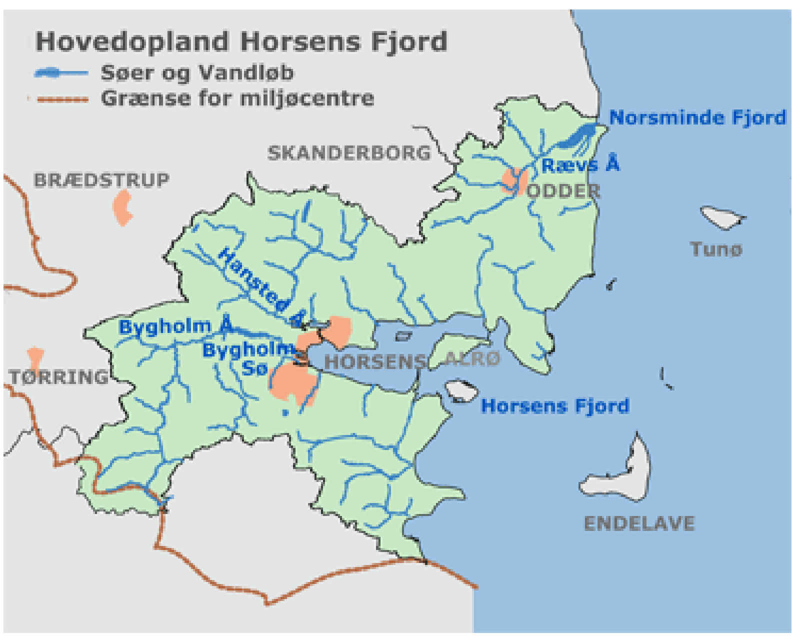
HORSENS FJORD CASE

Hans Jørgen Henriksen, GEUS

1. Background to the case

Introducing the catchment

Horsens Fjord is a shallow and eutrophic estuary located on the east side of Jutland, Denmark within the WFD catchment area Horsens Fjord (Fig. 1). The surface area of the Fjord is approximately 46 km^2 and the mean depth is 2.9 m besides a narrow shipping channel with a depth between 7 and 22 m. The catchment area is 517 km^2 and dominated by agriculture (75%) with small areas of forests, wetlands, lakes and urban areas. The annual freshwater input is in the order of 100 Mm3, where approximately 70% is channelled through two main creaks Bygholm å and Hansted å, located in the inner part of the fjord. Several smaller streams are located on the north and south coasts of the estuary. The average annual nutrient input to the Fjord from freshwater is 1503 tons N and 37 tons P (average from 1985 to 2006). The two main streams and the waste water treatment plant for Horsens town, which is located close to mouth of Bygholm stream, accounts for approximately 75% and 65% of the nitrogen and phosphorous discharges, respectively. The marine end member is water from the Belt Sea which forms the transition zone between the North Sea and the Baltic Sea and hence displays large variations in salinity and nutrient concentrations. Exchange of water masses between the estuary and the Belt Sea is mainly driven by wind stress and changes in sea surface level in the North Sea/Baltic Sea system whereas changes in sea surface level coursed by tides is small with a range of less than 0.5 m.



Figur 1. Horsens Fjord catchment. WFD main catchment area is 794 km^2

Physical features and ecosystem

The fjord landscape is formed by glacial deposits. The average depth is 5 meters and the residence time of water in the fjord is about 20 days. As to tidal variations the amplitude is about 0.4 meters. Horsens fjord consists of marine coastal ecosystems. There are three fairly large islands with cultivated land and scattered habitation. One of the most important plant community on the islands along the East coast of Jutland is saltmarsh. Furthermore there are heaths, moors, meadows and deciduous forests. Since the 1930s sedimentation around the islands and shoals has increased as a result of the disappearance for a number of years of eel-grass. North of Alrø Island, as a result of the construction of a causeway connecting the island to the mainland, sedimentation of silt is taking place. In the past years the grazing of the saltmarshes on Endelave has been reduced due to smaller numbers of grazing cattle. The taller vegetation is negative for the birds nesting and feeding there. Parts of the Horsens Fjord Ramsar site are wildlife and nature reserves, with no public access. By a ministerial order, hunting from motor boats has been prohibited in Horsens fjord west of the island of Alrø in order to reduce hunting pressure on the disturbance of waterbirds.

Hydrological modelling

A regional groundwater and surface water model is constructed in MIKE SHE / MIKE 11 in order to describe climate change effects on groundwater and surface water systems (Fig. 2 and Fig. 3)

