higher temperature and higher relative humidity, and to periods of extreme precipitation and drought. This will result in increased costs and greater demands for quality control in order to prevent an increase in food-borne disease and outbreaks.

Altered pattern as regards the spread of infection

Changes in the length of seasons and the climate will affect ecosystems and biodiversity. Early signs of climate effects can often be seen most clearly in areas close to the edge of a species range, both at the northerly boundary and at high altitudes. The climate in such places is often the limiting factor, as the seasons may be too cold or too short for a species to survive, reproduce or grow. In recent decades, a number of European species have altered their ranges. For example, bird species and insects have expanded to the north. Ticks are currently distributed across almost the entire country.

The displacement of seasons may have an impact on a number of vector-borne diseases, where the infectious agents in nature are transferred by different animal species, such as rodents, birds and foxes, in insects, midges, gnats, etc., or by arachnids, primarily ticks. Milder winters will increase the survival rate for species that spread infections. There is also a risk of indirect effects, such as milder winters, less crusted snow and a longer growing season, increasing the number of host animals in an area, which will make it easier for e.g. ticks to find blood, in turn enabling them to increase in number.

Changes to ecosystems can occur gradually or abruptly. Entirely new compositions of species can arise in an area, and this can create opportunities for new infectious agents to establish themselves locally. An infectious agent may e.g. be spread with a new type of vector.

Altered risk of infectious diseases

Table 4.36 presents a risk assessment for various diseases in the event of a climate change. The risk assessment gives consideration both to the link with climate change and to the potential seriousness of the consequences as regards the health situation in Sweden. Animal diseases are dealt with in section 4.4.2.

The infectious diseases that produce the greatest risks in the event of a climate change include various vector-borne diseases. This applies both to the tick-borne diseases borreliosis (Lyme disease) and TBE, which already occur in Sweden, as well as certain other vector-borne diseases that are currently not viewed as native. Only the borrelia infection is considered to represent a high risk. It is estimated that around 10,000 people fall ill in the country each year. An anticipated increased risk of borrelia infection in southern and central parts of the country will entail significantly more cases in these areas, and the disease is expected to spread to large parts of Norrland, except for the mountainous regions.

One very serious European vector-borne disease that could become established in Sweden during this century is visceral leishmaniasis, which is spread by the sand-fly and has a direct link to temperature. It is common to be temporarily infected with the Leishmania parasite without developing symptoms, although if a person is also HIV positive, the progress of the disease is particularly serious, with an average survival of just 13 months.

Vibriosis in people is also included in the high-risk group of infectious diseases, as the disease has such serious consequences. The disease can cause blood poisoning with a high risk of death. It is directly linked to water temperature and primarily affects elderly people. The disease, which was referred to as cholera in the media, gave rise to three deaths during an outbreak in summer 2006.

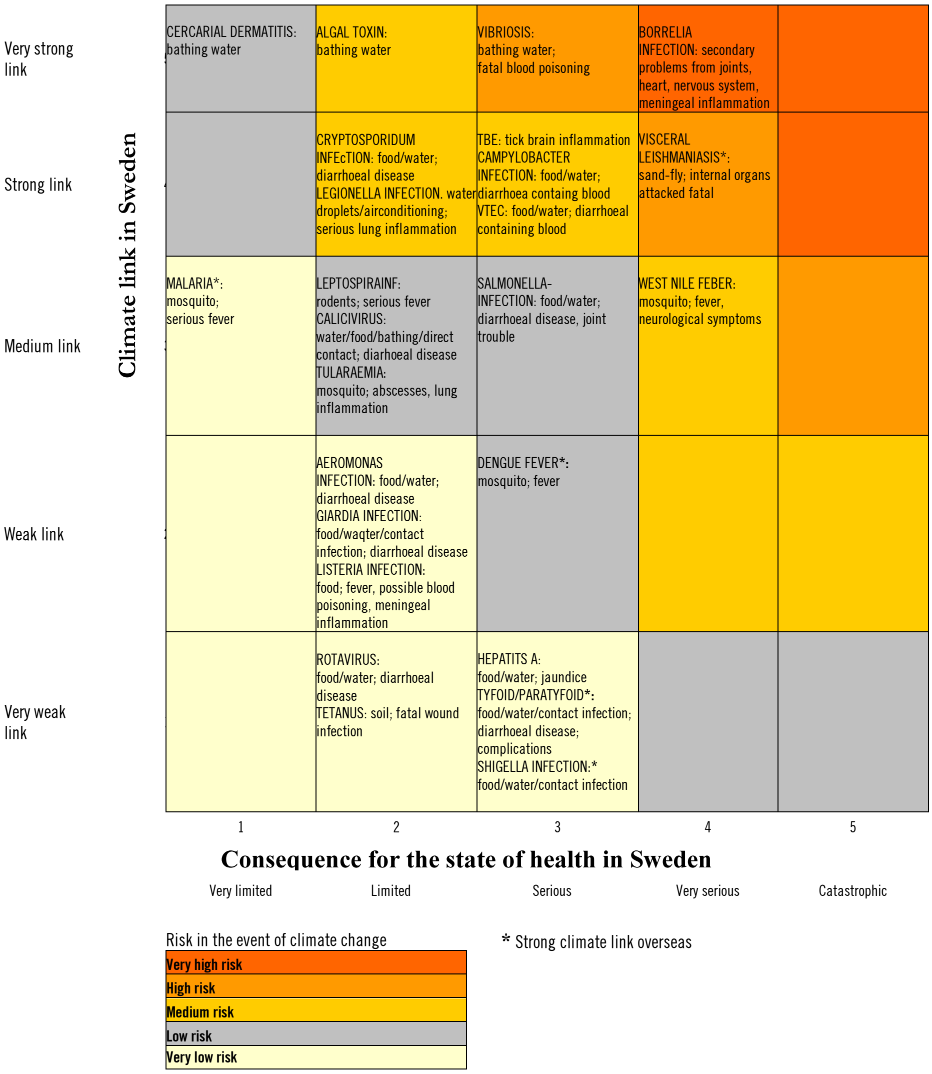
Some food-borne and water-borne infectious diseases also display an increased risk (medium-high) in the event of a climate change. This applies particularly to VTEC, cryptospiridiosis, campylobacter infection, algal poisoning, legionella and toxic food poisoning.

West Nile virus is a disease transferred by mosquitoes that occurs in Europe. Birds act as reservoir animals for the virus, which can affect people and horses. West Nile virus could become established in Sweden. The mosquitoes that spread the disease are already present in the country, although no spread of infection has yet been demonstrated.

Malaria, which often comes up in the debate, will probably not be a problem in Sweden, despite a probable increase in the occurrence of malaria mosquitoes in southern and central parts of the country. All spread of infection ceases if all infected people in an area are given treatment, which Swedish medical care is able to provide.

Sweden will also experience an increased number of cases of infectious diseases where the infection is contracted overseas due to increased global infection pressure.

Table 4.36 **Summary climate risk – impact assessment for infectious disease in Sweden affecting people. The risk assessment is based both on the strength of the link between the increase in the risk of disease and climate change in Sweden, as well as on how important the disease is, i.e. its consequences for the health situation in Sweden. For more detailed descriptions of the diseases, see Appendix B 34**



Climate link in Sweden

	1	2	3	4	5
Very strong link	CERCARIAL DERMATITIS: bathing water	ALGAL TOXIN: bathing water	VIBRIOSIS: bathing water; fatal blood poisoning	BORRELIA INFECTION: secondary problems from joints, heart, nervous system, meningeal inflammation	
Strong link		CRYPTOSPORIDUM INFEcTION: food/water; diarrhoeal disease LEGIONELLA INFECTION. water droplets/airconditioning; serious lung inflammation	TBE: tick brain inflammation CAMPYLOBACTER INFECTION: food/water; diarrhoea containg blood VTEC: food/water; diarrhoeal containing blood	VISCERAL LEISHMANIASIS*: sand-fly; internal organs attacked fatal	
Medium link	MALARIA*: mosquito; serious fever	LEPTOSPIRAINF: rodents; serious fever CALICIVIRUS: water/food/bathing/direct contact; diarhoeal disease TULARAEMIA: mosquito; abscesses, lung inflammation	SALMONELLA-INFECTION: food/water; diarrhoeal disease, joint trouble	WEST NILE FEBER: mosquito; fever, neurological symptoms	
Weak link		AEROMONAS INFECTION: food/water; diarrhoeal disease GIARDIA INFECTION: food/waqter/contact infection; diarrhoeal disease LISTERIA INFECTION: food; fever, possible blood poisoning, meningeal inflammation	DENGUE FEVER*: mosquito; fever		
Very weak link		ROTAVIRUS: food/water; diarrhoeal disease TETANUS: soil; fatal wound infection	HEPATITS A: food/water; jaundice TYFOID/PARATYFOID*: food/water/contact infection; diarrhoeal disease; complications SHIGELLA INFECTION:* food/water/contact infection		
	Very limited	Limited	Serious	Very serious	Catastrophic

Consequence for the state of health in Sweden

Risk in the event of climate change
Very high risk
High risk
Medium risk
Low risk
Very low risk

* Strong climate link overseas

Adaptation measures and considerations

The increased risk of a spread of infection in the event of a climate change is a significant potential problem. A number of different diseases and disease carriers can be identified that could spread across the country. However, it is difficult to predict and calculate the effects. There are a number of examples of a northerly spread in line with a warmer climate, such as the spread of ticks carrying borrelia and TBE. It is essential to focus greater attention on new diseases and disease carriers.

The risks of a spread of waterborne infection can be reduced through more effective treatment of drinking water. The cost of increased separation/inactivation of micro-organisms in water treatment plants has been estimated at SEK 1,300 million for the period 2011–2040 (see section 4.2.5 and Appendix B 13). These measures counteract the increasing risks of waterborne disease outbreaks. Additional changes to microbiological risks further in the future are difficult to assess, but will probably result in lower costs.

When planning the operation of beaches, the risk of the spread of infection from pasture should be taken into consideration. Longer distances are required between bathers and grazing animals due to the risk of leaching from pasture. Testing and monitoring may be necessary to a greater extent at beaches where risks remain. It is important for the general public to receive information about the risks associated with e.g. vibriosis, for example in the event of floods or prolonged high water temperatures.

Higher temperatures over several months will result in more dog days and increased problems with the handling of food. We will have a climate that places higher demands on food hygiene compared to what we are used to. Consumers require information about basic hygiene and about how food should be handled at high temperatures.

Climate change and increased global mobility produce an increased risk of the spread of infection. As the global range of many infectious diseases will change in the future, it is necessary continually to update risk information, vaccine recommendations, etc.

There are currently 2 million individuals in Sweden who use private water supplies. The National Board of Health and Welfare and the Geological Survey of Sweden should provide information about the risk of poorer water quality to permanent residents and summer residents with private water supplies. (See also section 4.2.5.)

Extended further training regarding infectious diseases is necessary for personnel within the healthcare and medical treatment sector, as well as for veterinary personnel, bearing in mind increasing infection pressure globally and the risk of entirely new infectious diseases becoming established in the country (see section 5.9).

Research and development issues

- New, fast and effective decontamination of drinking water systems needs to be developed.

- New methods should be developed, or adapted for Swedish conditions, for the handling and storage of food in a warmer, more humid climate.

- Increased knowledge is required about infectious agents' survival in the ground, following contamination in conjunction with flooding and flows that increase more slowly, as well as about potential countermeasures. This applies for example to Salmonella and VTEC.

- There are gaps in knowledge about the significance of the climate as regards:
  - The occurrence of vectors for relevant infectious diseases and their spread in the country, the current situation and changes.
  - The occurrence and spread in the country of vector-borne infectious agents, such as West Nile virus and Borrelia.
- There should also be more research about protection against vector-borne diseases, such as the tick-borne diseases TBE and Borrelia.
- Networks should be established internationally for R&D regarding the climate link for relevant infectious diseases in people and animals.

- A larger, more integrated investment in research regarding climate adaptation is proposed. This includes extended research into the spread of infection (see section 5.9).

Proposals

- In the instruction to the National Food Administration, the National Board of Health and Welfare and the Swedish Institute for Infectious Disease Control, it should be evident that the authorities are responsible for adaptation to a changed climate within their areas of responsibility (see section 5.10.2).
- The National Food Administration should be commissioned to review rules and guidelines for the handling of food against the background of the increased temperature in the summer and the increased risk of periods of extremely high temperatures. The Administration should also continually provide information to the general public about risks and precautions to be taken when handling food.
- The National Board of Health and Welfare should be commissioned:
  - to monitor the development of the epidemiology of new and known infections as a consequence of climate change, and if necessary to take the initiative for measures aimed at maintaining a high level of disease control,
  - to draw up supporting information that can be used in extended further training regarding infectious diseases for personnel within the healthcare and medical treatment sector.
- The Swedish Institute for Infectious Disease Control should be commissioned, in co-operation with the National Veterinary Institute:
  - to monitor and analyse the development of the epidemiology of new and known infections as a consequence of climate changes and, if necessary, to take the initiative for new research in affected areas due to climate change.
  - to formulate supporting information and to provide notification about the increased risk of the spread of infection and about new diseases as a consequence of climate change, as

well as to analyse potential countermeasures and to report these to other affected authorities.

4.7 Changes in the world around us and their impact on Sweden

Climate effects on human activities and systems are difficult to assess. Society's systems are changeable, which makes it complicated to assess climate effects, particularly a long time in the future. According to the IPCC's evaluation report in 2007, there are considerably more observations and studies of climate effects available now compared to the situation at the time of the 2001 evaluation report. At the same time, there are large differences between the continents as regards the number of observations and studies. The availability of data is best in Europe, poorer in North America and considerably poorer in the rest of the world (IPCC, 2007).

The following analyses and compilations are based on the IPCC's 2007 evaluation report, which in turn is based on several different socioeconomic future scenarios and a selection of results from various climate models and scenario periods. There will generally be more climate effects, and they will be more far-reaching, as the changes in climate become more extensive. The way in which different effects will manifest themselves varies depending on the sector, region and adaptation capacity. Vulnerability to climate effects can also increase as a result of other stress factors, such as environmental emissions, poverty, conflicts, epidemics and food shortages. Irrespective of the region, there are certain groups (children, the poor, the sick and the elderly) that are particularly vulnerable to climate changes (IPCC, 2007)

Impact on different geographic areas

The following tables present in brief selected climate effects in different geographic areas. The analyses and the compilations are based on the IPCC's report about adaptation and the Swedish Environmental Protection Agency's report *Climate effects, adaptation and vulnerability.*

Table 4.36 Africa

Sector	Anticipated effect
Water	Between 75–250 million people will be exposed to water stress in 2020.
Agricultural production	Production will decrease as a result of the areas suitable for production decreasing in size, at the same time as the growing season becoming shorter.
Access to food	Reduced agricultural production. Reduced fish stocks in lakes due to rising water temperatures.
Coastal areas	Low-lying coastal areas risk being flooded.
Health	Major regional differences, e.g. increase or decrease in the spread of and the infection risk as regards malaria.

New studies confirm that Africa is one of the most vulnerable continents as regards climate variability and climate changes, due to several simultaneous stresses and low adaptation capacity. The cost of adaptation could amount to at least 5–10 percent of GNP by around the 2080s.

Table 4.37 Asia

Sector	Anticipated effect
Water	The melting of glaciers in the Himalayas entails: – an increase in the number of floods and landslides (short term). – reduced runoff and access to fresh water, primarily along the major rivers (medium and long term). In total, more than a billion people may be negatively affected by around 2050.
Agricultural production	Grain harvests around 2050: – increase of up to 20 percent in eastern and south-eastern Asia. – decrease of up to 30 percent in central and southern Asia.
Coastal areas	Increased risk of flooding, particularly in the densely populated delta regions in southern, eastern and south-eastern Asia.
Health	Increased mortality as a consequence of diarrhoeal diseases, principally related to flooding and drought, in eastern, southern and south-eastern Asia.

