



THE CITY OF STOCKHOLM
STOCKHOLM'S ACTION PROGRAMME ON CLIMATE CHANGE

Adapting to Climate Change in Stockholm





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CONTENTS

I	Introduction	6
1.1	Purpose and objective.....	6
1.2	Stockholm climate programme	6
1.2.1	The role of the municipality in adapting to a changing climate	6
1.2.2	Connection between impact, climate change, effect and adaptation	6
1.2.3	Measures of adaptation.....	7
1.3	Greenhouse effect and climate change	8
1.4	Climate and climate effects	8
1.4.1	Recorded climate changes	8
1.4.2	Climate change prognosis.....	9
1.4.3	Observations made in Stockholm.....	11
2	Impact	13
2.1	Flooding	13
2.2	Operations and sectors affected.....	15
2.2.1	Physical planning and construction	15
2.2.2	Infrastructure	17
2.2.3	Industries and contaminated soil	18
2.2.4	Recreation and tourism.....	18
2.2.5	Biodiversity	19
2.2.6	Health	19
2.2.7	Insurances	19
3	Effects of a changed climate on soil contaminations	20
3.1	Run-off water	21
3.2	Flooding	21
3.3	Continual work requirements	23
4	Impact on biodiversity	24
4.1	Impact on the biodiversity and natural environment.....	24
4.1.1	Shift in climatic zones	24
4.1.2	A prolonged harvesting season.....	24
4.1.3	New species adds competition.....	25
4.1.4	The Baltic Sea.....	26
4.1.5	Lake Mälaren and other lakes.....	26
4.2	Local analysis.....	27
4.2.1	Biodiversity and ecosystem services	28
4.3	Wetlands and dams.....	30
4.3.1	Expected climatic impact on natural habitats	31
4.4	Ecosystem services.....	31
4.5	Future actions	32
4.5.1	In general.....	32
4.5.2	Actions to protect important ecosystem services.....	32

5	Continued work in the City of Stockholm	33
5.1	Vulnerability analyses	33
5.2	Targets of adjustment	33
5.3	Strategies and action plan.....	34
5.4	Follow-up and communication.....	34

FOREWORD

The manifesto of the City of Stockholm clearly defines the need to reduce greenhouse gas emissions and adapt to the changing climate. Rising temperatures, less rain in the summer and more rain in the winter, early spring floods, etc. means that Stockholm must be well prepared. It is important that the City is aware of the potential climatic consequences and how these will affect the city environment. Moreover, actions to counter these anticipated climatic changes are necessary.

The Environment and Health Administration embarked on its climate adaptation work concurrently with the Government appointing a commission on climate and vulnerability in 2005. The Environment and Health Administration asked the Swedish Meteorological and Hydrological Institute to provide examples of extreme weather conditions in Stockholm in an attempt to illustrate what may happen and how often. Concurrently, the Climate Change and Vulnerability Committee issued an interim report on the effects of a climatic change on Lake Mälaren (Flood Risk SOU 2006:94). In the spring of 2007, the Intergovernmental Panel on Climate Change (IPCC) set up by the United Nations issued an assessment report on the climate in the future.

This report consists of three separate detailed reports in Swedish; Adapting to climate change, Effects of climate change on ground contaminations and Effects of climate change on biodiversity. For further information about the City of Stockholm's climate policy visit www.stockholm.se/climatechange or to read the three reports in Swedish, visit www.stockholm.se/vaxthuseffekten.

Stockholm June 2007

A handwritten signature in black ink, appearing to read 'Gunnar Söderholm', with a long horizontal flourish extending to the right.

Gunnar Söderholm

I INTRODUCTION

I.1 Purpose and objective

The purpose of this executive summary is to identify and summaries the awareness of the impact that a climatic change will have on Stockholm. An in-depth study of the impact of a future climate change on areas of contamination and biodiversity has been carried out. The purpose is also to identify the need for the City of Stockholm to expand its awareness and analyse the matter in order to provide the City with the foundation required to adapt to a changing climate.

I.2 Stockholm climate programme

Stockholm has for many years been involved in the reduction of emissions of greenhouse gases. The work has been successful and emissions have reduced. In 1990, emissions of 5.3 tons of CO₂e¹ /person were registered compared with 4.0 tons CO₂e/person in 2005.

In addition, the City of Stockholm has started work to adapt to a changing climate by mapping out the environmental work of local businesses, trade associations and city administrations and by commissioning SMHI (Swedish Meteorological and Hydrological Institute) to evaluate extreme weather occurrences in Stockholm to form the basis of a vulnerability analysis. The City of Stockholm is part of national and international work groups and networks committed to facilitate the adaptation to a changing climate.

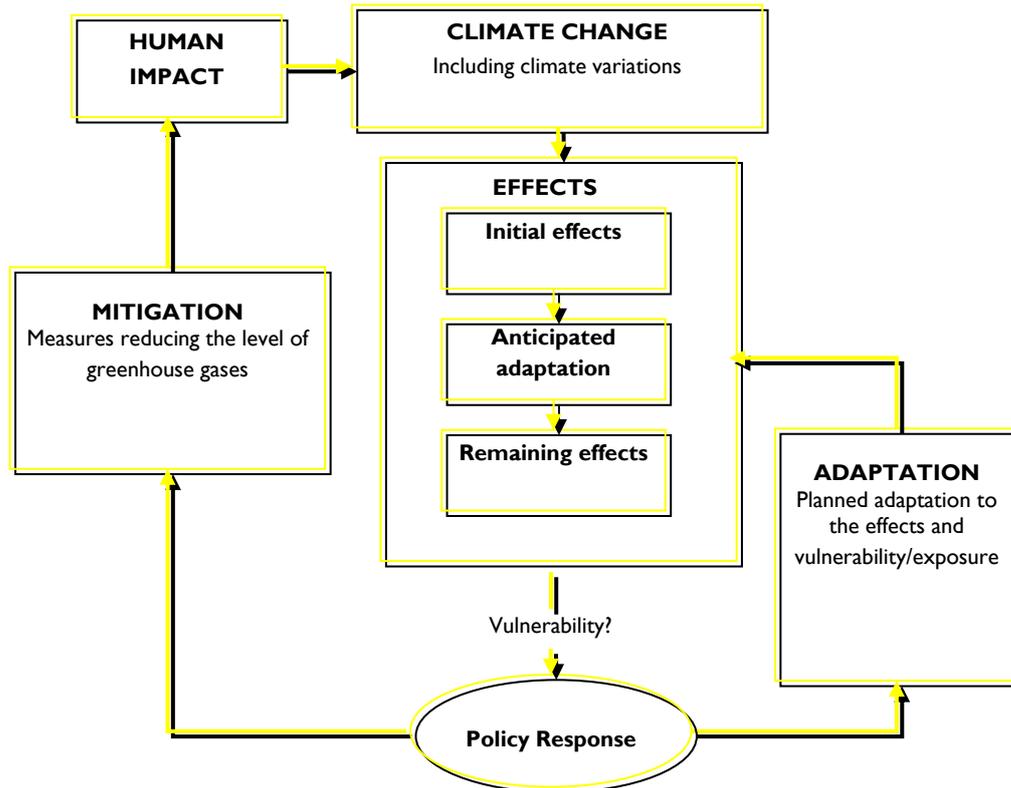
I.2.1 The role of the municipality in adapting to a changing climate

The municipality has an overall and continued responsibility for the health and safety of its inhabitants and environment. In addition, the municipality is responsible for a number of areas threatened by a climate change: Buildings, infrastructure, recreational areas, water supply, etc. Physical planning and local community development provides the municipality with an opportunity to reduce the consequences of a climate change, e.g. flooding.

I.2.2 Connection between impact, climate change, effect and adaptation

Humans contribute to the greenhouse effect by emitting greenhouse gases. The greenhouse effect leads to climatic changes, the consequences of which are can be flooding and torrential rain. The degree of greenhouse effect and consequential climate change is subject to the actions taken by the society to reduce emissions of greenhouse gases and how prepared the society is to deal with the effects of such climatic changes.

¹ CO₂e = Carbon dioxide equivalents. Means of specifying the effect of a gas on the emission of greenhouse gases compared to carbon dioxide.