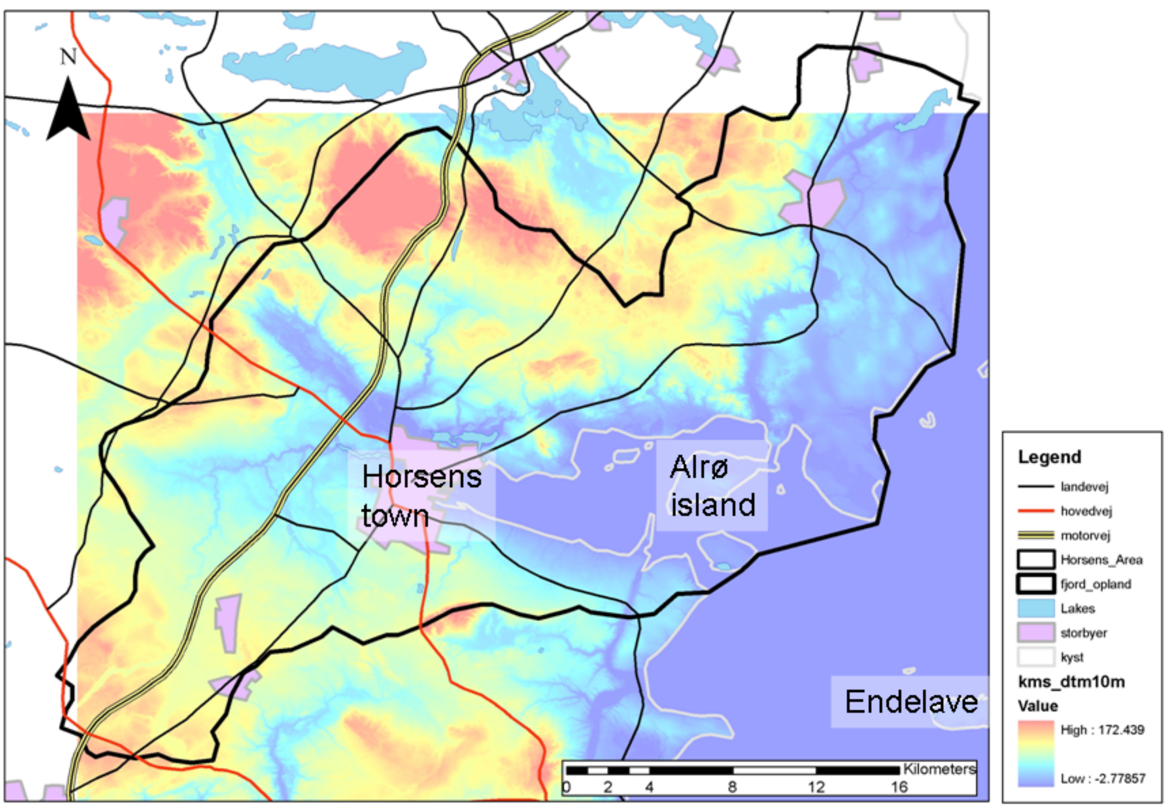


Figure 2 Regional flow model for catchment area to Horsens Fjord and Norsminde Fjord. The figure also show major highways, main roads and the topography in the area.

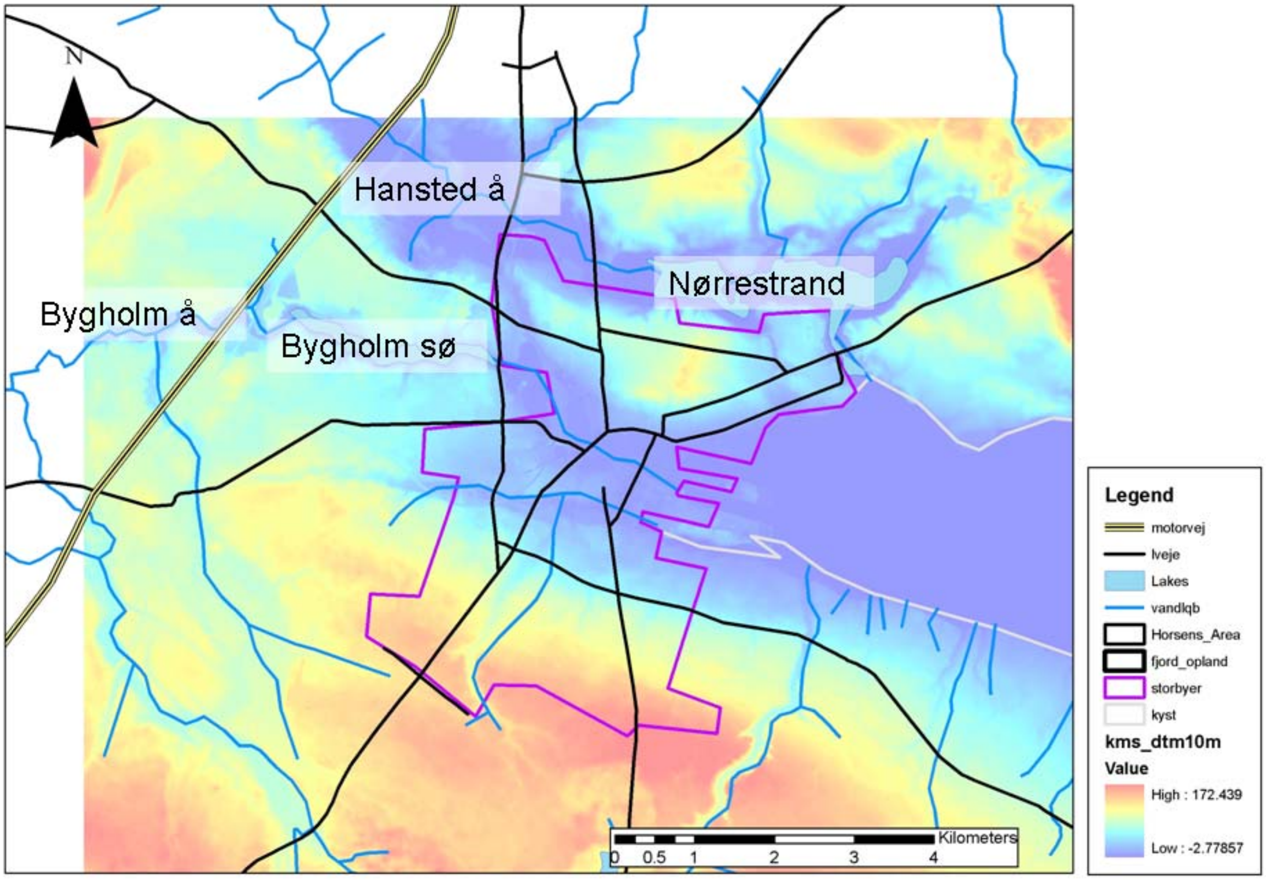


Figure 3 Zoom in on Horsens by area. Hansted å discharge to the fiord through lakes with a sluise at Nørrestrand. Bygholm å discharge through Bygholm sø which is regulated.

2. Estimated climate change effects

Climate change is expected to further increase the problems. Temperature will increase, and more rain water and increased runoff is expected especially in the winter season. Sea level is also expected to increase and combined temperature increase and increased nutrient loads to the fiord and to the lakes is expected to further strengthen the challenges of obtaining a future good ecological status of the fiord, lakes and good quality of the groundwater (See also Appendix 1).