The population growth in Asia is resulting in increased demand for the declining water resources. On the whole, and bearing in mind the effects of a rapid growth in population and urbanisation, the risk of famine is expected to remain at a very high level in several developing countries in the region.

Table 4.38 Australia and New Zealand

Sector	Anticipated effect
Water	Increased problems with access to water up until 2030 in southern and eastern Australia and in parts of New Zealand.
Agricultural production	Reduced agricultural production up until 2030 due to increased drought and more fires.
Forestry	Reduced forest production up until 2030 due to increased drought and more fires. (In southern and western parts of New Zealand, however, the conditions for forestry are expected to improve in the short term.)
Coastal areas	Increased risk of and more powerful floods up until 2050.
Biodiversity	Significant losses (e.g. the Great Barrier Reef) are anticipated up until 2020.

The region has significant adaptation capacity thanks to well developed economies as well as scientific and technical resources, although there are tangible obstacles to the implementation of adaptation measures. Extreme weather events constitute major challenges. The natural systems have limited adaptation capacity.

Table 4.39 Latin America

Sector	Anticipated effect
Water	The melting of glaciers and changed precipitation will entail reduced access to water across large areas.
Agricultural production	Increased salination and the spread of deserts. Impaired productivity for certain important crops and livestock management, with negative consequences for access to food.
Forestry	The tropical forests in the eastern Amazon are gradually being replaced with savannah. The vegetation in semi-dry areas is being replaced with vegetation typical of dry regions.
Coastal areas	Increased risk of flooding.
Biodiversity	Significant loss of species.

Some countries in Latin America have carried out adaptation efforts. However, the region's adaptation capacity is limited, for example due to the lack of basic information, observation and monitoring systems. The political, institutional and technical frameworks are also inadequate.

Table 4.40 North America

Sector	Anticipated effect
Water	Reduced access and increased demand. Reduced summer flows and more winter flooding.
Agricultural production	In total, harvests from agriculture watered by rainwater will increase by 5–20 percent in the short term.
Forestry	Disruptions as a result of pests, diseases and the risk of fire.
Coastal areas	The population growth and the rising value of the infrastructure in the coastal areas will increase the vulnerability to climate variability and future climate changes.
Health	Towns and cities that are already affected by heatwaves are expected to be further affected.
Tropical storms	The cost of damage may increase by 70–75 percent (ABI, 2005).

Communities and biotopes along the coasts will increasingly be affected by the effects of climate change in combination with increased exploitation. Adaptation in North America is currently being implemented unevenly, and preparedness for increased exposure is low.

Table 4.41 Europe

Sector/area	Anticipated effect
Water	Increased risk of flooding as a result of cloudbursts, as well as more frequent coastal flooding and increased erosion.
Southern Europe	Poorer conditions with high temperatures, droughts, forest fires and an increased risk of heatwaves. Reduced access to drinking water, harvest volumes, tourism, hydroelectric power production.
Central and Eastern Europe	Reduced summer precipitation and increased water stress. Increased risk of heatwaves and peat fires. Forest productivity is expected to decrease.
Northern Europe	Positive effects in the short term: reduced requirement for heating, larger harvests, increased forest growth and increased hydroelectric power production. Negative effects in the long term: more frequent winter floods, coastal flooding, flooding due to cloudbursts, threatened ecosystems and increased ground instability resulting in landslides.
Biodiversity	Major losses (particularly in the mountainous areas)

The climate changes are expected to increase the regional differences as regards natural resources and assets in Europe. Europe's earlier experiences of extreme climate events may make climate adaptation easier.

Table 4.42 Overall trends

Sector	Anticipated effect
Water resources	Access will increase in high latitudes and in certain tropical areas. Access will decrease in certain medium and low latitudes (dry areas).
Ecosystems	An increase in temperature of 1.5–2.5°C will result in 20–30 percent of the world's species being at risk of extinction.
Agricultural production	An increase in temperature of 1–3°C is positive for production. Greater warming will have a negative effect.
Forestry	Commercial timber productivity is anticipated to increase moderately in the short to medium term, although with large regional variations.
Coastal areas	Considerable risk of flooding. Low-lying, densely populated coastal areas in Africa, Asia and island nations will be particularly affected.
Industry, buildings and society	Coastal areas and river valleys are particularly vulnerable to flooding, changes in land stability, etc. Taken together, the net effects tend to be more negative the greater the changes in climate.
Health	Increased malnutrition. Increased number of deaths as a result of extreme weather events. Increased frequency of diarrhoeal diseases. Increased risk of cardiac and pulmonary diseases due to ground-level ozone. Altered spread of infectious diseases.

Impact on migration patterns

Research on the link between climate change and international/internal refugees is starting to become established. The research results point in different directions on several points, however, for example regarding whether there are any actual climate refugees, how many refugees there will be and where the flows of refugees are going (Haldén, 2007). Several calculations point to potentially large flows of refugees as a consequence of climate change; in Africa, for example, between 75–250 million people will be exposed to water stress by 2020, although they are expected to be geographically restricted. Future climate refugees will probably end up in camps in their own country (internal refugees) or in neighbouring countries. In large parts of the world there are extensive migration movements, above all in the form of internal urbanisation, and it is reasonable to assume that climate change will reinforce this process. Towns and cities that are relatively close to the areas affected by negative climate effects will constitute target destinations flows of refugees, which in turn will probably lead to the spread of slums. The spread of slums has a destabilising effect, as well as being economically costly for regions. The destabilisation of regions, in the form of slow impoverishment rather than sudden collapse, may in combination with poverty and institutional weakness exacerbate existing conflicts or generate new ones. Planned migration, which entails moving the population from areas that may be exposed to temporary or permanent flooding or droughts, may occur in certain areas with the aim of limiting adaptation costs, human suffering and instability (Haldén, 2007; WBGU, 2007).

Impact on European and Swedish security policy

Very little research has been conducted into the importance of climate change as regards international and regional co-operation patterns (Haldén, 2007). In recent times, however, the issue has been brought to the fore and has attracted considerable attention internationally. For example, the United Kingdom has raised the matter in the UN's Security Council, and a number of former American general and admirals have highlighted climate change as the greatest threat to global security in the report *National Security and the Threat of Climate Change.*

Climate change is not expected to create new conflicts in the first instance, but rather to reinforce and exacerbate existing conflict patterns. In a longer perspective, however, after 2050, there is a risk of new conflicts arising as a consequence of climate change, as the climate effects by this time may be more powerful and create more upheaval. In those regions where inter-state and intrastate forms of collaboration are well developed, such as Europe, there is less likelihood of conflict. In regions where the forms of collaboration are less well developed, such as Africa and the Middle East, there is a greater risk of conflict. A greatly impaired world economy can weaken many states and limit their ability to maintain order and security. At the same time, an impaired world company can restrict a state's ability to wage war (CNA, 2007; Haldén, 2007; Stern, 2006; WBGU, 2007).

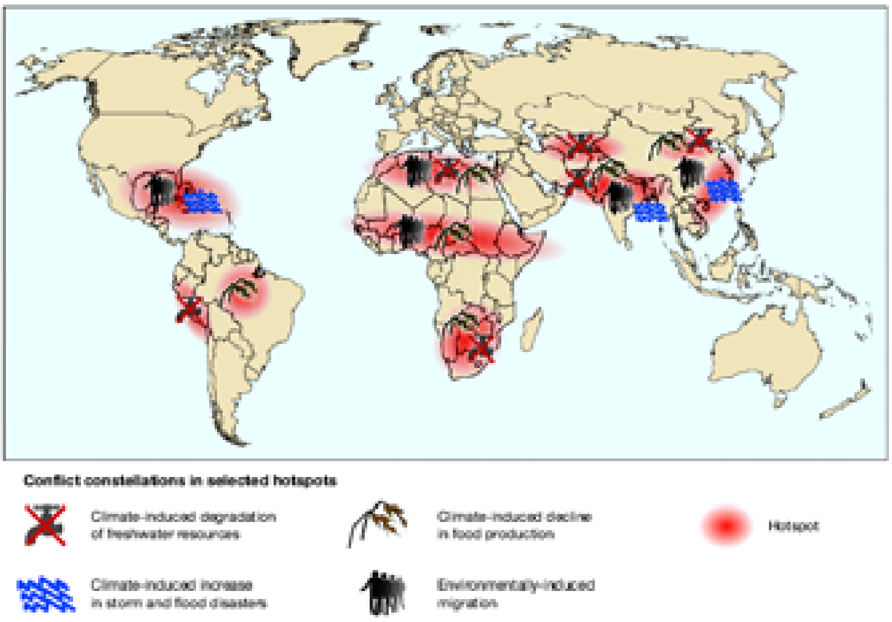
Climate change will probably affect different areas in Europe in different ways. In the short term, it will primarily entail certain advantages for Northern Europe, while Southern Europe will mainly be exposed to stresses. Europe, as a whole or in parts, may experience problems with the energy supply and agriculture sectors, which are important from a security policy perspective.

Europe's dependence on imported energy may increase in the future. By 2030, as much as 70 percent of the EU's energy requirements may be covered by imports, compared to 50 percent today. Around a third of Sweden's energy requirements, almost exclusively oil, is imported (COM 2006:105; IEA, 2004). Increased dependence on imports from regions that are currently unstable, and that could be further destabilised in a future climate, entails a risk of disruption as regards the security of supply. The EU, partially as a result of the future risks, has produced the green paper *A European strategy for sustainable, competitive and secure energy* and the report *Handling external energy risks*.

Agriculture and the supply of food, both globally and within the EU, are of interest from a security policy perspective, but also with regard to other policy areas. Within classic geopolitics, the importance of domestic provision is emphasised for a country's survival. Up until 2050, the EU is not expected to experience any problems in securing domestic food production within the Union (Haldén, 2007). Some Member States may have problems with reduced harvests, however, which is why it is important to have a well-functioning European food market. The original purpose of the Common Agricultural Policy (CAP) was to ensure that Europe would be self-sufficient in the event of a significantly deteriorated world situation. Climate changes may result in countries that at present are global exporters of food (such as Australia and New Zealand) having a poorer capacity to produce food. This could result in the original purpose of the EU's agricultural policy, which today might appear outmoded, once again becoming relevant. There may be increased pressure to redirect agricultural support to those areas that are particularly affected by droughts or extreme weather events. It may also be the case that those areas of Europe where the conditions for agriculture will improve to a greater extent will be used to guarantee the EU's ability to be self-sufficient. An important prioritisation issue may also be whether agricultural land is to be used for cultivating crops intended for biofuels or food (Haldén, 2007; IPCC, 2007).

It is very likely that European and Swedish security policy, as well as other policy areas, will be dependent on events in other, often poor, parts of the world as a result of climate change. For this reason, the security policy may need to be integrated further with the aid policy in future. Through comprehensive humanitarian interventions and peace-building, it is possible to prevent the destabilisation of regions, famine disasters, the spread of epidemics, flows of refugees, etc. (CNA, 2007; WBGU, 2007). Figure 4.54 shows potential trouble spots resulting from climate change.

Figure 4.54 Potential trouble spots resulting from climate change



Source: WBGU, 2007.

Impact on Sweden's aid policy

Sweden's aid policy and Sida's (Swedish International Development Co-operation Agency) overall goal is to fight poverty, i.e. to work to raise the living standards of poor people. On this basis, Sida, with regard to the climate issue, will both contribute to measures that prevent or minimise emissions of greenhouse gases, as well as reduce the vulnerability of poor countries and people and strengthen their capacity to adapt to climate change. The climate work is governed by a number of principles: that it is better to prevent than to cure, the precautionary principle, and the fact that the climate issue must be integrated in Sida's operations on the basis of the overall perspective of fighting poverty. Sida's current approach is that responsibility for the climate issue should be spread within the organisation in such a way that an integration of the issue becomes possible. Operations targeted at energy, transport and business are mainly focused on limiting emissions of greenhouse gases, while work on health and water resources focuses on counteracting the consequences of climate change. The emphasis of Sida's actions is currently on efforts that contribute to preventing and minimising emissions of climate gases (Sida, 2004).

The fact that the poor areas of the world are hit particularly hard by climate changes, combined with the fact that poor people are particularly vulnerable to these changes, means that aid policy has an important role to play in the climate adaptation work. According to article 4.4 of the Climate Convention (UNFCCC), the industrialised countries (Annex I countries) should support the developing countries that are most vulnerable to climate change. The industrialised countries have provided support to help the least developed countries produce National Adaptation Programmes of Action (NAPAs). These programmes are based on the countries' own assessments of which sectors in society are most vulnerable to extreme weather and climate changes, and consequently need to be adapted in the first instance. Effective aid work, where consideration is given to the changes in climate, can entail curbing the negative effects of climate change, e.g. the occurrence of climate refugees, political instability and/or escalation of existing conflicts, and the need for emergency humanitarian efforts.

Impact on the world economy

According to the Stern Review, the total cost of climate change could amount to at least 5 percent of the worlds GNP per year, both now and forever, if no measures are taken. If we extend the scale of risks and consequences, the damage could amount to as much as 20 percent of the world's GNP annually. The effects of climate change on the economy are on a par with the effects at the time of the World Wars or the 1930s economic depression. The report states that, if no measures are taken to limit the scope of climate change, it will damage the world's preconditions for growth. Northern Europe is one part of the world that will not be affected particularly greatly, at least in the short term, and to some extent may even benefit from a changed climate (IPCC, 2007; Stern, 2006). However, a small, open economy like Sweden can be affected indirectly if climate change results in a global recession with a reduction in global demand as a consequence. On the other hand, if climate change results in a smaller global supply but the same global demand, countries that are not greatly affected by the negative effects of climate change could benefit economically, provide the world market continues to function effectively.

The fact that extreme weather events are expected to become more common in much of the world in a changed climate may influence the global financial markets. Extreme weather events that cause extensive devastation can affect the world's stock markets and can result in a reduction in confidence in financial institutions. Disruptions to the technical infrastructure can result in liquidity problems in the financial sector, as experienced for example in conjunction with the extensive power failures in north-eastern USA and Ontario in 2003. Payment liquidity is critical for commercial banks, as it is the core of the banks' capacity to receive and make payments. One future scenario, whereby a number of simultaneous extreme weather events cause extensive damage at different geographic locations around the world, would seriously damage confidence in the financial institutions and hence the world's economic systems (Swedish Financial Supervisory Authority, 2004; Stern, 2006).

Extreme weather events and climate changes are also a global problem for the insurance sector due to the reinsurance system. Reinsurance entails primary insurance providers insuring themselves with reinsurance companies, which are often multinational businesses. As a result, the risk is spread globally. According to estimates produced by the Association of British Insurer (ABI), the insurance costs for damage caused by tropical storms will increase dramatically in a changed climate. It is also believed that the insurance system has a capital deficit in relation to these new risks, and that there is a need for more reinsurance protection. If reinsurance becomes more expensive as a consequence of an increased risk of climate-related damage, the prices on the Swedish insurance market may be affected (ABI, 2005).