Connection between mitigation and adaptation, free of IPCC²

1.2.3 Measures of adaptation

Adaptation involves reducing the many hazardous consequences of a climate change and enhance the constructive/advantageous outcome. Feasible measures of adaptation include:

- Changing regulations/guidelines or creating new regulations/guidelines such as flood and sea level controls and construction regulations.
- Changing work methods, e.g. within forestry or agriculture, in addition to cultivating new types of grains and trees that could thrive in a different climate.
- Tangible projects to improve flood barriers and protect cable tunnels in the form of embankments, tunnel reinforcements and relocation of technical infrastructures.
- Taking climatic changes into consideration in the everyday work, for example by selecting appropriate locations for the planning of new construction work and creating distribution corridors to protect the biodiversity.
- Using innovative or other technology, e.g. construction materials that can cope with the new environment and construct elevated buildings or impermeable foundations.

² <http://www.ipcc-wg2.org/> (presentation Research in response to the third Assessment Report of the IPCC).

1.3 Greenhouse effect and climate change

The climate has gradually got warmer since the middle of the 20th century and most experts now agree that today's climate change is the result of an increased greenhouse effect to which the humans contribute the most. The principal reason for the increased greenhouse effect is emissions of carbon dioxide from the incineration of fossil fuels.

Despite national and international endeavours to reduce emissions of greenhouse gases, the most optimistic computations indicate that a climate change is unavoidable.

A climate change is a complicated issue because of its many undesirable consequences. The society has adapted to the current climate and is vulnerable to any change. Therefore, in order to reduce its vulnerability, the society must start to adapt to the predicted changes. Climatic changes such as warmer weather, heavier rainfalls and higher sea levels will undoubtedly have an impact on various sectors and areas in our society.

1.4 Climate and climate effects

1.4.1 Recorded climate changes

The first part of "Climate Change 2007", the IPCC Fourth Assessment Report, was presented on 2 February 2007 reporting on recorded climate changes, climate change processes and future scenarios. A second part of the report will follow in the spring of 2007 covering the effects of a climate change, adaptation and vulnerability. The third part, expected in the summer of 2007, will deal with the prospect of reducing emissions of greenhouse gases.

The Fourth Assessment Report is more critical and less compromising than previous reports, stressing the need to assert the reasons for the global warming. It is evident from the report that the warming that has taken place since 1950 is most likely the result of increased levels of greenhouse gases in the atmosphere of which the most important is carbon dioxide produced by humans. The following important facts are extracted from that report³.

Temperatures

- The global increase in temperatures for the past 100 years is estimated to approx. 0.74 degrees (1906 - 2005), i.e. more than 0.6 degrees (1901 - 2000) as detailed in IPCC's Third Assessment Report from 2001.
- The last 12 years have seen the warmest 11 years since 1850.

³ Info from the home page of SMHI (www.smhi.se) relating to IPCC and analysis of Mr Erland Kjellén from the home page of the Swedish Environmental Protection Agency (www.naturvardsverket.se).

Gases and particles

- The level of carbon dioxide has increased by little more than 35 % since the middle of 19th century (from around 280 ppm in 1850 to 379 ppm in 2005), the highest level in 650,000 years.
- Other greenhouse gases (methane and nitrous oxide) have increased as a result of human activities.
- The amount of particles in the atmosphere has also increased as a result of human activities. These have cooling effect on the earth temperature.

The sea

- During the period 1961 – 2003, sea levels rose by 8 cm as a direct consequence of the expansion of sea-water (seas getting warmer) and glaciers melting.
- The rise in sea levels has doubled in speed compared to the period of 1961 - 2003.

Extreme weather

- The number of cold winter nights and frosty days has already decreased in terrestrial areas while the number of warm summer days and nights has increased as a result of the greenhouse effect.
- The number of intensive tropical cyclones has increased for the past 35 years (especially across the Atlantic).

According to SMHI (Swedish Meteorological and Hydrological Institute), a rise in temperatures in Sweden has clearly occurred from 1991 to 2005 compared with the average period of 1961 - 1990. In addition, Sweden has experienced a distinctive increase in the number of rainfalls throughout the country and predominantly so in the regions of Götaland and Norrland. Sweden has encountered a number of floods over the past thirty years. Inflows to lakes and watercourses have, with few exceptions, been very high since the middle of the 1980's. These occurrences are due to milder winters and heavier rainfalls.

In 2000 – 2001, the serious floods in Sweden were even noticeable in Lake Mälaren. In December 2000, the highest water levels so far were recorded since the regulation of Lake Mälaren in 1943, prior to which significantly higher levels were recorded.

1.4.2 Climate change prognosis

IPCC's climate change prognoses involve various scenarios of greenhouse gas emissions. Scenario A1F1 entails a severe increase while scenario B1 entails a limited increase in greenhouse gases. The following have been extracted from IPCC's Fourth Assessment Report.⁴

⁴ Info from home page of SMHI relating to IPCC and analysis of Mr Erland Kjellén from home page of the Swedish Environmental Protection Agency

Temperatures

- The global average temperature will rise between 1.1 - 2.9 degrees (B1) and between 2.4 – 6.4 degrees (A1F1).
- The world will not experience a uniform global warming. In the Arctic and across the terrestrial areas of the north half of the world, the global warming will be twofold the global warming elsewhere.

Gases and particles

In scenario A1F1, i.e. a severe increase in greenhouse gases (continued rise in the use of fossil fuels), the level of carbon dioxide is 3 times higher than pre-industrial levels. In scenario B1, i.e. a limited increase of greenhouse gases (due to technical and social developments), the level of carbon dioxide is double that of pre-industrial times.

Seas

- Sea levels will rise by 0.18 – 0.58 meters (scenario B1 = 0.18 - 0.38 meters, scenario A1F1= 0.26 – 0.58 meters).
- If the ice water melting in Greenland and Arctic accelerates (due to continued global warming), sea levels could rise a further 0.1 – 0.2 meters. This would mean a total rise in sea levels of 0.78 meters.

The Gulf Stream

- The Gulf Stream is unlikely to suddenly collapse.
- The Gulf Stream could decrease in strength resulting in a reduced thermal transmission to the ocean space around Iceland and Greenland at the same time as the temperatures of the North Atlantic fall below the global mean value.

Antarctic

- The ice sheet of the Antarctic will probably expand in a warmer climate seeing as a large part of the ice sheet is still colder than zero degrees.
- However, it is possible that large areas ice will detach in a warmer climate, causing a rise in sea levels.

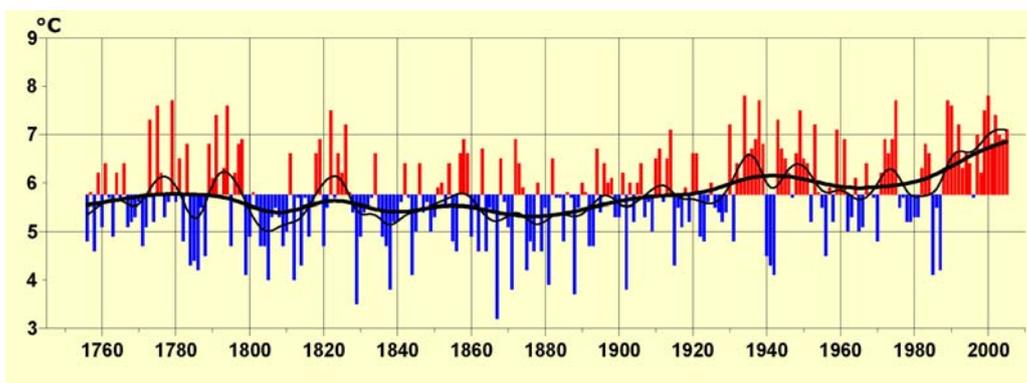
IPCC has come to the important conclusion that a continuous emission of greenhouse gases is likely to generate a global warming in the 21st century beyond what we have seen in the 20th century.

At SMHI's Rossby Centre, climate models are used to estimate scenarios of future climatic changes. Climatic change calculations have been made for the entire 21st century based on global climatic models and emission scenarios. By using various models and creating different scenarios, it is possible to analyse the likelihood and risks of a likely impact.

1.4.3 Observations made in Stockholm

Stockholm is unable to manage the climate of today and will find it increasingly difficult to manage the climate of tomorrow. It is therefore important to find out about the earlier climate of Stockholm in order to forecast its future climate.

As shown in the diagram below, temperatures have risen in Stockholm. The columns correspond to individual years. The red colour represents years with higher than average temperatures while the blue colour represents years with lower than average temperatures. Long-term variations are identified by two graphs; the thicker graph shows mean temperature values for a period of 30 years while the thinner graphs shows mean temperature values for a period of 10 years. Values recorded prior to year 1860 are too imprecise.



Reconstructed mean annual temperature in Stockholm from 1756 to 2005 (SMHI).

