Interreg
North Sea Region
FAIR
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EUROPEAN UNION

Pilot Ribe Polder

A Practice Brief from the Interreg North Sea Region FAIR project

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Preface

The FAIR project

FAIR brings together flood protection asset owners, operating authorities and researchers from across the North Sea Region (NSR) to share the policy, practice and emerging science of asset management. Despite the diverse character of the NSR, asset managers face common challenges across the region.

The FAIR project aims to develop and implement improved approaches for asset management of flood protection infrastructure. It will optimise investment planning by exploring mainstreaming of these investments with other policy domains, and by mapping planned investments across a wide portfolio of flood protection assets. FAIR will also identify cost-optimal adaptive infrastructure upgrades by exploring a variety of technical designs, with adaptability and life cycle costing for various performance levels.

This Practice Brief

FAIR supports the delivery of local upgrade or maintenance projects and schemes for flood protection assets or systems. This Practice Brief presents **why** the project or scheme has been proposed. It provides an overview of the key challenges and intended outcomes. It elaborates on **how** these challenges have been addressed, and presents **what** has been the outcome from implementing this approach. Finally, the Practice Brief reflects on the innovation of the pilot with respect to the best practices in the FAIR end report and the FAIR recommendations.

The FAIR results

The demonstration and subsequent widespread implementation of the improved approaches and techniques will reduce the probability of flooding and minimise the impact of floods across the North Sea Region. This will improve the climate resilience at target sites covering most of the NSR. 'Target sites' are those areas being protected by entire flood protection systems (e.g. Danish coast, Swedish Coast, Flemish Coast, Dutch Delta) and individual assets (e.g. Hollandse IJssel storm barrier, Hamburg flood gates, etc).

The result indicators for the FAIR project are:

1. Reduce the life cycle costs of flood protection infrastructure through better targeting of investment;

2. Encourage the multi functionality of flood protection infrastructure through mainstreaming (that is, connecting) investments with other policy objectives;

3. Increase the life span of flood protection infrastructure through smarter maintenance and renovation.

Summary

The town of Ribe is located in an area with multiple sources of flooding. To the west, a dike protects the town and its surroundings from flooding from the Wadden Sea. For now, this dike still has the capacity to fulfil its function, but climate change will put pressure on the dike through sea level rise and increased storminess. Flowing through the pilot area, two streams, the Rivers Ribe and King cross the dike through sluices. In the winter season, large amounts of water are present in the polder. The winter season also brings the highest discharge in the streams, which cannot flow into the sea, as the sluices are frequently closed for long periods of time due to high water levels in the sea. Pressures on the system will increase in the future, making the current state of affairs unsustainable.

Through FAIR, The Danish Coastal Authority and Esbjerg Municipality have gained understanding of the system surrounding Ribe. The experience from this pilot site is used in order to demonstrate the solutions of the FAIR project, and this experience is transferable internationally.

The Context

The city of Ribe as well as the area around Ribe faces special challenges according to future climate change. Historically the city of Ribe and the Ribe polder has suffered from many and severe storm surges. In 1912 a dike to protect the polder in which Ribe is located was established. Where the Rivers Ribe and King run to the North Sea, sluices were built. These assets have prevented the city of Ribe from being flooded but they will need renovation/improvements because of expectation of raised sea levels and more frequent and heavier storms in the Wadden Sea Region.

Due to climate change the sluice is expected to be closed both more frequently and for longer periods when compared to the present situation. This will increase the problems created by backwater from the Rivers Ribe and King, because the water will be stowed behind the sluices. The problems are already present in the towns of Gredstedbro and Vilslev, situated along the River King, where primarily agricultural land, but also a small number of residential houses have been suffering from flooding during the winter period.

Accordingly, it is expected that it will be necessary to invest in more adaptive solutions against flooding in the future. These solutions need to be cost effective under the uncertain impact of climate change and likely high levels of investment. It will probably be cost effective to implement some solutions continuously during urban development and during civil engineering works, while other solutions are expected to have their own planning and implementation cycles.

It is also characteristic to the pilot that in Ribe the water level upstream of the city is intentionally varied through the year, by the operation of three locks. The total catchment area is 925 km² and up to 55.000 litres/sec is distributed between the three locks and one stream (the Stampemølle stream). The locks are of tourist interest but their function as water level regulators is also important for the moistening of the subsurface layers of partly organic material/culture sponge of Ribe. If the cultural sponge is drying out, the old buildings are in risk of setting and will affect the cultural heritage of Ribe in a negative manner.