For the A2 scenario the following climate changes may be expected by 2100:

- Increased temperature and temperature variation (+ 3 ^{0} celcius in mean values)
- Increased wind and higher variability in velocities (4 % more wind and 10 % increase in the strength of storms)

- Increased precipitation and higher variation (+ 15 % in average precipitation, 43 % more rain in winter)
- More extreme events
- Increased sea level (between 0.9 and 1.6 m)
- Increased groundwater levels in most areas, decreased level in areas with shallow groundwater
- Increased runoff (max) of 20-30 % from the catchment (See Fig. 4)

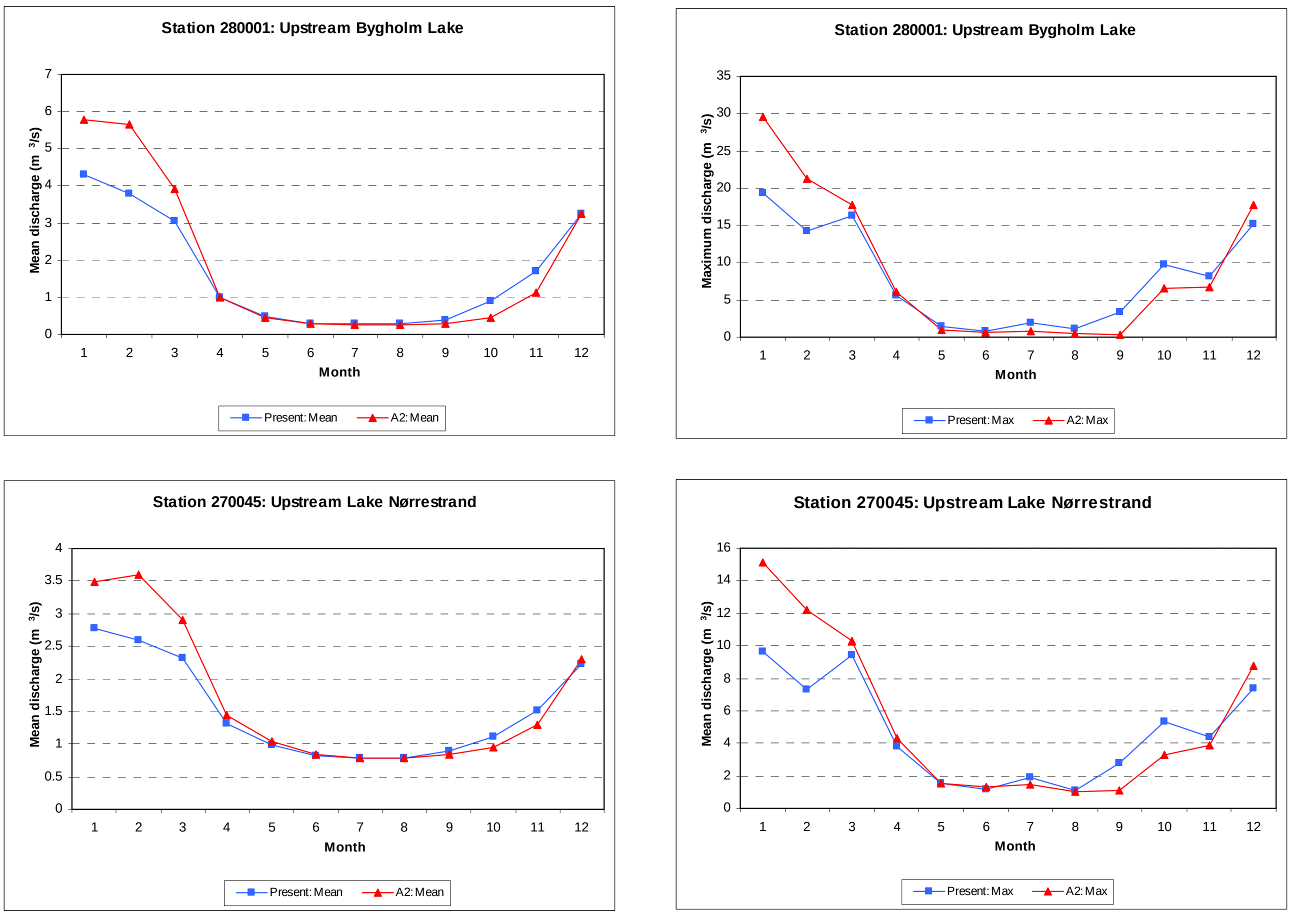


Figure 4 Simulated changes in monthly flow in Bygholm river (upper, left: mean, right: max) and Hansted river (lower, left: mean, right: max)

Indirect effects caused by changes in the "structure of ecological systems" due to increase temperature of 2-3 degrees, nutrient and pesticide leaching, possible leaching of contaminations from point sources etc. Effects on eelgrass and fiord ecosystem is complex and difficult to predict.

Preliminar modelling of dynamics of water level in river Hansted and river Bygholm and how the combined effects of increased runoff from the rivers and fluctuations in water level in the Horsens fiord threaten flooding of low lying areas in the City is illustrated for present climate in Figure 5. It is expected that the future water level of the Horsens fiord will increase by 1 meter by the end of this century.