Lake Mälaren has been regulated twice, in 1943 and 1968. The regulation of Lake Mälaren has had an impact on its water levels and stream flow. High water levels have decreased and low flow conditions have stopped altogether. However, the regulation has also led to high flows from Lake Mälaren becoming less unusual.

In 2000 – 2001, the serious flooding in Sweden was even evident in Lake Mälaren. In December 2000, the highest water level since 1943 was recorded. Prior to regulation, significantly higher water levels were recorded in Lake Mälaren.

SMHI has on behalf of the Swedish Rescue Services Agency (SRSA) mapped out the overall flooding from Lake Mälaren. The map shows that large areas around Lake Mälaren may become subject to flooding in the climate conditions of today.⁵

⁵ Overall map of flooding from Lake Mälaren.

The climate scenarios indicate a climate change for Stockholm that could entail:

- An increase in mean temperatures of between 2.5 and 4.5 degrees until year 2100.
- Coldest winter days diminishing (all cold winter days with a mean daily temperature of below -10°C will essentially diminish).
- Less snow and a shorter snow and ice season.
- Spring floods 2 - 4 weeks earlier.
- Harvest season between 1 and 2 months longer.
- Rainfall amounts increasing, especially in the winter (5 – 10 per cent increase in rainfalls is forecasted for 2011 – 2040 while a 25 per cent increase is forecasted for 2071 - 2100 compared to the reference period of 1961 - 1990).
- High and low water levels in lakes will become standard at the expense of average levels (high water levels in the winter and low water levels in the summer).
- Rising sea levels.
- Reduced sea salt content.
- Rising sea and lake temperatures.
- Flooding along the coast and around lakes and watercourses more common.
- Drier summers.
- Severe weathers such as torrential rain, storms, etc. more frequent.

Climate studies indicate that global warming could have an effect on most of the regional water circulation. This could subsequently affect fresh water and salt water inflows to the Baltic Sea. The Baltic Sea is already characterised by variations, but a climate change could influence the disposition of such variations. The temperature of the Baltic Sea will increase gradually and have an effect on ice, salt content and sea level. The SEAREG Project indicates a maximum water level increase in the Baltic Sea of around 0.5 metres in 100 years. The IPCC Report (Fourth Assessment Report) indicates a mean increase in sea levels of 0.2 – 0.8 metres until year 2100 (lowest and highest emission scenarios). At the same time, the Stockholm region will experience a land elevation of 0.4 metres in 100 years. Consequently, the worst scenario is a rise in sea levels of 0.4 metres.

Another aspect is the impact of winds on the Baltic Sea. The Baltic Sea can be likened to a bathtub with water splashing from one side to the other, with the wind driving it on and causing water levels to rise and fall. The Baltic Sea is different from the Atlantic as the water flow into the Sound is restricted. In January 2007, the water level was 104 cm above the norm in Lake Saltsjön, i.e. higher than in Lake Mälaren. Water from Lake Mälaren is discharged into Lake Saltsjön but if the outflow from Lake Mälaren is blocked, the areas around Lake Mälaren are at risk of being flooded.

2 IMPACT

What will be the impact on various sectors and activities in the society of current and forecasted climate changes?

2.1 Flooding

The Swedish Commission on Climate and Vulnerability has in their interim report of Lake Mälaren, Lake Hjälmaren and Lake Vänern examined the impact of flooding on the Stockholm region. The impact of Lake Mälaren flooding would be relatively significant to buildings, industries and arable farms, the cost of which in 100 years at a forecasted level of +1.30 metres would amount to 4 billion Swedish crowns. This does not include indirect costs such as disrupted communications and trading. At a dimensioned level⁶, e.g. +2.30 metres in the case of Lake Mälaren, the damages caused would be considerably worse and cost a minimum of 7 billion Swedish crowns, once again exclusive of indirect costs such as disrupted communications and trading.

The Commission on Climate and Vulnerability used a vertical reference datum of RH00. The table below is a comparison of different sea-level vertical reference datums.

Comparison between different sea-level vertical reference datums			
	RH00	RH70	Vertical reference datums for Lake Mälaren
Mean level of Lake Mälaren	30 cm	66 cm	414 cm
100 year level	130 cm	166 cm	514 cm
Maximum dimensioned flow	200 cm	236 cm	584 cm
Minimum dimensioned flow with wind	230 cm	266 cm	614 cm
Mean level of Lake Saltsjön	- 36 cm	0 cm	348 cm

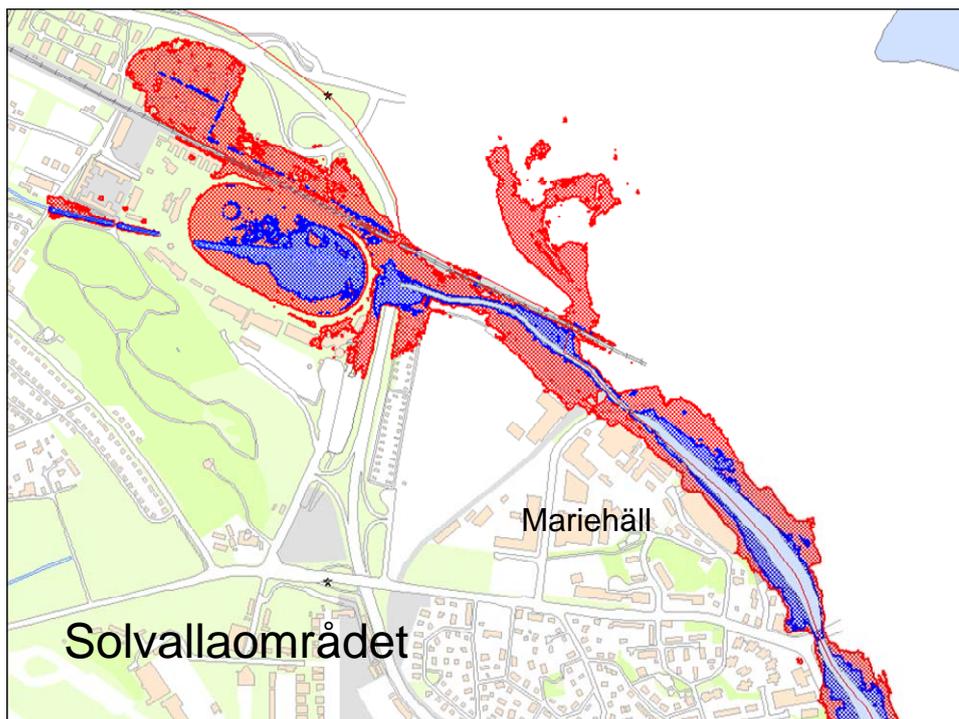
Compared with a mean sea level, the Baltic Sea has a natural sea level variation of 40 cm. The difference between the mean level of Lake Mälaren and the mean level of the Baltic Sea is 66 cm.

The interim report of the Swedish Commission on Climate and Vulnerability proposes to increase the capacity drawn from Lake Mälaren to around 1 750 m³/s.

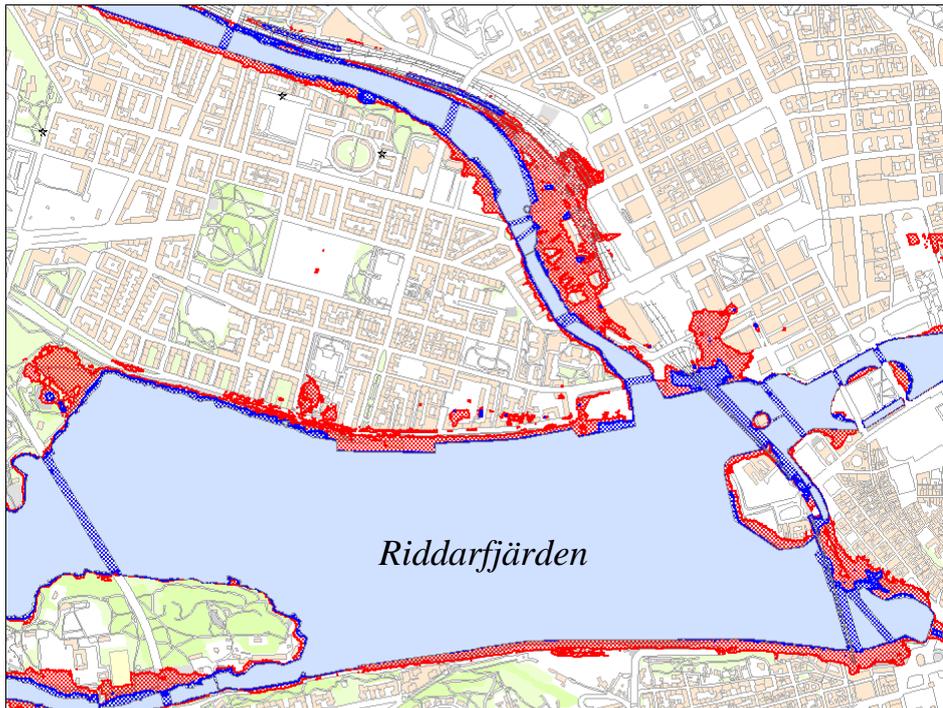
⁶ The dimensioned level for Lake Mälaren is 2.30. The dimensioned level is the level generated by the dimensioned flow for category 1 dams. This is a technique used by the Swedish Rescue Services Agency when mapping out watercourses and lakes around the country.