The 3 locks in the city of Ribe are owned and managed by Esbjerg Municipality as is the Kammer Sluice.

The dikes along the Wadden Sea and the sluice at the River King are owned and managed by local dike associations, but with significant economic help from the municipality and some limited technical guidance from Danish Coast Authority. Danish regulation demands municipalities to designate areas at risk of flooding and to include remediation in municipal planning. Also landowners are responsible for protecting their own land. Therefore the flood protection of Ribe Polder will have to balance rather complex circumstances and interests.

Why: The purpose

The key challenges

From ad-hoc management to strategic approach via tactical handshake. When renovating dikes and sluices or implementing other interventions in the polder it is of vital importance to integrate climate change predictions in the protection standards. Lack of standards regarding design levels, which include climate change, has been one of the challenges for Ribe polder.

To set these standards, a system analysis of the whole Ribe Polder is needed.

Another key challenge is the opportunity to analyse performance of existing assets with the right preconditions. An up to date flooding map is needed, considering the joint probability aspect of storm surges and long-lasting rainfall on a wet polder in wintertime, under different scenarios.

It is a yearly wintertime experience, that the polder will be wet with visible standing water on both sides of the ring road around Ribe. The water source can be ground water as well as runoff from the rivers.
This means, that it is necessary to set a basic water level before calculating the effect of rain events.

This has already been done in Esbjerg Municipality´s own previous flood mapping, but this simply adds rain events to a terrain model and does not include detailed modelling of river systems.

Ill: Ribe polder viewed from the Wadden Sea in a winter-situation, 2014.

Analysing performance of existing assets also includes asset strength calculations; in the case of Ribe polder it means calculation of dike strength as well as assessing the performance of the sluices.

As explained, the responsibility and expertise of flood protection is divided among different organisations. It is therefore beneficial for Esbjerg Municipality to strengthen both internal and external cooperation. Internal cooperation amongst the department responsible for managing the assets, the department responsible for the rivers and the department for climate adaption planning. External cooperation amongst the local dike associations, citizens, landowners, climate adaptation planning and Danish Coast Authority as well as the municipality in order to transfer knowledge and improve acceptance of possible new solutions as alternatives to existing pathways. Articulating this discussion between stakeholders with legitimate different interests is a key challenge.

Assets for flood protection usually require large investments, often made without certainty therefore, it is beneficial to use a decision-making tool/model to strengthen the basis for decision making. In FAIR it has been assumed relevant to use the so-called DAPP (Dynamic Adaptation Policy Pathways) for this purpose.

Explained in short, the model operates with certain adaptation pathways combined with different climate scenarios. See further explanation below.

The intended effects

The ultimate objective for Esbjerg Municipality and the Danish Coastal Authority in this project is to provide the citizens of Ribe with a safe, liveable and sustainable town. To support this objective, increased understanding of the system must be achieved, and knowledge gaps identified.

Considering limited availability of funds and the complexity of the task, asset management must become more effective. In practice, this means mainstreaming flood risk planning with other planning activities on a strategic level, setting requirements based on data on the asset-level, and linking these processes among other things.

On a practical level, FAIR aims to provide a good understanding of the following issues in order to reduce the future risk of flooding:

