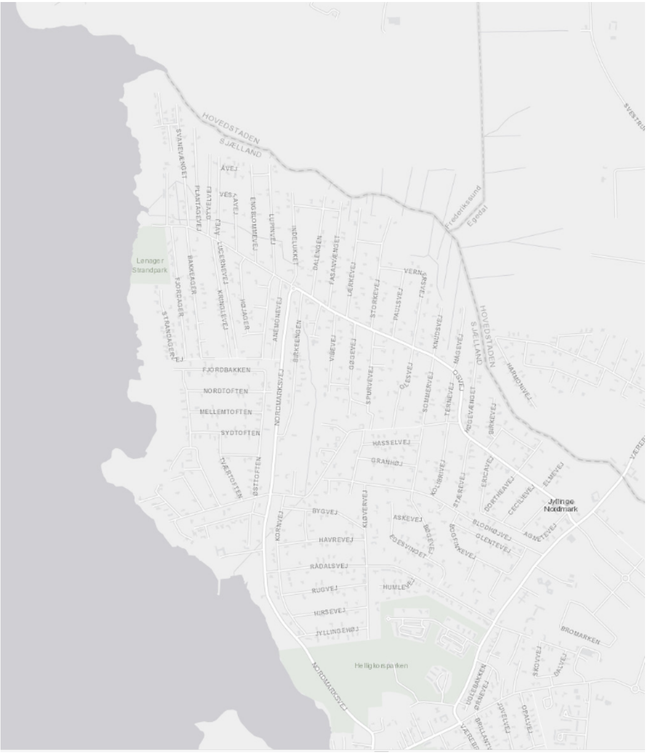

HOLISTIC APPROACH TO APPLICATION OF PHYSICAL GEOGRAPHICAL KNOWLEDGE IN MUNICIPAL STORM SURGE PLANNING IN THE LIGHT OF CLIMATE CHANGE

A case study of Jyllinge Nordmark

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Abstract

The holistic approach to application of physical geographical knowledge in municipal storm surge planning in the light of climate change is researched through a case study of Jyllinge Nordmark in the Municipality of Roskilde. Through document analysis of local plans, pilot projects, and newspaper articles, along with interviews and map analysis, it is studied how an extreme weather event like the storm “Bodil” of December 2013 has caused a shift in the utilization of physical geographical knowledge in development and planning of the flood protection project in Jyllinge Nordmark. Furthermore, it is examined how “Bodil” marks a turning point, after which a change has been made to the municipality's organizational structure and planning process of the Municipality of Roskilde. It is found that physical geographical knowledge existed but was not taken into account during the early development of Jyllinge Nordmark. Only after “Bodil”, the acknowledgement of the importance of physical geographical knowledge was recognized, which prompted a massive generation of knowledge. Furthermore, after “Bodil” the Municipality of Roskilde underwent significant organizational restructuring and produced a new, compressed time plan with parallel plan processes.

Preface

This project is a master thesis in Geography of 103,291 characters including spaces making up 43 normal pages.

The work of this project has been divided equally between the authors, with the exception of a few chapters. N. P. Zangenberg has had primary responsibility for the chapters 1.5, 2.1 and 2.4, and N. W. Jakobsen has had primary responsibility for the chapters 2.2, 2.3, 3.1, and 3.2.

It should be noted that the abbreviation "n.d." used in various references, means "no date". This is used when the date for the publication of the data is unknown. For the date on which the authors accessed the data, see reference list in chapter 7.

The front-page illustration is a map of Jyllinge Nordmark made with ArcMap using the World Light Gray Base Map from 2011 by Esri, Garmin, HERE, MapmyIndia, and the GIS community, updated 2018.

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Resumé

Holistisk tilgang til anvendelse af naturgeografisk viden i kommunal stormflods-planlægning i lyset af klimaforandringer - Et casestudie af Jyllinge Nordmark.

Dette speciale er et studie af hvordan naturgeografisk viden anvendes i kommunal planlægning i forbindelse med byudvikling og kystsikring, samt hvordan klimaforandringer påvirker denne proces. Dette gøres gennem et casestudie af udviklingen og stormflodssikringen af Jyllinge Nordmark. I denne forbindelse undersøges specifikt hvordan ekstremvejrshændelsen "Bodil" i december 2013 påvirkede Roskilde Kommunes videnshåndtering og planlægningsproces med hensyn til stormflodssikringen af Jyllinge Nordmark.

Casen undersøges gennem en triangulering af tre forskellige forskningsmetoder: (1) dokumentanalyse af lokalplaner fra Jyllinge Nordmark, skitseprojekter over kystsikringsprojektet i Jyllinge Nordmark og avisartikler helt tilbage fra 1961 omhandlende Jyllinge Nordmark, som er indsamlet gennem Det Kongelige Biblioteks mediesamlinger "Mediastream", (2) semi-struktureret interview med to ansatte fra Roskilde Kommune, som personligt har haft delvist ansvar for Jyllinge Nordmark kystsikringsprojektet, indsamles data om Roskilde Kommunes organisatoriske struktur, (3) analyse af historiske kort fra Styrelsen for Dataforsyning og Effektivisering indsamles data om historisk, naturgeografisk viden om Jyllinge Nordmark. De forskellige datatyper belyser forskellige facetter af casen og sætter rammen for specialets tredelte analyse.

Specialets analyse er opdelt i analyse af tilgængelig naturgeografisk viden før "Bodil", analyse af naturgeografisk viden produceret efter "Bodil" og analyse af "Bodils" påvirkning af Roskilde Kommunes organisatoriske struktur og planlægningsprocessen af kystsikringsprojektet i Jyllinge Nordmark. Første del af analysen viser at der var naturgeografisk viden om Jyllinge Nordmark før området blev udviklet, som der ikke er taget højde for i byudviklingen, hvilket har resulteret i udviklingen af et byområde med høj sårbarhed over for oversvømmelser. Anden del af analysen viser en mangel på naturgeografisk viden i forbindelse med etableringen af et kystsikringsprojekt i Jyllinge Nordmark, som først er blevet genereret efter "Bodil". Tredje del af analysen viser en markant ændring i Roskilde Kommunes organisatoriske struktur og planlægningsproces, med udarbejdelse af en ny tids- og procesplan med parallelprocesser, hvor udarbejdelsen og behandlingstiden af forskellige planer kører

parallelt, så de er færdige samtidigt. Ydermere har Roskilde Kommune igangsat et omfattende, integreret samarbejde i forbindelse med kystsikringsprojektet i Jyllinge Nordmark, som involverer flere kommuner og ministerier, hvilket stemmer overens med kravet fra EU om integreret kystzoneforvaltning.

Påvirkningen af en ekstremvejrshændelse på behovet for, og genereringen af, naturgeografisk viden er interessant, især set i lyset af at den allerede eksisterende naturgeografiske viden om området ikke blev taget i betragtning under byudviklingen af Jyllinge Nordmark. Ydermere, understreger Statens manglende udpegning af Roskilde Fjord som risikoområde - sårbar over for oversvømmelser - vigtigheden af tilstrækkelig korrekt naturgeografisk data, på hvilket udpegningen er foretaget. Denne manglende evne til at inddrage naturgeografisk viden i planlægningen af Jyllinge Nordmark har resulteret i et byområde med høj sårbarhed over for stormflodshændelser, som først er blevet håndteret, efter skaden er sket.

1. Introduction

During the course of study at university, it has become apparent that when planning the development of urban areas, the natural geographical knowledge of an area must be taken into account. With climate change it has become increasingly important to keep a long-term perspective when planning to secure resilient planning for future needs.

Jyllinge Nordmark has garnered much attention in resent time and is in many ways a prime example of planning and development where physical geographical knowledge was lacking, or simply ignored, the consequences of which is now felt, making Jyllinge Nordmark an interesting case.

This chapter provides an introduction to the underlying construct of the project, with a problem area introducing the different aspects leading to the problem statement. Subsequently, four working question are presented, which will aid in the process of answering the problem statement while also providing a structure for the overall project design. Finally, an introduction to the area of study and its historical development is given.

1.1 Problem area

Denmark has 7,300 kilometers of coast and is relatively flat and not very elevated above sea level, with its highest point being 170 meters above sea level (Geodatastyrelsen, 2005). Add to this that almost 1,000,000 people in Denmark live less than 1 kilometer from the coast, which is prone to flooding from the sea, making Denmark vulnerable to the rising sea level (Miljø- og Fødevareministeriet, 2016, p. 4).

Recent years have seen an increase in the mean sea level of 0.19 meters from 1901 to 2010 (IPCC AR5 WG1, 2013, p. 1150) and according to IPCC's emission scenarios the trend will continue, with an estimated increase in sea level in Denmark of 0.7 meters by the year 2100 (Roskilde Kommune, 2016a, p. 25). Furthermore, the intensity and frequency of storms is very likely to increase in the future, thus increasing the risk of storm surges (IPCC AR5 WG2, 2014, p. 370).

On December 5th, 2013 Denmark was hit by the storm dubbed "Bodil", which saw severe storm surges. This caused extensive flooding in Roskilde Fjord where sea levels were recorded at 2.06 meters above DVR90[1]. The flooding was especially extensive in the area of Jyllinge Nordmark, which is situated directly on the right bank of Roskilde Fjord and is partially encircled by the water course Værebro Å on the other side, which flows into Roskilde Fjord north of Jyllinge Nordmark. During "Bodil", the storm forced the water into the Roskilde Fjord system and further into Værebro Å causing Jyllinge Nordmark to be flooded from both sides, resulting in the damage of 200 residences (Roskilde Kommune, 2014a, p. 4). "Bodil" is considered a so-called 1000-year event, and thus is statistically only supposed to occur every 1000 years. However, historical records report of a similar local storm surge event back in 1962, only 50 years previous to "Bodil" (Roskilde Kommune, 2014a, p. 5).

In addition to "Bodil", Jyllinge Nordmark has seen several smaller floods from less severe storms in the recent years, most recently in December 2016 where the sea level reached 1.52 meters above DVR90 (DMI, 2018) and again in October 2017. Regular flooding and the prospect of a possible increase in the frequency and intensity of storms and sea level rise from climate change has urged the need for adaptation initiatives.

"Bodil" highlighted the vulnerability of Jyllinge Nordmark and has prompted action from the proper authorities, and since "Bodil" Jyllinge Nordmark has garnered an increased amount of attention in the media and from politicians. "Bodil" can as such be considered as a defining turning point for the future development of Jyllinge Nordmark. The Municipality of Roskilde has in a very short time provided a local solution for securing Jyllinge Nordmark from future floods. The latest adaptation plan from the Municipality of Roskilde is to build two dykes, respectively along the Fjord (pink on the map below) and Værebro Å (green on the map below), along with a sluice at the mouth of Værebro Å (pink on the map below), where it flows into Roskilde Fjord, as seen in figure 1 below. The Fjord dyke will protect until elevation water 2.75 meters DVR90, and the Værebro Å dyke will protect until water level 2.40 meters DVR90. This level of protection takes into account future sea level as an effect of climate change (Roskilde Kommune, 2017, p. 14).

[1] DVR90 refers to the Danish Vertical Reference (Dansk Vertikal Reference) which is an elevation reference level established in 1990 based on measurement of mean water level in the seas off the Danish coasts taken from 1982 to 1994. The DVR90 replaced the previous Danish Normal Zero (Dansk Normal Nul) from Den Danske Gradmåling DNN GM1891, which was measured in 1885-1905, and the more updated DNN GI1944 from Geodætisk Institut, which only covered Zealand, Lolland, Falster, Møn, and Funen, and was measured in 1940-1953 (Kort og Matrikelstyrelsen, 2005, p. 1).

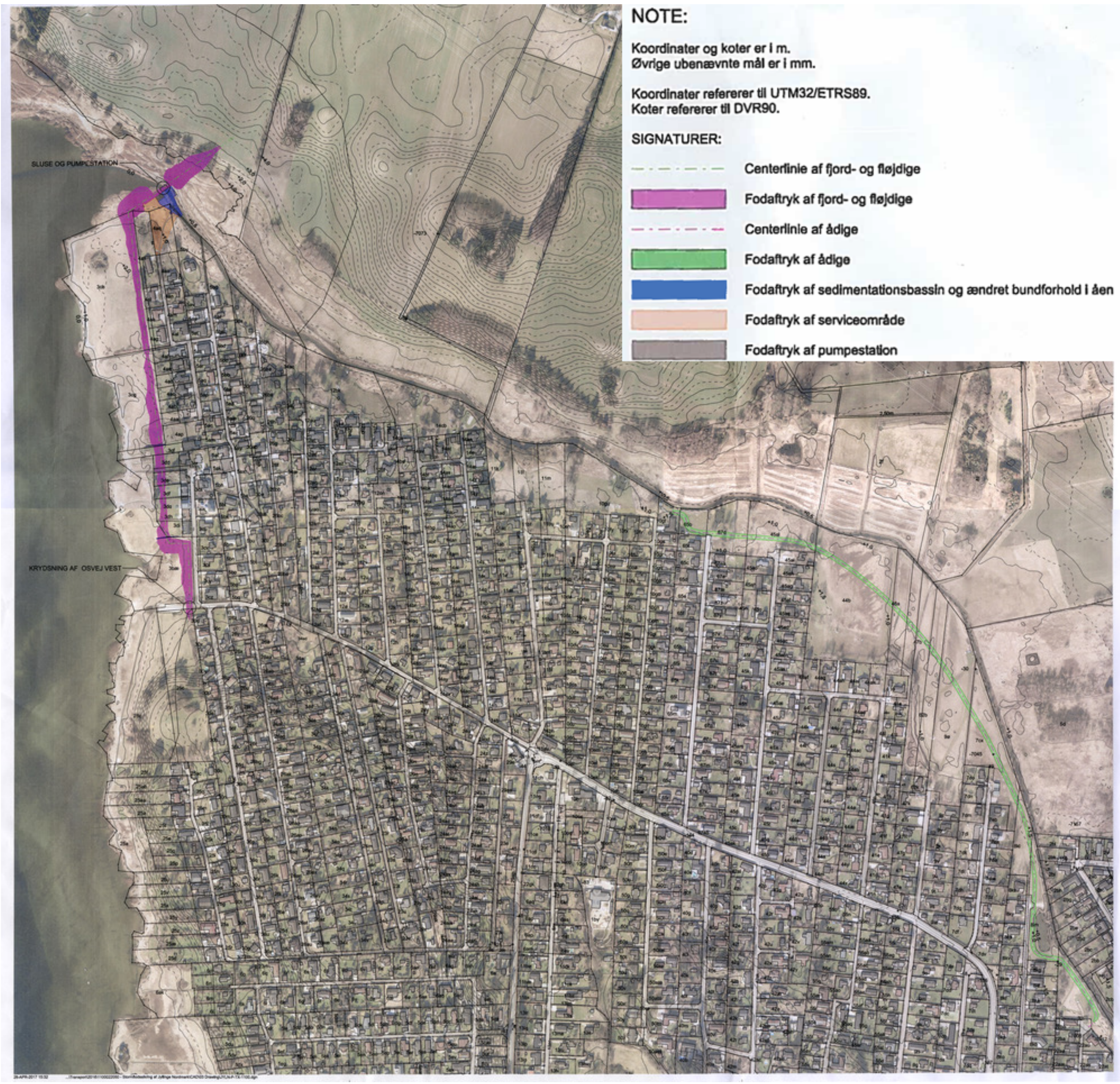

Figure 1: Map of the adaptation projects in Jyllinge Nordmark (Rambøll, 2017).