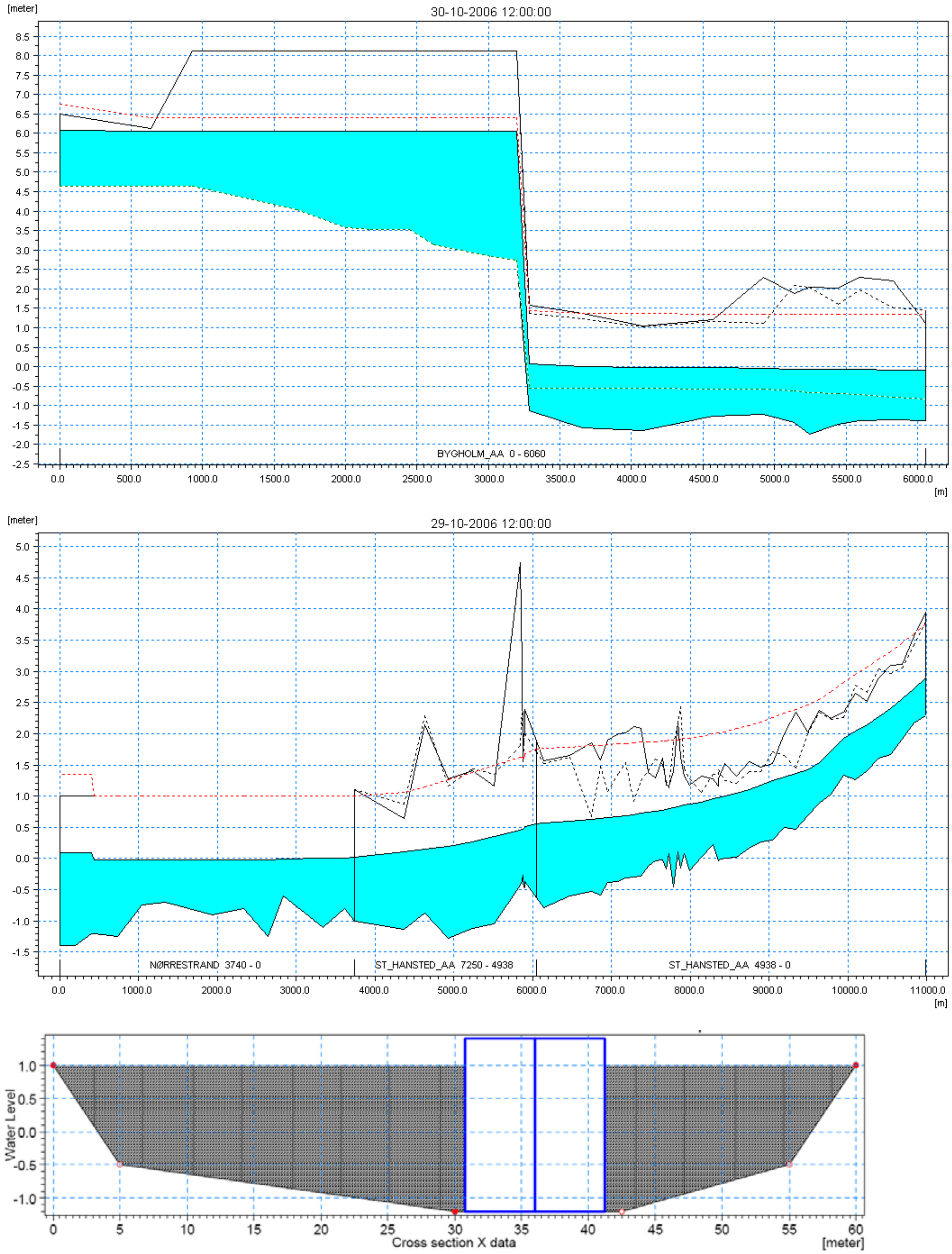


Figure 5 Longitutinal profiles of water level in rivers under average conditions (light blue). Max water level as estimated by the model is shown with red line. The figure also show bottom elevation of river and terrain level at both sides of the river (Upper: Bygholm river, Middle: Hansted river, Lower: Nørre Strand slues)

2. Adaptive challenges

Flooding and droughts

Lets take a closer look on the Horsens fiord catchment (Fig. 6) and the two main rivers: Bygholm å catchment (204 km^2) and Hansted å catchment (km^2) flowing into the eastern part of the city via a dammed lake. Discharge from the lake is controlled by a mechanical water sluice.

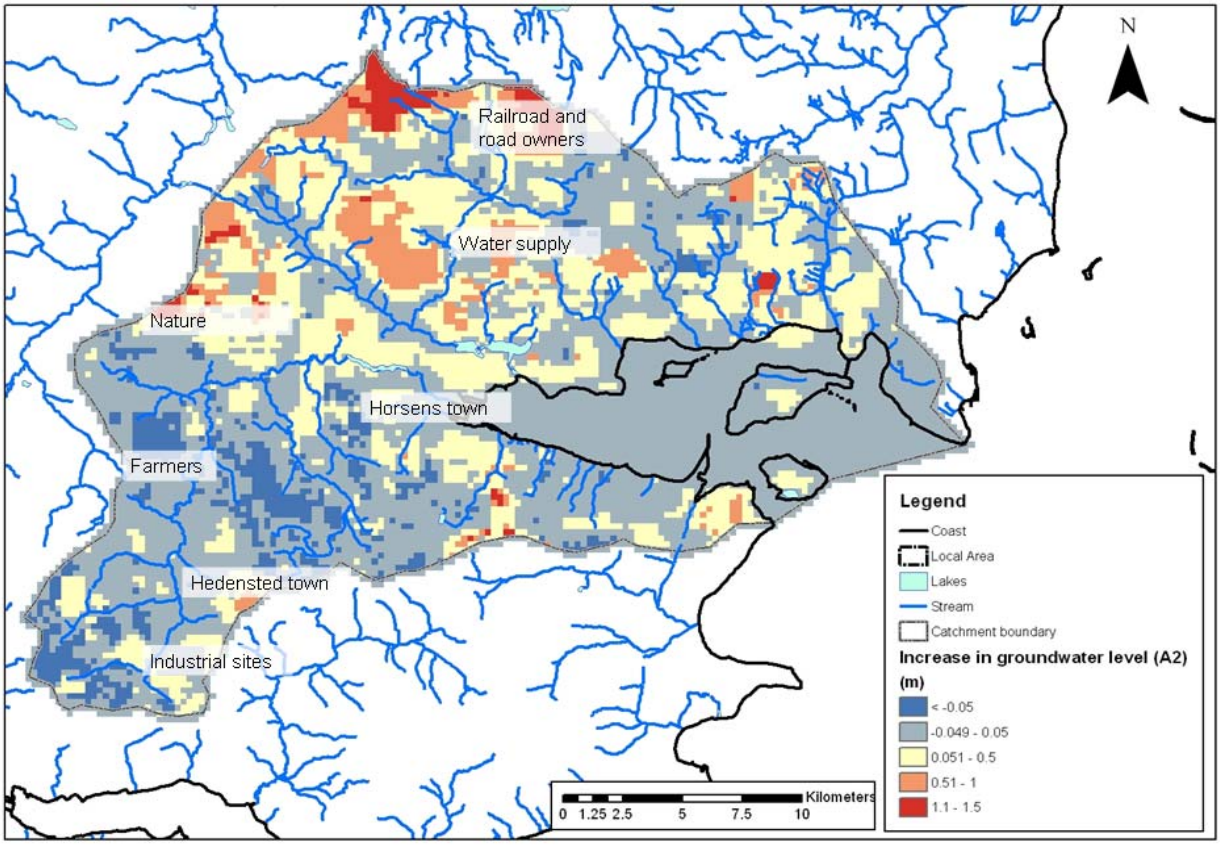


Figure 6 Horsens fiord area. Adaptive challenges due to changes in regional groundwater level

An increase in sea level will cause more frequent flooding in the town due to its low lying position by the fjord. In 2006, the local town hall was flooded when sea level rose to 1.76 m above normal. Simultaneously, increased net precipitation and increased rainfall intensity put pressure on the sewage system and the lake dam. Flooding of the town is expected to occur more frequently. Future flooding storms could be as high as 2,5 meters.

