# Adaptive management to climate change in Horsens Fjord using scenario development

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## Introduction

Horsens Fjord is an eutrophic estuary situated in east coast of Jutland, Denmark with approximately 46 km2 surface area. The Fjord is a part of bigger WFD catchments area with dominated agriculture area and small forest, wetlands, lakes, and urban areas. Present day condition shows that the fjord is facing various problem regarding groundwater, surface water system, and marine coastal ecosystem.

Climate change is most likely to increase the pressure to the fjord environment. Increasing temperature, sea level, wind, precipitation/evaporation, and more extreme event will generate:

- Change in the ecosystems
- Urban flooding from rain fall and storm surge
- Groundwater pollution by salt, nutrients, pesticides, and contaminants from landfills
- Changing groundwater table which likely due to more abstraction
- Droughts due to rising temperature

An adaptive management is needed to be applied to address those climate change effects. In this study, we developed scenarios for 50 years time frame to support a 20 years adaptive planning process in response to climate change effects in the Horsens fjord area and deals with its uncertainties. The adaptive planning would include all above listed aspects, but in this study this is exemplified for water quality both from upstream and downstream direction. In this regard, we positioned ourselves as a policy agency who responsible to develop this adaptive planning.

A backcasting method is chosen to build the scenarios. By choosing desired end-point in water quality management, various milestones and measures with its associated uncertainty are determined for the adaptive water management. Using this backcasting method, we ensure that the milestones and uncertainties can be iteratively evaluated.

## Method

### Planning process

With the case of Horsens Fjord as the starting point, the relevant themes of a 2009 stakeholder workshop are examined. In order to deal with the long term (20 years) planning process – in the role of a policy agency – a backcasting approach is used to develop scenarios (50 years).

The project is using scenarios to understand and structure the uncertainties related to the long term planning process. Furthermore the development of scenarios should support the involvement of stakeholders, which is crucial to adaptive management of climate change. Stakeholders should be involved very early in the process of planning and they should define relevant scenarios. The participatory process is supposed to strengthen the identification of problems and the choice of robust measures in an adaptive management strategy.

The first step in the planning process would be to deal with the knowledge gaps and the uncertainties, changes in research, planning and management processes is believed to be necessary. Among the most important changes are:

- More applied research in cooperation with planners and managers aiming to support implementation
- Closer relationship between researchers and planers to help to carry out the planning process
- Try to use state of the art methods
- Listen to stakeholders in terms of their needs and how to focus research
- Integrated, interdisciplinary research
- Use of scenarios in the knowledge development process (participatory methods, group modelling, causal loop diagrams)

## Scenario development

The scenario development is started by identifying a list of the major knowledge gaps and uncertainties in the Horsens Fjord catchment. These include:

- Hydrological variables (precipitation, temperature, evaporation, sea level rise, erosion of coast line, salt intrusion to freshwater aquifers), wind, extreme events, climate effects on existing systems
- Climate change effects on production systems (land use: agriculture, forestry, and biomass for energy, irrigation; energy production?, fishery, recreation & tourism, water supply)
- Knowledge about natural variability of hydrological variables
- Knowledge gaps: using knowledge about uncertainties in implementation (use of model ensembles), awareness of uncertainty and limitations of the hydrological model
- Use data available from the different sectors

In order to develop relevant scenarios the main specific uncertainties of climate change effects in the case study area are identified. This is used to define the frames of the backcast. Main uncertainties of climate change within the Horsens Fjord catchment are:

- Groundwater availability
- Sufficiency of dam and sluice gate
- Impacts on ecosystems and production systems?
- Impacts on infrastructure (houses, harbour, beach, sewage system, landfills, roads)
- Effects on land use (abandoned farms)

The uncertainties related to data, models, and different understanding/perceiving of the problem etc. should be investigated further by researchers, advisors (from our perspective as policy agency).

After choosing a relevant goal for a long term planning perspective, milestones are identified working backwards from the desired future end-point. This is done to determine the feasibility of achieving the goal and the relevant policy measures that would be required in the planning process.

For the actual development of backcasts different climate change scenarios and different socio-economic scenarios are used as frames for the study. This allows for stakeholders to evaluate different approaches and measures in achieving the long term planning objective.