The proposal also incorporates an increase in the capacity drawn at Söderström (Slussen) to around 700 m³/s and a reconstruction of the floodgates at Södertälje to boost the drawn off capacity by around 300 m³/s, i.e. more than double the current capacity. These measures would reduce the highest water levels by a little more than one metre and significantly lessen the risk of flooding. Other proposed measures involve inspecting and sealing floodgates and land to avoid low water levels and only a restricted number of new buildings being erected below the dimensioned level until additional facilities for drawing off water exist. Moreover, the Commission on Climate and Vulnerability proposes that the Stockholm County Administrative Board should map out and prevent the risk of flooding causing damage to the central functions of the network of underground tunnels in the City of Stockholm.

To enable an in-depth study of the areas at risk of flooding, taking into consideration the forecasted 100 year level and dimensioned level, Stockholm City Planning Administration and the Environment and Health Administration has produced a number of pertinent maps where the sea level in 100 years is highlighted in blue and the dimensioned sea level is highlighted in red.



Flooding in the area of Solvalla according to 100 year forecast (blue) and dimensioned level (red).



Flooding around Riddarfjärden according to 100 year forecast (blue) and dimensioned level (red).

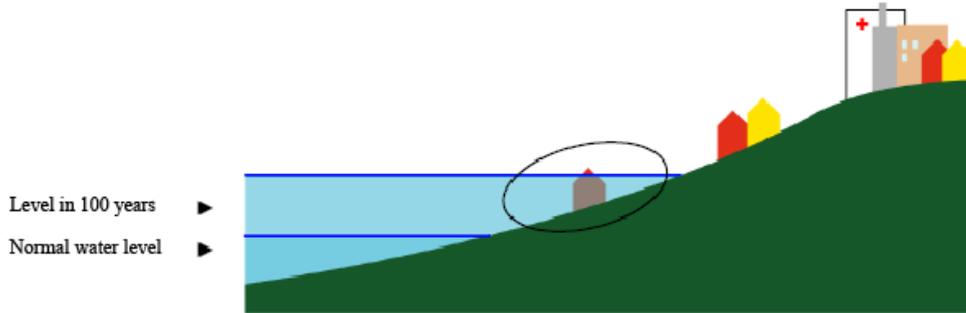
2.2 Operations and sectors affected

Below is a summary of sectors and operations affected by the climate change and examples of endeavours to adapt to the changing environment.

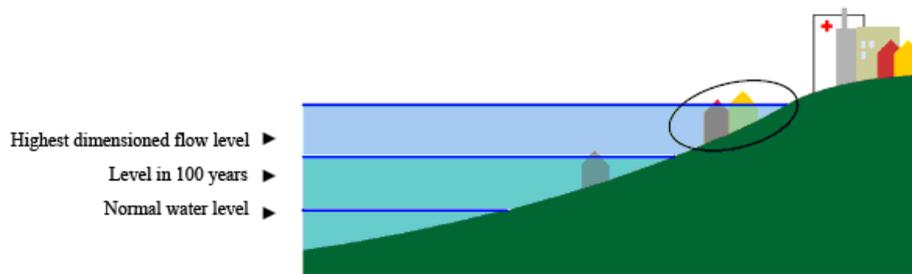
2.2.1 Physical planning and construction

The climate change necessitates a physical planning that gives greater consideration to climate variations, i.e. buildings in lowland areas prone to flooding and instability of land. A change in groundwater levels as a result of climatic changes could also pose a greater risk of landslides, erosion and soil chemistry variations with a potential impact on leaching of contaminations.

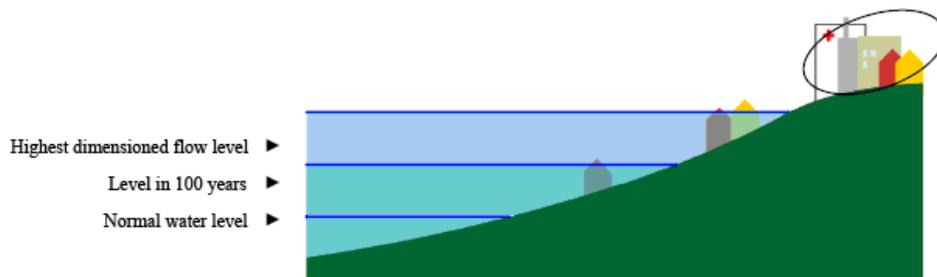
The County Administrative Board has recommended that no new constructions should take place in areas at risk of flooding within 100 years, i.e. where the likelihood of flooding within 100 years is 63 % or more, with the exception of unoccupied buildings such as garages and sheds. Elements of risk or important public services should only be considered in areas that are not at risk of flooding within 100 years or subject to the highest dimensioned flow, e.g. hospitals, nursing homes, schools or other significant infrastructures, water supply and sewage management plants, power plants and telecommunications as well as industries of a substantial environmental impact.



Recommendations of the County Administrative Boards in Central Sweden for areas of land exposed to a high risk of flooding. New constructions should not occur on land at risk of flooding with the exception of garages and sheds. (Source: Flood risks in physical planning – Land use recommendations for new constructions)



Recommendations of the County Administrative Boards in Central Sweden for areas of land exposed to a moderate risk of flooding. The construction of less important public services may occur here such as one or two detached houses, buildings of a more solid structure and roads with alternative routes. (Source: Flood risks in physical planning – Land use recommendations for new constructions)



Recommendations of the County Administrative Boards in Central Sweden for areas of land exposed to a low risk of flooding. The construction of important public services such as hospitals and schools, national trunk roads and railways may occur here. (Source: Flood risks in physical planning – Land use recommendations for new constructions)

The Commission on climate and vulnerability has examined the extent to which future construction areas may be exposed to the forecasted flood level in 100 years and dimensioned water level. Large sections of Stockholm with suburbs are situated near Lake Mälaren with both urban and isolated settlements as well as other buildings being in danger of flooding.

Level (m in RH00)	Living space at +1.30	Other space at +1.30	Living space at +2.33	Other space at 2.33
The City of Stockholm	189,457 m ²	81,611 m ²	350,217 m ²	168,980 m ²
The Stockholm-Mälars region in total	360,667 m ²	481,931 m ²	732,873 m ²	892,494 m ²

Living space expected to flood by 100 year level (+ 1.30) and dimensioned level (+ 2.33)

2.2.2 Infrastructure

The infrastructure, e.g. roads, railways, harbours, airports as well as water supply and power plants are of outmost importance to the society and hence, very vulnerable. They are also very receptive to the effects of a climate change seeing as they are often located underground (cable, car and railway tunnels) or adjacent to water (roads and railways). The establishment of infrastructures is usually long-term and it is therefore important to allow for a potential climate change in the lifespan of the relevant construction.

The interim report of the Swedish Commission on Climate and Vulnerability relating to Lake Mälaren, Lake Hjälmaren and Lake Vänern covers some of the infrastructure in Stockholm that could be at risk of flooding. In the centre of Stockholm, the busy roads around Gamla Stan (the Old City), Slussen and Tegelbacken will be affected. As to the railway network, Stockholm's Central Train Station and the tunnel underneath Riddarholmen (constricted area) are particularly exposed. Also the underground station at Gamla Stan falls within the risk zone. At the dimensioned water level, the railway traffic through the centre of Stockholm as well as underground services would come to a complete halt while bus services to Nacka/Värmdö would not be able to run from the existing station at Slussen.



The Munkbro Harbour in December 2000 (Lake Mälaren 89 cm in RH00). In the summer of 2000 and towards the end of the year, Stockholm experienced very heavy rainfalls, significantly more rain than usual. The Munkbro quay was submerged in water with the risk of flooding the tunnel to Stockholm's Central Underground Station and the ticket hall at Gamla Stan underground station. There was also a risk of underground signal/telecommunication stations and power supply systems being damaged by water.