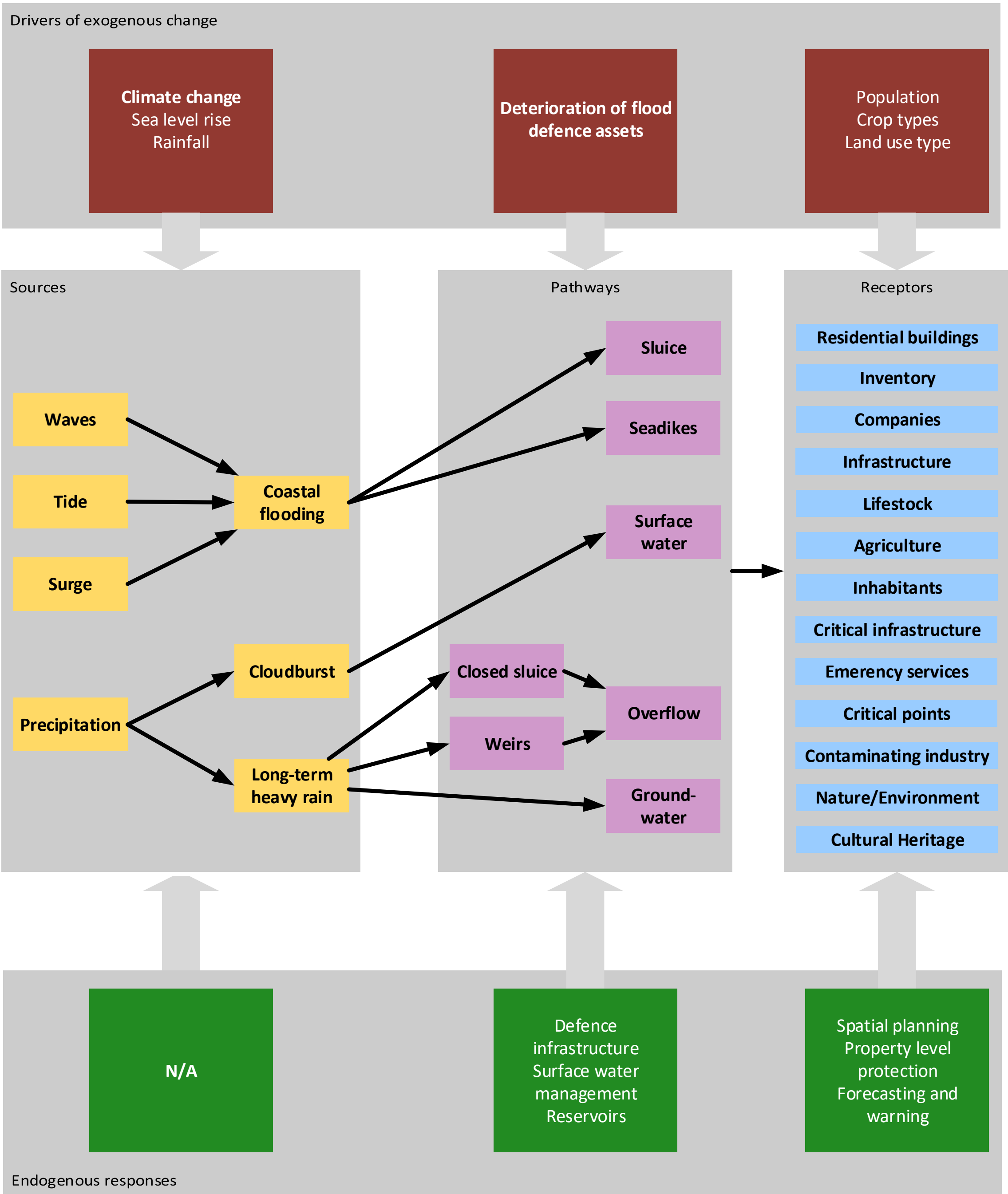
- Existing assets and their co-dependencies in a system context.
- The sources of flooding.
- Flooding mechanisms.
- How requirements can be set (Denmark does not have a national standard).
- Risk and acceptable risk.

Working with these issues will help the local authority, landowners and stakeholders to improve the strategic approach in climate adaptation planning and asset management.

How: The approach

The SPR analysis

The first step of the approach is making a low-level systems analysis, also called a "system description" using the SPR framework. The city of Ribe, where most of the flood receptors are located, lies in a flood plain of approximately 95 km^2. A flat sea dike and a sluice at the Wadden Sea are the main assets in the area. The dike is grass covered, with a sand core, a crown height of 6.88 m and 1:10 seaward slope. The main sources of flooding considered in the analysis are the sea and the watercourses. The largest watercourse in the area is the River Ribe , which flows through Ribe city and the polder. A sluice is located at the intersection between the sea dike and Ribe. The River King is the second largest watercourse in the area. It crosses the northern part of the polder and flows into the Wadden Sea through an outlet on the sea dike.



A preliminary analysis of flood sources has highlighted the need for better understanding of the causes of floods and the impact of climate change. Consequently, the main sources of flooding are analysed in detail in a series of technical reports that look at the joint probability of high sea levels and high discharge in the streams. This is especially important because of the mechanism of flooding of the Ribe polder.