Impact on the Swedish commercial sector

A key to economic success in the future and in a future climate is a country's ability to implement structural change. Structural changes include changes between different sectors, e.g. moving labour from goods production to the production of services, as well as changes within a sector, such as changes within a company as a result of the development of new production processes. Business's ability to change is decisive for achieving a high rate of growth and efficient utilisation of resources. A presumed increase in globalisation will lead to increased competition, which in turn is expected to lead to a greater need for good structural change opportunities. A commercial sector that has a good capacity to achieve structural change will be more competitive, as it is able to utilise its comparative advantages in a changing world and can quickly adapt production to changes in (other countries') supply and demand. This is particularly important for a small, open economy like Sweden, which is heavily dependent on the outside world. In an international perspective, it can be seen that Sweden's rate of structural change is slightly higher than in the majority of other OECD countries. However, Sweden's rate of structural change, calculated from official Swedish employment data, has been slowly declining during the period 1988–2004. In summary, the fact that Sweden has a relatively high rate of structural change indicates that the conditions for the Swedish commercial sector will be relatively good in a future climate. However, the fact that the rate of structural change in Sweden is declining, according to some studies, can be viewed as a worrying sign (Long-term study, 2007).

Table 4.43 Impact on Sweden of climate changes in other parts of the world – overview

Sector in Sweden	Anticipated effect
Agricultural and food production	Reduced supply of food on the world market, depending on the extent of the climate changes. Can entail increased demand for Swedish food.
Forestry	Large regional differences in the supply of commercial timber can affect the Swedish forestry industry.
Water assets	Increased demand for water on the world market. Possible future export product for Sweden.
Tourism	Regional climate effects in e.g. the Mediterranean and the Alps can lead to increased tourism in Scandinavia.
Energy	Increased demand for electricity from Europe. Risk of disruptions to imports of certain types of energy, e.g. oil.
Insurance operations	The reinsurance system may be affected, with more expensive insurance as a consequence.
Biodiversity	Increased migration of species.
Health	A poorer state of health globally, partly as a result of an increased number of conflicts, can result in an increased risk of the spread of infectious diseases.
Swedish business	Altered global conditions stipulate demands for countries to have a high rate of structural change in order to be competitive.
Security policy	Renewed focus on the EU's Common Agricultural Policy (CAP). Increased integration with the aid policy. Increased focus on water.
	Increased focus on energy.
Aid policy	Increased focus on climate adaptation issues.
Flows of refugees	Increased need for co-ordination at European level and preparedness for increased flows of climate refugees.

4.8 Combined effects on society

4.8.1 Socioeconomic development in Sweden

The emissions scenarios in the IPCC's SRES report (Special Report on Emission Scenarios) are based on assumptions about the development of a number of socioeconomic parameters, divided between around ten regions. Developments in individual countries are not covered. To gain an understanding of possible developments in Sweden under scenarios A2 and B2, we present GNP growth and population development in the various SRES scenarios scaled down to a Swedish level, and compare this with various Swedish long-term scenarios.

Economic scenarios for Sweden.

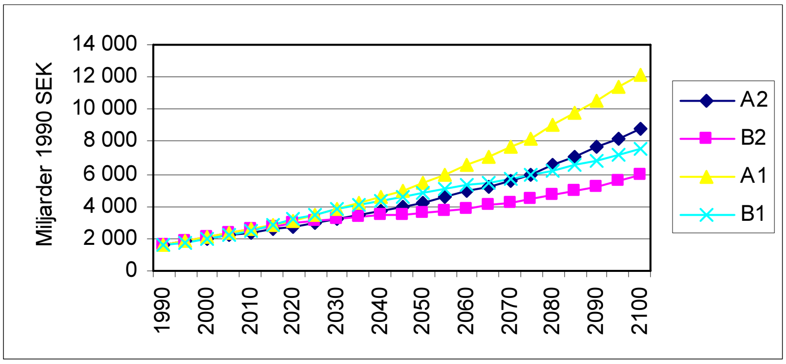
In the National Institute of Economic Research's simulations with the Environmental Medium-term Economic Model (EMEC) for the work with control station 2008, the assumptions that are made regarding e.g. productivity development and growth in various sectors result in a GNP growth of just over 2 percent up until 2025 in the reference alternative. It is assumed that exports will continue to grow relatively strongly. Investments will develop much more favourably than during the last decade, and will grow by 4.2 and 2.1 percent annually during the periods 2002–2015 and 2015–2025 respectively. In the alternative scenarios with a higher price for emissions credits, it is assumed that the marginal pricing of electricity will result in a dramatically increasing electricity price, which will entail some slackening of the economic growth.

Productivity development differs quite significantly from sector to sector. The engineering industry, the pharmaceuticals industry and the chemicals industry have a high rate of growth (between 2 and 3.5 percent annually), whereas the pulp, paper and graphic industries, iron and steelworks as well as metal works have a lower growth rate than the average for the commercial sector. The construction industry is expected to experience strong growth that is above the average for business. The assumptions regarding dramatically rising electricity prices until 2015 will lead to an increased switch to district heating and significant growth for district heating stations. The rising price of electricity will also affect the growth of electricity-intensive sectors such as iron and steelworks as well as metal works, which in turn will affect demand for products from the mining sector. Agriculture is expected to experience a relatively low growth rate, at around 1 percent per year, while forestry will be slightly higher. (Östblom, 2007)

The National Institute of Economic Research's scenarios extend as stated through until 2025. The major differences between the various SRES scenarios will not appear until after 2050, however. No economic scenarios have been produced for Sweden for that time period.

The SRES report only presented results for four regions: OECD, Asia, Eastern Europe and the former Soviet Union, and the rest of the world. The emissions scenarios were generated in models that had a resolution of between 9 and 11 regions. No country-specific projections were carried out. The Center for International Earth Science Information Network (CIESIN) at Columbia University in the USA has scaled down the IPCC's scenarios from the 11 regions to national level (CIESIN, 2002). The calculations were performed with a linear scaling, where each country's annual growth rates for population and GNP were assumed to be the same as the growth for the region to which the country belongs.

Figure 4.55 **GNP development in Sweden through until 2100, scaled down from the SRES scenarios**

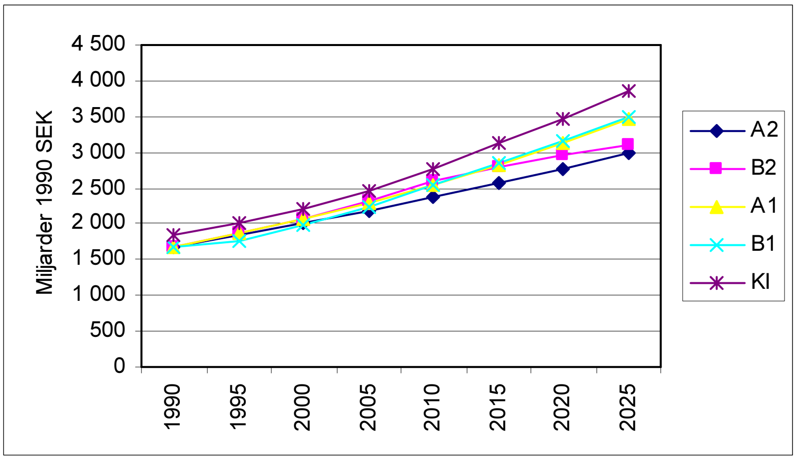


Billions 1990 SEK

Source: CIESIN, 2002.

Compared with the National Institute of Economic Research's scenarios, the GNP trend through until 2025 is slightly lower in the SRES scenarios (figure 4.56). A2 increases after 2025, however, and by 2100 is higher than B1 and B2.

Figure 4.56 GNP development in Sweden through until 2025, according to scaled-down SRES scenarios and the National Institute of Economic Research

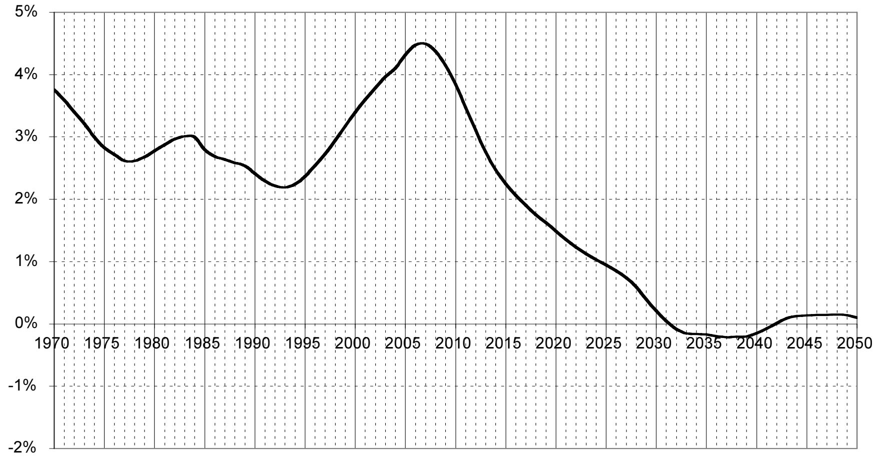


Billions 1990 SEK

Source: CIESIN, 2002 and Östblom, 2007.

The demographic trend has proven to be a good predictor of GNP development (Lindh and Malmberg 1999; Malmberg 1994). The analysis carried out by the Institute for Futures Studies is in sharp contrast to usual economic scenarios (figure 4.57). The analysis has used Statistics Sweden’s forecasts for population development.

Figure 4.57 Sweden's economic growth 1970–2050, according to the demographic model



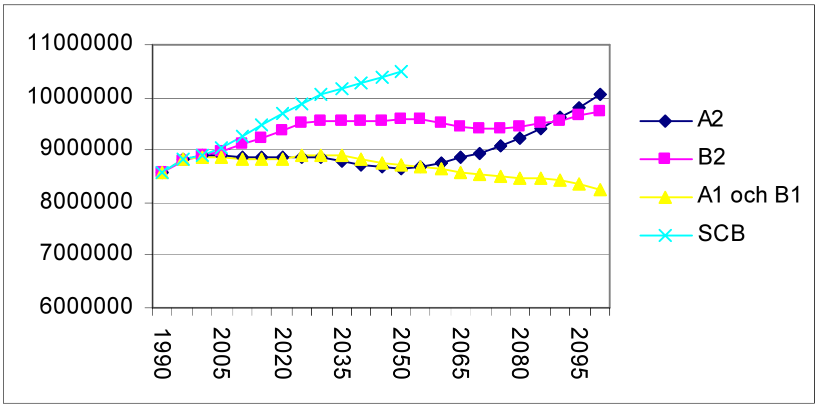
The age composition is the most important factor for GNP development. An aging population, as we have in Sweden, produces lower GNP growth. If this model is accurate, economic development will have a very different appearance compared to prevalent assumptions in economic analyses.

Population growth

Statistics Sweden produces projections regarding population development through until 2050. In these, it is estimated that the population will have grown to 10.5 million by 2050. This is based on the assumptions that both life expectancy and fertility will increase, and that Sweden will continue to be an immigration country.

For some of the scenarios in CIESIN's calculations, the population growth through until 2050 was taken from the UN's population forecasts, which are produced for each individual country. The scaling down method was then used only after 2050. The results for Sweden are shown in figure 4.58.

Figure 4.58 Population growth in Sweden: Statistics Sweden's projection until 2050 and the SRES scenarios scaled down for Sweden until 2100



Source: SCB and CIESIN, 2002.

A comparison with Statistics Sweden's projection shows that the SRES scenarios are significantly lower than the Swedish forecast in 2050. A2 and B2, where a higher population development is assumed than in A1 and B1, are closest. However, they are also a good bit lower than the Swedish forecast. B2 is highest in 2050, while A2 has a higher growth rate at the end of the century. If the assumptions on which the Swedish projection is based are accurate, we can consequently assume that population in 2100 will be higher than that shown in the diagram containing the scaled-down SRES scenarios.

Regional development

The Institute for Futures Studies has produced scenarios regarding the regional population trend in Sweden and the associated construction of housing. The trends that can be seen are that the city regions will continue to grow, while people will continue to move away from smaller towns. The Mälar Valley, the West Coast, Skåne, Åre-Östersund and Umeå are among the areas where the population will increase most. The age structure will become more favourable in these areas, and investments in housing will increase.

As in previous centuries, the population will increase significantly along the coast, although there will also be a fairly strong increase in the population in inland parts of Götaland, between 2.5–4 percent over a five-year period.

Importance of socioeconomic factors as regards consequences of climate change

The impact assessments and calculations of costs and earnings that are carried out in this report have generally been conducted without consideration to changes in socioeconomic factors. It is very likely that the assumptions about such development factors would overshadow the consequences of the climate changes, making it difficult to see which effects are due to the changing climate and which are due to the socioeconomic assumptions that have been made. In order for the assessments within various sectors to be consistent, it would also be necessary to have an overall socioeconomic scenario for economic, technical and regional development through until 2100. It is difficult to produce such a scenario, as there are very few assessments for such long time periods. The cost scenarios that are presented in this chapter are therefore calculated for the current situation, and illustrate how climate changes could affect Sweden, assuming that nothing else changes.

In the ongoing work on climate adaptation, there is however reason to take socioeconomic effects into consideration. It can generally be said that both population development and regional development affect the magnitude of the consequences of increased frequency of flooding, storms, erosion and landslides. An increased population means that the need for buildings and infrastructure will increase. An increase in the capital stock means that the value that can be damaged is greater. At the same time, the preconditions for adapting society to a changed climate are improving. The rate of adjustment is also increasing, which is making adaptation easier. The consequences of weather-related events in the city regions will be greater if the concentration of population to these areas increases. It will be extremely important for the physical planning of these areas to be carried out with consideration for future changes in the climate.

A strong economy with a high rate of change naturally has better potential that a weak economy to meet the stresses and implement the necessary restructuring and preventive measures. The way in which the prices develop also influences to a great extent both the vulnerability and the potential to make use of improved production potential due to climate change. The development opportunities for e.g. the tourism sector, agriculture and forestry, all of which are largely dependent on the climate, are also largely dependent on price development and competition with the outside world. For the energy sector, the price trend for different types of energy is extremely important, as are the export opportunities. Issues of this type are discussed in the sector analyses for the sectors where they have been deemed relevant and where supporting data has been available.

As climate change is an important factor for social development, it can be of interest to develop scenarios and models that can be used for analyses in the long term. This applies both to economic models with a high sector resolution and regional models with a bearing on regional development and physical planning.

4.8.2 Combined cost assessments

In the sector analyses, estimates of damage costs and costs for implementing action have been produced as far as possible, as have calculations of increases in income where appropriate. A compilation of the economic consequences that have been calculated is presented below. Many consequences in significant areas, such as the impact on the natural environment, cultural heritage assets and risk to human life, are not included. Important consequences for which cost calculations have not been possible or that are not of an economic nature are described in section 4.8.4. A compilation of damage costs and action costs for climate adaptation is presented below, principally based on data from the expert groups that have been linked to the study.

Which costs have we included?

Damage costs are the cost of the damage that would arise if no actions were taken to alleviate the consequences of various weather events. They can comprise the cost of repairing and restoring the damaged object, if this is possible, or the value of that which has been destroyed.

The damage costs include only part of the economic consequences that can arise. Costs that are not included are those relating to damage to municipal and private roads, the water and sewage network, as well as loss of production and loss of income for individuals. Costs resulting from indirect consequences of electrical and telecom failures, interruptions to water supplies, road and railway traffic, as well as disruptions to shipping, are not included either, other than to a certain extent with regard to flooding of Sweden's major lakes. In the event of natural disasters, small companies in exposed areas can also be affected, both by direct damage as well as by the consequences for other systems, such as power failures, telecom failures and disrupted road, rail and shipping communications. These costs have not been included either.

Of the positive effects that have not been included, the most important area is increased tourism.

Limited opportunities for carrying out detailed cost calculations and cost-benefit analyses

In most cases, the consequence descriptions have been based on the scenario RCA3-EA2. As scenario A2 entails higher emissions and hence greater climate change than B2, this means that the consequences, and hence the economic effects, will be lower if developments should follow the B2 scenario.