Water supply and sewage

The Stockholm region is completely dependent on Lake Mälaren for its supply of water. The capacity of Lake Bornsjön, a reserve water reservoir, is only enough to cover for a period of 2 - 3 months. The waterworks in Mälaren; Norsborg, Görväln, Lovö and Skytteholm, supply over 1.2 million consumers. According to the Climate Change Vulnerability Analysis, operations at the Norsborg plant could be directly affected if Lake Mälaren flooded.

Fewer rainfalls combined with higher temperatures in the summer could have an effect on the quality of drinking water, e.g. change in taste, colour and odour.

Energy production and energy supply

Warmer summers usually lead to an increased demand on cooling while warmer winters lead to a reduced demand on heating. Hydroelectric energy and wind energy are directly dependent on the climate and influenced by the frequency of wind, rainfall and temperature. According to the Swedish Emergency Management Agency⁷, the climate change may result in an amplified and more consistent hydroelectric energy production. More and more water reservoir constructions and reconstructions allow for the consequences of a climate change, e.g. extreme flooding, and work on increasing their safety margins⁸. Stronger winds may boost the production of wind energy, but they could also cause a lot of destruction.

Telecommunications network and switching stations may also be affected. In the event of a dimensioned water level, the supply of electricity to central parts of Stockholm is expected to be wiped out.

2.2.3 Industries and contaminated soil

See in-depth report, chapter 3, and page 20.

2.2.4 Recreation and tourism

A change in temperature, water levels and snowy and icy weather conditions will seriously affect recreation and tourism, which is very active in and around the archipelago and the sea of Stockholm. Many of the yacht/sailing clubs, beaches and golf courses near water will be affected by the changing climate. In the winter, the lakes and the sea are popular for long-distance ice-skating. However, this is an activity that will become scarce with milder winters to come. Then again, the warmer summers could have a positive influence on the development of tourism. SMHI⁹ points out that the expected hot summers in the south of Europe may attract more people to the slightly cooler cities in the north, Stockholm being one of them. The Baltic Sea may see a boost in tourism, as long as the problem with over fertilisation and algae can be controlled.

⁷ Municipal risk and threat perception – A summary 2006

⁸ Sweden's Fourth National Report on Climate Change

⁹ Rummukainen M, Bergström S, Persson G, Anpassning till klimatförändringar, SMHI, 2005.



A change in temperature and icy conditions may reduce the number of ice-skating opportunities.

2.2.5 Biodiversity

See in-depth report, chapter 4, and page 24.

2.2.6 Health

According to the Swedish Emergency Management Agency¹⁰, the climate change may affect people's health as disease is transmitted by insects and heat waves. A milder climate is also expected to boost the population of ticks, increasing the risk of *Borrelia* (Lyme disease) and TBE spreading. Heat waves are expected to become more common and severe. According to SMHI¹¹, exotic diseases and seasonal allergic rhinitis or hay fever will increase as a result of a prolonged growing season and higher levels of carbon dioxide in the air.

2.2.7 Insurances

Premium and excess insurances relating to risky activities and operations are likely to rise or such activities becoming uninsurable.

¹⁰ Municipal risk and threat perception – A summary 2006

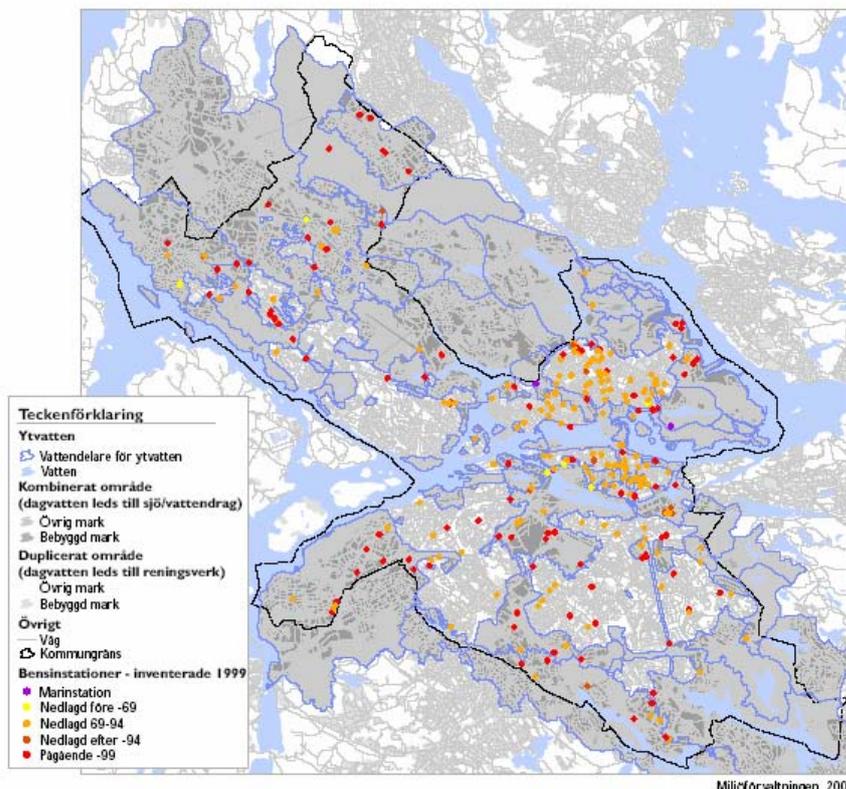
¹¹ Rummukainen M, Bergström S, Persson G, Anpassning till klimatförändringar, SMHI, 2005.

3 EFFECTS OF A CHANGED CLIMATE ON SOIL CONTAMINATIONS

Contaminated sites are areas such as refuse tips and disposal sites, closed down petrol stations, industrial sites, impregnation plants and contaminations in the sediments of lakes and watercourses, etc. Stockholm has been exposed to contaminations for hundred of years and large parts of Stockholm centre are landfill sites or ‘Stockholm soil’ which consists of everything from rubble stone to demolition waste and other debris. Depending on the contents of the landfill material, the ground is contaminated in one way or another.

Contaminated sites are a threat to the health of the City’s inhabitants and its environment. In addition to being acutely toxic, chemical substances can be allergenic and carcinogenic or interfere with reproduction or genetics. Persistent hazardous substances may spread through the air and water and cause long-term problems. Today’s society is host to a large quantity of chemical substances which in Sweden amount to around 20,000. This vast number of substances has led to an insufficient comprehension of how the substances may spread or affect the environment and people’s health.

The sites of closed down petrol stations are likely to be contaminated with petroleum. Stockholm City Environment and Health Administration has mapped out sites of closed down petrol stations. The properties identified on the map are properties from which sales of petrol have taken place but ceased to exist between 1969 and 1994. According to the map, Stockholm has 170 closed down petrol stations that could be in need of decontamination.



The picture shows past and present petrol stations in Stockholm. A total of 170 closed down petrol stations has been located, the land sites of which could be in need of decontamination.

3.1 Run-off water

Run-off water is rainwater, flushing and ice water that run off hard surfaces into ditches or trenches to recipients (Lake Saltsjön, other lakes and watercourses) or waste water treatment plants¹². The City of Stockholm's storm water strategy¹³ lists the following sources of contaminated run-off water:

- Heavy metals such as mercury, cadmium, lead, copper, zinc and chrome.
- Organic toxic substances injurious to the environment such as PAH and PCB.
- Oils
- Nutrients such as nitrogen and phosphor.
- Micro-organisms

The highest levels of pollutants are found on roads with more than 30,000 vehicles/day. Medium to high levels of pollutants are found in car parks, terminals, smaller roads and residential and industrial areas of the stone city. Lake Saltsjön, Lake Mälaren, other lakes and watercourses are separated into different categories depending on status and perception to various forms of human influence (organic pollutants, heavy metals, nutritive salts and changes in water circulation).

More heavy rainfalls during dry summer periods will lead to higher levels of pollutants from traffic and effluents flowing into surrounding lakes and sea water. The 'first flush', i.e. the surface dirt that is initially flushed away in heavy rainfalls usually contain high levels of pollutants that end up in the city's watercourses. Heavy rainfalls can also result in run-off and sewage water plants flooding and overflowing and sewage entering the watercourses of the city. Stockholm's stone city in particular lacks the capacity for handling run-off water from heavy rainfalls.