The floodgates on the River Ribe close automatically when the seawards water level exceeds the inland water level (this situation can sometimes last for several days). If the discharge is high enough, the stream overflows causing flooding. The amount of long-term rain is critical as it can saturate the polder and increase the discharge into the stream, leading to an increased likelihood of flooding, especially when the floodgates close because of high water levels in the sea.

Sea Water Level

The statistical return values for Ribe (Højvandsstatistikkerne 2017, Kystdirektoratet), at present and the future climate affected return values are presented below in Table 1.

The calculations of the future water level return values are based on:

a) DMI's expected water level rise for the IPCC scenario RCP 8.5 (Notat om havvandstand – Middelvandstand I Danmark, Juni 2015) and

b) The isostatic lift rate of Ribe area. The isostatic lift is subtracted from the expected water level rise resulting in a 32 cm water level rise for scenarios in the year 2065 and 80 cm for the year 2115.

Table 1

Univariate Statistical Data - Projected data

Water Source	MT50 2017	MT100 2017	MT50 2065	MT100 2065	MT50 2115	MT100 2115
Ribe Sea (m)	4.70	4.88	5.02	5.20	5.50	5.68
Ribe river (l/s)	42691	44825	47600	49735	52104	54239
King river (l/s)	24958	26333	27828	29203	30488	31862

Precipitation and discharge

Changes in the weather will influence the current amount of yearly precipitation. DMI have estimated a local increase in precipitation (up until year 2100) based on IPCC's global future precipitation models (scenario RCP2.6 and RCP8.5) (Fremtidige klimaforandringer I Danmark, Danmarks Klimacenter rapport nr. 6, 2014) and KDI have extended the curve for scenario RCP8.5 to reach year 2115 (see figure 1 below). KDI calculates and increase of 11.5% in year 2065 and 21% in year 2115 for winter scenarios.

For the modelled climate scenarios the increase in precipitation (+11.5% in 2065 and +21% in 2115) is used as a direct response in discharge. This means that an increase of 11.5% in precipitation equals an increase of 11.5% in discharge (for a winter scenario). This method produces a best estimate, and not a highly accurate description of the local situation. Table 1 shows the return values of the two streams in year 2065 and 2115. In both cases, an increase of 11.5% and 21%, for the respective return periods, is used.