If the dykes and the sluice are not built, and climate change projections are correct, the extent of an extreme flood event in the near future, where the water level reaches 280 centimeters above DVR90 for Jyllinge Nordmark, would be as illustrated on the map in figure 2 below. As evident from figure 2, some houses in Jyllinge Nordmark would be flooded by as much as 188 centimeters of water.

Figure 2: Extend of an extreme flood event in Jyllinge Nordmark with water level 280 centimeters above DVR90 (Own production, 2017 using GIS with OpenStreetMap and Kortforsyningen, made by Naturstyrelsen, map layer "Havstigning 210-300").

Climate change is a complex and multidimensional problem (NASA, 2017) which, undoubtedly, is a global issue, but it is mostly felt on a local scale, affecting various aspects of daily life such as economical, socio-cultural, political etc. Therefore, it is important to gather sufficient, relevant information in order to provide an effective plan and respond properly with the most suitable adaptation solutions, that is most cost-effective while raising the areas resilience, in order to mitigate future impacts of climate change, thereby increasing local resilience towards extreme weather events. Consequently, this project seeks to analyze what physical geographical knowledge was available during the early development of Jyllinge Nordmark before "Bodil", and to what extend "Bodil" - being a wakeup call regarding the effects of climate change - has emphasized the need for further physical geographical knowledge. Furthermore, this project will analyze the utilization of the available knowledge across different departments in the Municipality of Roskilde. This leads to the following problem statement.

1.2 Problem statement

To what extent has the storm "Bodil", as an effect of climate change, affected the municipal planning process in Roskilde with specific focus on the use of physical geographical knowledge in relation to the storm surge protection of Jyllinge Nordmark?

1.3 Research questions

The following working questions have been designed to structure the project, in that each working question relates to a chapter in the project:

Introduction:	How is Jyllinge Nordmark characterized geographically, and how has it developed historically?
Theory:	What is current state of the art knowledge about climate change? What are the basic concepts and principles for coastal management?
Analysis:	What physical geographical knowledge about Jyllinge Nordmark was available at the beginning of the development of Jyllinge Nordmark, to what extent has the need for additional physical geographical knowledge changed since the storm surge caused by the storm "Bodil" of 2013, and how has the Municipality of Roskilde responded to a potential need for additional knowledge?

1.4 Delimitations

This project focuses on risk of floods from rising sea levels and storms. Jyllinge Nordmark is also in risk of floods from torrential rain storms. The waste water system in the northern part of Jyllinge Nordmark is considered a vacuum system, which is insufficient during heavy rain, as the system is not adequately secured against the seeping in of rain- and groundwater. Furthermore, the groundwater table in Jyllinge Nordmark is very near to the surface (approximately 0.5 meters), thus the amount unsaturated soil is limited, restricting the drainage, causing runoff (Roskilde Forsyning, 2015, p. 2).

However, this project will not focus on the floods caused by rain, as the solutions for wastewater management are separate from the coast protection solutions, even though the flooding from the watercourse Værebro Å is sometimes caused by rain, from which the coast protection solutions will also protect. The waste water projects and the coast protection projects are collaborated upon, as the projects share a combined goal and will reinforce one another, but have a different planning process, other stakeholders and are financed differently.

1.5 Area of study

Jyllinge in its early days was part of Sømme district which in 1970 went under the jurisdiction of the Municipality of Gundsø (Rasmussen, 2004). In 2007 the municipality of Gundsø along with the Municipality of Ramsø, merged with the then Municipality of Roskilde to for the new, large Municipality of Roskilde.

Jyllinge is a relative small town with 10,207 inhabitants (Danmarks Statistik, 2017), which is approximately 14 percent of the Municipality of Roskilde, which, nevertheless, is a significant part. Jyllinge is situated directly on the east bank of Roskilde Fjord. Jyllinge is in close proximity to several large cities and towns, situated 40 kilometers east from Copenhagen, 14 kilometers north from Roskilde, 15 kilometers from Frederikssund, and 30 kilometers from Hillerød (see figure 3 below). Jyllinge is abundant in nature, and the banks of Roskilde Fjord is a Natura-2000 area, deemed important for preservation and thus protected by the EU.

Figure 3: Map of Jyllinge's proximity to large towns and the Capital of Copenhagen (Google maps, 2017).

Roskilde Fjord is - like most of the Danish landscape - the result of glacial advancement and retreat during several ice ages. Hence, the landscape is built up by moraine clay and meltwater deposits. When the last ice smelted approximately 16,000 years ago, it revealed a new landscape with hills and valleys. The Roskilde Fjord depression accommodated several lakes that were associated with streams that ran out east of what is now Halsnæs. The largest lakes, respectively, were south of Eskildsø, north of Frederikssund and west of Frederiksværk (Waneck, 2017). As the last ice melted away, the sea rose and reached the deep parts of the Roskilde Fjord depression approximately 8,000 years ago. Indeed, 7,000 years ago, the water level was 4 m higher than the present water level, meaning that Roskilde Fjord extended over a bigger area than today. The river valley became flooded and formed small sides, such as Værebro river valley, which stretched to Smørumnedre. But since the Stone Age an accumulation of sedimented material has resulted in an increase in the elevation level of the banks of Roskilde Fjord of 4 meters above sea level (Waneck, 2017). As a result, large flat areas have been thawed and gradually overgrown into beaches and coastal cliffs. Roskilde Fjord has a narrow opening to the sea, and this can have negative consequences especially when strong winds blow from west, north-west, forcing the seawater into the fjord and the pressure prevents the water from subsequently retreating back out to sea. Consequently, this leads to a rise in water level in the Fjord of on average up to 1-1.5 m above DVR90, causing flooding. As soon as the wind changes direction and/or loses force the pressure eases and the water can again retread into the Kattegat sea.

Jyllinge Nordmark has always been related to fishing activity, especially eel and shrimp fishing has a great importance for this place. Jyllinge has developed into a large town, from a small fishing village, and until the 1930s the development was largely confined to the historical center near the coast, where there were a few farms and several, small houses. All the area around the city was primarily used for agriculture purposes. From the late 1950s and during the 1960s, Jyllinge underwent a substantial development, and - by virtue of its scenic location - became a favorite holiday location and residential area in the region, possibly due to the areas close proximity to various larger cities, such as Roskilde, Copenhagen, Frederikssund and Hillerød (Gundsø Kommune, 1983). As a result, Jyllinge experienced an explosive population growth from some few hundred inhabitants, to over 10,000 by the turn of the century, as evident in figures 4 and 5 below, which are taken approximately 40 years apart.

Figure 4: Jyllinge 1928-1933 (Danmark set fra Luften, n.d. a).

Figure 5: Jyllinge Nordmark 1971. (Danmark set fra Luften, n.d. b).

The explosive population growth was related to the parceling of the Nordmark area, at first for leisure activities only, but later on, authorized for permanent residency. In general, urban development takes place as a thickening in already built area or by laying out new area, that was previously used for agriculture. The way in which Jyllinge Nordmark has developed is a clear exception to the rule (Præstholm, et al., 2011, p. 38)

The town has expanded primarily in two directions, preserving the historical fishing village as the center of the "new" town. As already mentioned, the first direction is north of the old city center, in the part called "Nordmarken", and later on south of the old city. However, these two areas have developed in two radically different ways (Jonasson, 2001, p. 27). In the 1960s, the Nordmark was plotted for leisure houses. The houses were initially relatively primitive leisure houses, as evident in figure 6 below, but gradually the houses were expanded and in local plan nr. 1.27 on May 9th, 1990, opened the possibility for permanent residence (Gundsø Kommune, 1990 – see appendix I). In 1989 the Ministry of Environment approved a regional plan converting the north area from rural to urban zone, allowing for permanent residency. Until then, the area had a special state of affairs, the municipality did not have the means to prevent the gradual increase in illegal permanent residency, and therefore no great efforts were made to stop the occupation (Jonasson, 2001, p. 27; Præstholm, et al., 2011, p. 38).

Figure 6: Jyllinge Nordmark 1961, set fra Dortheavej (Rasmussen, 2004).

In 1967, the development of the area south of the town began. Towards the south, this development started as permanent residences from the beginning. This part became a planned district, with the construction of a large number of detached houses for permanent residence near the fjord, unlike Nordmarken, which started as leisure houses and developed from there (Gundsø Kommune, 1990 – see appendix I; Gundsø Kommune, 1997). The plotting of the southern areas had begun on the early 1960s and been regulated through four different local plans. However, the increasing population growth caused a great pressure on the municipality around road, drainage, sports facilities, schools and daycare centers (Rasmussen, 2004).

2. Theory

In this chapter the historical formation of Denmark - during the ice ages – is presented. Furthermore, the science behind climate change is explained in the extent that is necessary for the understanding of this project. This includes the Greenhouse Effect, and the Albedo Effect with the feedback mechanisms related to this. In addition, the to-this-project relevant effects of climate change is described, which encompass sea level rise, alternate weather patterns, and subsequent flooding. Finally, the concepts of risk assessment and Integrated Coastal Zone Management is introduced.

2.1 Ice Age and the formation of Denmark

The climate has always been changing, and the history of Earth proves it. Some climate fluctuations occur over millions of years, while others happen over few decades (Houmark-Nielsen, et al., 2005, p. 2). These natural climate variations have led to climatic conditions that have greatly influenced the development of the Earth's landscape. Within the last billion years there have been three major ice ages that have affected Denmark; Elster (490,000-410,000 years ago), Saale (380,000-130,000 years ago) and Weichsel (117,000-11,500 years ago), as evident in figure 8. Figure 7 below shows the maximum extend of the glaciers for each period, where the Elster and Saale glaciers covered Denmark in its entirety, the Weichsel glacier only covered Denmark partially.

Figure 7: The glacial boundaries for the three major ice ages. (Dandebat, n.d.).

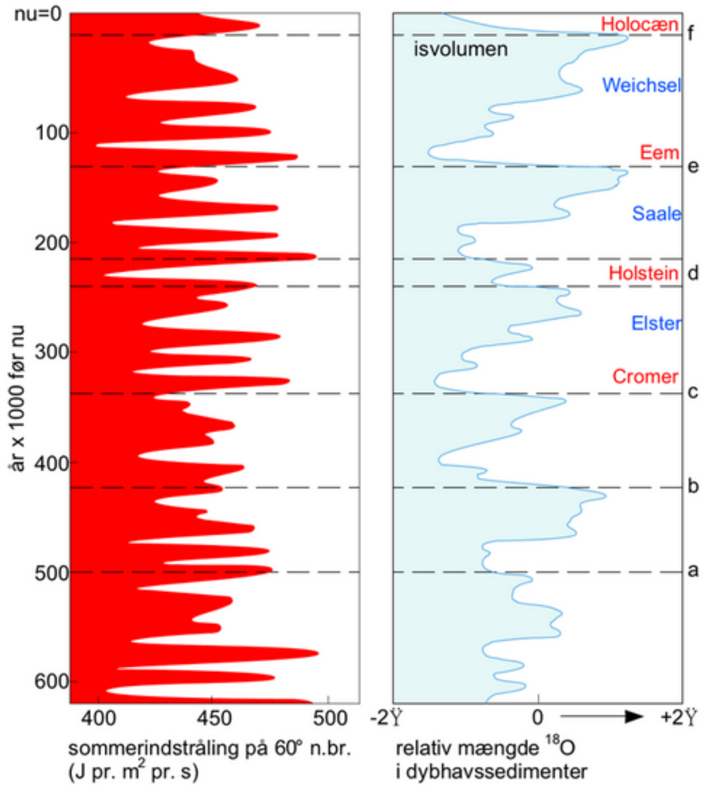

Figure 8: Times scale of glacial periods and interglacial periods (Gyldendal - Den Store Danske," n.d.).

The colder periods were interspersed by greenhouse periods (Houmark-Nielsen, et al., 2005, p. 2) where the climate was so hot that there were no glaciers. Figure 8 above is a timeline of summer solar radiation on the left (red) and ice volume on the right (light blue). During the ice ages the glacier covered approximately the 30 percent of the Earth's surface. Northern Europe was covered by the Scandinavian ice sheet that spread from the Norwegian and Swedish mountains (Houmark-Nielsen, et al., 2005, p. 3). At that point, the watershed in the oceans was 100 meters lower relative to today's sea level, which resulted in Denmark being connected to England by land, rather than by sea. The Danish landscape as known today was shaped especially during the last ice age, Weichsel, that began approximately 117,000 years ago and ended about 11,500 years ago. During this period, the glacier fluctuated between advancing and retreating, bringing with it vast amount of soil, rock, sand and gravel. The generic term used to define all the sediment deposited directly from a glacier is '*till'*. At that point, almost the entire Danish territory was covered by ice, with the exception of south-west Jutland. However, about 15,000 years ago the climate began to slowly get warmer, leading the ice to retreat from the north and east, and all the material accumulated along the way was transported by the meltwater. When the flow of the meltwater was weak, it would only transport clay and sludge, however, when the flow of meltwater was strong it could transport sand, gravel and even rocks. Thus, it was the melting ice that has determined how the soil in most places of Denmark is today (Houmark-Nielsen, et al., 2005, p. 4). The movements of the glacier created trays by pushing soil, rocks, sand and clay in front of them. Those types of hills are called push moraines (Holden 2012, p. 495). The glaciers also smoothed the slopes by simply tapping them flat. At the same time, the meltwater flowed into the soil and create valleys in different shapes and directions, as illustrated in figure 9 below.

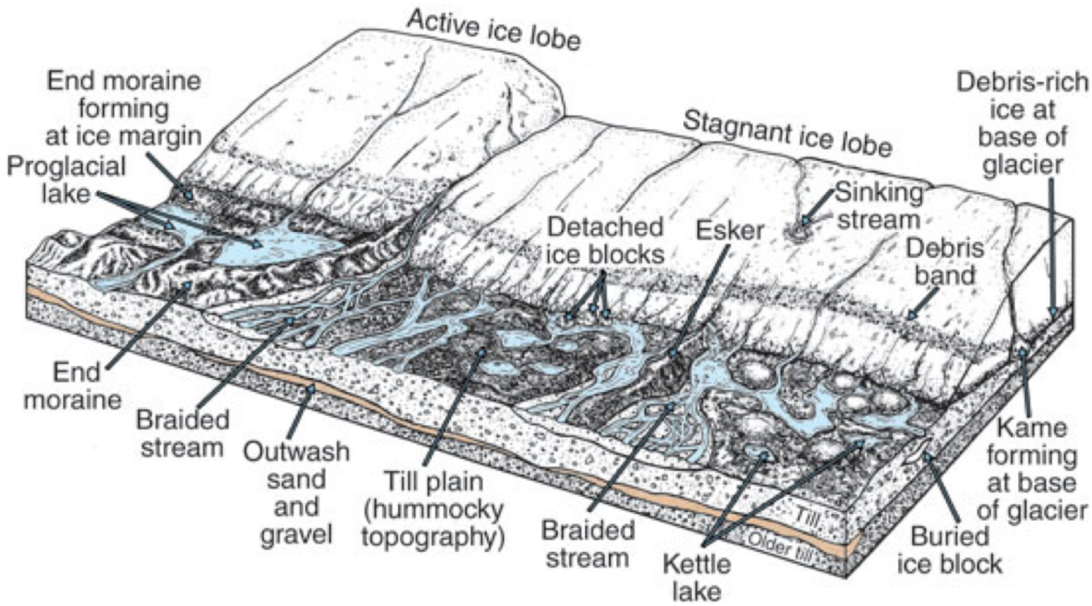

Figure 9. Glacial formation of the landscape (Geocoaching, 2017).