According to the Swedish Geotechnical Institute (SGI), the consequences of a climate change such as heavier and more frequent rainfalls, higher groundwater and increased water flows, flooding and erosion will intensify the leaching and spreading of pollutants¹⁴. The climate is closely connected to the characteristics of soil and water. Flooding, landslides and erosion are all problems related to the climate. The following are examples of possible consequences for the contaminated areas of Stockholm.

3.2 Flooding

When it floods, large areas of land are submerged under surface water. If these areas are contaminated, the water will bring with it particles, humus, fertilisers and other pollutants, affecting the water quality and ecosystem in and around the water. The quality of bathing waters will also be affected by run-off soil pollution.

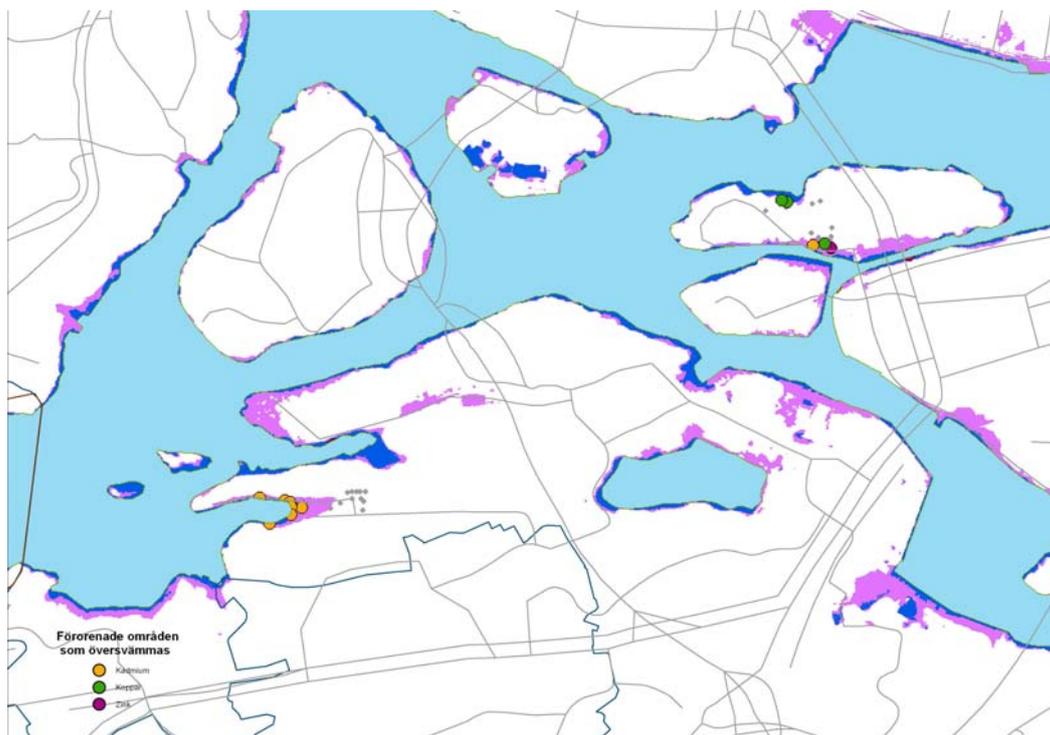
¹² Definition of run-off water from Stockholm's Water Programme.

¹³ Adopted by the City Council in October 2002.

¹⁴ Soil stability. Technical report for plan of action in order to identify and prevent natural hazards in Sweden due to climate change. Swedish Geotechnical Institute, 2006.

Areas and operations contributing to the spreading of pollutants in the event of flooding are contaminated sites, landfills, industries, industrial land, municipal effluents, petrol stations and toxic and dangerous waste storages.

Flooding will contribute to the dilution of existing contaminations but it will also intensify the level and dispersal of pollutants, the effects of which are dependent on local conditions. The corrosion of shoreline areas near fast flowing watercourses and sea beds will accelerate as a result of which pollutants (sea bed sediments often have a high concentration of pollutants) will silt up and pose an immense risk to the environment.



Vinterviken and Långholmen are areas polluted with cadmium, copper and zinc among other toxins. Floods as per forecasted 100 year level (dark blue area, + 1.30) and dimensioned level (cerise area, +2.30) are likely to affect the polluted areas.

Stockholm's groundwater is already problematic with variable groundwater levels¹⁵. The groundwater recharge is restricted by hard surfaces and the water being led away via a pipeline system. A future climate change with periods of drought and additional rainfalls could result in ever more variable groundwater levels.

Groundwater levels are vitally important to the stability of the ground, particularly in developed areas.

¹⁵ Information from Bertil Engdahl, Environment and Health Administration, Stockholm City

3.3 Continual work requirements

- Increased awareness
- Critical area analysis
- Additional inventory
- Increased awareness among municipal planners and land users
- Prioritising areas of after-treatment
- After-treatment of polluted areas
- Municipal planners to take into account areas subject to landslides and erosion – impact analysis to evade pollution
- Stability improving measures
- Environmental building materials that do not disperse toxins
- A storm water strategy that allows for a change in climate

4 IMPACT ON BIODIVERSITY

Accordingly, a change in the climate will affect a number of processes that control the structure and functioning of our ecosystem. Some of these effects are direct and comparatively easy to evaluate. Others are indirect and more difficult to evaluate such as the interaction of different species and their role in the ecosystem, e.g. purification of water and air, binding of soil, pollination. The biodiversity is also directly influenced by human activities.

Ecosystem services are the 'benefits' produced by various species and their habitat. Mother Nature provides us with these benefits at no cost, some of which include pollinating insects and water purification, organic pest control and soil fertilisation.

4.1 Impact on the biodiversity and natural environment

Due to the biological complexity, the extent and impact of a climate change vary dependent on region and the course of events. The following are examples of the potential impact on the biodiversity and natural environment of Stockholm.

4.1.1 Shift in climatic zones

A warmer climate will shift the climatic zones north. An average temperature increase of 1 degree will move us 150 km closer to the equator. A temperature increase of 5 degrees is almost equal to the distance between Stockholm and Berlin (750 km).

As our climate gets warmer, today's species will either start to move north or adjust to the changing climate - if given the time and opportunity. The change in temperature that we are currently experiencing and the change in temperature forecasted is taking place at such a rate that an adjustment or relocation to a more suitable habitat could be jeopardized. Relocation may also be hampered by various infrastructures.

4.1.2 A prolonged harvesting season

A milder climate will give a prolonged harvesting season. The length and start of the harvesting season is of great importance to the production of biomass as well as the composition and distribution of species. It is already evident from satellite data of changes in the quantity and density of vegetation that the harvesting season in large parts of south Sweden has been prolonged by more than four weeks from 1982 to 1999.

According to the Swedish Environment Protection Agency¹⁶, both farming and forestry should benefit from a longer harvesting season, a warmer climate and higher levels of carbon dioxide in the air. For the farmers, the climate forecast for year 2100 entails a harvest increase of 20 % while the forestry industry would see an increase of 10 - 15 %. However, this could be hampered by the lack of rain in the south of Sweden, an escalation of noxious insects and damages caused by torrential rainfalls.

¹⁶ <http://www.naturvardsverket.se/dokument/klimat/index.html>

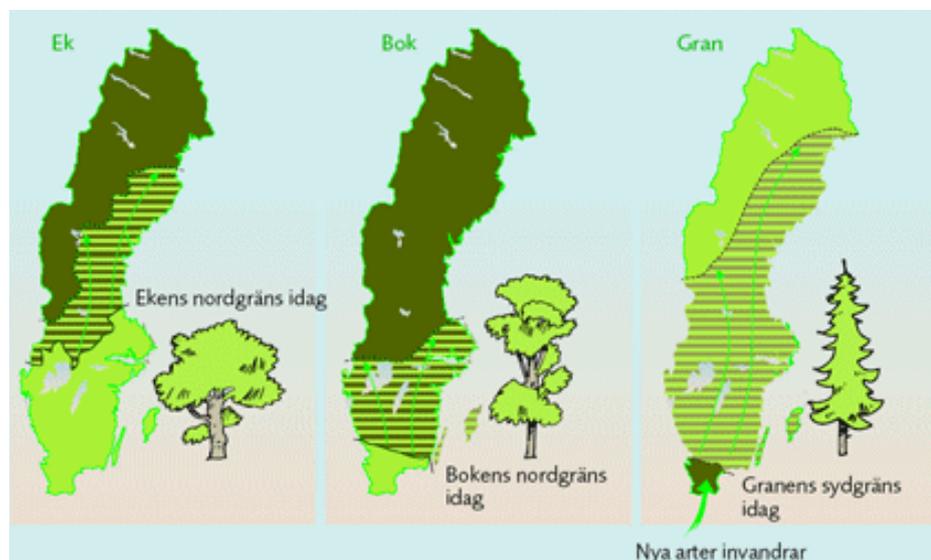
In addition, an early spring accretion could result in frost damaged trees and forest fires during hot and dry summers. Because of a changed wind climate, storm-felled trees will be more recurrent and/or ground frosts more unusual. However, the link between the temperature, ground frost and snowfall is complicated and could, despite a rise in temperature, lead to added ground frosts and fewer snowfalls.