The challenges have been divided into two main themes: sea level change and rainfall.

Rising sea level:

- Flooding and water quality - increased challenges for the sewage system and sewage plant's capacity
- Flooding and challenges for local land owners

Increased rainfall intensity, more water from the hinterland and groundwater

- Increased pressure on the sewage system
- Increased pressure on the local dam

Fig. 7 illustrate some of the issues in the local area around Horsens town.

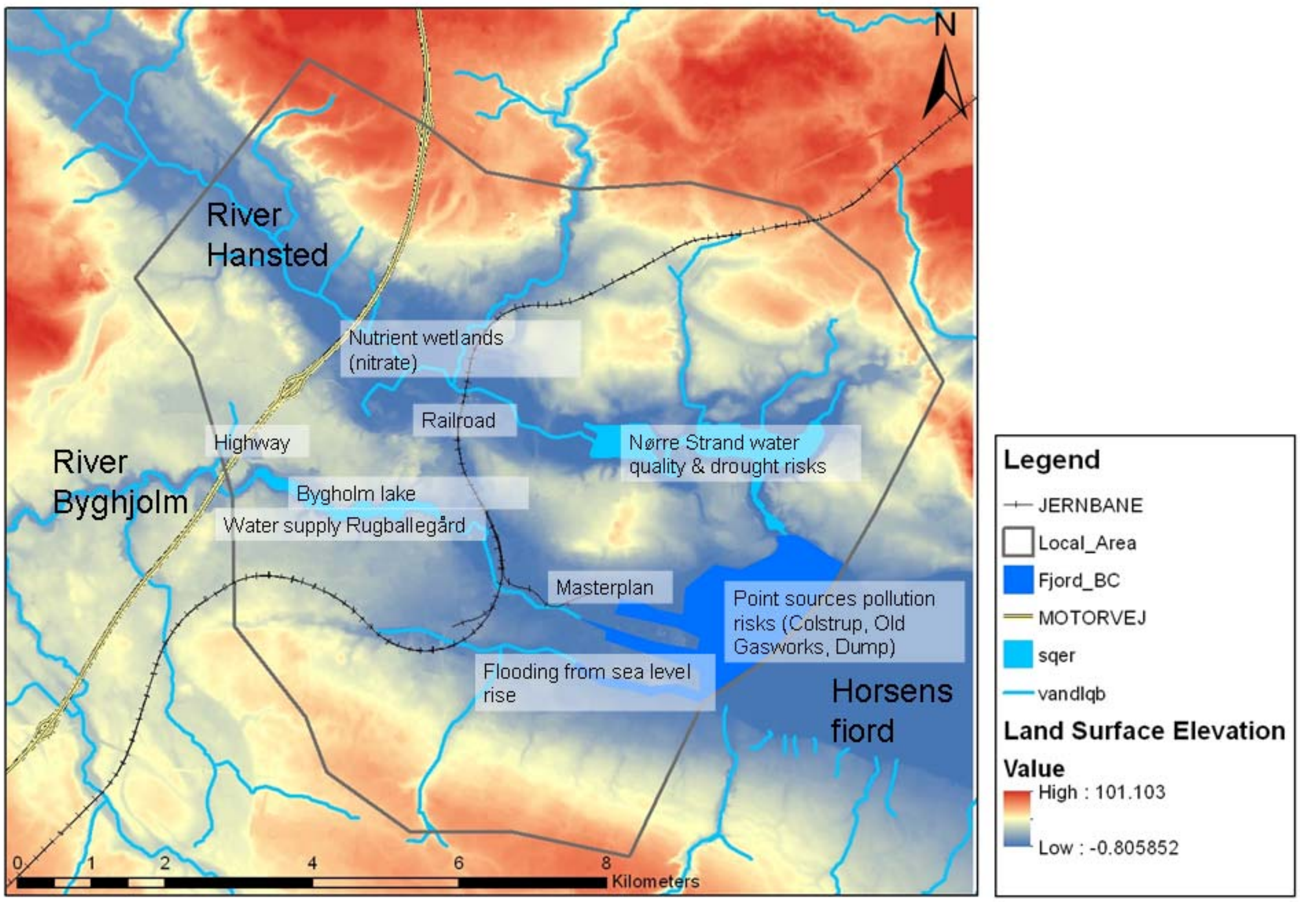


Figure 7 Lokal model area for Horsens town and challenges

In Figure 8 the local area urban area with point sources and evaluation of flooding risks are shown.

Figure 8 Water levels in the town of Horsens by 2,5 meter flooding (~1 m sea level increase). Also shown on this figure is the location of three significant point sources and contaminant sites: old Gas work, Colstrup and Dump. Waster water treatment plant is discharging water to Bygholm å at the outlet in Horsens fjord. At Dagnæs bæk there is a slues.

Summery of challenges in sectors/subareas:

Industrial Area Owners

- Excess water from (heavy) rainfalls from roofs, roads and parking areas. Cooling of buildings.
- Needs derating of water run-off, intelligent use of excess water.

Farmers

- Drought damage (summer), flooded areas (winter), erosion during heavy rain, outwash of nutrients and pesticides.
- Needs alternatives to traditional drainage and irrigation strategies, extra nutrients to grow quality crops, capital to adapt.

Hedensted City

- Located near narrowing of stream giving flooding risk to parts of the city. Vulnerable to rising groundwater table.
- Needs areas to host excess water and recreational areas to the citizens.