East of Roskilde, large parts of the landscape are shaped like a ground moraine landscape on top of an older meltwater lake. The land shape and composition of the soil is closely correlated to the way the ice melted, as figure 10 below presents.

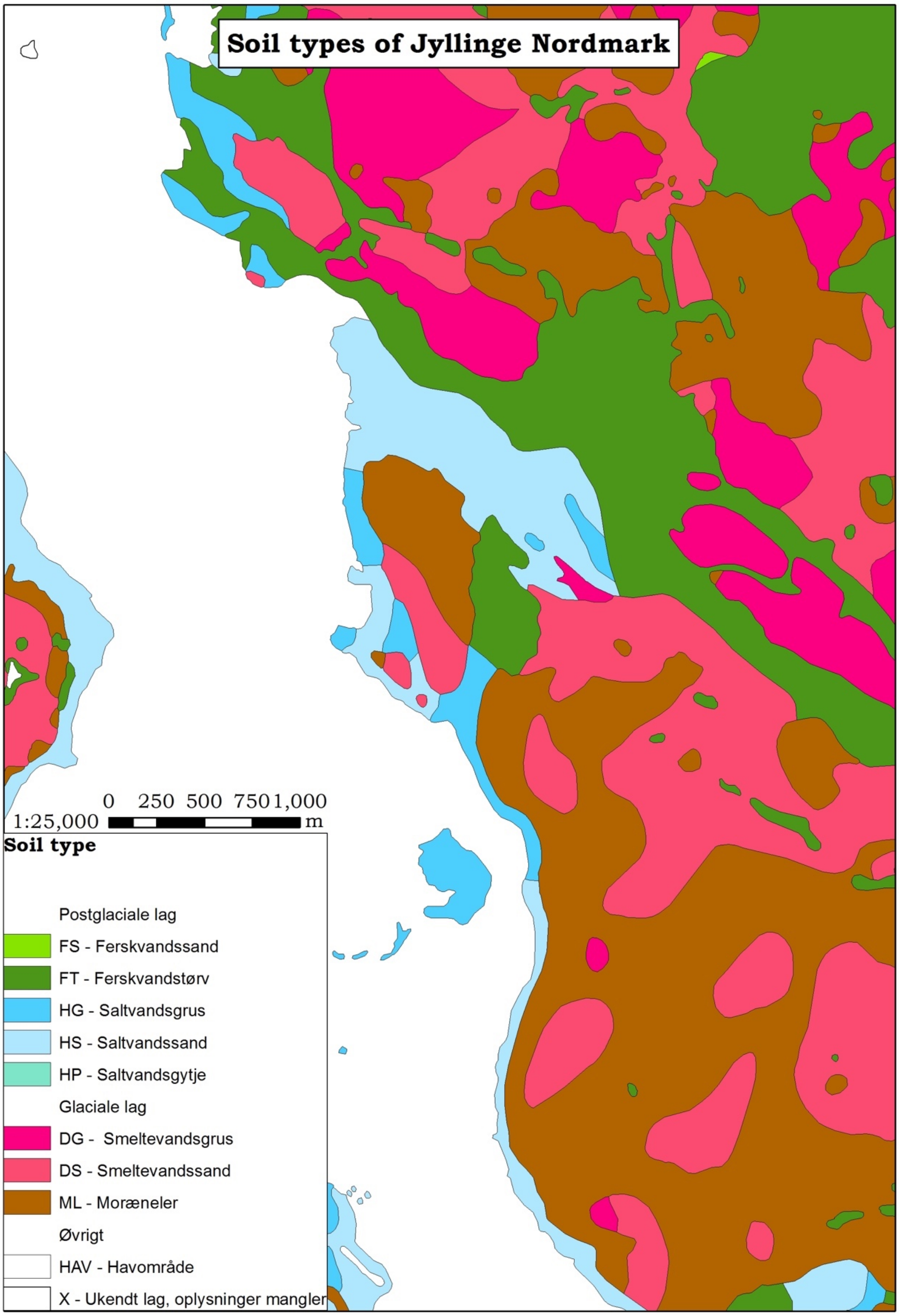

Figure 10. Soil types of Jyllinge Nordmark (own production, 2018)

2.2 Physical basis of climate change

This subchapter introduces the current state of knowledge about climate change including the science behind some natural and anthropogenic climate drivers long with the effect of these on climate feedback loops.

2.2.1 The Greenhouse Effect

Earth's atmosphere is highly influenced by the biosphere, and conversely the biosphere is strongly influenced by the atmospheric composition. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapor, along with a few other gases, are naturally occurring gases and, therefore, exist in a certain ratio in the atmosphere, which currently consist of 78.1 percent nitrogen (N_3), 20.9 percent oxygen (O_2) and 0.035 percent carbon dioxide (CO_2) (Holden, 2012, p. 77). The aforementioned gases are known as so-called "greenhouse gases" (GHGs), named thusly due to their shared trait of trapping heat in Earth's atmosphere - similar to the effect of glass in a greenhouse (Holden, 2012, p. 702). GHGs allow solar radiation to mostly pass through the atmosphere and down to the surface of Earth, reflecting only a small part back into space. Earth then reradiates some of the absorbed solar radiation back out in the form of infrared waves (heat) which does not pass through the GHGs, but is mostly absorbed, and partially reradiated back again, thus preventing a lot of the heat from escaping out through the atmosphere (Holden, 2012, p. 87).

Since the industrial revolution the world has seen an increase in anthropogenic GHG emissions, mainly due to a rise in the burning of fossil fuels, such as coal, gas, and oil along with gases from cement production, from the process of turning limestone into lime, and gas flaring (IPCC, 2014, p. 3). The increase in GHGs in the atmosphere enhances the effect of the otherwise natural Greenhouse Effect, causing further heat to be trapped and a global warming of the Earth to occur (Holden, 2012, p. 78).

2.2.2 The Albedo Effect

When the solar radiation reaches Earth's surface it is partially reflected, absorbed, and transmitted, the ratio of which is dependent on the surface type and the reflecting power of this. The reflective power of a surface is called "albedo" and is measured in the percentage of the received solar radiation that is reflected back. The higher the albedo, the less radiation is absorbed. The albedo of the surface of the Earth varies according to the change in type of Earth's various surfaces (Holden, 2012, pp. 87-88). As an example, coniferous forest has a low albedo of about 10-15 percent, meaning that 10-15 percent of the received radiation is reflected back and the rest is absorbed and/or transformed, contrary to this, fresh, dry snow has a high albedo of about 80-95 meaning as little as 5 percent of the received radiation is absorbed by the surface (Holden, 2012, p. 89).

Warming of the global climate from the aforementioned Greenhouse Effect causes glaciers - which are comprised of the buildup years of compressed snow - to melt at a greater rate than new snow accumulates, resulting in retreat of the glaciers, revealing the surface underneath. The glacier's underlying surface likely has a lower albedo than that of the glacier, causing a decrease in Earth's total albedo, which allows more heat to be absorbed and a further warming of the global climate to occur, in what is known as an albedo effect (Withgott & Brennan, 2009, p. 314). Thus, lowering Earth's albedo creates a positive feedback loop in which a system is brought out of equilibrium, the outcome of which serves as a further destabilizing mechanism driving the system further away from equilibrium and increasingly towards an extreme (Withgott & Brennan, 2009, p. 50), as illustrated in figure 11 below. The global climate system has been brought out of equilibrium by anthropogenic GHG emissions causing more heat to be trapped and, therefore, glaciers to melt, lowering the albedo and allowing more solar radiation to be absorbed and reradiated, causing further heat to be trapped in the atmosphere, increasing glacial retreat lowering albedo even more and so forth.

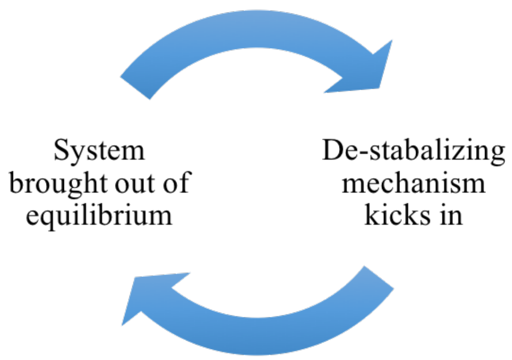

Figure 11: Positive feedback loop (own creation, 2017).

2.3 Impacts of climate change

This subchapter will introduce the impacts of climate change relevant to this project, including sea level rise, changing weather patterns and floods.

2.3.1 Sea level rise

As the global climate warms and the glaciers melt, the global mean sea level - which is the height of the sea at the coast measured with a local land benchmark and averaged over a period of time (IPCC TAR WG1, 2001, p. 643) - will rise as a result of the water that has been stored in the ice being released into the ocean as it melts (IPCC, 2013, p. 1139; Holden, 2012, p. 427). In addition to the sea level rising from melting glaciers, the global warming also causes thermal expansion which results in further sea level rise. Thermal expansion is a mechanism in which matter increases in volume or linear dimensions as a result of an increase in temperature (Merriam-Webster, 2017), meaning that global warming results in a reduction in density of water causing it to increase in volume (IPCC TAR WG1, 2001, p. 643).

Sea level rise has happened previously in the last 3 million years and the IPCC states with high confidence that for several thousand years the sea level was 5 meters higher than at present, albeit due to natural orbital forcing variations as opposed to anthropogenic enhancement of the greenhouse effect (IPCC, 2013, p. 1139).

2.3.2 Alternate weather patterns

Global warming also has an effect on weather patterns in which the frequency and intensity of extreme weather events increases. Since around 1950, changes in extreme weather and climate events have been observed, including decrease in cold temperature extremes, increase in warm temperature extremes, and increase in the number of heavy precipitation events (IPCC, 2014, p. 7).

Wind patterns are also estimated to change in the future. Denmark has seen an increase in the frequency of hurricanes and hurricane-like storms since 1965. Based on result from climate models, it is estimated that in the future the average mean wind speed for both summer and winter will increase slightly and the dominant direction of the wind will, to a greater extend come directly from west. Furthermore, the magnitude of storms and hurricanes will increase, and this - combined with the more western wind direction and rising sea levels - are expected to increase the severity of storm surges (DMI, 2014, p. 15).

2.3.3 Increased frequency and intensity of floods

The consequences of sea level rise and a rise in frequency and intensity of storms is an increase in frequency and severity of floods. Floods are caused be a temporary increase in the inflow of water, caused by e.g. heavy precipitation, storms and hurricanes, earthquakes, or malfunction of structures like for example dykes (Miljø og Fødevarestyrelsen/ Miljøstyrelsen, n.d.). Thus, it is increasingly important to take this into account when planning and managing the coastal zones.

2.4 Coastal Risk Management

Coasts are home for a large percentage of the world's population and here in Denmark almost 1,000,000 Danes live less than 1 kilometer from the coast (Miljø- og Fødevareministeriet, 2016, p. 4).

Coastal zone includes three geographical components: coastal land, the coastline and the coastal water (Bjerregaard & Grolin, 1998). The coastal zone is in other words the coastal land and water areas with interference, defined as 3 km inland and 12 nautical miles at sea (Anker, et al., 2014, p. 66) as illustrate in the figure 12 below.

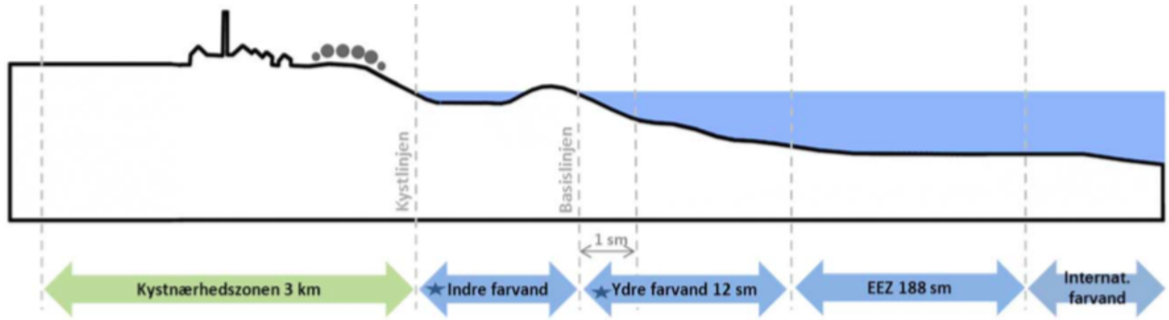

Figure 12: Coastal zone extent (Anker, et al., 2014, p.71).

Coastal zones are geographical areas that are difficult to manage, because they are exposed to both climate change and natural hazard, which are "*the threat posed by the natural processes that cannot be influenced*" (Kron, 2013, p. 1369). Therefore, coasts are dynamic systems, they are always reacting, (re-)forming, adjusting themselves to all the natural disturbances, such as surges, erosion, waves, and rising temperature, and to environmental stress such as, pollution, and habitat changes as well as to socioeconomic changes such as the rising of coastal population and change in coastal economy (Zanuttigh, 2015).

Coastal zones can be described as the interface between land and sea, and since they are affected by so many different factors that occur in different spatial and time scales, the possible solutions to those are deeply related to the variability of the scale requiring the combination of different discipline (physical geography, hydrography, geology) (Malvárez, et al., 2015, p. 633).

Coastal flood is just one of the many challenges that affect the coastal zones, and it is a complex issue and is due to several factors. In order to, be able to handle it in a proper and effective way, it is first necessary to understand this phenomenon in its entirety. Climate change is undoubtedly a related factor for coastal floods, as sea levels have increased and are expected to continue in the next century due to global warming and other possible climate changes (IPCC, 2014, p. 3).

As already outlined, the key factor to provide an effective solution is to be able to collect all the possible available information, presenting a holistic understanding of how all this information links together (Commission of the European Communities, 2000) and use them properly for the development of current and future policies, enabling not only adaptation but also mitigation of those environmental challenges. Adaptation is "*the process of adjustment to actual or expected climate and its effects"* (IPCC, 2014, Annex II, p. 1758). Mitigation is the effort to reduce or prevent the emission of greenhouse gases (IPCC, 2014, Annex II, p. 1758). But the more important principle in policy making process is always to work respecting the limits imposed by nature, and never against it (Commission of the European Communities, 2000).

2.4.1 Coastal Risk management assessment - flooding

Flooding of coastal systems and rivers is the most frequent and harmful natural hazard on the globe (Jongman, et al., 2014, p. 1245). Flood is a natural phenomenon characterized by physical aspects that are rather easy to understand. In the EU Floods Directive (Directive 2007/60/EC) a flood is defined as "[…] *the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewage systems.*" (EU, 2007, p. 29). However, other concepts related to flood as *flood risk*, *flood vulnerability* and *flood resilience* might require a closer explanation to avoid misunderstanding. *Flood risk* is an expression of statistics on the number of victims, and damaged property. It is the *"combination of probability and consequences"* (Zanuttigh, 2015, p. 13). A risk assessment has to take into account all risk factors, from the economical to the social (Rumson, et al., 2017, p. 102). The consequences of floods as well as every natural catastrophe can be divided in four categories: (1) direct (related directly to the area and time of event), (2) indirect (effects occurring outside the flooded area), (3) tangible (effects can be monetized), and (4) intangible (all the elusive effects). The combination of probability with consequences makes it possible to estimate and monetize the damage (De Moel, et al., 2015, p. 870).

The notion of *flood vulnerability* is used to describe to what extend the particular area or system is capable of managing the adverse effects of a flood. (Zanuttigh, 2015, p. 13).