Judging how different technical and ecological systems will be affected on the basis of climate scenarios with maps of different climate indices is a difficult task. These climate scenarios are in themselves uncertain (see section 2.2.1). Added to this, there is considerable uncertainty regarding the lifetime and future development of various systems. The impact assessments and cost calculations that are presented here should therefore be interpreted with considerable caution. They are intended primarily to show possible magnitudes.

Action costs are usually easier to calculate than damage costs, even though they are also associated with uncertainties, particularly in the longer term. In cases where both action costs and damage costs are calculated, a cost-benefit assessment can be carried out. For several sectors, it is clear that it is socioeconomically beneficial to implement preventive measures rather than waiting until the damage occurs. This applies for example to the road and rail sectors, rainwater and waste water systems, as well as measures against landslides in certain areas. In most cases, preventive measures can be implemented successively in conjunction with new investments and regular maintenance. In this way, considerable additional costs can be avoided.

For many sectors, it has not been possible to produce a general assessment of whether it is cost-effective to implement preventive measures now or whether it is better to wait. The costs for implementing preventive measures against the effects of a climate change can be reduced through improved technology and improved methods, which is an argument for waiting when it comes to measures that are not currently deemed to be cost-effective. In many cases, however, the action costs are already lower than the damage costs, particularly if measures are implemented at the same time as ongoing maintenance work.

Sectoral presentation of calculated costs and earnings

Roads

Additional costs for repairs to roads and bridges due to landslides, washed away roads and floods have been estimated at between SEK 80–200 million annually. If it is assumed that the risk will gradually increase during the century, and that the damage will reach the indicated cost level by 2080, the total cost though until 2100 will be between SEK 9–13 billion. The cost for preventing 50 percent of this damage is estimated to be between SEK 2–3.5 billion. Implementing measures is consequently very worthwhile (see Appendix B 1).

The costs for certain types of damage are not included in the above calculations, above all costs for major landslides. The cost of the landslide in Munkedal amounted to SEK 120 million, of which diversion costs constituted more than 50 percent (see section 4.1.1).

Flooding of the major lakes can cause considerable costs for the restoration of roads. The total cost of the current 100-year level in Lake Vänern was calculated at approximately SEK 900 million, and SEK 1.9 billion at the current dimensioning level. The total cost of Lake Mälaren flooding was calculated at SEK 8 million at a 100-year level and SEK 150 million at the dimensioning level (see progress report, SOU 2006:94).

We have no information about costs for municipal and private roads.

Railways

The railway network has been affected by storms, floods and landslides in recent years. The damage costs for the landslides in Ånn and Munkedal and the flood in Mölndal amounted to a total of SEK 35 million, while damage following Hurricane Gudrun and Hurricane Per together cost around SEK 180 million. The Swedish Rail Administration has estimated that the cost of traffic disruptions and restoration work in the event of Lake Vänern flooding could amount to SEK 150–550 million, depending on water level and duration. High water levels in Lake Mälaren could affect the railway tracks through Stockholm, with significant costs relating to traffic disruption as a consequence (see SOU 2006:94).

Adaptation measures for reducing the risks include staff training, mapping the risk areas, increased maintenance, replacing drainage facilities and erosion protection, reviewing dimensioning requirements and securing trees to prevent power failures. The cost of implementing these measures is estimated at around SEK 100 million. After this, approximately SEK 20 million is required annually in the form of increased maintenance costs (see Appendix B 2).

Flying

Flying is expected to benefit from reduced costs for de-icing and anti-skid treatment totalling around SEK 60 million annually. Some adaptation measures must be implemented, such as thicker pavement structures on runways and improved cleaning facilities in some airports. The cost of these is estimated at just over SEK 300 million through until 2080 (see section 4.1.4). The renovation of surface water systems that is already required at many airports is even more urgent, due to the increased precipitation that climate change will cause. The reconstruction of pipelines entails an additional cost of around SEK 100 million (see Appendix B 4). Only part of this cost is climate related, however. The damage costs that could arise if these measures are not implemented have not been estimated.

Shipping

Milder winters mean that there will be less need for ice-breaker assistance. The cost of the Swedish Maritime Administration's ice-breaking activities currently amounts to between SEK 150–250 annually. A considerable proportion of these costs are fixed, as ice-breakers have to be kept in readiness. The extent to which the costs can be reduced depends on when the change in the climate appears so stable that the state of readiness can be reduced and some ice-breaker capacity can be phased out (see section 4.1.3).

Telecommunications as well as radio and television broadcasting

The costs associated with telecommunications failures can be high, although it has not been possible to calculate a figure. Hurricane Gudrun is estimated to have cost Telia SEK 500 million in direct costs for restoring the network of lines, auxiliary power, mobile masts, etc. (see Appendix B 5). It has not been possible to calculate the costs for all the subscribers who were affected. The failure of telecommunications networks can cause significant problems in emergency situations (see sections 4.1.5 and 4.1.6). No major costs are anticipated to arise for preventive measures, as the rate of renewal within telecommunications is relatively high. Neither will costs arise for preventive measures regarding radio and television broadcasting, as these are not judged to be sensitive on the basis of current climate data.

Electrical systems and power potentials

An increased water supply means that the production potential for hydroelectric power will gradually increase during the century (Andréasson, 2006b). In model simulations, the increase has been calculated to lie between 7 and 22 percent for the B2 scenarios and between 10 and 32 percent for the A2 scenarios up until the end of the century. A successive increase of up to 15–20 percent produces increased earnings of around SEK 190–260 billion through until 2100, based on an electricity price of SEK 0.40. However, this will require some reconstruction of power stations and storage reservoirs.

According to RCA3-EA2, the wind's energy content will also increase. It is estimated that the wind power potential could increase by 5–20 percent over the next 30 years, which is equivalent to approximately 2 TWh, assuming that the plans to expand wind power to 10 TWh are implemented (Gode et al, 2007). With an electricity price of SEK 0.40 and a gradual increase in wind energy, earnings will increase by SEK 26 billion through until 2100 according to RCA3-EA2. Both of these calculations refer to gross earnings, i.e. the costs for the increased investments are not included.

Hurricane Gudrun entailed costs totalling SEK 2.6 billion for the power companies, of which SEK 650 million comprised compensation paid to customers for power failures (Swedish Energy Agency, 2005). The compensation rules were altered in the aftermath of Gudrun, and the damage costs resulting from Hurricane Per totalled SEK 1.4 billion, of which SEK 750 million was compensation for power failures (Swedenergy, 2007). It is anticipated that the electricity networks will not suffer such large damage costs once the current plans for rectifying critical stretches of line have been implemented, although significant damage costs can still arise.

Landslides can affect switching stations and pylons. Repair costs for individual breakdowns amount to SEK 0.5–4 million for switches in stations, and SEK 3–5 million for minor pylon collapses (2–3 pylons) (see section 4.2.1). Flooding can affect network stations, resulting in power failures and restoration costs. The damage costs as regards the electricity networks due to flooding around Lake Vänern have been estimated at SEK 100–150 million. In addition to this there is the cost of operational disruptions, which can amount to around SEK 1 million per day (SOU 2006:94).

Dams

Climate change entails a risk that the dimensioning flow will increase for dams in the highest risk category, although there is still considerable uncertainty. The 100-year flood is increasing in some parts of the country and decreasing in others. It has been estimated that the cost of adapting to climate change could be of a similar size to adaptation to today's climate according to the Flow Committee's guidelines, i.e. approximately SEK 2 billion (see section 4.2.2).

Heating and cooling requirements

The heating requirements will decrease in a warmer climate. Calculations of the reduced heating requirements have been carried out on the basis of the change in the number of degree days, the existing stock of buildings and unchanged prices. It is assumed that no rationalisation will take place (see Appendix B 11). During the period up until 2040, it is estimated that the cost for heating will fall by approximately SEK 4.7 billion per year for the A2 scenario compared to the current situation. In the period 2041–2070, the cost will decrease by SEK 6.6 billion annually, and between 2071 and the end of the century it will fall by approximately 9 billion compared to the current situation. The cost reduction over the entire period 2010–2100 would be approximately SEK 690 billion. According to the B2 scenario, the energy requirement is estimated to be 12 percent higher, which means that the saving would be approximately SEK 600 billion.

The cooling requirement is expected to increase in the future, partially due to climate change. The calculations for premises are based on the current floor area and unchanged prices. Under these conditions, the climate-related increase in demand for cooling in premises and homes is anticipated to increase energy costs by approximately SEK 150 billion during the period 2011–2100 for the A2 scenario (see Appendix A 6). For the B2 scenario, the energy cost will increase by approximately SEK 135 billion.

District heating system

Increased precipitation volumes and consequences such as flooding and raised groundwater levels will increase the stresses on the district heating culverts. An increased rate of renewal of the vulnerable culvert sections is estimated to cost SEK 1.35 billion through until 2020 (see section 4.2.4).

Drinking water supplies

The total cost of damage due to disruptions to drinking water supplies is difficult to calculate and has not been estimated, as it is difficult to judge the number of cases in which the drinking water will become unfit for consumption and what consequences this will have for the general public.

The cost to society of an outbreak of a microbial, waterborne disease can vary from a few million kronor to several hundred million kronor on each occasion, depending on the extent of the outbreak. The cost of replacing small water sources in the event they are contaminated or become unsuitable for consumption due to high humus levels can vary from a few tens of millions to more than a billion kronor for large water sources. If water pipelines are destroyed by a landslide, the cost to society can be between SEK 10–50 million on each occasion.

In a situation where water from the taps is undrinkable, the cost to consumers is very great, as are the increased transport costs and associated emissions. A litre of bottle water can cost between SEK 5–15, while a litre of water from the tap currently costs just a few öre. Poorer raw water quality and increased treatment costs will result in the price of drinking water increasing, approaching the prices in Europe and the USA (see section 4.2.5).

According to a rough estimate, the cost of adapting Swedish drinking water preparation to a changed climate amounts to

SEK 5.5 billion for municipal water supplies and around SEK 2 billion for private water supplies.

Rainwater and waste water systems

Increased precipitation and overfull drainage systems result in an increased risk of flooding, due in part to back-flowing water. In 2004 and 2005 there were approximately 1,600 cellar floods per year. The majority of these are not related to natural damage. In 2002 and 2003 there were two instances of extreme precipitation, in Kalmar and on Orust, which entailed costs of SEK 60 million and SEK 120 million respectively.

In order for the drainage systems to cope with significantly increased precipitation, the rate of renewal must increase. The additional cost of an increased rate of renewal is probably in the order of SEK 10–20 billion (see Appendix B 16). Other possible measures, such as reducing the volume of additional water entering the waste water systems and creating retaining reservoirs, have not been costed. The above costs do not include the renewal costs for private service pipelines. A rough assessment is that private costs for renewing the water and sewage installations in private properties would amount to approximately 40 percent of the figure for public facilities, which gives a cost of approximately SEK 4–8 billion over the 25-year period (see Appendix B 16).

Impact on building constructions

Higher temperatures and a damper climate will give rise to cost increases due to increased maintenance requirements and a shorter lifetime of the building envelope. The increases in costs have been calculated at a total of approximately SEK 100 billion through until 2080 (non-discounted values, cf. discounted values in Appendix B 17). The damage costs that will arise if this maintenance work is not carried out have not been calculated. This relates primarily to the health effects of mould and costs for repairs that are more extensive than regular maintenance (see section 4.3.5).

Flooding of coastal buildings

Raising sea levels and increased flows in watercourses mean that there will be an increased risk of flooding along Sweden's coasts, watercourses and lakes. The study's progress report (SOU 2006:94) presented calculations regarding floods around Lake Vänern, Lake Mälaren and Lake Hjälmaren. In the ongoing work, corresponding calculations have been conducted for watercourses and coastal areas. However, it has not been possible to calculate altered return frequencies for high flows in the same way as for the major lakes. This means that an estimate of the combined costs up until 2100 is more general.

Within those areas along watercourses that are at a high risk of being affected by a hundred-year flood in today's climate are houses, holiday cottages, multi-dwelling buildings, offices and industrial premises with a total floor space of 6 million square metres. Assuming that these buildings will be affected by such a flood once in the next century, the cost of restoring them will be just over SEK 18 billion (Appendix B 14). In addition to this there will be floods that recur at shorter intervals, which will probably occur several times during the century. These have not been costed.

These damage costs only cover buildings. Damage to roads and other infrastructure can entail significant sums. Earlier floods can give an idea of the extent of the damage costs that could arise. The flooding of Arvika in 2000 cost a total of around SEK 200 million (rescue services, protective measures and damage to technical municipal installations, as well as damage to private buildings, facilities and companies). Of this, SEK 29 million related to costs for rescue services and SEK 100 million to costs for private buildings, companies and facilities. The cost of protective measures and damage to municipal technical installations totalled around SEK 59 million. These were divided according to table 4.44 below.

Table 4.44 Distribution of damage costs for Arvika Municipality from the flood in 2000

Management and co-ordination	SEK 300,000
Buildings and properties	SEK 7,900,000
Streets, roads, quays, car parks	SEK 7,700,000
Water and sewage	
Pumping stations	SEK 1,200,000
Sewage treatment plants	SEK 1,500,000
Pipeline network	SEK 35,900,000
Parks and green areas	SEK 4,000,000
Total	SEK 58,500,000

Source: Arvika Municipality.

In Arvika, the local authority's costs for damage to streets etc. were consequently as great as the costs for damage to buildings. The proportions as regards costs for damage to buildings and to infrastructure in Arvika can be used as a rough estimate of the costs for infrastructure on a national level. If we assume that half of the permanent residences and industrial premises that are threatened with flooding are situated within densely populated areas, the damage to infrastructure will amount to approximately SEK 6 billion.

In the progress report (SOU 2006:94), the cost up until 2100 for the flooding of buildings around the major lakes – Vänern, Mälaren and Halmaren – was estimated at a total of SEK 7.9 billion at today's hundred-year flood. Damage costs for shipping, roads, railways, agriculture, forestry, water treatment works, sewage system, power station and industries totalled an additional SEK 3.2 billion.

Today's hundred-year flood, as well as smaller floods with shorter return frequencies, will have a reduced return frequency in some parts of the country. In the area around Lake Vänern, for example, it is estimated that the hundred-year floods will have a return frequency of 20 years. The hundred-year floods in a changed climate will therefore be higher than at present in these areas, which means that larger areas will be flooded. The return frequency will be longer in other parts of the country (see section 4.3.1).

The most common measure for reducing the flooding risk is building embankments to protect the threatened areas. The cost of embankments varies between SEK 300 and SEK 10,000 per m^2, depending on the ground conditions and whether the embankment is located in a built-up area (Swedish Rescue Services Agency, verbal communication). Pumping stations are also required. The extent to which it is cost-effective to build permanent embankments depends on the value of the assets that are threatened and the anticipated extent of the flooding risk. One alternative might be preparedness to place out temporary embankments supplemented with pumping.

In the event of flooding of Lake Vänern and Lake Mälaren, the most cost-effective measure is judged to be increasing the drainage potential. The cost of this amounts to approximately SEK 650 million for Lake Mälaren. For Lake Vänern, the cost has been specified as being in the range SEK 1–6 billion. A more accurate cost estimate for Lake Vänern requires landslide mapping for the Göta Älv river valley.