Horsens City *(see Fig. 8)*

- Rising sea-level and storm surge is a problem to the city centre, flooding from Bygholm river and rising groundwater level.
- Needs strategy to protect the city, to use excess water as an integrated and interesting part of the city "landscaping". Cleansing strategy for drainage of diffusely polluted groundwater.
- Point source pollutions and changing groundwater level fluctuations/and flow directions that threaten contamination of Horsens fiord
- Urban development planning and climate proofing
- Management of waste water and rain water discharges
- Habour and city master plan with future goals for improved beach access and clean water in the inner fiord near city centre
- Established nutrient wetlands in Hansted å with flooding risks and risk of drought impact on the Nørre Strand estuary

Road and railway owners

- Foundation of road and rail constructions is threatened by rising groundwater and flooding.
- Need knowledge of where to reconstruct and if possible identify where roads can act as dikes or reservoirs in case of flooding.

Nature

- Diversity is threatened due to intensive land use and changes in water quality that threaten water quality and temperature in Nørrestrand and Horsens fjord during extreme climate events

Water supply

- Groundwater ecosystem services tradeoff between water for drinking water supply, industrial supply, irrigation, fish farms and water for aquatic environment during droughts (socio-economic versus environmental)
- Some wellfields are threatened due to drought and flooding events and changing groundwater levels with possible deteriorated water quality due to pollution from surface water

Nutrients and good ecological status of the fiord

The fjord is heavily eutropicated and dominated by phytoplankton blooms, and thus the river basin management plans require reduction of nitrate and phosphorus loads as the measure to reach "good status". There has been a significant reduction of phosphorous (71 %) and nitrate (40 %). Results of a recent analysis showed that concentrations of nutrients have been reduced over the period 1985-2006 as a consequence of reductions in nutrient loadings from the catchment. However, for most of the growing season, concentrations of inorganic nutrient concentrations are still above values limiting for phytoplankton growth. This can explain why the response for chlorophyll concentrations and light

attenuation are weak and in some cases absent. The results indicate that until now the reductions in loadings have mostly removed a surplus of nutrients in the estuary.
Observations of depth limits for occurrence of eelgrass over a period of hundred years showed that macro-vegetation was widespread also at great depth. The models for light attenuation of DMU are unable to predict values low enough to simulate this, even at zero loadings. This indicates that the present state of the estuary is very different from the situation before loadings increased in the 1950s. Most likely the present state, without widespread macro vegetation, will change in a non-linear way when loadings are reduced. However, a considerable time lag must be expected when loadings are reduced, due to the pool of nutrients stored in the sediments and the time lag for re-growth of eelgrass. Based on an overall assessment of parameters it is concluded that the maximal allowable loadings are about 13 tons of phosphorous and 560 tons of nitrogen per year in order to re-establish good ecological status of the estuary. There is a considerable uncertainty in these numbers. DMU estimate that the uncertainty is +- 2 tons for phosphorous and +- 150 tons for nitrogen. However, even applying these reductions, it will probably take about 20 to 30 years before the good ecological status is reached. Hence, it is probably not possible to fulfil the requirements in the water framework directive by 2015. Greater reductions in nutrient loadings or the use of alternative measures will probably speed up the process. The WFD water action plan calls for a reduction of 538 tons of nitrogen (36 % reduction compared to current load), and a reduction of 3 ton phosphorous. The reduction in nitrogen primarily is focused toward the good status of Horsens Fjord and Norsminde Fjord, whereas the reduction of phosphorous primarily is due to the five lakes in the WFD catchment. In order to reach these goals, it is suggested by the state to establish 9 ha of phosphorous riparian wetlands (~ 90 kg Phosphorous reduction). Furthermore, 248 ha wetlands is proposed for N-reduction. It is still not resolved how half of the reduction from the catchment in N will be achieved. Different proposals have been made, but at the moment measures like N-quotas, 10 meter buffer zones along streams, reduction of leaching from vulnerable areas are not operational (Fig. 9).

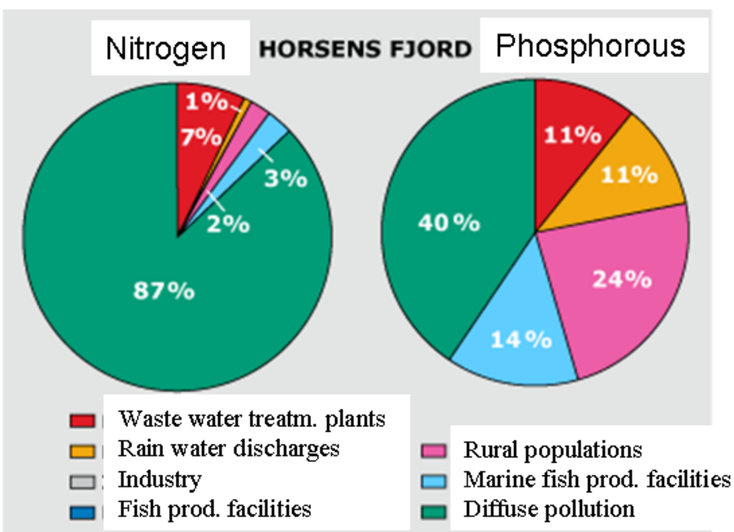


Figure 9 N and P discharges to WFD Horsens Fjord catchment

Appendix 1: Climate in practice – Key outcome from 7 workshops 2009/2010

Introduction

Central Denmark Region has participated in seven workshops and identified climate change challenges faced by society in relation to water and water resources: The project is called "Climate in Practice" The project will inform the municipalities and businesses based in Central Denmark Region about the local impact of climate change on water and water resources. Furthermore, the project will work with relevant professional consultants to put forward the first proposals for practical solutions.

This short paper can be used as a checklist when working with adaptations related to climate-change impact on water and water resources. It is an overall paper that presents key points for each individual theme. The themes are grouped as follows:

- Surface water, sewage and drainage systems, and wastewater treatment plants
- Groundwater, water supplies and groundwater protection
- Open countryside
- Protecting houses, roads, railway lines and other technical installations
- Physical planning
- Cross-organisational theme

Each individual theme was examined in a one-day workshop. Workshop participants included staff from knowledge institutions, engineering consultancies, national, regional and municipal departments. A list of the project participants is given at the end of this paper.

A selected group of engineering consultancies were given the professional responsibility of compiling the generated knowledge in turn. These companies were as follows (in no particular order): Alectia, Rambøll, Grontmij|Carlbro, Niras, Orbicon|Leif Hansen and COWI.