The concept of *flood resilience* expresses more the ability of the system to cope with those extreme and adverse weather effects, enabling the minimization of damage and guaranteeing a more rapid recovery (Zanuttigh, 2015, p. 14). It can be everything from ingenious engineering solution, to emergency plan of evacuation, plan of insurance etc.

The main goal in every policy is to reduce vulnerability and this can be accomplished in several ways. The first step is the ability to identify all the areas with high risk of flooding. Therefore, it is important to conduct a proper preliminary risk assessment that take in consideration the potential impacts on both human life, environmental issues, and commercial- and social activities. A risk assessment makes it possible to provide a map over the areas at risk, a clear picture of the damages and consequences expected from a flood and enables to choose the best possible solution for the specific area, an example of which is visualized in figure 13 below. Nevertheless, it is important to keep in mind that different scales require different solutions, and different methods (De Moel, et al., 2015, p. 871). But more important in order to understand the specific phenomenon is to define the interactions between all the different components and to provide a scale of the effects of such interactions, pointing out who and/or what are the receptors (urban areas, infrastructure, farmland etc.) and all the consequences of the impact of the flooding on the receptor. Therefore, it is necessary to identify the source of e.g. flooding, the different pathways, enlightening how the source reaches the receptor.

Finding the best way to adapt to climate change is not an easy task. It requires "*the assessment of a wide range of impacts on multiple sectors, whose vulnerability and adaptive capacity depend on physical, environmental and socio-economic conditions varying from region to region*" (Torresan, et al., 2016, p. 61).

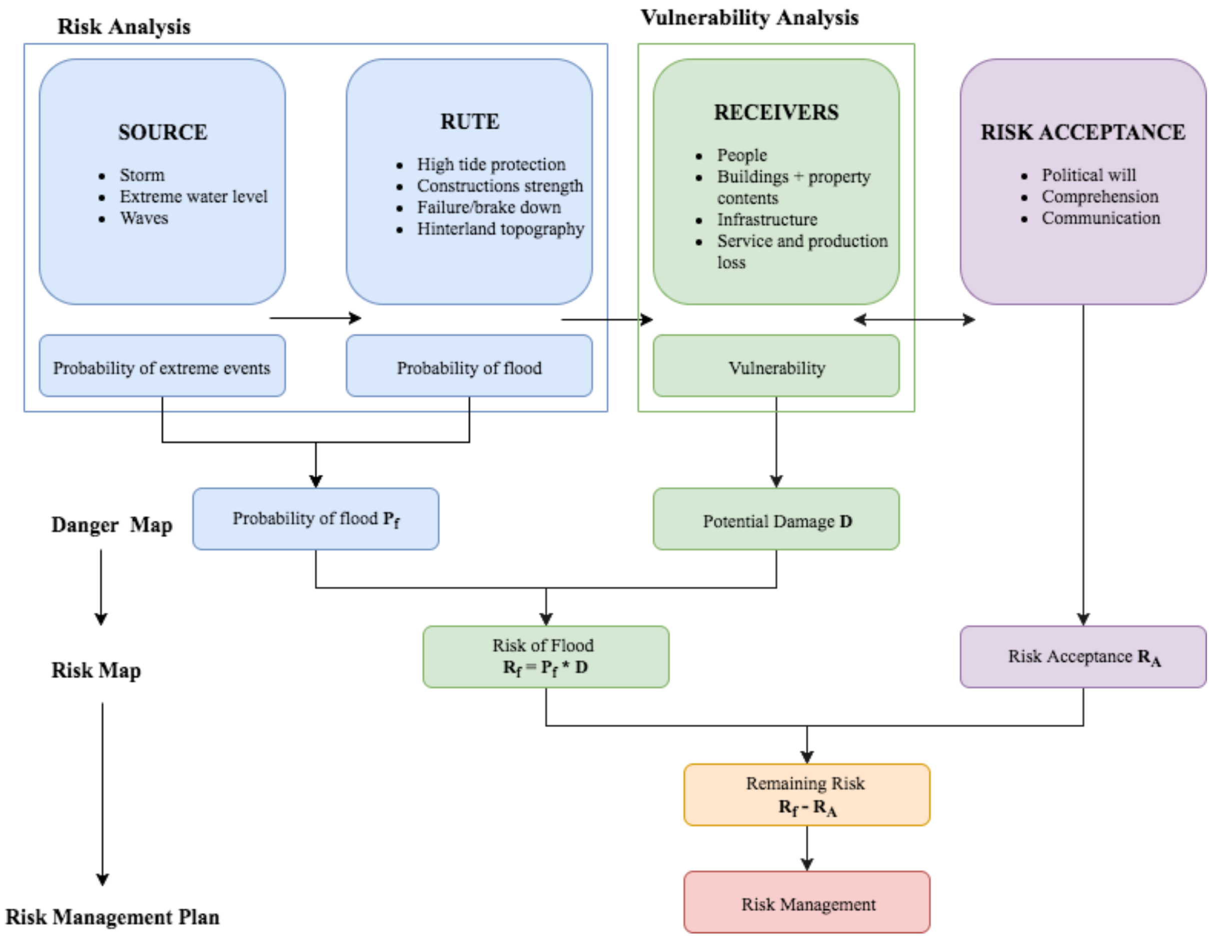

Figure 13: The steps of a flood risk analysis (Personal collection, 2018, with inspiration from Alectia for Aabenraa Kommune, 2013).

2.4.2 Integrated Coastal Zone Management (ICZM)

It is not an easy task to forge a solution that not only responds to the effect deriving from climate change, but at the same time is able to ensure both the respect for the natural system and the sustainable development of the society. This process requires clear guidelines that guarantee and provide a general and common framework, in order to be able to provide effective solution first on the local scale, where the effects of climate change are felt and experiences directly by the local communities, but then indirectly and/or directly will have consequences on all different scales, both on regional, national and global. Integrated Coastal Zone Management (ICZM) is a tool for holistic planning taking the various scales into account.

Coasts play a strategic role in the development of both commercial and leisure activities. It is undeniable that coasts are facing serious environmental problems of habitat destruction, water contamination, coastal erosion and resource depletion, which result not only in a weakening of social and economic activities but also affects the value of private and public property (Commission of the European Communities, 2000, p. 2). Because coastal zones play such a vital role in today's society, it is necessary to develop common and integrated territory approaches. On that grounds, the EU Commission developed a Demonstration Programme on Integrated Coastal Zone Management (ICZM), to "*show the practical conditions that must be met if sustainable development is to be achieved in the European coastal zones in all their diversity*" (Commission of the European Communities, 2000, p. 7). The Integrated Coastal Zone Management (ICZM) is defined as:

> "[…] *a dynamic, multi-disciplinary and iterative process to promote sustainable management of coastal zones. It covers the full cycle of information collection, planning (in its broadest sense), decision-making, management and monitoring of implementation. ICZM uses the informed participation and co-operation of all stakeholders to assess the societal goals in a given coastal area, and to take actions towards meeting these objectives. ICZM seeks, over the long-term, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics.*"
>
> (Commission of the European Communities, 2000: Annex I).

The key word here is 'integrated' and therefore it is important to elucidate what connotations are associated with it.

> "*"Integrated" in ICZM refers to the integration of objectives and also to the integration of the many instruments needed to meet these objectives. It means integration of all relevant policy areas, sectors, and levels of administration. It means integration of the terrestrial and marine components of the target territory, in both time and space.*"
>
> (Commission of the European Communities, 2000, Annex I).

The EU Commission has in this way provided an integrated legal and constitutional frame, which enables the different nations not only to collaborate with each other, but more importantly allows them to develop the best suitable policies. It is on the regional and local scale that the vital information and data are collected, and the collaboration, awareness and involvement of the citizens happen.

The success of ICZM lies on the following 8 principles:

1. A Broad "Holistic" Perspective (Thematic and Geographic).

The coastal system is complex. It is the result of the combination of physical-geographical, socio-economic, cultural, and institutional systems, which go beyond the national borders. Therefore, it is important to provide a broad and holistic understanding of how all this elements links together, beneficial to a legal and common framework.

2. A Long Term Perspective.

It is necessary to act now taking in consideration the needs of the present and future generation to guarantee the best possible scenario.

3. Adaptive Management during a Gradual Process

ICZM is a process, thus it is in constant development. It does not guarantee for an immediate resolution, but makes it possible to collect, analyze and share all the relevant information in the interest of a mutual solution in the long term.

4. Reflect Local Specificity

Every coastal zone is different from another. Therefore, the specific physical, socio-economic, cultural, geographic characters of every coastal zone have to be taken in consideration to enable the best possible solution for that distinct area.

5. Work with Natural Processes

ICZM enables the possibility to work with nature and not against nature, respecting the limits imposed by it.

6. Participatory Planning

It is important to establish collaboration between all the involved stakeholders in order to share responsibility, information, fill knowledge gaps, enlighten significant issues and build commitment.

7. Support & Involvement of all Relevant Administrative Bodies

Mutual supportive actions can be made only having the backing from all the levels of administration. This collaboration and awareness is a key factor for a successful solution.

8. Use of a Combination of Instruments

ICZM requires the use of different and multiple instruments: laws, economies, information provision, different kind of technologic solutions, research and education. (Commission of European Community, 2000).

2.4.3 ICZM in Denmark

As described above, ICZM has the purpose to ensure the best possible development of the coastal zone, through a harmonic interaction between nature and society (Bjerregaard & Grolin, 1998).

The only way to achieve the best possible result is by integrated policies which are in turn made conceivable through active collaboration between the different authorities. In this regard, the European Commission has presented a new directive on Maritime Spatial Planning and Integrated Coastal Management in March 2013, that aims to help the various member states carry out a simplification of the legal and jurisdictional system where necessary (Anker, et al., 2014, p. 29).

The Danish management structure is based on three different levels: state, region and municipality. Those three levels can collaborate in different ways: both in a vertical way or in a horizontal way, as illustrated in figure 14 below.

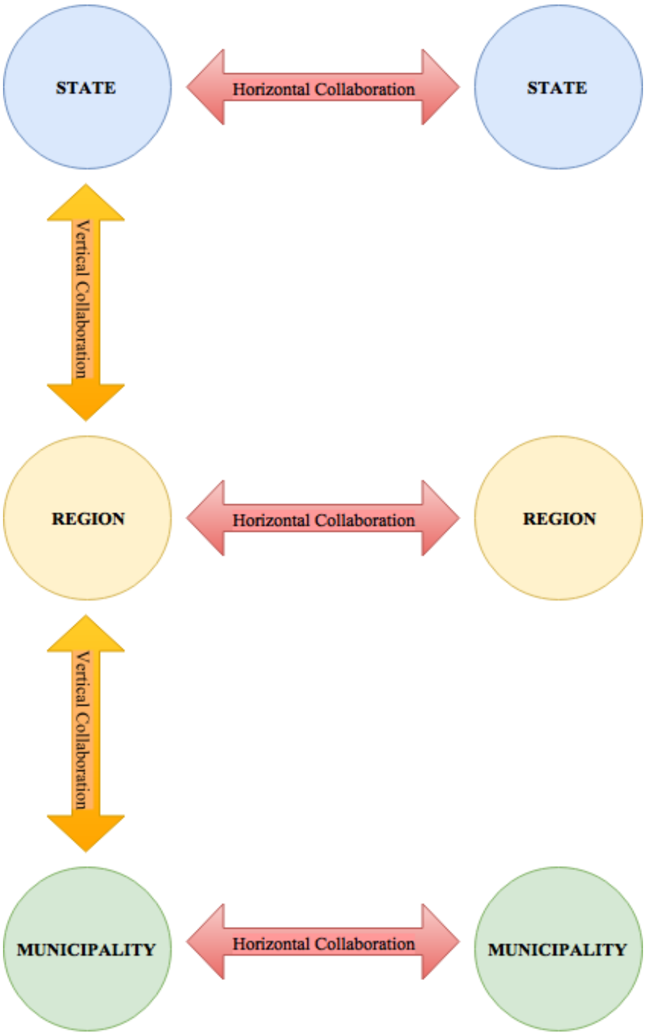

Figure 14: Collaborations way (Own production, 2017).

The specific areas of competence of each authority, and the way in which these can enable an effective collaboration, are facilitated by a strong and regulative legislation in both natural- and environmental field. The two more important tools for the protection of the coast in Denmark are: ´The Planning Act in Denmark Consolidated Act No. 813 of 21 June 2007', and 'Nature Protection Act, Consolidated Act No. 85/2002' (Anker, et al., 2014, p. 498).

In the Planning Act it is explained the followed:

> "*People use planning to form the surroundings of daily life. Planning should be based on visions of how we want to live now and in the future and what we need to preserve from the past.* […] *Planning is both the basis for and the concrete result of policy-making. This Act shall ensure that the overall planning synthesizes the interests of society with respect to land use and contributes to protecting the country's nature and environment, so that sustainable development of society with respect for people's living conditions and for the conservation of wildlife and vegetation is secured.*"
>
> (Naturstyrelsen, 2007).

The Planning Act points out that the development of coastal zones can be influenced by five different needs:

1. "*Nature and the environment, including recreational purposes*
2. *Business, including tourism*
3. *Employment*
4. *Education and training*
5. *Culture*"

(Naturstyrelsen, 2007, part 3, p. 15)

The implementation and development of the ICZM in Denmark seems to be based on solid legislation as well as on engaging in open collaboration between all the different authorities in charge (see table 1 below).

The future challenges that the Danish coastal zone management has in sight are still many, as for example to create a clear overview over the competent authorities and their respective jurisdictions. There are many different kinds of permit-, dispensation- and authorization procedures both on land and water (Anker, et al., 2014, p. 67-69). Figure 15 presents an overview over the jurisdiction of the various legislations in Denmark. Furthermore, figure 16 shows the actual Coastal Zone Management in Denmark.

But still, all those acts do not assure that there are going to occur issues in the future. In fact, problems can easily arise in the moment when the national or regional protection interests are in conflict with local development interests (Anker, et al., 2004, p. 512).

Act	Application area	Measures, e.g.	Authorities
The Planning Act	Land-based activities	Coastal planning principles, e.g. avoid non-coastal dependent developments. Coastal planning zone (3 km—outside urban areas), e.g. only development with specific justification. Regional planning, e.g. for coastal land. Municipal and local planning, e.g. visual impacts in urban areas	Regional and local
The Nature Protection Act	Land and sea	Prohibition zone (300 m in-land). Conservation orders	Regional (land) / National Forest and Nature Agency (sea areas, dunes)
The Environmental Protection Act	Land and sea	Environmental licences Waste water permits Marine aquaculture	Regional/local
The Marine Environmental Protection Act	Territorial seas and continental shelf	Licenses	Ministry for the Environment/Regional (dumping of dredged material)
The Raw Materials Act	Land and sea	Licenses	Regional (land)/ National Forest and Nature Agency (sea)
The Underground Act	The under-ground and continental shelf	Licenses	Ministry for Economics and Business
The Coastal Protection Act	Coastal areas	Licences for coastal defence works	Ministry for Transport
The Harbour Act		Permits	Ministry for Transport
The State Supremacy Regulation	Territorial seas	Permits for all installations	Ministry for Transport
The Fishery Act	Salt and fresh waters	Catch quotas, etc. Marine aquaculture	Ministry for Food, Agriculture & Fisheries

Table 1: Overview of the various laws and acts in Denmark (Anker, et al., 2004, p. 502).