For buildings along the cost, there is currently no height data that is sufficiently detailed to determine actual flooding risks. The area of floor space that is less than 5 metres above sea level amounts to approximately 60 million m^2. The three municipalities that have been studied in detail indicate considerable variations in the proportion of floor space below the 5-metre curve that will be in flood-threatened areas by the end of the century. In Ystad, around 20 percent of the buildings that are below the 5-metre curve will end up under the hundred-year water level in the event of a global rise in sea level of 88 cm. For Sundsvall, the corresponding figure is 6 percent (see section 4.3.1 and Appendix B 14). These relationships between actually threatened floor space and floor space below the 5-metre curve can be used as a rough rule of thumb when carrying out cost calculations. If we assume that the proportion of the floor space below the 5-metre curve that is threatened with flooding is 20 percent in Skåne and Blekinge, 10 percent in the rest of Götaland and Svealand, and 5 percent in Norrland, the restoration costs will amount to approximately SEK 25 billion for the whole country.

Landslides

The risk of landslides is predicted to increase in many parts of Sweden. Towards the end of the century, it is estimated that around 220,000 properties will be situated in areas prone to landslides. The value of these amounts to almost SEK 320 billion. The cost of damage to electrical, water and sewage systems has been estimated at approximately SEK 15 billion. The value of the forest and arable land that is situated in areas where there is a risk of landslides is approximately SEK 14 billion and SEK 1.5 billion respectively (see Appendix B 14).

It is very difficult to assess what proportion of these areas may be affected within the next hundred years. According to the statistics that the Swedish Geotechnical Institute (SGI) has for the Göta Älv river, at least 2 percent of the areas prone to landslides (clay ground) have been affected by landslides over a period of 50 years (SGI, 2007). If this were to apply for the whole country, it means that 4 percent of the areas of Sweden prone to landslides would suffer landslides over the next 100 years. This is equivalent to a property value of SEK 12 billion, as well as electricity, water and sewage networks, forest and agricultural land worth just over SEK 1 billion.

The Swedish Rescue Services Agency has conducted various case studies, including calculations of the costs for preventing landslides compared with the costs that would arise in the event a landslide occurs (see section 4.3.2). These show that preventive measures in the vast majority of cases cost significantly less than if a landslide occurs, even just a small landslide. It is therefore important for society to implement measures at those locations where the risk of landslides is judged to be great. However, the risks at an individual location cannot be assessed on the basis of this general analysis, but must be assessed on a case-by-case basis. There is therefore no point in producing a calculation of costs and benefits at national level.

Coastal erosion

Beach erosion along the coast will be affected by raised sea levels as well as altered wave and wind conditions. The preconditions for erosion exist along approximately 15 percent of Sweden's costs. Approximately 220 km of these stretches have been built on. Estimates of the impact on coastal stretches that are susceptible to erosion show that around 150,000 properties are within the risk area (see Appendix B 14). The value of these properties amounts to approximately SEK 220 billion (see section 4.3.3).

SGI has produced a rough estimate of the cost of protecting against beach erosion along these 220 km (Rydell, 2007). The investment cost for beach protection and beach nourishment is estimated to be in the region of SEK 2.7–5.4 billion. In addition to this, the annual maintenance cost amounts to SEK 3,000–4,000 per metre of coast.

Forestry

A warmer climate is expected to give rise to increased forest growth in Sweden. Towards the end of the century this will be 20–40 percent higher than the current approximately 100 million cubic metres (solid volume excluding bark). This corresponds to increased earnings of SEK 4.5–9 billion annually, calculated with an average net conversion value of approximately SEK 230 per cubic metre. For the period 2010–2100, this entails increased earnings of between SEK 300–600 billion.

The increased presence of pests is expected to increase costs in forestry, however. Damage costs for increased damage caused by spruce bark beetles has been estimated at approximately SEK 300 million per annum. Costs will also arise due to difficulties in felling, transporting timber to main roads and on to industry due to wetter winters and less frost. Costs for more expensive felling have been estimated at SEK 600–1,200 million per annum. The cost of various technical aids that could reduce problems during logging, as well as improving 70 percent of the forest roads to a higher standard, is estimated at approximately SEK 300 per year (see section 4.4.1). These measures would consequently be very profitable.

Damage resulting from storms, droughts and fire is also expected to increase. The cost of this is difficult to calculate, but could amount to several million kronor.

Agriculture

The warmer climate means that the yield from agricultural land will increase and that the growing zones will move northwards. One estimate is that the yield will increase by 50 percent in Norrland, 30 percent in Svealand and 20 percent in Götaland (see Appendix

B 23). If prices, land area and choice of crops remain unchanged, this would result in increased grain harvests worth SEK 1 billion annually at today's prices. If we assume that the distribution between the crops is optimised as well, earnings will increased by approximately 60 percent, or SEK 2.8 billion annually. Assuming that no extra investment is required, the increases in harvests would mean increased earnings of SEK 65 billion up until 2100 for increased yield, and SEK 180 billion in the event of optimised crop selection.

An increased occurrence of pests and weeds is expected to increase crop losses. It has not been possible to estimate the amount by which this loss could increase. However, this will probably result in an increase in the use of control measures. A reasonable guess is that their use will increase to the Danish level, which is equivalent to almost a doubling of the current level. The cost would then increase by approximately SEK 600 million annually (see section 4.4.2). Calculated on the basis of a linear increase over the century in the same way as for growth, this would total approximately SEK 40 billion through until the end of the century.

The cost estimates to not include change-over costs, increased costs for improved drainage or increased costs for input goods. For example, costs for increased fertilisation, which has been deemed necessary to achieve the higher yield, are not included. However, a general estimate of the potential increased costs for watering has been produced. Based on the assumption that 40 percent of the agricultural land will need to be watered by the end of the century, and based on a price of SEK 10 per m^3 of water, the cost for this will be approximately SEK 500 million per year.

Cloudbursts, flooding of watercourses and lakes, as well as storms, are other factors that will probably result in increased damage costs for agriculture. The future extent of cloudbursts is difficult to estimate. It is estimated that the flooding of watercourses could affect around 2 percent of arable land (see section 4.3.1). Two percent of Sweden's annual grain production corresponds to around SEK 90 million. The value of agricultural land that lies with risk areas for landslides amounts to approximately SEK 1.6 billion. Based on historical landslide frequency within the risk areas, landslides can be expected to occur on approximately 2–4 percent of the land with a high landslide risk within 100 years.

This corresponds to agricultural land at a value of approximately SEK 65 million.

It has not been possible to calculate increased costs for keeping livestock due to the lack of data. According to the Ministry of Enterprise, Energy and Communications' compilation (Ministry of Enterprise, Energy and Communications, 2005), agriculture's costs from Hurricane Gudrun amounted to SEK 750 million.

Fishing industry

The reduced salinity that is predicted in RCA3-EA2 will result in cod being wiped out in the Baltic Sea, which will entail a reduction in catches equivalent to SEK 200 million annually. Increased wind strengths will result in fishing becoming more difficult. It is estimated that this will result in reduced catches equivalent to SEK 50 million annually. Lake fishing, on the other hand, is expected to increase, equivalent to a value of SEK 15–20 million annually, primarily due to improved conditions for crayfish and zander. In total, the fishing industry will suffer losses of around SEK 230 million annually (see section 4.4.3). Calculated on the basis of a successive change through until 2100, this will give rise to reduced earnings of approximately SEK 15 billion.

Reindeer herding

Difficult snow, frozen crust and ice conditions entail that it will be necessary to provide supplementary food for the reindeer to an increased extent (see section 4.4.4). Supplementary feeding costs approximately SEK 4 per reindeer per day. There are currently around 200,000 reindeer in Sweden. Increased supplementary feeding for 50 days a year would entail an increased annual cost of SEK 40 million. Calculated on the basis of a successive increase in supplementary feeding, the cost through until 2100 will be approximately SEK 2.6 billion. There will also be other costs, but also possible savings.

Natural environment

The consequences have not been evaluated in economic terms.

Tourism

The conditions for winter tourism will probably deteriorate as a result of poorer access to snow. With linear trends regarding turnover in the skiing industry, the loss by the end of the century could amount to between SEK 0.9–1.8 billion annually (Moen et al, 2007). The combined loss through until the end of the century could therefore amount to approximately SEK 20 billion, assuming that the changes start to become noticeable in around 2050. This estimate does not take the possibility of producing artificial snow into consideration, however.

At the same time, summer tourism can be expected to increase. Swedish tourists will probably choose to stay in Sweden to a greater extent, and it can be surmised that some Mediterranean tourism will be redirected to Northern Europe. There are no direct, quantitative calculations for this, but the trends are confirmed in several reports (European Commission, 2007, and Hamilton et al, 2003) (see also section 4.4.5).

Health

It is difficult to assess which health effects may arise as a result of the changes in climate (see section 4.6). Cost estimates based on estimates of increased frequency of cases of disease have only been carried out for the health effects of extreme temperatures. It is not possible to assess the potential increase in the number of cases of disease due to increased spread of infection via food and drinking water; this is only illustrated with a few sample calculations.

Registered cases of illness caused by the spread of infection via drinking water stand at 63,000 over the past 25 years, and there is believed to be a significant dark figure. Various studies have calculated the cost per case of illness at between SEK 160 and SEK 28,000 This wide range is largely due to the fact that different studies include different costs. Appendix B 34 presents cost estimates for various outbreaks of disease (see e.g. pp. 47 and 50.).

It has been calculated from various studies that there are between 340,000–500,000 cases of food poisoning in Sweden each year, at an estimated cost of approximately SEK 730 million. The average costs is between SEK 1,500–2,000 per case. This only includes nursing and medication costs. Studies of salmonella outbreaks in Sweden indicate costs of between SEK 10,000–160,000 per case (see Appendix B 34). These figures do not include costs for pain and suffering. In stated preference studies, the discomfort of a day of sickness has been valued at approximately SEK 350 per day. The acute phase of a salmonella infection lasts on average for a week, which means a further SEK 2,500 per case. Difficulties can last for up to several months, making this an underestimate.

If the frequency of disease outbreaks should increase by 10 percent, and if we assume an average cost of SEK 10,000 per case of illness, the cost due to increased spread of infection via water would be approximately SEK 250 million through until the end of the century. The cost for increased spread of infection via food would be considerably greater, at between SEK 34–50 billion.

Costs for rescue services

The local authorities receive compensation from the state if their costs exceed an excess, which amounts to 0.02 percent of the tax capacity. In recent decades, a number of applications for such compensation have been submitted. The costs for rescue services for which the local authorities have applied for compensation are presented in table 4.45. The high figure in 2000 derives mostly from Arvika Municipality, which applied for an amount of SEK 23 million.

Table 4.45 Rescue service costs for floods, compilation of costs for local authorities that have applied for compensation from the state

Year	Rescue service costs, SEK thousand
1990	387
1991	
1992	
1993	227
1994	
1995	
1996	
1997	1,091
1998	525
1999	
2000	35,991
2001	5,762
2002	6,087
2003	1,244
2004	13,066
Total	71,898

Source: Swedish Rescue Services Agency.

The average value over the period amounts to SEK 5 million annually. This excludes rescue service costs that did not exceed the excess for the local authorities, and which consequently are not included in the costs in the table above.

Costs in the event of extreme weather events

The damage costs that are presented can be set in relation to the actual costs for natural damage in today's climate. Several major landslides, storms and floods have occurred in Sweden over the past ten years. The extent of the costs these events have caused has only been compiled in exceptional cases. One indication is the insurance companies' compensation for natural disasters. Table 4.46 presents the four largest companies' estimates of their compensation payments for a number of major instances of natural damage. The excess payments, which can amount to 10 percent of the damage cost, must be added to this.

Table 4.46 Damage compensation within the insurance sector for major natural disasters during the period 1997–2007

Incident	Year	Number of injuries/instances of damage			Damage cost (SEK million)			Comments
		Private individuals/ housing	Companies	Total number	Private individuals/ housing	Companies	Total cost	
Landslide, Vagnhärad	1997	34	0	34	50	0	50	
Storm Anatol	1999	15,620	6,745	22,365	202	768	970	
Flood, Lake Vänern	2000	951	84	1,035	38	19	57	
Flood, Central Norrland	2000	1,908	192	2,100	73	18	91	
Flood, Orust	2002	4,663	190	4,853	106	17	123	Cloudburst
Flood, Kalmar	2003	977	117	1,094	42	21	63	Cloudburst
Flood, Småland, Northern Skåne	2004	626	147	773	21	20	41	
Hurricane Gudrun	2005	56,917	33,303	90,220	604	3,361	3,965	
Flood, Western Sweden	2006	833	248	1,081	19	79	98	Prolonged rain
Hurricane Per	2007	7,537	9,623	16,334	78	473	551	

The statistics are based on calculations and estimates from the four largest property insurance companies (Folksam, If, Länsförsäkringar and Trygg Hansa), which together have a market share of 67.8 percent of the corporate and property market and 80.6 percent of the home market for insurance in 2005.

It can be noted that Hurricane Gudrun caused twice as much damage as all the other weather events in the table put together. Yet this does not include a large proportion of the losses incurred by the forest owners, which totalled SEK 16 billion. Sweden's costs arising from Hurricane Gudrun were calculated in total to SEK 20.8 billion (Ministry of Enterprise, Energy and Communications, 2005). The largest individual costs from Gudrun are listed in table 4.47 below. As can be seen, by far the most significant item is damage to forests, although several other sectors also incurred considerable costs.

Table 4.47 Damage costs for Hurricane Gudrun (SEK million).

Forestry	15,800
Power companies	1,750
Agriculture	750
Municipalities	305
Swedish Rail Administration	180
Swedish Road Administration	180

Source: Ministry of Enterprise, Energy and Communications, 2005.

However, there are events that may not give rise to such great economic consequences, but which can still be viewed as disasters. The landslide in Tuve in 1977 is an example of such an incident, where the combined costs may not have been that large, but where many were seriously affected and many people lost their lives. The landslides in Ånn and Munkedal in 2006 are other events that were very close to being a disaster for those travelling on the affected sections.

The estimates of potential costs for disasters in the British Stern Review (Stern, 2006) are based in part on the insurance sector's costs as a consequence of extreme weather events, which have increased by 2 percent annually since the 1970s. The report also maintains that if this trend continues, the annual costs caused by extreme weather events could increase to 0.5–1 percent of global GNP by 2050. It is not possible to conduct a corresponding analysis for Sweden, as there are no comprehensive statistics that distinguish the costs for natural damage in Sweden. Insurance compensation payments purely for major natural disasters for the period 1997–2007, dominated by the costs for Hurricane Gudrun, averaged at SEK 600 million annually. If this is extrapolated at 2 percent per annum, the annual costs will be SEK 1.4 billion by 2050 and SEK 3.8 billion by 2100. Excess payments and costs that exceed the compensation amount must be added to this.

4.8.3 Damage cost scenarios

Two scenarios for costs and earnings

In order to gain an understanding of the costs that may arise as a result of the climate changing, we have produced cost calculations for two possible scenarios, a High scenario and a Low scenario. The High scenario is based on RCA3-EA2, which is the scenario on which this study is based. This represents a medium-high development path for the changes in climate. The Low scenario is based on RCAO-HB2, which is a medium-low climate scenario.

The purpose of presenting damage costs in two scenarios is primarily to illustrate how society may be affected by climate changes in economic terms. There is no point in setting damage in Sweden in relation to measures for reducing Swedish emissions of greenhouse gases, as climate change is a global phenomenon. However, the difference between the high and low scenarios illustrates the benefit of global development towards lower emissions. The calculations of the economic effects of climate change also provide an indication of the areas in which adaptation measures may be required. A cost-benefit analysis of such measures may be implemented for each measure individually, and an assessment of the current cost situation, the conditions for technical development and the possible cost trend are balanced against the damage that is to be prevented.

The scenarios relate to costs for damage that can arise if no preventive measures are taken. The precondition is consequently that no banking up, erosion protection, raising of roads, etc., have been implemented. In cases where it is possible to predict damage, it is probable that measures will be implemented before the damage occurs. The time perspective is through until 2100. The calculations are based on the systems' current vulnerability and scope.