Certain types of trees that need the winter cold, e.g. the common spruce, will not benefit from a warmer climate. The absence of wintering will reduce the vitality of the tree and expose it to pests in the form of insects and fungus. A warmer and more humid climate will benefit pests such as cryptogamic and viral diseases, bacteria, nematodes and insects.

4.1.3 New species adds competition

A change in the climate will change the composition of species; an immigration of species from the south and east will occur and these will compete with the species that already exist. Some species will benefit from a changed climate while others will not.

Tree lines will shift north and the common spruce with its southern tree line running through the north of the provinces of Skåne and Blekinge will be in serious competition with pine trees and other new species from the south. From a long-term perspective of a couple of hundred years (2 - 3 rotation periods for the forestry industry), naturally growing spruce trees will only exist in the far north. One type of tree that may establish itself in the Mälär Valley region is the common beech, the north tree line of which currently runs through the south of the province of Småland. The oak will also benefit from a warmer climate.



In a few hundred years, the north tree line of the oak, currently at level with the Dala River, will run through the region of Umeå. The north tree line of the common beech, currently in the south of the province of Småland, will run through the Mälär Valley region.

4.1.4 The Baltic Sea

A climate change will not only raise the sea temperature but will also affect the salt content and currents of the sea. The forecasted increase in rainfalls in the catchment basin of the Baltic Sea will result in a reduced salt content. If the salt content falls below 3 - 4 permillage, marine species that depend on a salt content will disappear, e.g. the common mussel, kelp, cod and herring. This will threaten the existence of other species in the same food chain such as the eider which lives off common mussels.

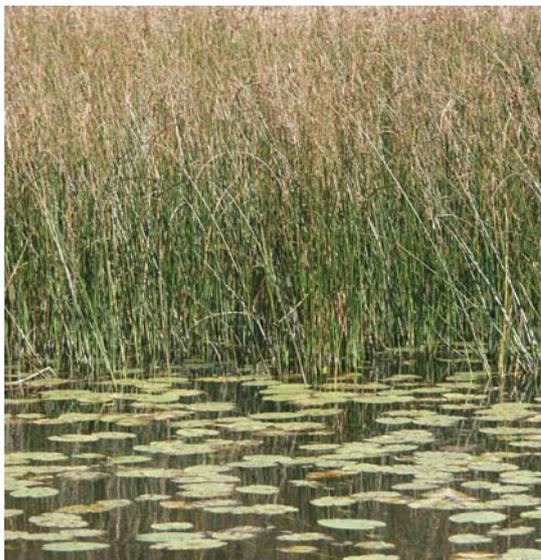
A rise in temperature could also increase the outflow of nutrients from agricultural areas in the winter with an added risk of flooding and the dispersal of soil pollutants and noxious waste from landfills and industrial areas.

However, the forecasted change in the temperature and salt content of the Baltic Sea is not considered to benefit important species for the fishing industry such as herring, cod and salmon. Another consequence of rising water temperatures is a reduced vertical mixing of the water mass and a greater risk of oxygen deficiency along areas of the sea bed, to a certain degree counteracted by the reduced amount of ice and stronger winds.

4.1.5 Lake Mälaren and other lakes

In a change climate, the water levels of Lake Mälaren will gradually become average to low with larger water level variations throughout the year. From the perspective of an ecological aspect, it is important that Lake Mälaren maintains a high water level throughout most of the spring (from the middle of March to the middle of May).

Today, the fish stock of Lake Mälaren consists mostly of warm water fish that spawn in the spring. Warm water fish such as pike-perch, pike, perch, roach and tench will benefit from a warmer climate while cold water fish such as trout, four-horn sculpin and smelt will be disadvantaged.



The reeds are pulled up with the melting ice, restricting re-growth. A climate change with less ice would benefit the reeds and allow it to spread.



A warmer climate may benefit the algal growth in lakes and the sea. Blooming of the cyan bacterium *Microcystis aeruginosa* from Lake Mälaren in August 2006. Photo: Helena Högländer

Warmer summers will benefit the algae blooming in the Baltic Sea, Lake Mälaren and other lakes. Today, the effects of an early break-up of the ice are noticeable in the form of an early algae blooming and changes in the composition of algae. A rise in the water temperature would also increase the risk of toxic algae with a potentially serious outcome for the marine environment. Other effects of a rising water temperature include a reduced destratification and oxygen deficiency along the sea bed. Oxygen deficiency is a serious threat to some species of animals such as the whitefish and four-horn sculpin, the latter being less common in Lake Mälaren.

4.2 Local analysis

Local analysis is an assessment of how the diversity in the Stockholm region will be affected by the anticipated climate changes described above. The report is based on the following questions:

- What happens if there is a rise in the mean temperature of 2.5 – 4.5 degrees before year 2100?
- What happens when the harvesting season is prolonged by 1 - 2 months?
- What happens if there is an increase in rainfalls, particularly in the winter?
- What happens when high and low water levels in the lakes become the norm at the expense of an average level?
- What happens if the sea level rises?
- What happens if the salt content in the sea is reduced?

- What happens if the temperature rises in the lakes and sea?
- What happens when flooding becomes frequent along the coast, lakes and watercourses?
- What happens when the summers become drier?
- What happens if severe storms become more frequent?

4.2.1 Biodiversity and ecosystem services

There is an evident risk of forecasted climate changes affecting Stockholm's natural environment and hence, endangering vital values. A priceless nature, protected species and important ecosystem services may change beyond the point of preservation unless urgent measures are taken. Moreover, it is possible that these changes will take place fairly quickly compared with earlier changes in the natural environment.

New research indicates that natural environments with a maintained biodiversity are better equipped to adjust to a changing climate¹⁷. The same applies to ecosystem services on which the human is dependent such as the pollination of flowers and crops or degradation of underground substances and bacterium. By maintaining the biodiversity of natural habitats, species and genetic resources, we can help the nature to cope with climatic changes and thereby lessening the risk of the society being negatively affected.

Maximum values of biodiversity

The following are considered to be of maximum natural value to the city of Stockholm:

- Broad-leaved deciduous forests with old oaks and solitary giant oaks
- Well-established coniferous forests and solitary giant pine trees
- Saltsjö beach and the islands in Lake Saltsjön
- Mälär beach and the islands in Lake Mälaren
- Natural lakes and watercourses
- Wetlands

A number of biotopes are also of interest because of their unusualness to the City of Stockholm and their biological or educational significance. Coniferous forests (Norway spruce with blueberry) are not so common in the City, but have an important educational value as the most common type of forest in the country. Grasslands rich in species are few and diminutive in the City, but a great source of enjoyment and education.

¹⁷ Suttle, etc. (2007) *Science* 315, p. 640-642; Reusch, etc. (2005) *Proc Nat Acad Sci USA* 102: 2826-2831.

Most important ecosystem services

At present, the following ecosystem services are considered the most important:

- Infiltration, purification and flux flattening of run-off water
- Protected beach areas
- Air purification and influence on the local climate of trees
- The role of nature from a recreational and health point of view

Other ecosystem services are also important. However, it cannot be ruled out that the productivity of the natural environment will become ever more important in the future, e.g. the capacity to produce energy crops or local cycle integration.

Impact on Stockholm

Groups of old oak trees are one of the most valuable natural environments in Stockholm. The oak trees found at Djurgården, Sättra, Flaten and Sickla contains a large number of protected species (primarily insects, wood lice, beetles and wood fungi).

Valuable oak trees are characterised by their sturdy and hollow appearance in addition to being in a fairly open location with the sun warming the tree trunks. In addition, oak trees should have plenty of coarse woody debris.

The oak trees and their flora and fauna are in fact better adjusted to a warmer climate. Many of the endangered insects and creepy-crawlies that are part of the oak tree environment now exist near their north limit.

Other broad-leaved deciduous forests such as maple and linden consist of relative small groups of broad-leaved deciduous trees. However, a rise in temperature will expand and spread these groups. Beech is thought to replace the common spruce in nutrient-poor areas where common coniferous forests usually grow.