## Results

For the study area the goals of good water quality, minimized damage from flooding, sustainable agriculture and health of ecosystems were defined. However, water quality was selected as focus of the study and the scenario development process evolved around this goal.

A combination of climate conditions and socio-economic conditions envisioned in 2050 were used to frame the scenarios developed for Horsens Fjord in a wider context. The climate conditions (Table 1) address the uncertainties related to future climate effects. Climate 1 illustrate a future with rather strong climate effects, including a strong increase of sea level rise, change in precipitation patterns, increased frequency of storms and higher temperatures. Climate 2 consists of a moderate change in all climate variables, while Climate 3 includes the possibility of climate cooling in the case study area due to reached tipping points.

**Table 1: Climate conditions envisioned in 2050, quantified using the notion +/- for slight increase/decrease, ++/-- for moderate increase/decrease and +++/--- for strong increase/decrease.**

| | Sea level | Precipitation | Wind | Temperature | Extreme events | |
|---|---|---|---|---|---|---|
| | | | | | Droughts | Storms |
| Climate 1 | +++ | ++/-- | + | ++ | + | +++ |
| Climate 2 | ++ | + | + | + | | + |
| Climate 3 | - | +/- | +++ | - | ++ | ++ |

The socio economic conditions in 2050 describe three different worlds, which are represented by the pictures in Figure 1.


**Figure 1: Qualitative description of the three different socio economic set of conditions (Society 1 to 3).**

In the first case the society is conservative and prefers traditional solutions to problems. People are not willing to accept policies that might change their lifestyle significantly. By contrast the second set of socio economic conditions describes a society which is very flexible, meaning that both society and different sectors are willing to explore new ways to adapt to changing climate conditions. This includes changes in production modes and infrastructure. In the third set of socio economic conditions the society is willing to change their lifestyle, which allows the implementation of adaptive measurements which can be considered as out of the box solutions, e.g. abandoning agriculture completely. In general in all three socio economic condition sets it is assumed that the high development of the Horsens municipality and a general awareness that climate change adaptation is important makes money available to implement the adaptive planning. Noticeably, these societies have different values and norms (Figure 2) which influences their risk perception and willingness for behavioural change.

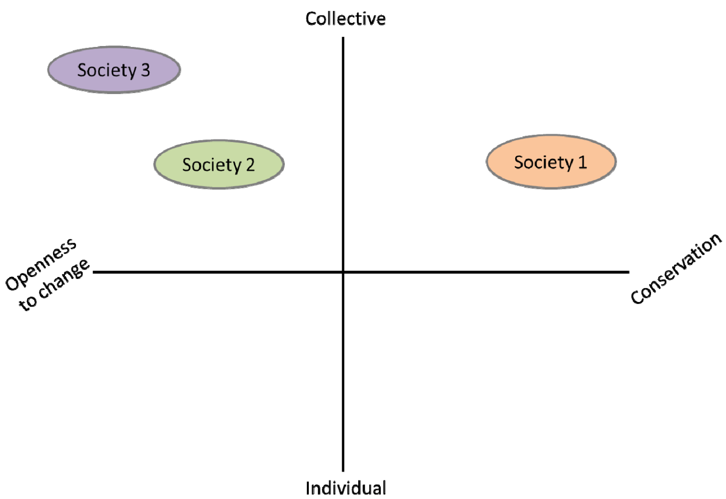


**Figure 2: Risk perception and behavior (Society 1 orange, Society 2 green, Society 3 purple).**

The combinations of climate conditions and socio economic conditions are frames which are used for back casting, i.e. the goal of good water quality is achieved by measures which are consistent with the frame. This study is limited to three frames, consisting of the combinations listed in Table 2. The scenario consists of a set of measures and milestones which are specific for the frame (Figure 3).