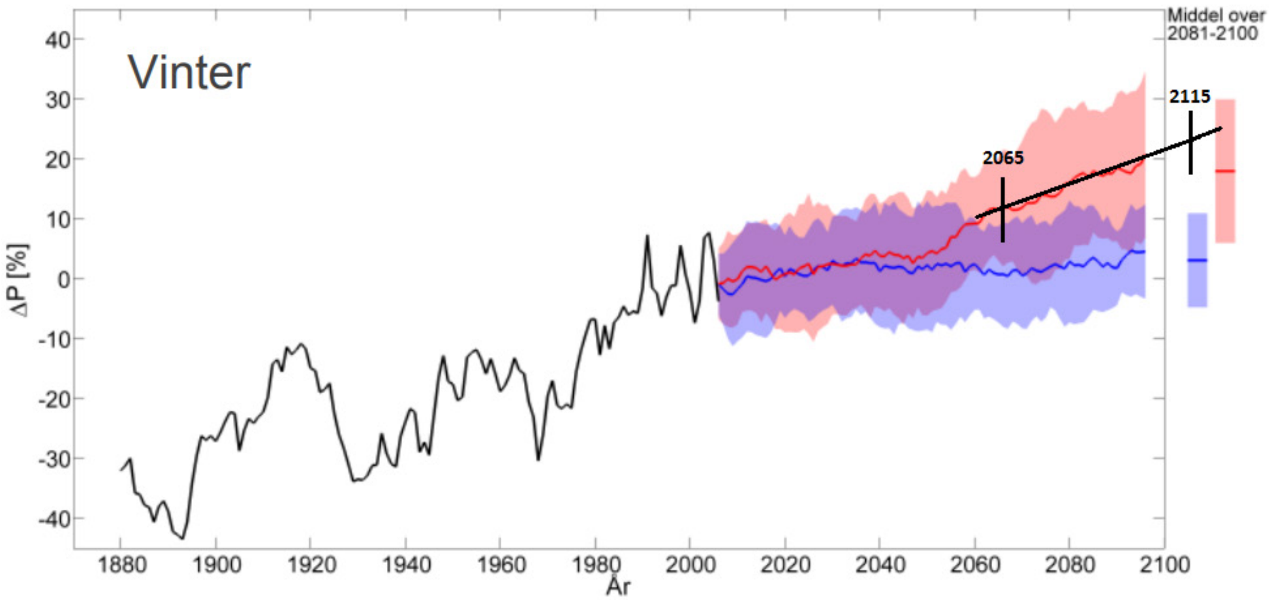


Figure 1

The statistical return values for the discharge can be seen in table 1. The original statistics are then projected to fit the model boundary. Data is projected upstream for both Ribe river and King river. The future scenarios are produced by adding 11.5% and 21% to the MT50 and MT100 scenarios (for the year 2065 and year 2115) see above.

The event length (in days) of the Rivers Ribe and King is 5 days for MT50 and 7 days for MT100. The lengths are estimates based on a comparison analysis between several catchments (around Denmark) and the lasting time of the respective events.

A quick analysis of the uncertainties related to flood sources highlight that any technical solution for the system has to be adaptable. The main sources for uncertainty are data quality, sea level change, and river discharge scenarios and data series length.

Pathways

A preliminary analysis is made based on earlier work and using a static flooding model. Given present conditions, the main dike is predicted to withstand a 400-year event from the Wadden Sea. It is also expected to be able to withstand a 100-year sea level in 2065 but not in 2115. Flooding from the stream occurs in the event of a discharge greater than a 20-year level in 2019. The main failure modes for the dike are, overflow, overtopping and breaching.

For the sluice, two failure modes are considered. Open and shut. In addition to this it is important to note that the height of the gates is 1 metre lower than the djacent dike.

In Denmark, the construction and maintenance of flood defence infrastructure is decentralised. The dike is maintained by a local board, which collects a dike tax from the protected properties in the polder. Following the biannual inspections performed by the dike board and the Danish Coastal Authority, condition grade reports and recommendations are compiled.

Historically, the state, the regional administration and the local authority have jointly financed large reinforcement works, with the local authority being responsible for regular maintenance. Future work on the dike and sluice is not expected to follow the same financing model, as no party is legally required to do so. All major reinforcement and maintenance works are currently performed impromptu, typically in the aftermath of flood events or significant degradation. The main weakness of the model is the diffusion of responsibility and lack of provisions for long-term planning of reinforcement and maintenance. Future projects should include a life-cycle study that includes building, inspections, maintenance, reinforcements and, if relevant, removal/demolition.

To further the understanding of the system, the Danish Coastal Authority is performing a performance analysis for the most important assets.

Flood modelling

The extent of the flood given different scenarios is calculated using a dynamic numerical model using an unstructured mesh. The model takes into consideration the terrain surface and type, but does not account for infiltration, precipitation or evaporation.

A precise model has been created for the two watercourses: the Rivers Ribe and King. The model includes structures such as bridges, culverts, weirs and sluices and accounts for longitudinal difference in rugosity along the streams.

Two flood scenarios have so far been modelled in detail:

1. 50-year seawater level for the Wadden Sea, 50-year level discharge for the two streams.
2. 50-year seawater level for the Wadden Sea, 50-year level discharge for the two streams in the year 2065, considering expected changes in sea level and river discharge.

The municipality manages the rugosity of the river by biannual interventions. The positive effects of this are also apparent in the model. Seasonal differences in rugosity or difference along the same watercourse have a great influence on flood extent. Careful management of the rugosity of the riverbed can lead to better control of flood extent. This can be studied further by using the river part of the model.

The models produced by the Danish Coastal Authority appear to underestimate the extent of flooding for the given scenarios. The main reason for this is the lack of a groundwater model and the relatively short modelling period. Suggestions for improvement of the model are provided.

The model can accommodate changes in order to explore different technical solutions for the system. For example, different operating rules for the Frislusen weir can be simulated using the river model. Further refinement of the model is possible, as will be described later.

Vulnerability analysis

For the mapping of the receptors, the following indicators are considered:

- Residential buildings
- Inventory
- Companies
- Infrastructure
- Livestock
- Agriculture
- Inhabitants
- Critical infrastructure
- Emergency services
- Critical points
- Contaminating industry
- Nature/the environment
- Cultural heritage

Each type is then assessed using five vulnerability categories: 1/Very Low, 2/Low, 3/Medium, 4/High, 5/Very High.