Climate change adaptation is in its infancy but it is an area of growing focus.

Adaptation to climate change scenario:

The individual workshops took their point of departure from the IPCC’s Working Groups' published A2 climate scenario.

Based on key climatic parameters in the A2 scenario, we can expect in 2100:

• Temperature	Higher	Greater variation
• Wind	More	Greater variation

• Precipitation	More	Greater variation
• Extreme events	More	Greater variation
• Sea level	Higher	Still increasing

There are 20 climate models set up worldwide, and there are 11 climate models for Europe. The models are predominantly unequivocal for the period 2010–2050. After 2050, model prediction diverge and thus post-2050 scenarios are subject to a great deal of uncertainty.

Table 1: *Results from the HIRHAM climate model for A2 scenario in the year 2100. This scenario, supplemented with the prediction that sea level will rise by up to a metre in 2100 has formed the basis of this work. * In 2006 a storm surge in Horsens Fjord was measured to 1.96 m. Climate change is predicted to add 1 m over and above this.*

Scenario	***A2***
LAND	
Annual mean temperature	+3.1 ºC
Winter temperature	+3.1 ºC
Summer temperature	+2.8 ºC
Annual precipitation	+9 %
Winter precipitation	+43 %
Summer precipitation	–15 %
Maximum daily precipitation	+21 %
SEA	
Average wind	+4 %
Max. water level at east coast*	1.96m + 1m
LAND AND SEA	
Max. storm strength	+10 %

The changes are predicted to take place long in the future, so it's natural to ask why should we work on the problem now? A short answer to that question is: Prudent planning and adaptation saves a great deal of money. Climate change adaptation costs approx. 20% of the costs of repairing damage in a situation where there has been no adaptation.

The Danish government has identified 11 sectors that are affected

The government has identified 11 sectors affected by climate change adaptation. Some of these sectors will need to adapt before others.

Table 2: The individual sectors and an assessment of their planning schedules

Coasts	10–100 years
Buildings and facilities	10–500 years
Water supplies	5–60 years
Energy supply	5–60 years
Land	1–5 years
Forestry	40–120 years
Fisheries	2–10 years
Countryside and countryside protection	2–10 years
Land use planning	6–30/500 years
Health	1–20 years
Emergency readiness	1–20 years
Insurance-related aspects	0–1 year

Individual themes (5 workshops autumn 2009)

As a starting point, the problems were divided into six geographically distinct themes. The themes themselves significantly overlap, which underlines the need for crossover themes.

Surface water, sewage and drainage systems, and wastewater treatment plants

Fundamentally we can distinguish between different water types: waste water, lightly-polluted water from overgrown areas and drainage from town areas, and pure water overflow from watercourses and groundwater.

Sewage systems are dimensioned to be able to deal with daily events, so the challenge is to keep the other types of water away from the sewage system. Thus the motto: "Keep water locally and use it in new ways in production, urban spaces and in the countryside.

Points for reviewing:

- How do we reduce or lower water flow from heavy downpours to a level that our systems can manage?
- How do we handle floods from the sea or larger watercourses?
- Should sensitive buildings or installations be pulled back from flood-threatened areas (planning) or be made safe (adaptation)?
- How do we create simple wastewater plants to deal with lightly-polluted runoff from roads and drained groundwater?
- How can we work with green solutions in construction (e.g. green roofs and walls) and parks and countryside management (e.g. local lakes or moors for filtration) to strengthen evaporation and cooling and minimise runoff?

Groundwater, water supplies and groundwater protection

The increased precipitation and the changed precipitation patterns, with more rainfall in winter and less in summer, will lead to more groundwater. Fundamentally, this is positive because it means we can take more water from our deep groundwater reservoirs but it can create problems in the form of flooded fields and cellars in areas where extra water is being added to the local groundwater reservoirs. We can fairly confidently see what the future means for groundwater reservoirs but this is not so when we examine local problems that will arise from secondary groundwater reservoirs.

It is unclear that the quality of the formed groundwater will remain the same. Increased leaching from agricultural areas may be a problem, which may only be remedied by adding other kinds of crops, and roots systems will strengthen because of increased CO_2 levels in the atmosphere. Leeching from polluted areas may increase but it is unclear if concentration levels in the filtered water will change.

Points for reviewing:

- Waterworks – survey facilities and bores to find out if they are at risk from flooding
- Assess the possibility of the catchment area of waterworks changing as a consequence of the volume of groundwater
- Identify potential waterlogged areas in the future
- Consider a strategy to manage field irrigation in dry summers and if reservoirs of water collected during the winter can be installed to irrigate fields
- Consider the possibility of strengthening the capacity of the soil to retain water by using a greater quantity of organic material
- Consider the possibility of using targeted afforestation to reduce the formation of groundwater in key areas
- Ascertain if there are polluted sites that are especially exposed to runoff, flooding or increased leaching
- Carry out a study of areas to ascertain where it is possible to filtrate roof water and street water and where it is not

Open countryside

The altered precipitation pattern means that more areas in the open country will be waterlogged for most of the year, the watercourses must be able to handle more powerful downpours and dry summers must be dealt with.

The open countryside is characterised by the fact that there is more space to accommodate large solutions, but the many small solutions that can be found in the countryside (hydro brakes) could provide a high degree of multi-functionality (more attractive countryside, less erosion, reduced nitrogen and pesticides, and function as reservoirs that can be used in the dry summers) and be a valuable part of the solution.

Points for reviewing:

- Analyse catchment watercourses and identify storage points and watercourse constriction areas with the potential for retaining water in extreme situations
- Consider where waterlogged land in catchment areas will be
- Consider catchment areas where wetlands can be established permanently and area for temporary flooding in shorter periods
- Consider which functions can be placed in any new wetlands (e.g. countryside close to the city, new biotopes, nitrogen removal, sedimentation areas, etc.)
- Ascertain if infrastructure, such as road embankments can interact with wetlands
- Plan how and where protected areas for cultivation can exist
- Examine the catchment area widely and find small areas that can be used as hydro brakes and local reservoirs that perhaps have several functions
- Consider how to establish cooperation with landowners regards projects

Protecting houses, roads, railway lines and other technical installations

The most significant effects come from rising sea levels and respective increased storm floods, and from increased precipitation, both from long-term winter precipitation and from more extreme and intensive downpours in summer and autumn.