**Table 2: Frames used for back casting.**

| | Socio economic 1 | Socio economic 2 | Socio economic 3 |
|---|---|---|---|
| Climate 1 | Frame 1 | Frame 2 | Frame 3 |

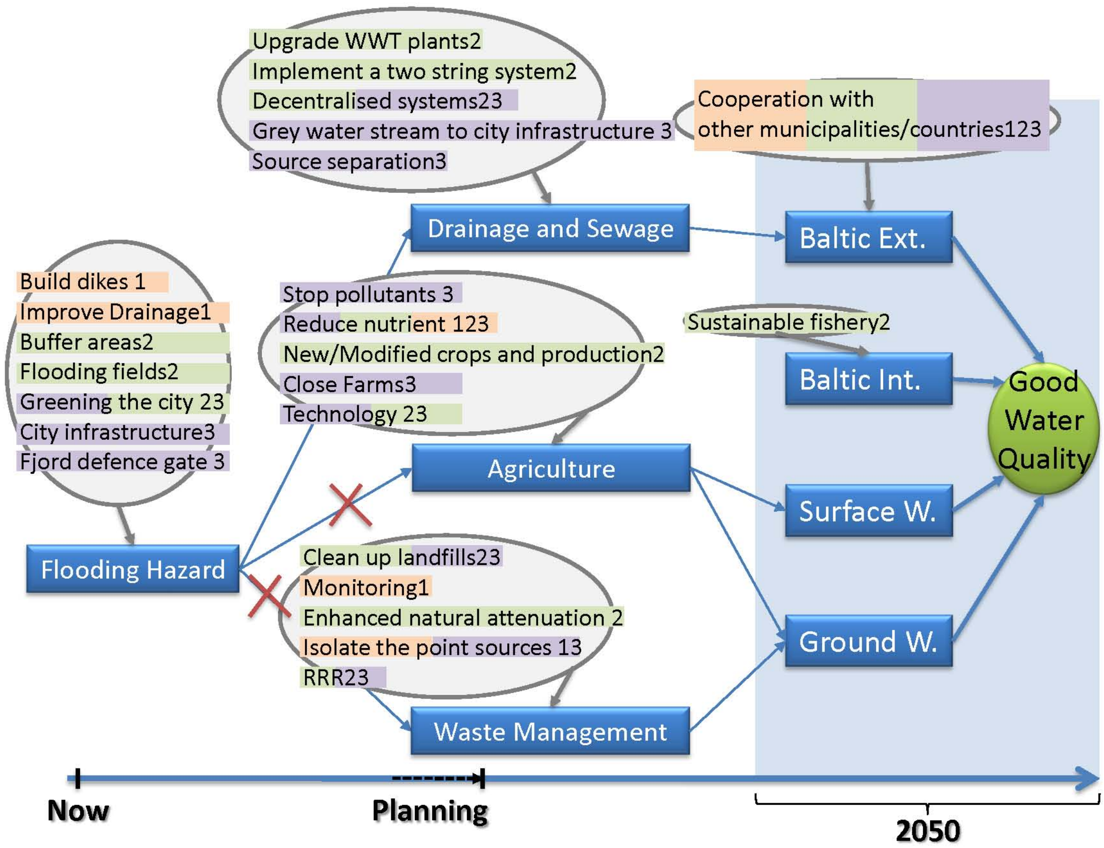


**Figure 3: Different measures taken to achieve milestones, depending on scenarios (Scenario 1 orange, Scenario 2 green, Scenario 3 purple).**

The process of backcasting resulted in identified milestones, which are achieved by implementing adaptive measures according to the frame. In an iterative process measures for different goals could be identified, allowing a comparison of measures and identifying robust measures. Comparing the scenarios presented here results in that the measure of e.g. reducing nutrients is robust and thus should be prioritised to be implemented. This work should be supplemented with an uncertainty matrix for all goals.

Further the comparison of different scenarios allows the identification of tradeoffs and synergies. The exact technology or method to implement the measures would be developed with the stakeholders. However, it should be kept in mind that flexibility of the measures is important in order to make the scenarios more robust.

## Conclusion

By following the outlined planning process we can ensure a constant communication and interaction among stakeholders and the planning agency. The flexibility of this process allows dealing with uncertainties of changing climate and socio economic conditions. The participatory approach supports the robustness of the decisions and links the policy and learning cycle. This creates the opportunity to achieve not only single, but double, and maybe even triple loop learning, which is key to adaptive management.