Vulnerability mapping

The figure below shows where the receptors are located within the risk area. The area around the town of Ribe is shown in the second image.

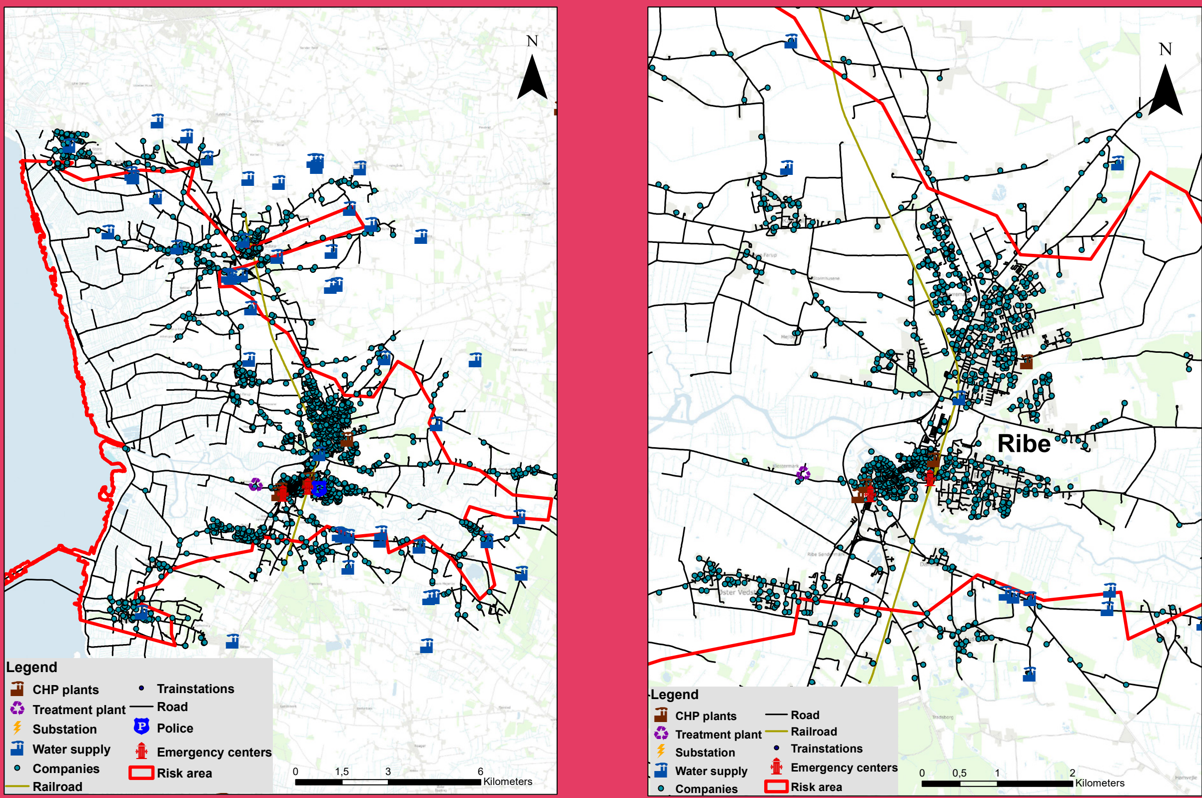


Figure 2

In the event of flooding it is important to know which areas are likely to be affected and the extent of damage the flooding may cause. Therefore, several vulnerability analysis models are produced to map the areas which could be affected by the different flooding scenarios. The vulnerability models are divided into tangible and intangible models. The vulnerability and risk models are listed in table 1. For more information on the models, see Kystdirektoratet, 2013.