In most cases there are no regular probability calculations for the various weather that cause the damage. In many cases, the cost calculations apply to a restricted incident, such as a stretch of road being washed away or a water source becoming contaminated. In most cases, however, it is not possible to estimate how often such events will occur based on the climate scenarios and the produced climate indices. This means that it is impossible to produce a compilation of the costs covering the entire period up until 2100 other than in the form of a general sample calculation that illustrates what the cost could be in the event of certain possible courses of events.

Table 4.48 provides an overview of the assumptions that have been made for various sectors. For a more detailed presentation, refer to Appendix A 6. There is no information regarding damage costs for district heating systems and dams, only action costs. These are therefore not included in the scenarios. Tourism has also been omitted. The positive effects of summer tourism are anticipated to be significantly greater than the negative consequences for winter tourism. Including only one side would therefore produce a distorted picture.

Table 4.48 Assumed changes regarding weather events and damage. Increase up until 2100 compared with today. Calculations and assumptions are presented in Appendix A 6.

	Low scenario (based on RCAO-HB2)	High scenario (based on RCA3-EA2)
Roads	Lower limit for the Swedish Road Administration's cost calculations.	Upper limit for the range in the Swedish Road Administration's cost calculations.
Railways	Half as much as for RCA3-EA2	Three large landslides, two large storms
Shipping	Half as much as for RCA3-EA2	Halving of ice-breaking costs
Electricity and telecom networks	Slight increase in damage due to increased storm damage to forests	More frequent and more powerful storms*
Hydroelectric power	Increase of 14%	Increase of 20%
Wind power	No increase	Increase of 10%
Drinking water supplies	Costs half those in the high scenario	Greater increase in damage to water pipelines and water sources. Increased costs for treating drinking water.
Heating/ cooling requirements	12 percent lower than in the high scenario	Reduced heating requirement based on increase in number of degree-days
Building constructions	Half as much as for the high scenario	The National Board of Housing, Building and Planning's calculations of increased maintenance requirements under EA2
Flooding of buildings		

	Low scenario (based on RCAO-HB2)	**High scenario (based on RCA3-EA2)**
Coast	Flooded area half the size of the area in the high scenario	Threatened area calculated with GIS data and case studies. Flooding of all buildings in a threatened area.
Watercourses	Increased frequency and scope according to regional changes in precipitation	Increased frequency and scope according to regional changes in precipitation
Cloudbursts	Increased frequency of extreme precipitation over cities based on precipitation index	Increased frequency of extreme precipitation over cities based on precipitation index
Flooding of the large lakes		
Lake Vänern	Five high water levels of 46.5 m	One high water level of 47.5 m and five high water levels of 46.5 m
Lake Mälaren	No increase	One hundred-year level
Lake Hjälmaren	No increase	One hundred-year level
Landslides	Landslides occur on 2% of threatened area (increase of 50%)	Landslides occur on 4% of threatened area (increase of 100%)
Coastal erosion	10% of threatened area erodes	40% of threatened area erodes
Forestry		
Growth	Increase 20%	Increase 40%
Pests etc.	Lower limit of specified range	Higher limit of specified range
Storm damage	No increase in storm frequency but increased damage due to forests that are more susceptible to wind, approx. 50% of the High scenario	More frequent and more powerful storms*
Drought and fires	Approximately 50% of the High scenario	Approx. 9 major fires and 5 instances of extreme drought
Agriculture		
Increased yield	Half as much as for the high scenario	According to the Swedish University of Agricultural Sciences' estimates for RCA3-EA2
Pests, control measures	50% increase in the use of control measures	Doubling in the use of control measures
Storm damage	0	More frequent and more powerful storms*
Watering	Watering 20% of the area	Watering 40% of the area

	Low scenario (based on RCAO-HB2)	High scenario (based on RCA3-EA2)
Fishing industry	Reduced catches of cod, better lake fishing	Cod disappears, fishing more difficult due to stronger wind, better lake fishing
Health		
Heat	Increase in number of deaths according to Stockholm study and scenario B2	Increase in number of deaths according to Stockholm study and scenario A2
Spread of infection	Increase of 25 percent by the end of the century	Increase of 50 percent by the end of the century
Storms, costs for local authorities	0	More frequent and more powerful storms*

* 5 storms the size of Hurricane Per, 2 storms the size of Hurricane Gudrun, 2 storms with costs 50% higher than Gudrun.

Preconditions for the High and Low scenarios

Our assessment of the increase in the number of storms and the strength of the storms in the High scenario is based on climate indices for average wind, the number of days with gusts of more than 21 m/s, as well as the increase in the maximum speed of the gusts. In RCAO-HB2, on which the Low scenario is based, no increase in wind is anticipated, and it is therefore assumed that the storm frequency will not increase. The assumptions regarding the flooding of buildings along watercourses are based on the change in the return frequency of today’s hundred-year floods, as well as the climate index for extreme precipitation. Other flooding levels (with longer and shorter return frequencies) have not been considered. The calculations for Lake Vänern, Lake Mälaren and Lake Hjälmaren have been taken from the study’s progress report.

The increase in coastal erosion is due partly to the sea level and partly to wave movements. The extent of the difference as regards coastal erosion is difficult to estimate. The assumptions that have been made here are fairly cautious, and have only been prepared to show the potential extent of the capital losses that could occur.

The increase in the likelihood of landslides is based on hundred-year floods, average runoff, intensive precipitation and precipitation during the summer. SGI has calculated that landslides have occurred on approximately 2 percent of those areas in the country with a tendency to suffer landslides over the past 50 years. If landslides occur on those areas that are predicted to be more likely to suffer landslides with the same frequency as in previous years, 4 percent of the threatened areas would suffer landslides over the next 100 years.

The estimates of increased costs for forestry due to pests, more difficult logging, etc., have been drawn up by the Swedish University of Agricultural Sciences and Skogforsk (Forestry Research Institute of Sweden) for the A2 and B2 scenarios. Storm damage in Sweden's forests is also expected to increase in the Low scenario, despite the fact that storm frequency is not predicted to increase in this scenario, as the forests will become more wind-sensitive. For agriculture, changes in average temperature and the start and end of the growing season are used. The difference between RCAO-HB2 and RCA3-EA2 for these indices is approximately 50 percent.

In RCA3-EA2 it is estimated that fishing will be affected by increased wind strengths, higher temperatures and reduced salinity in the Baltic Sea. In RCAO-HB2 it is assumed that the wind will not increase and that salinity of the Baltic Sea will not decrease as drastically. This means that the losses will be restricted to less than half compared to the A2 scenario.

The Swedish Road Administration has calculated a range for the damage costs that are expected to arise in a changed climate. The lower limit of the cost range has been used here in the low scenario and the upper limit in the high scenario. Assumptions for hydroelectric and wind power are based on assessments in (Gode et al, 2007).

It is difficult to assess the frequency and extent of the costs that can arise due to shortages in the water supply. The cost examples for the water supply are consequently only indirectly linked to the percentage differences for various indices in the climate scenarios. For the sake of illustration, we have drawn up two different compilations for the damage that is costed: one with a low frequency and low scope, one with a higher frequency and greater scope. We have also counted on increased costs for drinking water treatment due to poorer raw water quality.

The increase in heat-related deaths has been scaled up to a national level based on a study of Stockholm carried out by Umeå University. They are valued with a standard value for a statistical life, corresponding to that used in infrastructure planning. The calculations regarding increased spread of infection are based on a standard assumption based on the increase in average temperature. Cases of illness are valued with an average cost from a number of studies into outbreaks of disease, and encompass nursing, medication and an increment for indirect costs, which can include e.g. pain and suffering and loss of production.

Results

The estimated costs and earnings for the two scenarios are shown in table 4.49. All calculations are based on the assumption that the changes will take place gradually through until 2080, and thereafter the conditions will be constant. This is because the damage costs and earnings that are used in the scenarios are based in most cases on what the climate is expected to be like in 2080 or on average during the period 2070–2100. The calculations are presented in Appendix A 6.

The climate indices that affect the various sectors vary, in many cases approximately twice as much in RCA3-EA2 as in RCAO-HB2. In those cases where better data has not been available, costs and earnings have therefore been assumed to be half as large in the Low scenario as in the High scenario.

Table 4.49 **Cost calculations for Low and High scenarios. Combined damage costs for the period 2011–2100.**

	Low (RCAO-HB2)		**High (RCA3-EA2)**	
	Earnings	**Costs**	**Earnings**	**Costs**
Roads				
State roads		-9		-13
Municipal and private roads		-3		-9
Railways		-0.2		-1
Flying	2	-0.2	4	-0.4
Shipping	2		5	
Telecommunications networks		0		-1
Electricity networks		-1		-4
Power potentials				
Hydroelectric power	193		261	
Wind power	0		26	
Heating and cooling requirements				
Reduced heating requirement	606		689	
Increased cooling requirement		-135		-153

	Low (RCAO-HB2)		High (RCA3-EA2)	
	Earnings	**Costs**	**Earnings**	**Costs**
District heating		-1		-1
Drinking water supplies		-62		-124
Building constructions		-50		-100
Flooding of buildings				
Watercourses		-24		-48
Coastlines		-12		-23
Cloudbursts		-1		-3
Flooding of Lake Vänern, Lake Mälaren and Lake Hjälmaren				
Buildings		-29		-53
Infrastructure, industries, etc.		-53		-87
Rural businesses		-0.4		-1
Landslides (damage to buildings, electricity, water and sewage, agriculture and forestry)		-7		-14
Coastal erosion (damage to buildings, water and sewage, agriculture)		-22		-88
Forestry				
Increased growth	307		614	
Damage from storms, fires, etc.		-49		-97
Other damage (logging etc.)		-48		-184
Agriculture				
Increased yield	36		72	
Altered land use	37		74	
Increased expenditure for control measures		-20		-39
Increased costs for watering		-16		-33
Storms		0		-4
The fishing industry		-3		-15
Reindeer herding		-1		-3
Health				
Heat-related deaths		-502		-661
Spread of infection		-69		-138
Costs for local authorities				
Storms		0		-2
Floods		0		-1
Total	**1,183**	**-1,118**	**1,745**	**-1,900**

In total, the costs in the High scenario correspond to a loss during this century of approximately two-thirds of a year's gross production, measured against current GNP (SEK 2,600 billion in 2006). Earnings will increase by approximately the same amount. As the players and geographic areas that will receive the earnings are largely different from those that will be affected by the costs, it is important to study the distribution of costs and earnings.

The structure of the scenarios differs between different areas, which should be taken into consideration when interpreting the results. Several of the positive effects, which have reduced heating requirements and increased forest growth, are more directly linked to the development of various climate indices than is the case for e.g. outbreaks of disease. The frequency of extreme weather events is also difficult to assess.

The largest single item in the calculations is reduced costs for heating houses and premises. This reduction in costs will benefit most members of society. In addition, it does not require any particular adaptation in order to come about. The increased power potential for wind and hydroelectric power, on the other hand, may require investment in order to be utilised. Forestry and agriculture will enjoy improved yields due to the warmer climate, which will be partly counteracted by increased damage. There is considerable potential to increase the yield and reduce damage through active adaptation measures. It has not been possible to estimate the cost of such measures.

One potentially significant positive impact that is not included in the quantitative calculations is the improved conditions for summer tourism. These parts of the tourism industry can be expected to enjoy increased growth. In monetary terms, the negative consequences for winter tourism are not expected to be as great as the positive consequences for summer tourism.

The largest negative items are health effects, flooding, coastal erosion, effects of storms, increased costs for maintenance of buildings and increased cooling requirements. The combined cost for flooding of buildings and flooding of the major lakes, which include effects on several sectors of society, is SEK 80 billion in the Low scenario and SEK 140 billion in the High scenario. It should be emphasised that all of these cost items, as with drinking water supplies, are based on estimates, not probability calculations.

The consequences of natural disasters such as floods and landslides will probably be distributed fairly unevenly across the country. The companies and households that are affected will therefore have to bear a relatively large proportion of the costs of climate change.

The differences between the low and high scenarios are greatest as regards the negative effects. This is due primarily to the assumptions regarding more storms, floods and large landslides in the High scenario, which are based on the differences in precipitation and wind in the different scenarios. Heating costs also decrease dramatically in the Low scenario, as the average temperature also increases significantly in RCAO-HB2.

The damage costs can be influenced both upwards and downwards by a changed cost situation. The value of properties in attractive locations, which often entail positions close to lakes, may have risen manyfold if demand increases due to population growth and a better economy. Over the past century, the development of infrastructure in the form of properties, roads, water and sewage, electrical and telecommunications systems has been dramatic. For example, flooding around Lake Mälaren equivalent to that which occurred in 1924 would cause many times more damage today. There are currently no signs of this development coming to a halt. However, new systems may be either more or less vulnerable that those currently in place. Society's heavy dependence on electricity entails greater vulnerability than previously, while wireless telecommunications networks are less sensitive to storms than the fixed networks.

The economic effects will be affected by many factors that are not included in the analysis, such as prices, capital accumulation, development of the world market and the development of foreign trade. The National Institute of Economic Research's economic scenarios up until 2025 assume that economic growth will be good and that the rate of investment and construction will develop favourably. The population will increase, and there are signs to indicate that there will be increased centralisation to certain city areas (see section 3.4.1). This means that society will have good economic resources to invest in measures aimed at meeting the changes in climate, but also that larger values will be affected in the event of extreme weather events, and hence that the costs may be greater than if the same events were to occur today. This demands good forward planning by the relevant sectors and within physical planning to ensure that vulnerability does not increase.

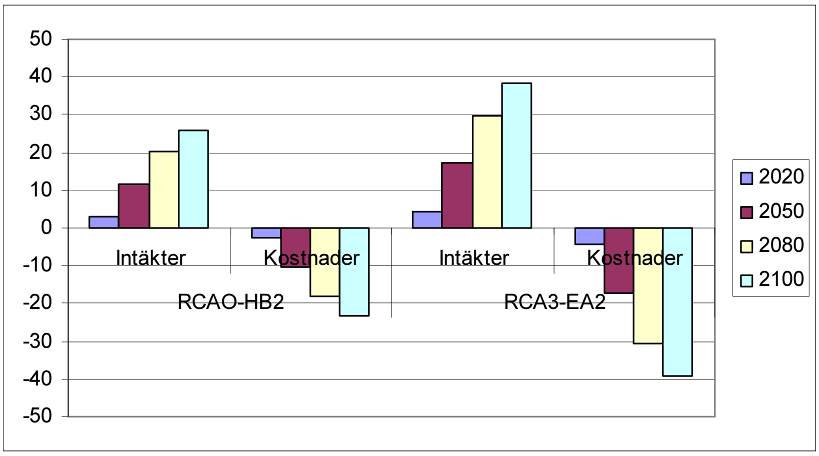
Effects in the short and medium term

It is difficult to say anything about how soon some of the effects of the changed climate will come about. In the scenarios we have used as a basis, RCAO-HB2 only gives an idea of what the climate will be at the end of the century, while RCA3-EA2 gives results for the entire century, divided into three periods.

In the calculations presented above, it is assumed that the effects of climate change will increase linearly in both scenarios. Both costs and earnings will rise from SEK 3–4 billion in 2020 to around SEK 25–40 billion in 2100, depending on the scenario. If we assume a growth in GNP of 2 percent, the costs will be equivalent to approximately 0.2 percent of GNP in both 2050 and 2100. As pointed out above, however, the capital stock will probably also be larger, which means that the proportion of GNP will probably be larger than that in reality.