Though it is not just the effects of water that will increase in the future. Temperature, wind and sun will also be crucial factors. The increase in temperatures, together with the increased sunlight in summer, will lead to greater demand for cooling in buildings and in towns and cities as a whole. The indoor climate of buildings is affected by increased heat and humidity. Changes in the wind with no design consideration given to it has already led to buildings and infrastructure becoming damaged, but there has especially been an increase in storm damage, which in some cases has caused fatalities. The wind will become more intensive in the future and lead to increased demands for protection, reinforcement and sealing of infrastructure and houses.

The essential problem is that many of our towns and transport lanes are placed in locations that were appropriate for water levels, climate, forms of transport, manufacturing and living accommodation in the past. These relationships have now changed so much that we must consider if some of our towns, infrastructure and similar is correctly located and the technologies we are using are sustainable and future-proof.

On the positive side, climate change means greater utilisation of increased solar energy, wind energy, temperature, and increased volumes of rainwater and groundwater.

Points for reviewing:

- Map where there is a risk of damage from rising groundwater, storm floods or watercourses
- Carry out an analysis to ascertain if there are any facilities in risk areas
- Consider if individual buildings/installations should be protected from climate change or if there should be centralised solutions for large areas, e.g. towns and cities

- Consider if the establishment of climate change protection can provide several functions and interplay with other functions in the area
- Compile a catalogue of simple technical solutions that can be continually and successively implemented, e.g. in the case of maintenance
- Establish a demonstration area, where specialists and the general public can see examples of climate solutions

Physical planning

Climate change adaptation planning is not yet an area incorporated into planning in Denmark.

Planning for climate change adaptation requires a high degree of cross-organisation work and total solutions. Everyone contributes and owns the solutions. The optimum is integrating reductions in CO_2 emissions and climate change adaptation in concerted planning. The publication of climate change adaptation planning requires care, so that no single landowner is unnecessarily disadvantaged when pointed out.

Points for reviewing:

- Make if possible a factual theme map that shows flood-threatened areas (from watercourses, lakes and sea) and flood-proof areas
- If possible, make a map showing risks Risk = damage extent x probability
- Using the above-named maps, a vision plan should be prepared at a regional and municipal level In connection with this, consider how interested parties can be involved in a debate about visions
- Prepare a climate change adaptation plan with maps that show:
    - Dry areas
    - Flood-threatened areas with shared protection (dykes, etc.)
    - Flood-threatened areas with individual flood-proof buildings
    - Areas exempted from future construction
    - Areas where water can be stored
    - Areas laid out as future storage basins
    - Areas where local filtration of rainwater can take place

- Consider whether contingency plans should be prepared for specially threatened local areas
- Consider establishing beacon projects with examples of exciting integrated planning

Cross-organisational theme

The specialised seminars have shown that climate change adaptation is not necessarily rocket science. Solutions for many of the described problems already exist today.

What is crucial is the ability to combine individual solutions from different sectors and think about the positive aspects of climate changes. A good combination can actually create new values for society and make the coming work considerably less expensive.

The key concept is good processes between different players involved in climate change adaptation. With an open mind, participants can discover together and search for the win-win situation, where individual sectors use each other in useful ways.

All of the elements should provide multifunction in the future, in such a way that they contribute to good climate change adaptation.

Appendix 2: Case example Horsens town from cross sectoral workshop February 2010

During a three hour brainstorming meeting, a group of technicians representing expert knowledge at many levels and public authority sectors (Horsens municipality, other municipalities, advisory consultants from different companies, The Geological Survey of Denmark and Greenland, Danish Coastal Authority, Danish EA and Central Denmark Region, etc.) worked to find solutions that would meet the challenges.The meeting produced a number of proposals:

Sea level - daily variations and extremes

- Build a new dam at the eastern end of the fjord. At high tides the dam will prevent flooding of the inner fjord. Water from the hinterland could be pumped passed the barrier. At normal water levels the water from the river basin should be led through sluices. The disadvantage of this is that the global sea level rise would require large volumes of water being pumped from the inner fjord to the sea
- Use the water! The increased amount of water can be utilised commercially. This will call for the conversion of some areas. However, there is a considerable time in advance of the climate change to take place and this allows a long planning period. This calls for a long-term vision of urban development. A proposal was to build on floating structures.
- Attitudes about building in the port area and low parts of the town have to be challenged. Today new constructions are built with a plinth height of 2.20 m when plinth height should be around 3 m to prevent flooding in the next 100 years
- Building a dynamic sea barrier which can quickly be set up by if the sea is rising. The wharf area should have closed roads and pedestal heights. The areas in between can contain regulated terrain. All together this would create a barrier against rising sea water
- Sewage systems are separated into waste water and rain water

Increased knowledge

There is a need for building up a dynamic groundwater/surface water model which will inform planners about the critical levels for sea level rise. Furthermore, the model could be used for the development and analysis of critical duration of sea level and precipitation. In addition, there is a need for an economic analysis of the different solutions.

The local creek and precipitation

- Seeping and retain water in the river basin - likely to be local solutions upstream. The more the better to prevent a massive volume of water from quickly entering the city. Examples like less draining in the agricultural fields, roofs made with acidophilous on top.
- To alleviate the water from the hinterland entering the city, lay a pipe from Bygholm Lake to the fjord outside the city

Planning

- Instead of traditional planning in the prevailing planning period of every 2–8 years, take an alternative approach. Turn it on its head and start looking at how we want Horsens town to deal with water in 2100. This perspective might bring a broader vision and lead to pioneering solutions
- There is a need to think about how we build today

Horsens city is in a complex situation like many other Danish towns facing Kattegat.
The case shows how important it is to bring together knowledge and perspective to come up with alternative and more sustainable solutions.

What is interesting about the Horsens case, is not just the exact ideas, but the synergy of bringing together different sectors and expertise, and taking a long term holistic approach. Some of the challenges the town faces, can be met by agriculture many kilometres away. Other challenges can be met via local solutions, e.g. roof materials and the local diversion of water.