Table 2

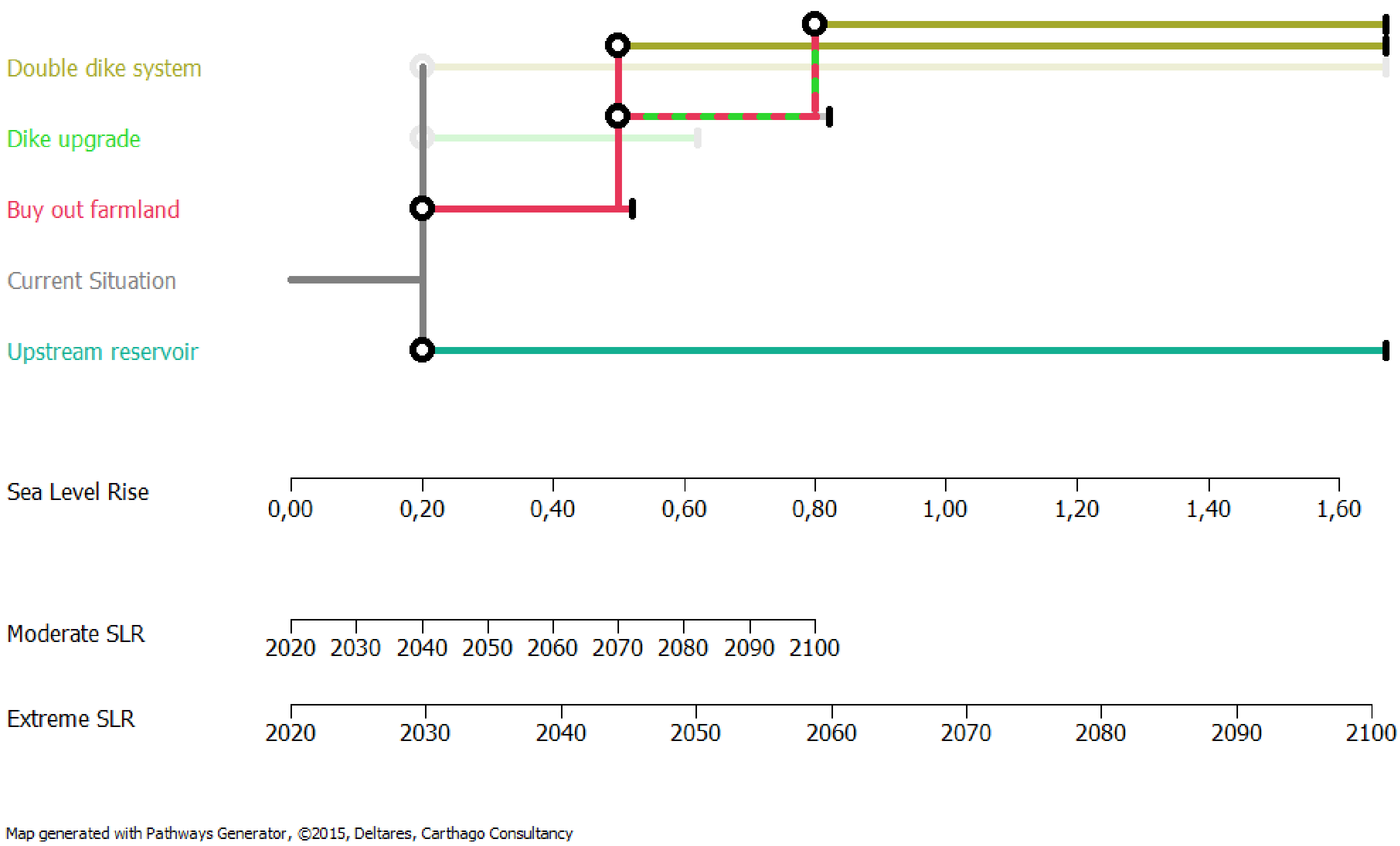
Vulnerabilty/risk models			
Tangible Damage maps	**Intangible Vulnerability maps**	**Flooding Danger maps**	**Risk Risk maps**
Damage to buildings	Inhabitants	Flooding extent	Total economic damage
Damage to inventory	Critical infrastructure	Flooding depths	Risk
Company damages	Emergency centres (first responders)		Risk area
Damage to infrastructure	Polluting companies		
Crop damage	Cultural heritage		
Damage to livestock	Nature & environmental interests		
	Vulnerable infrastructure (daycares, schools etc.)		

A large number of businesses operate in Ribe (figure 2) and a flooding of a number of these will potentially have severe economic impacts as stock/inventory can be damaged and those businesses affected may have to close during the clean-up period. Therefore, it is important to assess which are most susceptible to flooding. It is also important to know which roads may be affected by flooding, as well as the flooding depth, in order to secure safe and direct passage for emergency vehicles and residents. During extreme discharge events in combination with closed floodgates, the main road around Ribe may get flooded and hinder direct passage for emergency vehicles.