Elm and ash tree forests offer a better environment than beech forests for an abundance of species as the well-established landscape provides atolls for growth and dispersion.

One of the more common types of forests in the Stockholm region is the flat-rock pine forest. Established common pine trees can be found in parks and local natural environments and throughout the urban landscape. Unlike the common spruce, the common pine will benefit from a climate change. Droughts in the summer have a greater impact on the common spruce than on the common pine.

Coniferous forests only make up a small part of the City's natural environment. Compared to today, the common spruce will have more competition from deciduous trees as these profits from a warmer climate and are better equipped to cope with harsh winter storms.

Stockholm's beaches along Lake Mälaren are relatively steep with rock hillocks leading down into the water and as a result, generally unaffected by changing water levels. Low-lying beaches are few in numbers and often subjected to human influences. There are no shoreline meadows and marsh woods are very fragmentary. The fishing in Lake Mälaren is of a national concern.

Stockholm's beaches along Lake Mälaren are thought to be relatively tolerant to the effects of the climate change such as increased changes in the water level and ice abrasion. However, changes in the water temperature could be of significance in combination with a possible escalated eutrophication as a result of more rainfalls in the winter and run-off of nutritive salts into the lake. Fast-flowing run-off water is also expected to increase the influx of nutritive salts and pollutants.

However, it is very difficult to forecast how the climate change will affect the aquatic environment and fish stock. The fish in Lake Mälaren most endangered by rising temperatures or reduced oxygen contents is the salmon and the protected four-horn sculpin while carp, pike, perch, trout and pike-perch are likely to benefit from a rise in temperature.

Since living conditions are determined by an intricate link between temperatures, eutrophication, oxygen contents, algae blooming, etc., forecasting future environmental changes is very difficult. For example, the effects of a shorter period of ice are unclear. A long period of ice is considered to benefit the fish fauna of Lake Mälaren and the archipelago as the fish/fishing gets a rest from predators (humans, seals and cormorants). In addition, a long period of ice coverage lessens the cooling of the water, stabilising the thermocline layer for longer periods, a positive development for deeper waters. However, longer periods of ice/thick ice can be a disadvantage to fish and crayfish in small lakes as it could result in an oxygen deficiency in the early spring with an excess release of nutrients from sediments at the bottom of the lake¹⁸.

Species immigrating to Lake Mälaren often originate from the south and therefore, should benefit from a warmer climate. The freshwater medusa and zebra mussel would both benefit from a rise in temperature. The medusa is not thought to be a threat to the biodiversity but a boost in population could have an effect on the plankton communities on which they feed. The zebra mussel will benefit from a rise in temperature and eutrophication as well as from the absence of ice, the consequences of which however are uncertain. Water-weeds are widespread in the western parts of Lake Mälaren and very competitive, benefiting from eutrophication and rising temperatures. Crayfish become stressed in high temperatures and are prone to disease.

4.3 Wetlands and dams

The natural environment of Stockholm is relatively free of wetlands and ponds. Wetlands in the form of small bogs can be found in woodlands or as overgrown marshy grasslands. Many of these wetlands house an abundance of insects and amphibians. Protected varieties of birds are often found adjacent the overgrown grasslands. Dams such as Isbladskärret and Lappkärret are of considerable importance to bird life while smaller dams are of importance to numerous amphibians. Many small dams in the City are the home of the protected giant salamander.

¹⁸ Sverker Lovén, Fishery Consultant, Stockholm Sports Administration (Stockholm Idrottsförvaltning).

4.3.1 Expected climatic impact on natural habitats

The catchment basins of most wetlands in Stockholm are very limited and in the past, inflow of water has often been used for the draining of houses. Hence, the wetlands are receptive to a varied amount of rainfall. It is therefore reasonable to expect that the forecasted summer droughts will expose wetlands and dams to stress with the risk of an accelerated overgrowth. Winter rainfalls would perhaps benefit deciduous trees at the expense of the common spruce.

The impact on the insect fauna is dependent on the impact on the flora and whether there is more shade. The impact on amphibians is dependent on the development of water as a consequence of the diverse distribution of rainfalls. Many species will benefit from winter rainfalls producing high water levels late spring and summer. An early spring drought would result in the number of potential sites for procreation in Stockholm will decrease. At the same time, new dams and ponds in Stockholm are being created to provide habitats for amphibians. If a sufficient number of wetlands and dams/ponds are established or restored, the water holding capacity of the land will hopefully improve in general and the number of amphibian spawning sites increase.

Large overgrown grasslands are primarily located near large lakes (such as Lake Magelungen and Lake Älta) and are therefore dependent on the water regimes of these lakes. Regulating these lakes could potentially impede the forecasted changes.

4.4 Ecosystem services

The most important ecosystem services expected to be affected by a climate change are primarily those that concern the movement of water through for example the management of run-off water and protected areas. The air purification and influence on the local climate of trees can also become affected. Since many biotopes are expected to change, e.g. coniferous and deciduous forests, the role of the natural environment as regards recreation and health will change. There is a risk of a poor water quality and subsequent flooding will lead to an inferior bathing water quality. In addition, the diminishing ice sheet in Stockholm will be a drawback for all long-distant skaters. Fewer snowfalls will also have an effect on other winter sports.

4.5 Future actions

4.5.1 In general

- Environmental monitoring of the effects of a climate change on biodiversity and ecosystem services
- Minimise landscape fragmentation
- Maintain pathways for dispersal
- Create areas for new habitats
- Take climate change into consideration when planning for the preservation of protected areas
- Take climate change into consideration when planning and caring for municipal parks, plants and trees
- New run-off water and surface drainage strategies

4.5.2 Actions to protect important ecosystem services

- Protected areas of vegetation around lakes and watercourses
- Review the City's tree maintenance programme (root care and watering essential)
- Continually review the role of nature for recreation and health in Stockholm

5 CONTINUED WORK IN THE CITY OF STOCKHOLM

What contributions should the City of Stockholm make? An answer to that question requires both expertise and analyses. The City of Stockholm is a member of ICLEI (International Council for Local Environmental Initiatives) and involved in the CCP campaign (Cities for Climate Protection Campaign). CCP has identified a number 'milestones' to support the work of reducing emissions of greenhouse gases and adjusting to a changing climate:

1. Record emissions of greenhouse gases (actual and projected emissions) and perform a vulnerability analysis.
2. Decided municipal targets for the reduction of emissions and necessary adjustment.
3. Develop municipal strategies and action plans for all areas.
4. Implement the relevant strategies and actions in all areas.
5. Follow up, resume and report to the rest of the world.

5.1 Vulnerability analyses

More detailed vulnerability analyses are required in each area. A vulnerability analysis should identify a number of areas such as previous climatic incidents and recurrent extreme incidents as well as assess future climates and the impact of these on the weather and environment of Stockholm.

Examples of important matters that ought to be addressed by the City of Stockholm:

- In what way are the consequences of a climate change relevant to this area/sector?
- What is the potential impact? In the short and long run.
- Which geographical areas will be affected?
- What extreme weathers have occurred previously and how frequently?
- What is the scenario for the area? In the short and long run.
- What are the consequences of ice, snow, wind, rain and drought?
- What areas are prone to flooding?
- What does the geology look like in this area?
- What is the impact on geology of a changing climate?

5.2 Targets of adjustment

It is important to decide on and identify mutual targets. One example of such a target is to integrate the climate adjustment of all sectors and major investment projects.

5.3 Strategies and action plan

Relevant operations should be provided with a long and short-term action programme which includes an estimate of costs. These costs should then be compared with the costs of not implementing the action programme, e.g. the cost of flooded tunnels and land.

Examples of important issues:

- What adjustments are needed?
- Can we cope with the current commitments?
- Can we cope with the future commitments?
- Which organisations are affected?
- Which operations within the geographical area are affected?
- Positive aspects to learn from?
- What adjustments are feasible? The feasibility of adjustments should be studied together with other local trends.
- Which contributors will affect the criterion and what forms of collaboration exist?
- What measures of adjustment could be relevant, what does it cost and what would it cost if nothing is done?
- Which preventative and operative actions could be implemented?
- What does it cost to implement the actions and what does it cost not to?

5.4 Follow-up and communication

In order to decide whether the development is going in the right direction, i.e. in the direction of the identified targets, a follow-up of such targets and actions must be carried out.



STOCKHOLM'S ACTION PROGRAMME ON CLIMATE CHANGE

ENVIROMENT AND HEALTH ADMINISTRATION

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www.stockholm.se/climatechange