If GNP growth develops instead in accordance with the calculations produced by the Institute for Futures Studies based on the population trend and the age structure (section 3.4.2), the growth will decrease and will stand at zero between 2030–2050. The costs will then constitute a larger share of GNP. The proportion of GNP in 2050 in this case will be 0.5 percent.

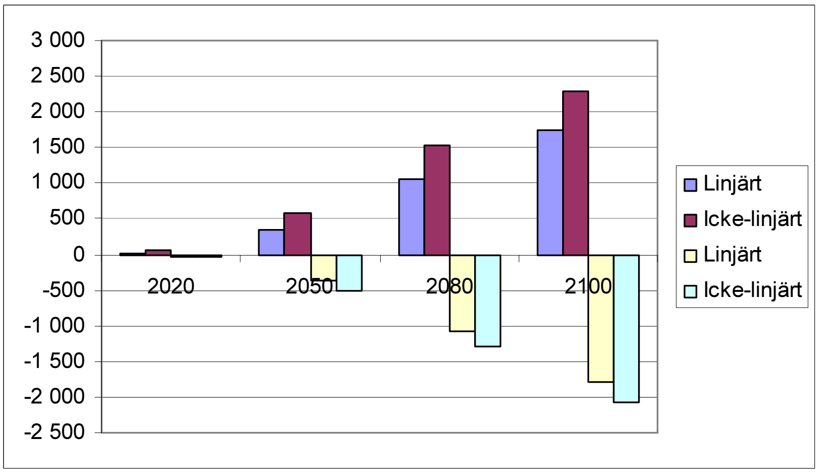
Figure 4.59 Annual costs and income for the High and Low scenarios, assuming a linear increase in climate changes. SEK billions



Earnings
Costs
Earnings
Costs

In order to illustrate how costs would be affected if the climate changes take place more rapidly, an alternative development path has been produced based on RCA3-EA2. The annual costs and earnings compared to a linear development are presented in figure 4.60.

Figure 4.60 Accumulated costs and earnings for RCA3-EA2 for various development paths. SEK billions



Linear
Non-linear
Linear
Non-linear

Many of the climate parameters change linearly, although some may demonstrate a different development. Sea level rises are slower and may increase more towards the end of the century, while there are indications that average precipitation and average wind may increase dramatically as early as 2020 due to changes in the paths taken by weather systems. This could result in both costs and earnings increasing earlier, and as a consequence the combined costs and earnings would increase during the century. With the development that is presented in figure 4.60, the costs would be up to 20 percent higher than with a slower, linear climate change, while the earnings would be 30 percent higher. This difference is dependent on which climate factors are the driving force for the included items. If a positive discount rate of interest is used, the difference will be even greater, as earnings and costs that take place sooner will gain in importance.

Discounting

Economic effects that occur in the future are generally discounted with a discount rate of interest, which is intended to place earnings and costs today on an equal footing with earnings and costs in the future. The discount rate that is currently used in cost-benefit analyses for infrastructure investments is 4 percent. Of this, 2 percent corresponds to the anticipated average growth of the Swedish economy, and 2 percent corresponds to an assumed time preference. This *pure time discounting* is based on the fact that we have a tendency to value earnings today higher than earnings tomorrow, which is reflected for example in the level of savings. This is due in part to uncertainty about future results.

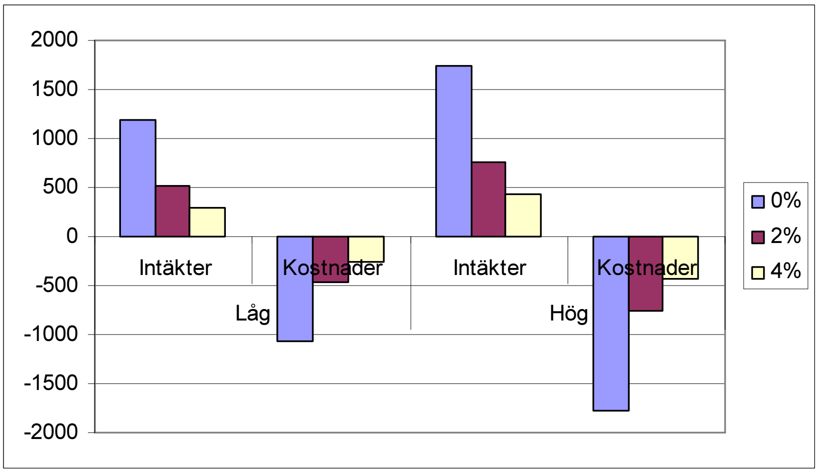
The process of discounting future effects is standard in economic analyses, and is performed in order to compare economic effects that take place now and in an uncertain future. This has been questioned, however, on the basis that it is not reasonable for the benefit for future generations to be devalued in relation to the benefit for generations alive today, as this relates to actions that provide welfare now, but whose cost is incurred much later, or vice versa. The debate has been particularly lively when it comes to environmental economic analysis, as this relates to negative effects that will primarily affect future generations, but that are arising from consumption that provides benefits for today's generations.

The British Stern Review reported considerable damage costs due to climate change, which were calculated to be much greater than the costs for reducing emissions of greenhouse gases (Stern, 2006). The results were dependent in part on the fact that Stern had chosen to use a discount rate for the pure time preferences that was close to zero (0.1 percent). The justification for this was that a higher discount rate indicates that the welfare of future generations is not important, which Stern felt did not correspond with society's preferences. The Stern Review highlighted the fact that the costs for reducing greenhouse gases will always be high if the costs in the future are given very low importance, as the effects of emissions are felt much later.

The decision basically not to discount the costs has given rise to a lively debate among economists (see e.g. Weitzman, 2007; Nordhaus, 2006; Sterner and Persson, 2007). The argument against such a low discount rate is primarily that it means that current generations have to make large sacrifices in order to avoid uncertain effects in the future, to the benefit of a future generation that will have much high income levels and for whom the same costs would represent a relatively small proportion of income. There has also been discussion on the possibility of using different discount rates depending on the types of damage and action to which the analysis refers, i.e. whether the effects that are to be averted are reversible or not. A diminishing interest rate has been discussed for environmental effects, with the rate approaching zero for effects a long time in the future. Climate change is a typical example of a case where the changes are irreversible from a human perspective, and where the effects of both emissions and actions have a long delay. Reducing emissions at the end of the century is not equivalent to reducing them now, which should be taken into consideration when performing a cost-benefit analysis of reductions in emissions.

The choice of discount rate significantly affects the size of future earnings and costs. The results that are presented above have not been discounted. Figure 4.61 shows the results for the High and Low scenarios discounted by 2 and 4 percent.

Figure 4.61 **Earnings and costs according to the Low and High scenarios, discounted by 0, 2 and 4 percent assumed interest rate**



Earnings
Low
Costs
Earnings
High
Costs

As mentioned above, a proportion of the assumed interest rate comprised anticipated real growth in the economy. It is reasonable to consider that a large proportion of the costs to which climate change can give rise will occur in an economy that is significantly stronger than the current one. At the same time, it is probable that there will be buildings and infrastructure of a much higher value in those areas that are affected by floods, landslides and storms than there are at present, which means that larger values will be threatened than would be the case if the same events were to occur today. Our scenarios are calculated for unchanged capital stock, which means that the costs have probably been underestimated.

4.8.4 Other consequences

Section 4.8.2 describes the effects of climate changes for which it has been possible to calculate costs. Many of the effects that can be expected to occur do not have any direct impact on the economy, however, or have effects whose cost is difficult to calculate. The impact on ecosystems, the cultural environment and human health are examples of such effects. There are also effects on technical systems for which quantification or calculation of costs has not been possible. Below is a summary of these consequences.

Most of the changes that are predicted will take place gradually. This means that the consequences will probably not be perceived as dramatic. A gradual adaptation through conscious planning can also help to alleviate the negative consequences.

Natural environment

The effects of climate change on the environmental objectives are largely dependent of how the adaptation measures are formulated. However, climate change in itself will not have a direct impact on the potential to achieve several environmental objectives. The objectives that we believe will be affected most are *A rich diversity of plant and animal life*, *Healthy forests*, *A varied agricultural landscape*, *A magnificent mountain landscape*, *Zero eutrophication*, *A balanced marine environment – flourishing coastal areas and archipelagos*, *Flourishing lakes and streams* and *Clean air*.

The preservation of species in forest ecosystems is currently being made more difficult by fragmentation, impairment and destruction of living environments, the spread of invasive non-native species and pollutants. This means that a large number of species are threatened with extinction. Climate changes, including weather extremes, reinforce this effect as the conditions in a particular location are altered. In many cases, milder, damper winters and increased nutrient cycling mean that more species will be able to compete for space in a particular habitat, occasionally to the detriment of a species requiring protection on site, occasionally to the benefit of a species from the south. There is consequently a risk that species that are now found naturally in the countryside will be replaced by other, more competitive species. Species with a limited capacity to spread and specific habitat requirements, such as species that require lime or that require a light climate, can find it particularly difficult to move north. The choice of adaptation strategies within forestry, such as the choice of tree species and rotation periods, will be extremely important for biodiversity and the environmental objectives *A rich diversity of plant and animal life* and *Healthy forests*.

The mountain ecosystems that in many cases have remained relatively unaffected to date will change in line with rising temperatures, altered snow conditions and a rising tree line. Overgrowing is a threat to many groups of species. If pressure from reindeer grazing is reduced, overgrowing will take place even more quickly. Several alpine species and species dependent on palsa bogs that are not very competitive will be outcompeted in a warmer climate. The potential to achieve and maintain the environmental quality objective *A magnificent mountain landscape* will consequently also be impaired.

The potential to maintain open landscapes and thereby contribute to the environmental objective *A varied agricultural landscape* should benefit from the changes to the climate. However, the need for pesticides against pests and fertiliser to optimise harvests will increase, as far as we can judge. The way in which agriculture meets this development will influence a number of environmental objectives: *A rich diversity of plant and animal life, A non-toxic environment, Zero eutrophication, Flourishing lakes and streams* and *A balanced marine environment.* The development of cultivation systems, fertilisation regimes, growth sequences, etc., can reduce nutrient leaching and the need for pesticides. Increased restoration of wetlands in the agricultural landscape would have extremely positive effects on biodiversity, for example, at the same time as potentially reducing the leaching of nutrients into watercourses, lakes and the sea.

Biodiversity within coastal and beach ecosystems will also be affected by a warmer climate. Reduced ice lift, reducing spring floods and higher winter flows will probably reduce the spread of wetlands close to beaches. In areas where there is currently significant uplift and where special biotopes are being formed, considerable effects on biodiversity can be anticipated when the raising of the sea level compensates for the uplift. This affects the environmental objective *A rich diversity of plant and animal life*. Biotopes near the coast, such as coastal meadows primarily in southern

Sweden, will be trapped between increased sea levels and the use of the land situated directly inland.

The freshwater environment will be affected, both by a raised temperature and by increased runoff. All future simulations show clearly that the leaching of nutrient salts will increase in a warmer, wetter climate. This will result in increased overgrowing of lakes and watercourses. Many lakes are already in need of action in order to achieve good ecological status, particularly in southern Sweden. This means that it will be difficult to achieve the objectives *Zero eutrophication* and *Flourishing lakes and streams*.

The water will become more discoloured in up to 90 percent of all lakes in southern Sweden. The situation will continue to deteriorate in line with the change in climate. The reduced nitrogen fallout will probably entail that the total phosphorus levels will increase more rapidly than the total nitrogen levels, which will lead to an increased risk of harmful algal blooms. The changes in the Baltic Sea's environment and ecosystems may be dramatic if the Echam4 model's scenarios take effect. The salinity level currently found in the North Kvarken region will extend as far south as the Bornholm depths. Freshwater environments will then replace marine environments. Cod will disappear, with major consequences for the entire marine ecosystem. The Echam4 model is extreme as regards precipitation and wind. The Hadam3H model's scenarios give different, milder effects, primarily shifts between cold and warm-water species. The nitrogen and phosphorus load will probably increase in the Baltic Sea as well. Along with the increased surface water temperature, there is a risk of major changes to the biological systems, such as increased algal blooms. However, there is insufficient knowledge about this. The research situation is uncertain, with partially contradictory results.

Recreation patterns and outdoor activities can be expected to be influenced by the altered conditions in the natural environment. The overgrowing of the bare mountain areas with bushes will affect mountain tourism. There is a risk of increased pressure on the remaining bare mountains above the tree line, with more tourism and noise disruption affecting the overall impression. There is a risk that the qualities that constitute the cornerstones of outdoor life in the mountains will be lost.

Another aspect that will probably have a negative impact on outdoor activities is the reduction in levels of game fish (charr, brown trout) in many waters. Alternative species such as pike, perch and carp that can come in their place are not perceived to be of the same value.

The opportunities for hunting should improve in the future climate, thanks in part to greater production of forage. However, the elk may decline in southern Sweden, which could reduce elk-hunting opportunities in this region. On the other hand, the conditions for other wild deer should improve.

The time-honoured way of life of reindeer-herding Samis is at risk, as adaptation to an annual cycle that is not natural to the reindeer may be required. This entails both an increased need for supplementary feeding, as well as an increased requirement to move reindeer by lorry etc. This can result in the emotional value of reindeer herding being perceived as undermined, and threaten a trade that is deeply rooted in historical cultural traditions.

Health and loss of human life

Thanks to our cold climate, we in Sweden have been relatively spared from the spread of infection by bacteria that benefit from warmer temperatures. This has also meant that the handling of food has been easier for us. The higher average temperature means that we will have more dog days, instead of just in August as at present. More careful food handling will become necessary to protect against food poisoning. The treatment of drinking water is also simpler for us than in developed countries with poorer raw water. The deterioration in raw water quality due to more rain and extreme weather is predicted to require adaptation methods.

The spread of infection via drinking water will also increase. Flooding can also give rise to toxins entering drinking water supplies through e.g. overdrainage of pasture, overflowing of sewage and leaching of contaminated land. The number of ticks and other disease carriers will increase, which means that we have an increased risk of contracting infections when out in the forest or countryside. One serious threat is the risk of new, potentially life-threatening diseases becoming established.

The discomfort of being ill is an expense over and above the purely economic consequences in the form of loss of production and loss of income. The increased risk of being infected by disease also entails discomfort and increased anxiety, as well as increased inconvenience and expense in protecting yourself.

High temperatures during the summer months can result in a significant decrease in life expectancy for the sick and the elderly. This also has other, less dramatic yet still significant effects, such as discomfort and a poorer state of health, resulting in a negative impact on productivity. During the winter months, on the other hand, we will have the opposite effect, with mortality falling as a consequence of fewer cold days. However, this effect is not as great as the increased mortality resulting from warmer temperatures.

The increasing frequency of landslides, floods and storms entails a risk of people being injured or losing their lives. If roads and railways are affected, this will entail considerable risks for those who travel on the affected sections. In addition to the direct risk of being injured in the storm or landslide itself, there are also risks when carrying out rescue work and working subsequently to restore the land, pipelines and buildings.

Just about all sectors of society will be affected by indirect consequences of flooding and storms, as they often give rise to power failures. Many important social sectors either have no auxiliary power or do not have sufficient reserves. Those that have auxiliary power units often have limited access to fuel to operate them. At the same time, transporting fuel in emergency situations is often problematic. The electricity and telecommunications sectors are also highly dependent on each other. Most sectors of society are extremely dependent on functioning telecommunications.

According to the Echam4 model, an increased frequency of storms can be anticipated in the southern Baltic Sea. The risks within fishing may therefore increase if due consideration is not given to the weather situation or if the communication of weather warnings does not function properly. It is not certain how the frequency of storms over land will change in Sweden, but everything is pointing to an increased risk of storm damage to forests. The risks associated with processing wind-felled trees are always considerable. Ten people lost their lives when dealing with wind-felled trees following Hurricane Gudrun. Low-spirits and depression among forest owners was a relatively widespread phenomenon in the aftermath of Hurricane Gudrun. There were also reports of suicides. Increased storm damage to forests can also have negative consequences for systems of overhead power lines.