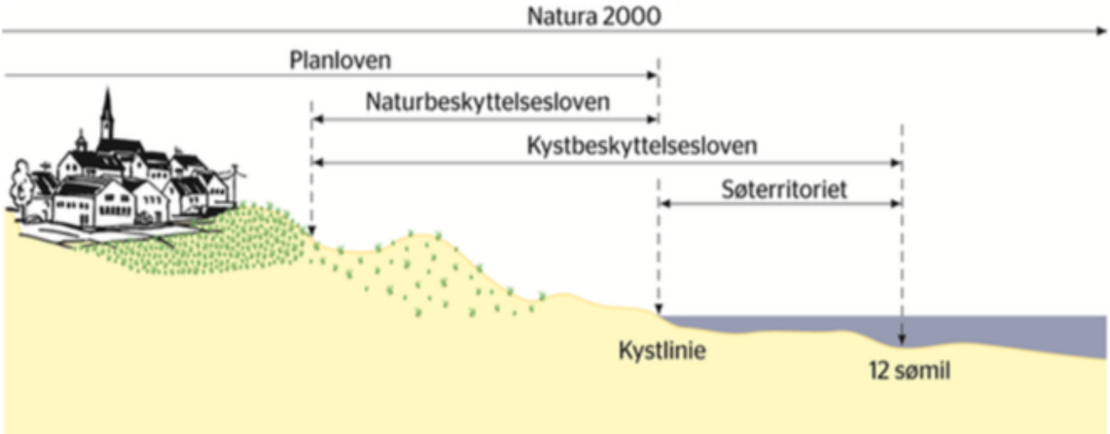

Figure 15: Overview of the jurisdiction of the various legislations in Denmark (Miljø- og Fødevareministeriet, 2016, p. 24).

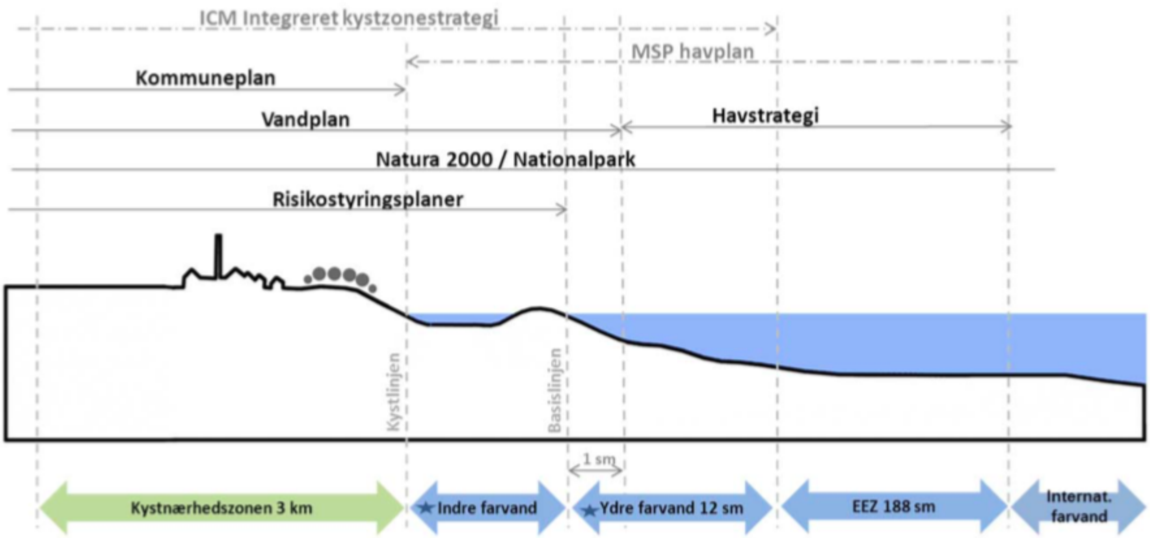

Figure 16: Actual coastal zone management in Denmark (Anker, et al., 2014, p. 71).

3. Methods

This chapter accounts for the considerations regarding the argumentation of the project. The case study as a research strategy is introduced, and the strengths and weaknesses of the strategy are weighed. Furthermore, the mixed research method of triangulation is presented along with the various methods employed in this project for the gathering and utilization of the empirical data.

3.1 Case study

This project is a case study of the area of Jyllinge Nordmark and the problems experienced in this area, particularly in regard to floods, which illustrates how physical geographical knowledge - or lack thereof - affects the planning process.

The case study is the study of specific phenomenon with the purpose of achieving detailed knowledge about the phenomenon (Flyvbjerg, 1991 in Ramian, 2012, p. 11). The phenomenon can be either a system, a process, or people (Ramian, 2012, p. 17). The case study is tied together by a logic which links together research questions, phenomenon, data collection, analysis, and generalization in a research strategy (Ramian, 2012, p. 15).

> *"Case study is a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence"*
>
> (Robson, 2002, p. 150).

Empirical research is concerned with data being the foundation for conclusions. The data collected through empirical investigation is an important source of acknowledgement, and thus, without concrete evidence, no conclusions can be drawn (Ramian, 2012, p. 16). Therefore, empirical research is the cornerstone of the case study.

The case study's narrow research focus makes it unsuitable upon which to base generalizations of the entire population. The Penguin 'Dictionary of Sociology' explains:

> "*The detailed examination of a single example of a class of phenomena, a case study cannot provide reliable information about the broader class, but it may be*

useful in the preliminary stages of an investigation since it provides hypotheses, which may be tested systematically with a larger number of cases."

(Abercrombie, Hill and Turner, 1984, in Flyvbjerg, 2011, p. 301).

To what extend this project can be generalized in other cases, then those examined in this project, can best be evaluated by others in a so-called "situated generalization" (Ramian, 2012, p. 21).

The case study often incorporates various data sources, including observations, interviews and literature in order to substantiate the conclusions. This type of research method is called triangulation (Ramian, 2012, p. 19), the utilization of which, in regard to this project, is explained further in the subsequent chapter 3.2.

3.2 Triangulation

It can be difficult to gather all the needed knowledge about a phenomenon through a single research method, thus the need for a combination of different research strategies arises. Triangulation is a type of mixed research method, in which the same phenomenon is illuminated through different data sets (Ramian, 2012, pp. 19 + 32), as illustrated in figure 17 below. A strength of this strategy is the ability to research complex problems through knowledge both in depth and in width and requires the researchers to possess a knowledge about an array of different research methods. A weakness of the strategy is the unclarity about who or what is in charge, how to collaborate in regard to inconsistencies, and the significance of each research method on the final conclusions (Campbell, et al., 2001 in Ramian, 2012, p. 33). The mixed methods research differs from the case study in that it encompasses researches which are not by default based in a case and in that the existence of a cohesive analysis strategy is a rarity (Ramian, 2012, p. 33).

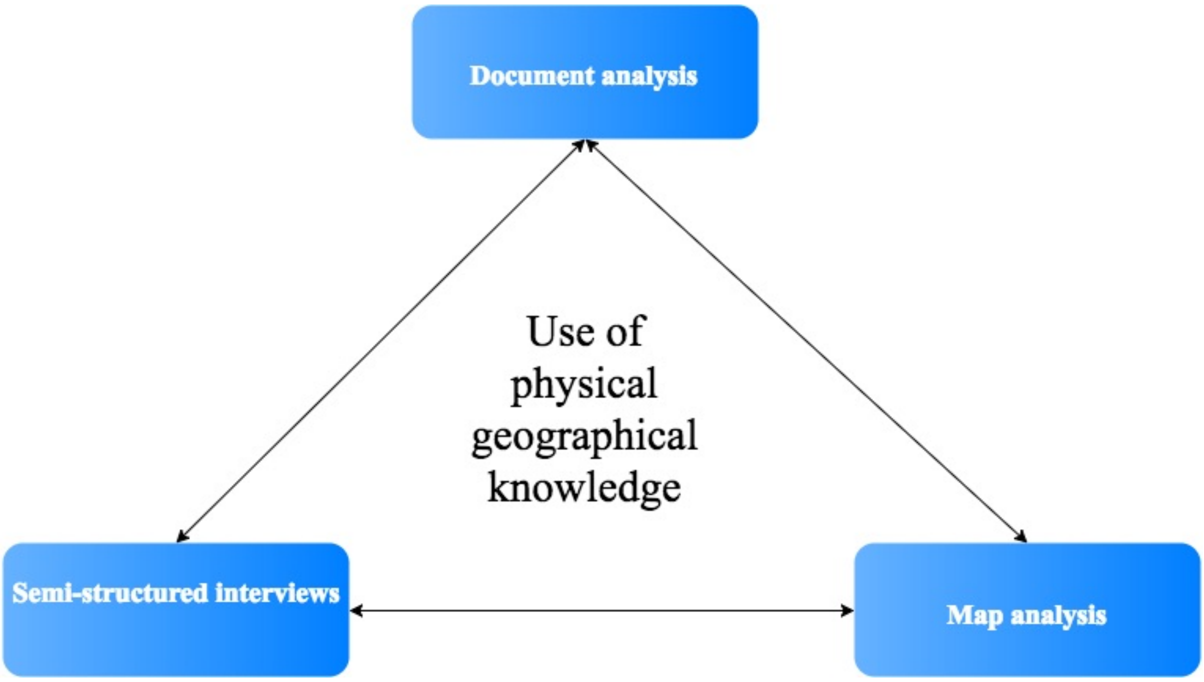

Figure 17: Illustration of the triangulation of data (Own production, 2018).

3.3 Empirical data

This subchapter introduces the various empirical data collected which will provide evidence to substantiate the findings of the case study. This includes document analysis, interviews, and maps.

3.3.1 Document analysis

For this project, several documents have been analyzed in order to gain insight into the past and current planning of Jyllinge Nordmark through various sources. The documents analyzed include municipal local plans for Jyllinge Nordmark, pilot projects for the coast protection project in Jyllinge Nordmark, and newspaper articles from Danish newspapers about the area.

3.3.1.1 Municipal plans

Through the study of various municipal plans, dating back to 1982, the historical, urban development of Jyllinge Nordmark will be provided. These will serve as historical records to elucidate the process of the development of the area. Furthermore, the plans will be utilized to clarify the extent of which physical geographical knowledge has been implemented in the planning of the area.

3.3.1.2 Pilot projects

Immediately after "Bodil" two pilot projects on the flood and flood adaptation in Jyllinge Nordmark were produced by the consulting firms Grontmij and Orbicon, respectively. Through the study of these reports, the development process of the adaptation solution for Jyllinge Nordmark will be examined, including the knowledge which has been produced during making of these pilot projects.

3.3.1.3 Newspaper articles

Newspaper articles dating back to 1961 from different newspapers will be utilized in order to shed light on past and current debate regarding the planning and development of Jyllinge Nordmark, including the positioning of the public, officials, councils etc. For this Mediestream (The Royal Danish Library) will be used, which is a media collection from the Royal Danish Library of Danish newspapers, Danish radio- and TV broadcasts from Danish channels, and commercials from TV and cinema. Currently, Mediestream has 6,146,653 newspaper pages with free access and 29,265,035 newspaper pages with limited access (Det Kongelige Bibliotek, 2018). The newspaper articles are protected by copyright law, which states that the material can only be made available for public access and use 70 years after the death of the owner/creator. All newspapers published before January 1st, 1919 are available for free access (Det Kongelige Bibliotek, n.d.). In order to gain access to the newspaper articles that are not available for public accesses the computers at the Royal Danish Library - which have full access to all Mediestream content – were used. With Mediestream it was possible to search using keywords, making the search process more efficient and allowing for easier access to relevant knowledge for the entire public. For this project, the primary search words have been: "Oversvømmelse" (flood), "Jyllinge Nordmark", "Værebro Å", and "Roskilde".

3.3.2 Semi-structured interview

Part of the empirical data collected for this project is based on interviews with various people who have experience with the case of Jyllinge Nordmark and who have been directly involved in the process of planning the adaptation project. The data is collected using the semi-structured interview method, which is based on a series of questions prepared beforehand but allows the interviewer to ask further questions and the interviewee to elaborate beyond the question (Bryman, 2012, p. 212). The data collected in the interviews supplement the types of data collected and strengthen the understanding of the case which will allow the analysis of the problem.

For this project two employees of the Municipality of Roskilde's technical and environmental department are interviewed.

3.3.2.1 Julie Nyrop Albers (JNA)

Julie Nyrop Albers works as a special consultant in the technical and environmental department in the Municipality of Roskilde. She gathers information from the different project groups in the municipality and passes it on to the steering committee, thus having a coordinating role along with some direct involvement in each project (Interview, 2:30).

3.3.2.2 Hans Christian Jensen (HCJ)

Hans Christian Jensen works as a chief consultant at the technical and environmental department in the Municipality of Roskilde. Prior to this, he worked with climate adaptation planning and transversal water planning in the municipality (Interview, 4:29). Hans is a part of the cross-field task force in the municipality where he works with public authority conditions regarding applications, permissions and coordination (Interview, 5:15). He is the head chief for the project of Jyllinge Nordmark (Interview, 6:03).

3.3.3 Maps

Through the analysis of historical maps an understanding of the physical geographical knowledge of the area and the character of the landscape through time can be achieved. The maps include historical maps in the form of high and low plain tables and topographic maps dating back to 1896 from Styrelsen for Dataforsyning og Effektivisering, and a soil classification map of Roskilde Fjord from 1978 from the Danish Centre for Food and Agriculture (DCA). The historical maps are used to analyze the knowledge about the character of the landscape through time, and the soil classification map is used to gain insight into the available knowledge about the predominant soil type under the area of Jyllinge Nordmark.

4. Analysis

This chapter analyzes the use of physical geographical knowledge in relation to the planning process in Jyllinge Nordmark, before and after the storm "Bodil" in December 2013 and in regard to the climate change adaptation projects in the area. The chapter is divided in three parts, that of knowledge existing "pre-Bodil" and that of knowledge existing "post-Bodil", with "Bodil" being the defining point for the need for physical geographical knowledge. The last part of the analysis examines the mobilization of knowledge since "Bodil", and how this has affected the Municipality of Roskilde.

4.1 Pre-Bodil knowledge

In this subchapter, the physical geographical knowledge from maps, local plans and newspaper articles, which was available "pre-Bodil", is analyzed.

4.1.1 Maps

Figure 18 below shows different historical, topographical maps of Jyllinge Nordmark. On maps A and B, the contour lines show that the northern part of Jyllinge Nordmark is low-lying and flat under elevation level 2.5 meters[2]. Furthermore, parts of the low-lying area are marked with meadow signatures, which indicate that the land was wet, some parts of the year (Svenningsen, et al., 2015 p. 3-4).

On map A in the northern low-lying area towards the fjord, the sharp unnatural boundaries between meadow signature and sandy color indicate that the characterization of the land is likely made on the basis on land use rather than soil analysis, as the unnatural boundary suggest human interference possibly in the form of drainage of the land for agricultural purposes. Historically, it has been common practice in Denmark since 1600 to drain wet soil in order to cultivate the land (Kristiansen, 2012, p. 141). Thus, it can be assumed that drainage has occurred in the area in order to utilize the area for agriculture, which has resulted in the unnatural, straight boundary between field and meadow.

Maps C and D show that some of the properties are situated in the low-lying area which on the older maps are marked with meadow signs. This was later confirmed and acknowledged by the Municipality of Roskilde in local plan 668 of 2017 (Roskilde Kommune, 2017, p. 10).