In addition to the features shown in the vulnerability maps, agriculture and livestock, schools, day-care centres, houses and others are susceptible to flooding. In Ribe, vast agricultural areas in vicinity to the major streams are prone to flooding which may have economic impact.

Policy Pathways

Issues regarding planning are being addressed by the use of a decision making tool called Dynamic Adaptive Policy Pathways. In a workshop organised by Esbjerg Municipality, experts highlighted several possible solutions for the system at Ribe. These solutions are mapped below based on their expected effects. In the diagram, circles represent tipping points, where a choice can be made. Lines represent stops, where a certain measure no longer can fulfil its function.



What: The outcomes

Accompanying the DAPP map, the scorecard below illustrates the expected costs and effects of different actions based on a first estimate.

Color	Action or pathway	Target effects	Costs	Side Effects
	Current Situation	0	0	0
	Double dike system	+++	---	0
	Dike upgrade	++	--	0
	Upstream reservoir	+	-	0
	Buy out farmland + Dike upgrade	0	0	0
	Buy out farmland	++	--	0
	Buy out farmland + Double dike system	0	0	0
	Buy out farmland + Dike upgrade + Double dike system	0	0	0

As more information becomes available, the tool can be updated. The FAIR project has created closer and increasingly beneficial cooperation between internal teams in the Esbjerg Municipality for asset management, river management and climate adaptation planning management.

Discussions on objectives and alternative pathways for the Ribe Polder will have to take place in steps. Many different interests are present and a close dialogue between these stakeholders as well as the municipality and the national level is needed.

A policy debate around adaptive pathways has been set up in order to highlight the key challenges of the Ribe Pilot. A workshop was held in the organisation Esbjerg Municipality, with external participation of the Danish Coast Authority (DCA) and members from FAIR Scientific Team to assist facilitate the discussions on alternatives.

The system analysis used in FAIR was presented and DCA presented preliminary flood maps for the polder. Limitations and improvements in the model were discussed. Two groups worked on different flooding scenarios and suggested objectives and which alternative pathways to explore.

The policy debate will be followed soon by a phase 2 debate and a similar workshop with the politicians from two City Council boards at Esbjerg Municipality; Planning & Environmental Board and Technique & Building Board.

These initiatives are expected to improve the agenda of the strategic approach to flood protection for Esbjerg Municipality.

Results and discussions can be incorporated in the further climate adaptation planning for Esbjerg Municipality.

Reflection on innovation

Given the complexity of the task and the limited time and knowledge available, it has not been possible to perform a precise calculation of the contribution of each factor to the overall result uncertainty. However, an analysis based on current expertise shows that prediction of the flood sources is by far the main source of uncertainty, followed by the limitations of the hydraulic model. Some recommendations for managing these uncertainties are given.

Based on the work so far, technical recommendations are formulated and ranked. The ranking is based on the ratio between how much effort is required to implement a recommendation and the expected improvement. Recommendations are thus listed in order of expected efficiency:

- Keep updated on the newest IPPC and DMI assessments and update the models accordingly.
- Include infiltration and evaporation maps in the flood model.
- Include rainfall as a flood source in the joint probability analysis (including long-term rain scenario and torrential downpour).
- Ensure the quality of input data for the statistical calculations by having the data supplier verify the raw data source and performing quality checks .
- Extend the model to include three extra branches of the River Ribe.
- Extend the model to include groundwater.
- Extend the length of data series for the flood sources by analysing correlation with other physical factors.
- Find a more accurate way of calculating the expected increase in discharge. Including, for example, evaporation.
- Compare univariate and bivariate statistics and the corresponding models to evaluate the effect of shorter e.g. data series.
- Find out when a water level in the streams becomes critical (closed sluice scenario) and explore the sensitivity of the water level.

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Further reading

The documents relating to the FAIR project can be found on the following websites:

http://www.fairproject.org/

https://northsearegion.eu/fair/

Partners

FAIR brings together Asset Owners (facing real problems and challenges) and leading scientists (with domain expertise) to share and develop innovative solutions to the management of flood protection assets. In doing so, FAIR is the first collaboration of its kind.