Higher flows entail an increased risk of dams and embankments being breached. If areas threatened with flooding are protected to a greater extent through banking up, this also entails a risk of the embankments bursting in the event of high flows and water levels. This in turn entails a risk of injury and death. The areas that are banked up are often urban areas where many people live and spend time, which underlines the importance of building with a high degree of safety.

Culture and cultural environments

In many ways, a warmer climate can be positive for Sweden. Higher average temperature and more sunny days during the summer frequently deliver improved comfort and quality of life. The milder winters mean that snowy winter landscapes will not be as common, but fewer days with the temperature below zero can also be perceived as positive. The number of rainy days will increase during the winter, however.

A changed climate will probably give rise to changes in cultural patterns and habits. The potential exists for new environments and cultural patterns that are associated with a warmer climate to emerge. On the negative side, existing values will be threatened.

Affected areas can suffer considerable damage in the event of natural disasters. These can include environments that are extremely important to the local population and cultural environments with a more general cultural history value. The stresses on buildings that are of interest from a cultural history perspective will be greater in a warmer, damper climate. Measures such as banking up can also impact on cultural environments such as old city centres and buildings that are valuable in terms of cultural history in agricultural landscapes. Similarly, marine communities along Sweden’s coasts and in the archipelagos in the southern half of the country are also threatened. A further reduction in the profitability of coastal fishing can result in the loss of culturally valuable coastal environments such as fishing villages. On the other hand, increased profitability for agriculture that could result from a change in the climate could in turn bring about a greater potential to preserve culturally interesting buildings in the agricultural landscape The Sami’s culture, buildings that are of interest from a cultural history perspective and other cultural environments risk being affected in the event of reindeer herding becoming less profitable and reindeer husbandry declining.

Employment in the tourism industry and rural businesses

The tourism industry is expanding rapidly. The number of people employed in the sector is increasing year on year, totalling around 152,000 in 2006. A general continuation of this increase can be expected, with the exception of some locations dependent on winter sports. In the longer term, an expansion of the tourism industry based on sun-related and bathing-related tousim may result in a significant positive impact on employment. Considerable opportunities for growth will probably be generated in these parts of the tourism industry in line with the accentuated warming up over Southern Europe and the increase in air and water temperatures in the summer along our coasts and lakes, provided the quality of the water and access to drinking water is sufficient.

With significantly shorter winter seasons, however, the conditions for winter tourism will deteriorate. Parts of the tourism industry based on alpine tourism, including many small companies, risk suffering a loss of earnings and decreasing competitiveness due to reduced access to snow in the winter, a shorter season and increased costs for the production of artificial snow. This applies in particular to centres and locations in Götaland and Svealand, as well as southern Norrland except for the mountains in the short term. In the longer term, southern Norrland's mountain regions will also be affected. The nature of developments is also heavily dependent on the potential of the tourist facilities to diversify their operations.

Sparsely populated areas may benefit from an improvement in the conditions for agriculture and forestry. Increased production in the forests and in agriculture will benefit the growth in value and profitability within forestry and agriculture, which is particularly positive for the many small companies in these sectors. The processing industry should also be able to benefit from the increased growth, although investment for increased production will be required in many cases in the form of new facilities for processing pulpwood, wood and timber raw materials, as well as facilities for processing food. Companies within the fishing industry, in particular those that have specialised in cod fishing, may be seriously affected if the climate scenarios that indicate significantly reduced salinity in the Baltic Sea take effect.

Employment within agriculture, forestry and fishing has been declining over many decades. Barely 174,000 people were employed in agriculture in 2005 (Statistics Sweden, 2007), around 95,000 people were working in forestry in 2006 (Swedish Forest Agency, 2007), while the fishing industry, production industry and aquaculture employs around 5,000 people (Appendix B 26). A continued reduction in employment in these sectors can be anticipated as a consequence of continued rationalisation, even in a warmer climate. However, the reduction may be less than it would otherwise have been, with an increased production potential from agriculture and forestry. The processing of agricultural, forestry and fish products also employs many people, although these sectors are also being greatly rationalised. An increased raw material base within agriculture and forestry will increase the conditions for more employment opportunities within the processing industry. Proximity either to infrastructure for exporting or to consumers often governs the location of the processing industry. It is probable that this relationship will remain, which means that the regions that already have processing facilities will be favoured.

Reindeer herding is essentially made up of small companies, and these risk being affected by a deterioration in the conditions for reindeer husbandry. Relatively snow-rich winters and significant bare mountain areas will continue to characterise northern Norrland's mountainous regions, despite some reductions. As a result, the potential for combining reindeer husbandry with various tourism activities will probably be strengthened in this area which, in a European perspective, will become increasingly unique in line with the changes to climate.

In the event of natural disasters such as floods and storms, companies in the exposed areas can be affected, both by direct damage as well as by effects on other systems, such as power failures and interrupted communications. If the electrical and telecommunications systems are not robust, this can also have more long-term effects, such as making it difficult for sparsely populated municipalities to encourage companies to establish themselves there.

4.8.5 Global and regional studies of climate consequences

There are many analyses of the impact of climate change on the world economy. Most of these are produced using Integrated Assessment Models (IAM); these simulation models include dynamic functions for both economy and climate effects. The (Nordhaus and Boyer, 2000), (Tol, 2002) and the Stern Review (Stern, 2006) are among the most comprehensive studies. The Stern Review had a significant impact when it was published due to its powerful results, which differed from previous studies on several points. The models that were used in the studies mentioned above include market-related and non-market-related effects of a change in climate.

The results from Nordhaus and Tol demonstrate a relatively large impact on global GNP, despite their more cautious assumptions. In the event of warming of 2–2.5°C, global production is expected to decrease by between 0.5 and 2 percent. The greatest effects are anticipated in developing countries. In Northern Europe, it is predicted that the effects could initially be positive. In the event of more dramatic warming, 4–5°C, the Nordhaus model indicates GNP losses of between 4 and 6 percent, while GNP losses according to Tol's analysis do not exceed 2 percent in the event of a 6°C increase in temperature. The primary difference between these two reports is that Nordhaus includes probability estimates for disasters and the costs of these.

IPCC's fourth evaluation report

The IPCC does not conduct any quantitative calculations of the effects of climate change in different regions. Both positive and negative effects are anticipated in Northern Europe. The positive effects that have been highlighted are reduced heating requirements, increased harvests and increased forest growth. Negative effects, primarily more frequent flooding in the winter, threatened ecosystems and increased frequency of landslides and coastal erosion, are expected to neutralise the benefits as the climate change strengthens.

The Stern Review

The main difference between the Stern Review and previous analyses is that disaster risks are included in a more comprehensive manner, which means that potentially very significant costs are included in the analysis. They will have a great impact, despite the fact that the statistical probability is deemed to be low. The analysis also covers a long period of time, through until 2200, which means increased uncertainty. The estimated costs over the next century are given great weight by means of the use of a low discount rate of interest, which means that costs in the future are given almost as much weight as costs today. All of this taken together means that the damage costs are estimated to be many times greater in the Stern Review then in other studies.

The analysis in the Stern Review is based on individual studies of the effects of climate change and simulations using an IAM model, PAGE 2002, similar to those used in Nordhaus and Tol. The base scenario, which includes disaster risks but not non-market-related effects, indicates a reduction in GNP per capita globally of 0.9 percent by 2100. The GNP losses increase dramatically to 5.3 percent by 2200. In addition to the base scenario, simulations of a *High Climate scenario* are also produced, which include the effects of the presence of feedback mechanisms for climate changes (increased greenhouse effect due to a weakening of natural carbon sinks and increased methane emissions, for example from areas than now have permafrost). Including these assumptions, the costs increase to approximately 2 percent in 2100 and 7.3 percent in 2200. If non-market-related effects are also added, the estimate is 13.8 percent by 2200.

The level of uncertainty increases significantly over time, which is reflected in the anticipated confidence ranges. For 2100 the confidence range for the base scenario is between 0.1 and 3 percent of global GNP per capita, and for 2200 the confidence range is between 0.6 and 13.4 percent. For the High climate scenarios, the range is many times greater. The upper limit for costs stands at a 35 percent loss of global GNP.

The PESETA study

The Joint Research Centre at the European Commission, DG Research, has initiated a study, PESETA, which is intended to analyse the effects of climate changes in Europe over the time periods 2011–2040 and 2070–2100 using a quantitative model-based approach (European Commission, 2007). Two global scenarios have been selected, which are considered to cover the uncertainty range for the driving forces for global emissions: demographic, economic and technical development. The two scenarios that have been selected are the main scenarios from the A2 and B2 groups from the IPCC's Special Report on Emissions Scenarios (SRES), i.e. the same as in this study.

The areas on which the study focuses are effects on agriculture, health, coastal protection, flooding risks along watercourses and tourism. Only a few results are available yet. Preliminary results show that the yield from agriculture can increase by 3–70 percent in some northerly regions, assuming some adaptation to the changed climate, while the yield in southerly regions is expected to decrease by between 2 and 22 percent. In the next phase, the intention is to calculate the economic values to which this equates. It is estimated that the yield will increase by 5–15 percent in southern Sweden and by 15–30 percent in northern Sweden under the A2 scenario. In the B2 scenario, the increase is predicted to be slightly smaller, at 5–10 percent in southern Sweden and 10–15 percent in northern Sweden.

With regard to health, preliminary results are presented regarding cold and heat-related mortality. The analysis shows that the increase in heat-related deaths will probably be greater than the decrease in cold-related deaths through until 2080. It is estimated that the number of deaths may increase by 86,000 per year under scenario A2, with a global temperature increase of around 3°C by 2070–2100. Under scenario B2, the increase will be half as great, approximately 36,000. These results do not include either acclimatisation effects or adaptation measures.

In addition, calculations have been performed regarding damage due to raised sea levels. These calculations have assumed an average increase in sea level of 47 cm for scenario A2 and 36 cm for scenario B2. For the latter scenario, the damage was estimated at EUR 9.3 billion annually by 2080 – assuming no protective measures are taken. If some protective measures are implemented, such as beach nourishment and embankments, the total cost for both of these measures and remaining damage is estimated to amount to approximately EUR 1.3 billion. The corresponding figures for the A2 scenario are EUR 42 billion per year and EUR 11 billion if protective measures are implemented.

The flow of tourists to southern Europe is the largest single flow of tourists worldwide. It encompasses 100 million people every year, and these people spend around EUR 100 billion. The results that have been presented indicate that the area with ideal conditions, which the Mediterranean is currently deemed to have, particularly as regards bathing-related tourism, will move to the north, perhaps as far as the North Sea or the Baltic Sea (European Commission, 2007). On the other hand, the conditions in the spring and autumn are expected to become better, and the way this may affect travel patterns is of decisive importance. Spain, Italy and Greece are expected to have poorer conditions for bathing-related tourism, while northern France, the United Kingdom, Ireland, the Netherlands, Denmark, northern Germany, Poland, the Baltic States, Finland and Sweden are expected to enjoy improved conditions.

Studies of tourism

Model studies in (Hamilton et al, 2005) show that the climate changes will shift international tourism up towards the poles and up mountains. The total number of tourists will decline however; international tourism is dominated by the British and the Germans, and these groups are expected to prefer to stay at home if the climate becomes warmer in their own countries. However, this reduction is expected to be swallowed up by the increase in tourism that is expected to arise due to population increased and economic growth.

(Lise and Tol, 2002) show that tourists from all around the world appear to prefer the climate that currently exists in the south of France and in California, i.e. a stable, warm and sunny climate. A warmer climate may not increase attractiveness as much unless it is accompanied by stability as regards sunny and dry weather.

In a quantitative analysis using a global general equilibrium model (GTAP5), (Berritella et al, 2004) found that overall tourism will not be affected by a change in climate, but that there will be a significant redistribution between destinations. North America, Eastern Europe, the former Soviet Union and Australasia are expected to enjoy positive effects. The negative changes will amount to 0.3 percent of global GNP in 2050, while the positive changes will amount to 0.5 percent of global GNP.

National analyses

The consequences for Scandinavia differ markedly from the global analyses, as the considerable negative effects of climate change will arise in countries at more southerly latitudes. In contrast, it is anticipated that the effects could initially be positive further north, e.g. in Northern Europe. There are many national studies regarding vulnerability to climate change, including studies for the Netherlands (Netherlands Environmental Assessment Agency, 2005), Germany (Zebisch et al, 2005) and Denmark (Danmarks miljøundersøgelser, 2002). However, these are mainly qualitative analyses, in some cases with quantitative calculations for some sectors, such as agriculture and forestry. The descriptions of the effects correspond closely with the results for Sweden.

In the Finnish research programme FINADAPT, calculations have been performed regarding the impact of climate changes on rural businesses, tourism and the energy sector, as well as flooding of buildings. The calculations show a slight positive net effect, primarily due to improved higher growth in forestry and increased tourism (Perrels et al, 2005). Agriculture is expected to enjoy increased productivity and decreased production costs; negative effects from flooding etc. are not included. The net effect as regards reduced heating requirements and increased cooling requirements is expected to be positive, as is the hydroelectric power potential. An increased flow of tourists from Europe is anticipated, both for summer and winter tourism, despite the shorter winter season. The damage costs for flooding and costs for preventive measures against flooding are expected to increase by a total of approximately SEK 200 million per year. All in all, there will be a small positive effect corresponding to approximately 0.06 percent of GNP in 2020 and 0.02 percent in 2080. Increased costs for transport infrastructure, industry and service sectors are not included in the analysis. Costs for storms and landslides have not been included either.

Comparison with the cost scenarios for Sweden

In addition to the difference in geographic scope, our calculations differ in many ways from the global studies that are often quoted. The analyses in this study are not based on model simulations, rather on a bottom-up method using sectoral studies. Our results are based on scenarios only for the next hundred years, and on the warming in our region not exceeding approximately 3.5°C. Feedback mechanisms such as those in Stern's *High Climate* scenario are not included. The scenarios incorporate an increased frequency of certain extreme weather events: a few more storms of the size of Hurricane Gudrun and a major flood of Lake Vänern. The risk of disasters with consequences that are greater than or of a different nature to previous events, such as major flooding in the Mälar Valley or in Göteborg, has not been included. Neither do the calculations include non-market-related costs.

It can be noted that the major costs in the Stern Review mainly arise after 2100. We have not performed any calculations that extend beyond 2100. Calculations so far into the future are naturally very uncertain, and we have seen no point in performing these in this calculation. Nevertheless, it is important to emphasise that climate changes will continue after the end of this century and can entail much more powerful events than those that have been discussed here.

The Peseta study includes estimates of the increase in agricultural yield. These are lower than the estimates prepared within the expert groups linked to this study. In particular, the yield from the soils in Norrland is expected to increase more. The costs associated with the rise in sea level have only been calculated at a European level in Peseta. The assumptions that have been made for the High scenario in our calculations entail that the costs arising from the flooding of coastal areas and coastal erosion would amount to SEK 0.7 billion per year by 2080, which would correspond to approximately 0.2 percent of the costs for the whole of Europe. It is difficult to assess whether this is reasonable or not, as the underlying calculations have not been presented in the general report that PESETA has submitted to date; the costs are dependent both on how low the coastline is in various countries and on the amount of buildings and infrastructure in the threatened areas.

The cost calculations in the Finnish study in the FINADAPT programme only cover a proportion of that included in our scenarios, but the results for the sectors that have been included are of a similar magnitude to the calculations for Sweden.

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