[2] The equidistance on map A is in Danish "foot", while map B is in meters, as the metric system came into effect in Denmark in 1907, with a transition period 1907-1916 (Aarhus Universitet, n.d.). However, upon inspecting the contour lines and comparing them on map A and B, it became evident that the contour lines were the same. Thus, the contour lines on map A must have been applied from a newer map.

Furthermore, the parceling shows a maximum exploitation of the area permitted for development with plots of land in many cases following - and even exceeding - the coastal protection line of 300 meters. This could be due to Jyllinge Nordmark's past as a leisure housing area, in which the coastal protection line is only 100 meters. As the area underwent a transition from leisure housing area to permanent residential area, the coastal protection line remained unaltered (Miljø- og Fødevareministariet, 2017).

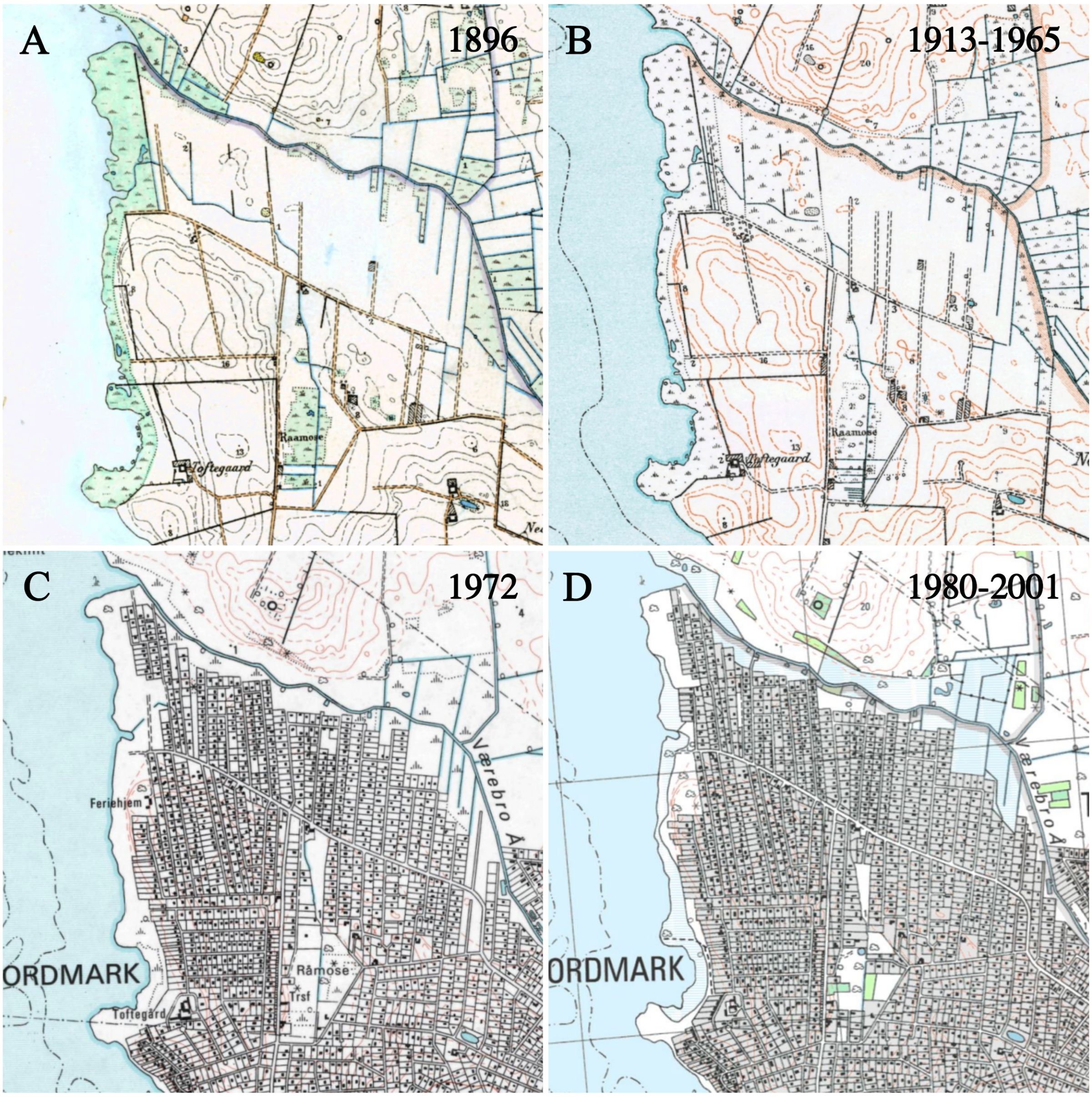

Figure 18: Historical maps of Jyllinge Nordmark. A: High plain table 1896, B: Low plain table 1913-1965, C: Topographic map 1972, D: Topographic map 1980-2001 (Styrelsen for Dataforsyning og Effektivisering, 2017).

The map of soils classification in figure 19 below shows the presence of humus on the opposite bank of the watercourse Værebro Å from Jyllinge Nordmark, in the Municipalities of Frederikssund and Egedal. This suggests a probable similar occurrence of humus on the bank of Værebro Å in Jyllinge Nordmark. However, this can only be assumed on the basis of this map, as the soil under Jyllinge Nordmark has not been classified due to the area being urban, residential zone.

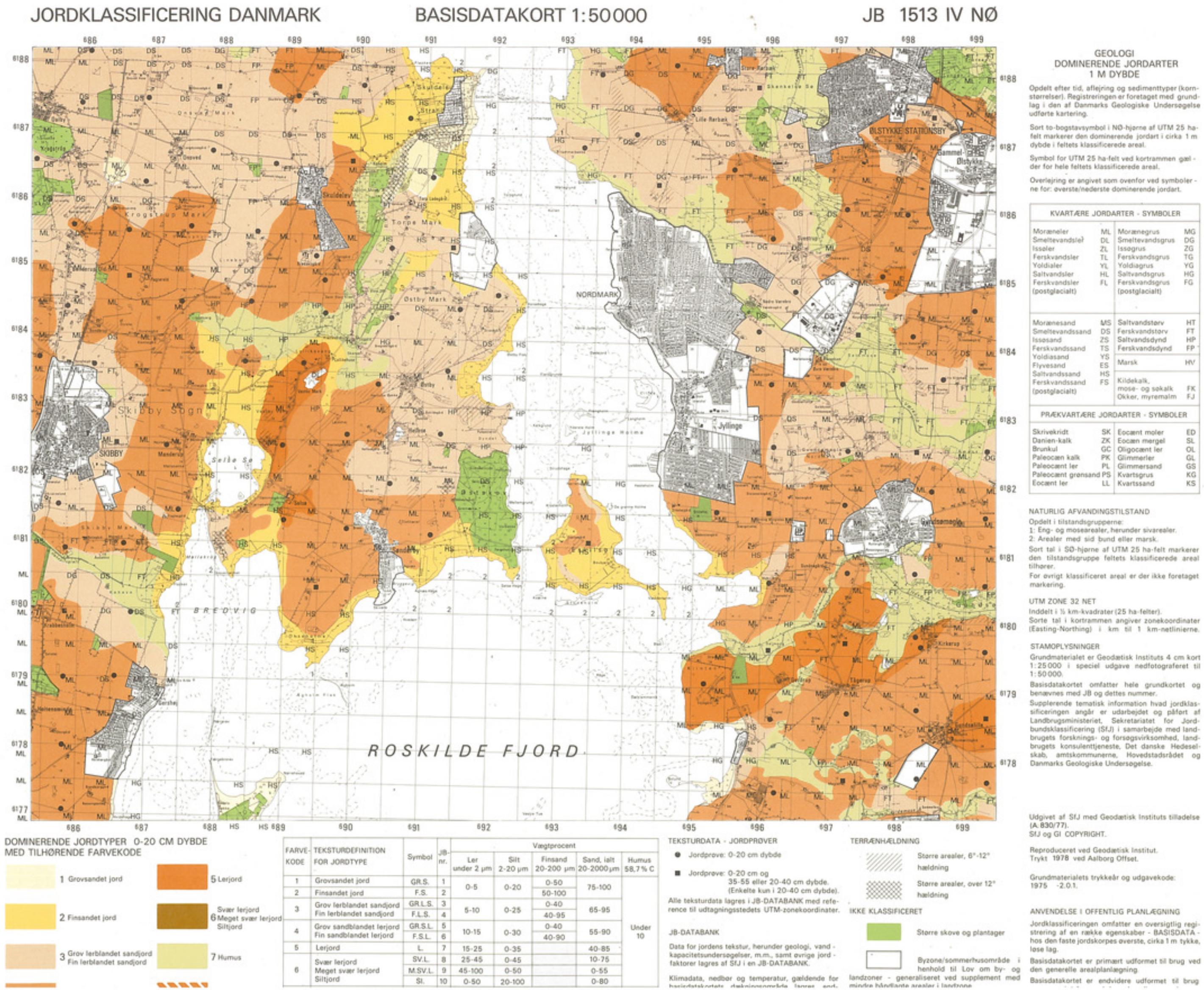

Figure 19: Soil classification around Jyllinge Nordmark, showing the predominant soil type (Nationalt Center for Fødevarer og Jordbrug, 1978).

From the map above in figure 18, it is evident that knowledge about the areas low elevation level, natural characteristic as a wet area with permanent grass cover (Svenningsen, et al., 2015, p. 6). Figure 19 shows the presence of humus in the surrounding area. The soil classification map was available before Jyllinge Nordmark was converted from rural to urban zone and before leisure homes were replaced by permanent residences in 1990.

4.1.2 Local plans

Jyllinge Nordmark has had three local plans pre-Bodil, 1.01[3], 1.27 and 1.37. Table 2 below gives an overview of the local plans of Jyllinge Nordmark and their mention of different subjects. This includes floods, requirements for terrain, climate change, maximum plot ratio, minimum limit between residence and boundary, maximum limit for both building facade and building height, number of leisure houses and permanent residences, and whether the area is officially an urban zone. Local plans 1.01, 1.27 and 1.37 are pre-Bodil, and is thus included in this subchapter of the analyses. Local plan 668 is post-Bodil and will thus be addressed in the subchapter Post-Bodil knowledge below.

Both pre-Bodil local plan 1.27 of November 14th, 1990 and 1.37 of June 24th, 1998 mention several instances of floods of up to 1.5 meters above DVR90 (Gundsø Kommune, 1990, p. 4; Gundsø Kommune, 1998, p. 3). Consequently, the local plans dictate regulations on terrain adjustments when building houses on low-lying land, with a requirement of terrain adjustment up to elevation level 1.5 meters (Gundsø Kommune, 1998, p. 8). It is unknown whether local plan 1.01 mentions floods, but since 1.01 has the same requirements for terrain adjustments of 1.5 meters when building, it is likely that floods are also mentioned in local plan 1.01.

Additional terrain adjustment of +/- 0.5 meters can be granted upon application. The maximum plot ratio has been increased from 15 percent in local plan 1.27 to 25 percent in local plan 1.37, which is a result of the area's reclassification and transition from rural area to urban zone (Gundsø Kommune, 1998, p. 7), which, as mentioned in the subchapter "Area of study" in the introduction, officially happened in 1989. Furthermore, the minimum distance between house and the boundary of the plot, has been reduced from 5 meters in local plan 1.27 to 2.5

[3] Local plan 1.01 is not available for public access, and thus the reference to the plans content is made deductively from the content of the later local plans.

meters in local plan 1.37, to accommodate the increase in plot ratio (Gundsø Kommune, 1998, p. 7).

	1.01 (20 July 1978)	1.27 (14 November 1990)	1.37 (24 June 1998)	668 (29 November 2017)
Municipality of Gundsø	x	x	x	-
Municipality of Roskilde	-	-	-	x
Rural zone	x	-	-	-
Urban zone	-	x	x	x
Leisure houses	NA	~1,200	~950	~240
Permanent residences	NA	~600	~950	~1,740
Floods	NA	x	x	x
Climate change	NA	-	-	x
Building terrain level min. 1.5 m.	x	x	x	x
Additional building terrain adjustment +/- 50 cm.	NA	x	x	x
Plot ratio max. 15%	x	x	-	-
Plot ratio max. 25%	-	-	x	x
Limit from residence to boundary min. 5 m.	x	x	-	-
Limit from residence to boundary min. 2.5 m.	-	-	x	x

Table 2: Overview of the local plans of Jyllinge Nordmark and the mention of subjects deemed pertinent for this project (Personal collection, 2018).

The pre-Bodil local plans depict an area, where floods have been a frequent occurrence, and have even influenced requirements for terrain and buildings. Thus, knowledge about Jyllinge Nordmark's challenges with flooding has been available pre-Bodil, and even as the area was converted from rural to urban zone.

4.1.3 Newspaper articles

Through the years, several articles have been written about Jyllinge Nordmark in various Danish newspapers. Table 3 below show an overview of the newspaper articles about Jyllinge Nordmark - collected through research in Mediestream - and the subjects of the articles. The articles span from 1961 to 2008, and are thus all pre-Bodil, in consistency with what was available through Mediestream.

The articles from 1961 to 1998 primarily mention the development undergoing in Jyllinge Nordmark, both before and after the area was officially reclassified as an urban area, and before living in the area permanently was permitted. A few of the articles from 1961 and 1978 mention the watercourse Værebro Å and modification of the preservation line, respectively. In the article from September 9th, 1961 about Værebro Å, it is stated that the watercourse was dug out and broadened during the 1950s in an attempt to drain the watercourse in order to utilize the area for agricultural purposes and for building leisure houses (Christiansen, 1961, p. 7).

The article from August 2nd, 1978 is a notice from the Board of Preservation (Fredningsstyrelsen) under the Danish Ministry of Environment (Miljøministeriet) about the abolition of building boundary for the area of Jyllinge Nordmark, which at that time was covered by the then valid local plan 1.01. This is due to an appendix in the local plan with a map showing a new "preservation line" along the watercourse Værebro Å (Fredningsstyrelsen, 1978, p. 17).

The first article mentioning flooding and weather in Jyllinge Nordmark is on February 19th, 1999, in which the then Storm Surge Committee (Stormflodsrådet)[4] declare the flood of 4th-7th February 1999 an official storm surge, making the residents of Jyllinge Nordmark eligible for applying for compensation (Andersen, 1999, section 2, p. 2). However, a year later Jyllinge Nordmark again experiences a flooding on January 30th. In an article from February 8th, 2000, the Storm Surge Committee declared the flood this time was not a storm surge, rendering the affected residents' ineligible to apply for compensation. The reason why this flood was not recognized as a storm surge was due to the frequency of flooding to this extend, which occurs in Jyllinge Nordmark approximately biannually. This article is also the first one mentioning flood risk (Andersen, 2000, section 2, p. 5).

The articles from October 17th, 2000 are the first to mention the idea of flood adaptation in Jyllinge Nordmark, the suggestion being put forth by the Storm Surge Committee. However, the project of building a dyke was deemed too costly for the then Municipality of Gundsø, consequently leaving the house owners in the area to pay for the damages to their houses caused by the flood, since the insurance does not cover it, as the flood was not an official storm surge. Marie Egsgaard from the Technical- and Environmental Services at the Municipality of Gundsø is quoted in the articles saying:

> "*It must be up to the plot owners themselves to do something. We do not consider this to be the Municipality's problem - people knew that the houses were low lying when they bought them.*"
>
> (Marie Egsgaard in Møller, 2000, p. 1).

The Storm Surge Committee justified their decision for not ruling the flood in Jyllinge Nordmark a storm surge, due to the frequent occurrence of floods in the area. According to the law on storm surge and storm damage, a storm surge only statistically occurs every 20 years

[4] The Storm Surge Committee was established in 1991 with the purpose of evaluating and determining the severity of a storm and weather storm afflicted are eligible to apply for compensation (Andersen, 1999, section 2, p. 2). The Storm Surge Committee was later changed to the Storm Committee (Stormrådet) in 2000, after the implementation of the law on storm surge and storm damage of May 17th, 2000.

measured in flood level above DVR90, and since the flood of 2000 reached 1.5 meters above DVR90, which happens annually in Jyllinge Nordmark, it was not deemed a storm surge. The Municipality of Gundsø suggests instead to possibly allow for further terrain adjustments when building new houses, to avoid flooding (Møller, 2000a, p. 1; Møller, 2000b, section 2, p. 5).

Despite the frequent flooding of Jyllinge Nordmark, the article of November 2nd, 2000 reports of record high relocation to Jyllinge Nordmark, with it being the 6th most popular place in Denmark to move to. The main reasons given for moving to Jyllinge Nordmark are the beautiful surrounding, cheap plots, close proximity to Roskilde, and easy access to Copenhagen. From 1995 to 2000 Jyllinge overall saw a 14 percent increase in population, while Jyllinge Nordmark alone experienced an 8 percent increase in population, despite the national average being 2 percent (Møller, 2000, section 2, p. 6).

In the article from November 3rd 2006, a more detailed explanation is given for the physical scientific causes for storm surges in Jyllinge Nordmark, where it is explained how the water is pressed into the fjord and further into Værebro Å, where the water's retreat back into the fjord is restricted by the wind and the high water level in the fjord itself (Anon, 2006, section 2, p. 3).

Finally, in the articles from May 16th, 2008 the possibility of building a sluice at the end of Værebro Å is mentioned, in relation to a suggestion regarding digging out and partially draining Værebro Å in order to lower the water level, which is deemed impossible, due to this having been done before back in the 1950s, which was also mentioned in the article from 1961. An unfortunate and unforeseen consequence of lowering the water level has resulted in several houses sinking with between 80-200 centimeters from the humus settling and compressing, as explained by biologist Kåre Fog, causing some already low-lying houses to lie even lower, further increasing the risk of floods (Kimer, 2008a, section 2, p. 3; Kimer 2008b, section 2, p. 3). This is in accordance with the soil classification map in figure 19, which indicates the presence of humus in the Værebro river valley. "*Basically, many of the houses in Jyllinge Nordmark should never have been built*" (Kåre Fog in Kimer, 2008b, section 2, p. 3 – our translation).

	Reference	Flood	Flood risk	Weather	Geology / Terrain	Flood adaptation	Areal Development	Water Course Værebro Å	Preservation line modification	Houses sinking
09.09-61 - Berlingske Aftenavis	Christiansen, p. 7						x	x		
09.09-76 - Dagbladet	Anon, p. 11						x			
14.03-77 - Frederiksborg Amtsavis	Anon, p. 14						x			
14.03-77 - Frederiksborg Amtsavis	Anon, p. 14						x			
01.07-77 – Dagbladet Roskilde og Omegn	Anon, p. 9						x			
02.08.78 - Frederiksborg Amtsavis	Fredningsstyrelsen, p. 17								x	
15.02-83 - Frederiksborg Amtsavis	Anon,12						x			
14.03-87 - Dagbladet Roskilde Tidende	Neersø, s. 2, p .6						x			
02.09-87 - Dagbladet Roskilde Tidende	Neersø, p. 11						x			
19.03-90 - Dagbladet Roskilde Tidende	Kure, p. 9						x			
19.03-90 - Dagbladet Roskilde Tidende	Kure, p. 9						x			
08.08-90 - Dagbladet Roskilde Tidende	Westpahl, p. 9						x			
14.11-90 - Dagbladet Roskilde Tidende	Hansen, p. 10						x			
18.06-94 - Dagbladet Roskilde Tidende	Anon, s. 2, p. 4						x			
09.09-95 - Dagbladet Roskilde Tidende	Gram, s. 2, p. 5						x			
04.10-95 - Dagbladet Roskilde Tidende	Gram, s. 2, p. 5						x			
15.01-98 - Dagbladet Roskilde Tidende	Skovse, s. 2., p. 3						x			
27.03-98 - Dagbladet Roskilde Tidende	Lynerup, s. 2, p. 6						x			
19.02-99 - Dagbladet Roskilde Tidende	Andersen, s. 2, p 2	x		x						
08.02-00 - Dagbladet Roskilde Tidende	Andersen, s. 2, p. 5	x	x	x						
17.10-00 - Dagbladet Roskilde Tidende	Møller, p. 1	x	x	x	x	x				
17.10-00 - Dagbladet Roskilde Tidende	Møller, s. 2, p. 5	x	x	x	x	x				
02.11-00 - Dagbladet Roskilde Tidende	Møller, s. 2, p. 6						x			
03.11-06 - Dagbladet Roskilde Tidende	Anon, s. 2, p. 3	x		x				x		
26.05-07 - Dagbladet	Kimer, s. 2, p. 4								x	
07.07-07 - Dagbladet	Andersen, s. 2, p. 3	x		x						
16.05-08 - Dagbladet	Kimer, s. 2, p. 3			x		x		x		
16.05-08 - Dagbladet	Kimer, s. 2, p. 3	x			x	x	x	x		x

Table 3: Overview of the newspaper articles regarding Jyllinge Nordmark and the content of these (Personal collection, 2018).

It seems that before Jyllinge Nordmark was converted from rural zone to urban zone in 1990 - and people started living there permanently - that annual floods that occur in Jyllinge Nordmark's low-lying areas, were not reported on in the newspapers. Only after an above average population growth and more permanent residences in the area, articles regarding floods, eligibility for compensation, and suggestions of flood adaptation were published. This suggests that when it was primarily leisure houses that were flooded, the knowledge about the annual floods were not shared, as they were possibly considered a minor problem, due to the limited extent of damages. However, the development of the area seems to have made the floods problematic, as the floods now affect people's permanent houses and their daily life, and the flood damages are now costlier, which has resulted in more articles reporting on the knowledge of floods in the area.

4.1.4 Pre-Bodil summary

The result of the gathered pre-Bodil data, as introduced in this subchapter, shows varying types of pre-Bodil knowledge about Jyllinge Nordmark from several different sources of media. Thus, there were a considerable number of warnings about the difficulties experienced in the area. This includes maps - as introduced above in figure 18 and 19 - as old as about 100 years showing that the low-lying area of Jyllinge Nordmark was classified as "wet" even back then. Moreover, a soil classification map from 1978 show the presence of humus along the Værebro river valley on the side of the Municipalities of Frederikssund and Egedal, which can be presumed to be similar on the Jyllinge Nordmark side in the low-lying area. This is later confirmed by the Municipality of Roskilde in local plan 668 of 2017. Furthermore, an article from May 16th, 2008 reports that several houses has sunk as a result of the humus settling and compressing. Moreover, every local plan for Jyllinge Nordmark since 1990 has mentioned regular flooding in the area. Despite this the area was still officially converted into an urban residential zone with permanent houses which is evident from multiple articles as well as the local plans. Jyllinge Nordmark even became one of the most popular zip-codes to move to in 2000, even after several articles about regular floods of up to 1.5 meter and ineligibility in regard to storm and flood damage compensation in these cases. Knowledge about the frequent floods of Jyllinge Nordmark was, however, only reported on in the newspapers after an increasing number of people started to live there permanently, making the damages of the floods more extensive, and thus the floods more problematic.

4.2 Post-Bodil knowledge

In this subchapter, the physical geographical knowledge from the local plan and pilot projects, which was available "post-Bodil", is presented.

4.2.1 Local plan

Disregarding local plan 612[5] of 2015, local plan 668 is the first post-Bodil local plan for Jyllinge Nordmark. As it is evident in table 2 local plan 668 includes the same requirements for terrains adjustments, plot ratio, and limit to boundary as the previous local plan 1.37. Local plan 668 is much longer than the previous local plans. The main additions to the new local plan is a summary of the effect of "Bodil" and a presentation of flood adaptation projects for Jyllinge Nordmark. In addition to the coastal protection project in form of dykes along the banks of Roskilde Fjord and Værebro Å and the sluice at the mouth of Værebro Å, local plan 668 also includes suggestions for wastewater management and rainwater discharge and percolation. In connection to the coastal protection projects in Jyllinge Nordmark an environmental impact assessment (Vurdering af Virkning på Miljøet, VVM) has been devised, due to the projects extending into the Natura-2000 protected area of Roskilde Fjord, onto nationally protected nature, and along a nationally protected watercourse (COWI in Roskilde Kommune, 2017, 104), which is included in local plan 668 in a, for the local plan, special edition specifically for the local municipal plan. Furthermore, local plan 668 states that new requirement for basement flooring, which must be at elevation level 1.5 meters above DVR90 (Roskilde Kommune, 2017, p. 22). Moreover, local plan 668 is the first local plan to address the issue of a high groundwater table in parts of Jyllinge Nordmark (Roskilde Kommune, 2017, appendix 2), and the fact that parts of the area was once characterized as wetland (Roskilde Kommune, 2017, p. 10).

Local plan 668 is also the first local plan for Jyllinge Nordmark to take climate change into consideration which includes prognosis that show an increased frequency in both storm surges and torrential rain storms and a sea level rise of 80 centimeters before the end of the century, and a 40 centimeter sea level rise by 2060 (Roskilde Kommune, 2017. p. 7). The results of these prognosis have been taken into account in the planning of the climate adaptation projects.

[5] Local plan 612 for Jyllinge Nordmark, was a post-Bodil local plan that was declared invalid due to procedural errors and replaced by local plan 668. Local plan 668 is thus almost identical to local plan 612, apart from adjustments in regard to the flood adaptation projects along the bank of Roskilde Fjord and the watercourse Værebro Å, and a few other adjustments (Roskilde Kommune, 2017, p. 9). Due to the cancellation of local plan 612, this is not included in the collected empirical data and thus neither in table 2 in the above subchapter "Pre-Bodil".

Since "Bodil", a lot of new knowledge has been produced about the physical geography of Jyllinge Nordmark, floods in Jyllinge Nordmark, and climate change and the effects of this. This is evident when comparing the new local plan 668 to the old local plans 1.01, 1.27 and 1.37, where local plan 668 contains a lot of additional information on these areas compared to the old local plans.

4.2.2 Pilot projects

In the wake of "Bodil", the municipality of Roskilde has had several reports made about the flood adaptation projects in Jyllinge Nordmark by different consultant firms. This includes reports by Grontmij and Orbicon, to which a variety of new knowledge was produced for the presented flood adaptation solutions.

4.2.2.1 Grontmij

The Grontmij report was the first report made about Jyllinge Nordmark after "Bodil", published May 26th, 2013, 6 months after "Bodil". In the report, Grontmij recommends that the flood adaptation projects protect against flood events up to 2.2 meters DVR90 in Jyllinge Nordmark. Furthermore, depending on whether or not a regional flood adaptation project is established, an additional 55 and 20 centimeters should be added on the fjord and watercourse protection project, respectively. If a regional solution is established, no further addition to the local solutions are needed (Grontmij, 2014, pp. 7-8). The protection level is assessed on the basis of high tide statistics from Roskilde Fjord measured from 1992 to 2012 and historical flood tide levels estimated by the Municipality of Roskilde on the basis of archive information and compared to information gathered about "Bodil" (Grontmij, 2014, p. 7). However, the high tide statistics has several disruptions in the measurements with missing data, resulting in an effective measuring period of only 17.8 years. To compensate for the short measuring period and the missing data from Roskilde Fjord, the high tide measurement has been correlated to the high tide measurements of nearby measuring stations of Holbæk and Hundested, which measured from 1972 to 2012 but also experienced disruptions in the measurements, resulting in an effective measuring period of 28.8 years. It is on the basis of these high tide measurements the Storm Committee (Stormrådet) assess the severity of the storm compared to a storms statistical occurrence, deeming "Bodil" a statistical 1000-year event. However, even with the added data, the effective high tide measuring period is still short, impugning the reliability and validity of assessments based on these measurements (Grontmij, 2014, p. 6).

In addition to the high tide measurements and the estimated, historical flood tide levels, the prognosis about climate change and future sea level rise from IPCC is also taken into account, in the assessment of the needed protection level for the flood adaptation projects. The IPCC estimate, with great uncertainty, that future sea level will rise 9-88 centimeters during this century. A sea level rise of 30 centimeters is thus considered realistic (Grontmij, 2014, p. 7).

The report from Grontmij highlights the need for further knowledge about the soil composition. It is noted that there are reports of "soft soil", presumably in the form of old watercourse deposits and sedimentations, for up to several meters in depth at the low-lying areas of Jyllinge Nordmark. This is consistent with the assumptions made on the basis of the soil classification map in the subchapter "Maps" in the "Pre-Bodil" subchapter above. Furthermore, the Grontmij report urges for a clarification of the need for protection against the reported phenomenon of groundwater being pressed up to the ground surface in the events of high water level in the fjord and Værebro Å, which geotechnical borings could explicate (Grontmij, 2014, p. 11).

The Grontmij report highlights the need for proper data and further knowledge in various fields, including high tide frequency and level, effects of climate change, soil composition, and groundwater level, in order to best assess and plan for Jyllinge Nordmark.

4.2.2.2 Orbicon

December 16th, 2014, a year after "Bodil", Orbicon published a comprehensive report about local solution for protection against floods in Jyllinge Nordmark. In the report several technical solutions and even different variations of the different solutions were presented, allowing the Municipality of Roskilde to choose the combination of solutions most appropriate, in regard to cost-effectiveness, impact on nature, planning etc. In relation to the drawing up the various solutions, Orbicon conducted research in the area using models and samplings.

To determine the dimensional, extend of a flood event with high tide in Roskilde Fjord and high water level in Værebro Å, the hydrological and hydraulic investigation the hydrodynamic integrated hydrological and hydraulic models, MIKESHE and MIKE11 respectively, have been used to convert precipitation, temperature, evaporation in the topographical catchment area into runoff, water flow and water level for Værebro Å. This was combined with data on the physical dimensions of Værebro Å from 2008 and measurements of water level in Roskilde Fjord from 1993 to 2002, Værebro Å from 1978 to 2014, and the water flow of Værebro Å from 1979 to 2013 (Orbicon, 2014, p. 10). The maximal measured water level of Roskilde Fjord and the maximal simulated water flow of Værebro Å was then combined as an expression of the most critical possible situation under current climate. Future climate was then taken into account with reference to IPCC's 5th assessment report in regard to future sea level rise, and GEUS (Geological Survey of Denmark and Greenland) in regard to future water flow in Værebro Å (Orbicon, 2014, pp. 11-12). In the final assessment of Værebro Å the manning value was calculated, showing that the correlation between water level and water flow increasingly weakens downstream Værebro Å due to stowage, until the correlation is practically non-existent at the mouth of Værebro Å, where the watercourse meets the fjord, due to the bottom of the watercourse being below elevation level 0 DVR90, as is evident from figure 20 below, and the high water level in the fjord reversing the current, as it presses into Værebro Å (Orbicon, 2014, pp. 12-17).

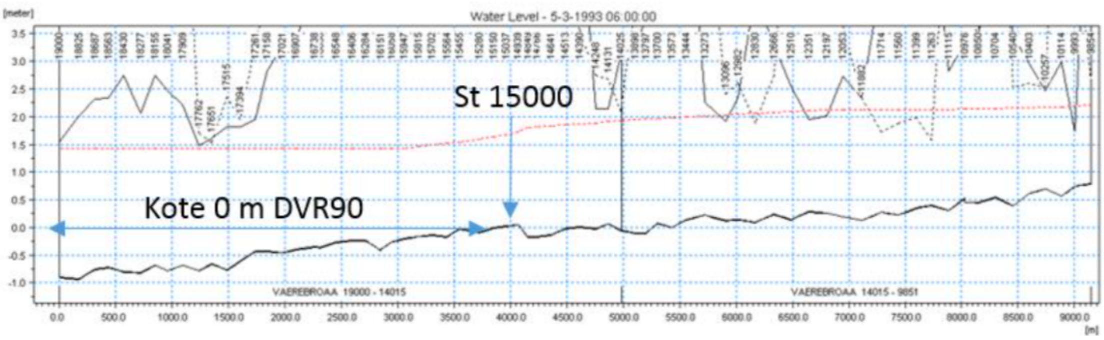

Figure 20: Elevation level of the bottom of Værebro Å. The elevation level is below 0 DVR90 downstream from water level measuring station 15000, which is located 4 kilometers upstream Værebro Å (Orbicon, 2014, p. 13).

In order to determine stability-, setting- and water flow capacity of the soil layers below the future dykes, geotechnical research of the Jyllinge Nordmark was carried out, consisting of 10 geotechnical borings, of up to 12 meters in depth, along Værebro Å. In each boring depth of the groundwater table measured, and a slug test was conducted in order to study the flow capacity of the surrounding soil layers. Additionally, geophysical measurements were made using the DUALEM method, an electromagnetic inductive method for mapping, with a differential GPS, variations in soils electric conductivity for up to 8 meters in depth. This data was then coupled with the geological data from the borings, and a profile line was made for the entire stretch of Værebro Å in Jyllinge Nordmark, which can be seen in figure 21 below (Orbicon, 2014. pp. 18-21). The final assessment of the geology was that the water flow capacity of humus and sand/gravel and the high groundwater table could result in water flowing under the dykes at high water level in the fjord and Værebro Å, causing structural impairment of the dykes and flood behind the dykes, if the water flow is not prevented (Orbicon, 2014, pp. 22-23).

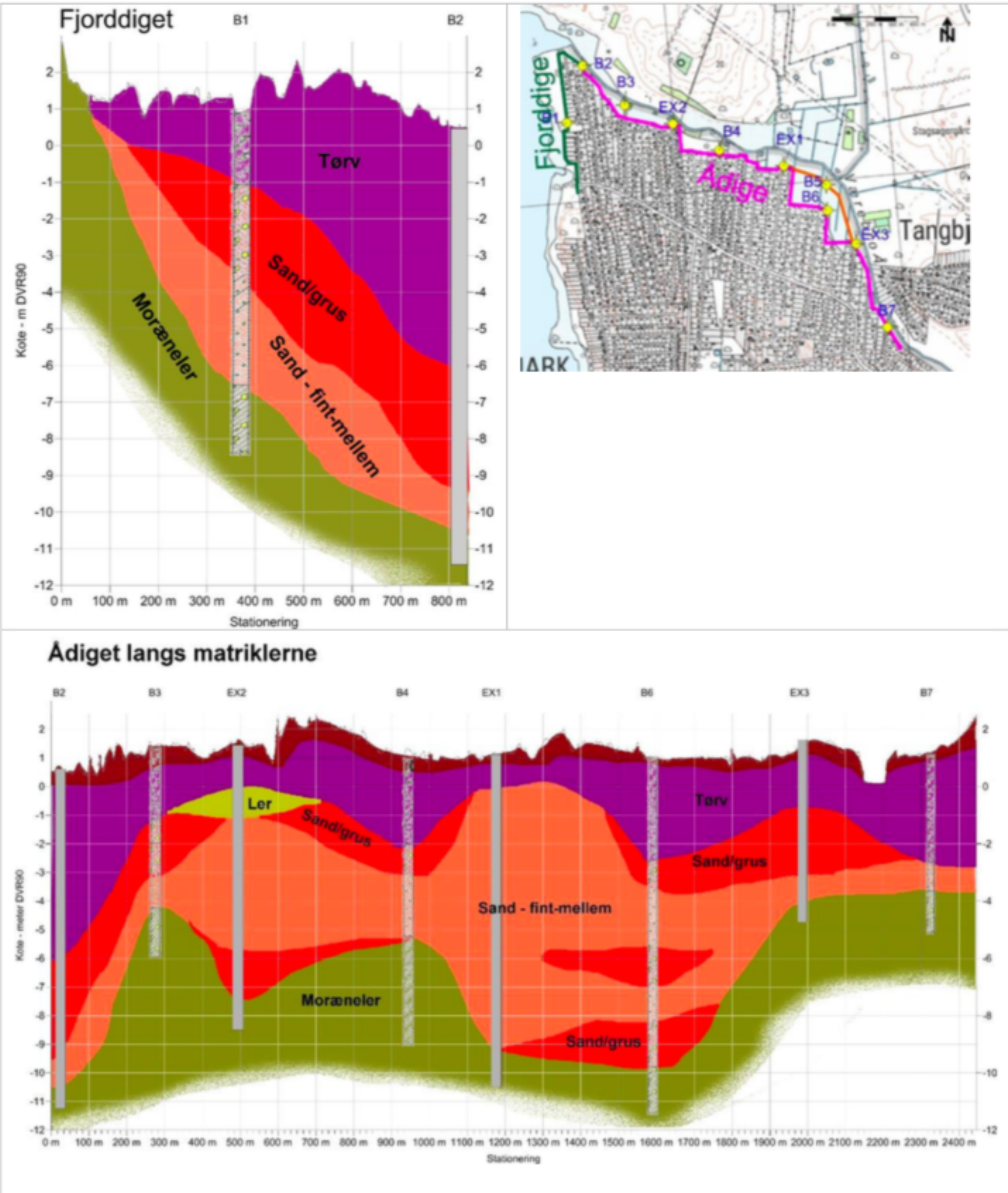

Figure 21: Geological section along Værebro Å's dyke-line (Orbicon, 2014, p. 22).

The Orbicon report has produced a massive amount of knowledge about Jyllinge Nordmark, using both measured and modelled data in order to gain a better understanding of the hydrological system of Værebro Å, the groundwater level, and water flow capacity of the soil in Jyllinge Nordmark. Furthermore, Orbicon has conducted extensive research in the area with borings and electromagnetic inductive mapping of the soil, which has confirmed the suspicion of the presence of a large amount of humus in the upper soil layers, which can cause houses to sink and water to flow under the dykes causing further flooding, factors that must be taken into account when planning the final solution.

4.2.3 Post-Bodil summary

The pilot projects from Grontmij highlighted the problems related planning, and decision- and policy making on the basis of insufficient data with the high tide measurements. The report also points out areas where further data is needed in order to properly plan, including effects of climate change, soil composition and groundwater level.

The Orbicon report produces extensive data about soil composition and groundwater through sampling and testing using both measured and modelled data. The research revealed soil conditions that needs to be taken into account when planning the coast protection project, and in general in the planning of the area, in order to avoid it becoming a future problem by undermining structures and/or causing further floods.

The newly produced knowledge from the pilot projects, and the increasing amount of reliable knowledge about climate change from the IPCC reports, has given rise to a more comprehensive local plan 668 from the Municipality of Roskilde, in which planning on a larger scale is taken into account, including municipal, regional and national planning. This results in planning of Jyllinge Nordmark which incorporate several different aspects resulting in more integrated and long-term solutions.

4.3 Mobilization of Knowledge

The storm “Bodil” of December 5th, 2013 was in many ways an expression of climate change, and a turning point for flood adaptation planning in the Municipality of Roskilde. The Municipality of Roskilde did have a climate adaptation plan prior to “Bodil”, but after “Bodil” the focus on climate adaptation increased, especially for Jyllinge Nordmark. After “Bodil” the Mayor of the Municipality of Roskilde, Joy Mogensen, at a public meeting, promised that the Municipality of Roskilde would work towards finding the best and right solution together with the affected citizen. She further stated that the solution must not be dragged on, and the Municipality of Roskilde has the financial means to pay their share of the solution, and therefore should finance the project to the extend the law permits (Roskilde Kommune, 2014b, p. 1). The Mayor closed the public meeting stating:

> “*I hope that you will continue to suggest ideas for how the Municipality can help you make your daily life function. I know that that does not help in regard to insurance and economy, but we must get all families safely through this - take care of each other. And voice how the Municipality can help you - get home safely!*”
>
> (Joy Mogensen in Roskilde Kommune, 2014b, p. 4 - our translation).

These statements from the Mayor of Roskilde positioned the Municipality differently in the coast protection project than other municipalities previously in similar projects. Usually coast protection is considered a private problem planned, executed and financed by the individual plot owners, but in the case of Jyllinge Nordmark the Municipality of Roskilde agreed to help the affected citizens plan, execute and finance the project, thus taking on the conflicting roles of both building planner and the coordinator of the authorities that issues permits (Interview, JNA, 9:41 – see appendix II). The “final” license according to the Coastal Protection Act is issued by the Ministry of Environmental protection and Agriculture (JNA, mail correspondence, see appendix II).

However, the political commitment to the Jyllinge Nordmark situation and the Mayors ambition to expedite the solution process resulted in an immediate generation of an extensive amount of new knowledge in a short amount of time. Within a year after “Bodil” two pilot projects were produced by Grontmij and Orbicon respectively, as mentioned in the previous chapter. The data and knowledge generated is then stored in an Electronic Project and Document Handling (Elektronisk sags- og dokumenthåndtering, ESDH) system, which is a software program designed for storing documents using individual ID numbers in an internal database, for easy search and access, and is commonly used in municipalities and private companies (JNA, mail correspondence – see appendix III).

In addition to expediting the generation of knowledge, "Bodil" resulted in a structural change made to the organizational framework of the various departments in the Municipality of Roskilde. A Steering Group, as an internal organization, was formed and consisted of the Municipality's Technical Director (Teknisk direktør), Chief of Roads and Green Areas (Chef for veje og grønne områder), and the Chief of environment (Miljøchef), as seen in figure 21 below in purple (Interview, JNA, 2:07 - our translation, see appendix II).
Furthermore, a Task Force was established which included the Department of Roads and Green Areas in regard to maintenance of the construction, expropriation and nature; the Department of Environment in regard to rain- and wastewater management, the process in accordance to the Coastal Protection Law and the acquirement of the ten necessary separate licenses or dispensations according to other Acts and regulations[6] including residential involvement, and establishment of a dyke guild (digelag); the Department of Planning and Development in regard to the local plan, the management plan for water and climate change, and the environmental impact assessment (VVM); and finally the Secretariat for City, Culture and Environment in regard to press and communication (Interview, JNA, 1:05 - our translation, see appendix II + mail correspondence, see appendix III).

In the Task Force, several sub-projects were formed including a project group for the local plan, rain- and wastewater management, management plan for water and climate, Jyllinge Nordmark, inner fjord west, inner fjord east, the Viking Ship Museum, and the regional coastal protection, as seen in figure 22 below in yellow. Press and Communication then works across all the sub-projects, as seen in figure 22 below in white. The taskforce holds weekly meetings, communicating across the various sub-projects, and then "feed" knowledge and information to the Steering Group, which then make decisions and coordinate based of this (Interview, JNA, 1:29 – our translation, see appendix II + mail correspondence, see appendix III). The Steering Group thus essentially work as a facilitator, coordinating the knowledge received from the sub-

[6] The Nature Preservation Act (Åbeskyttelseslinje, 2 fredninger), The River and Watershed Act (reguleringssag).

project groups via the Task Force, making decision on an informed basis, resulting in a more integrated project solution.

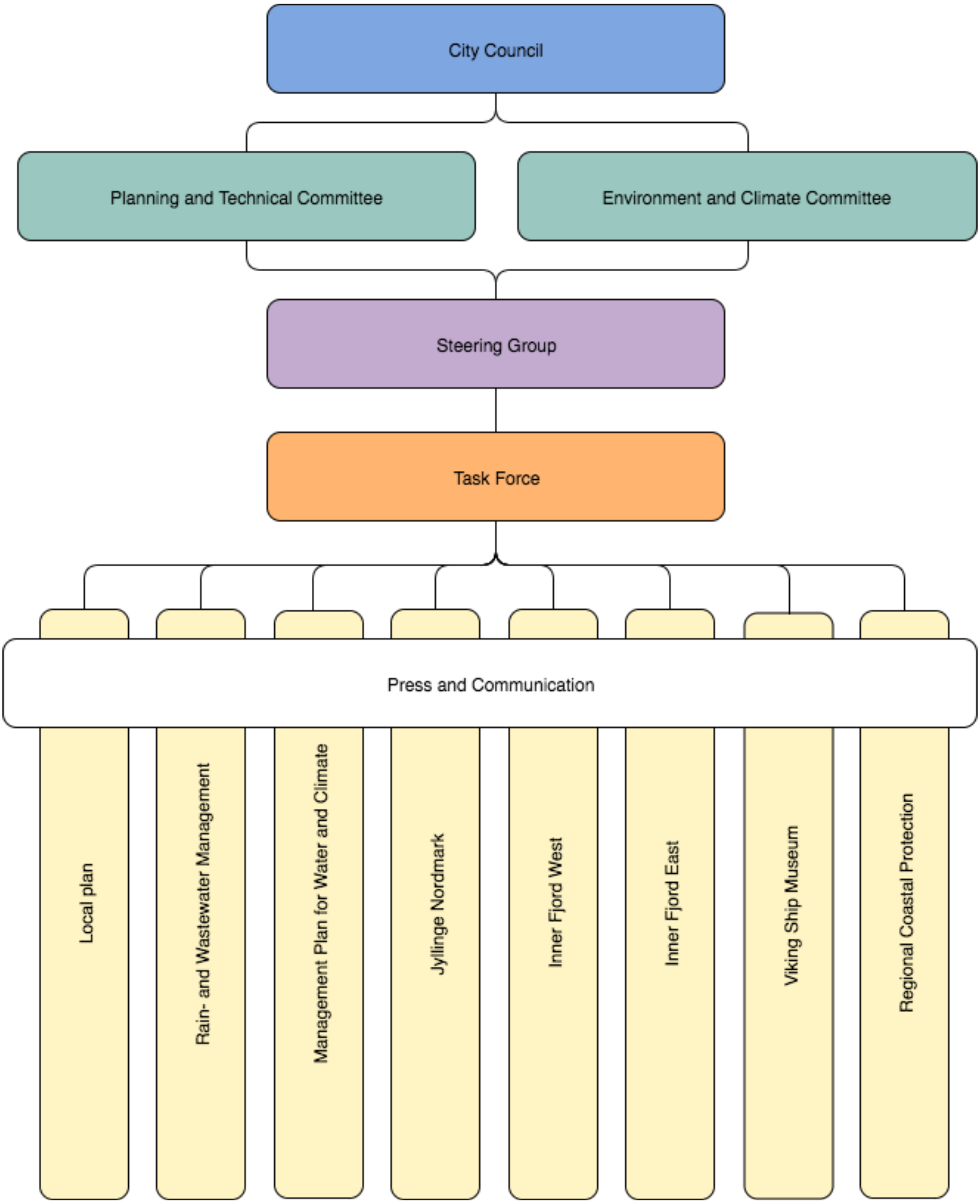

Figure 22: The organizational framework of the Municipality of Roskilde (Own production, 2018).

In the interview, Julie Nyrop Albers gives insight into the process the Municipality of Roskilde initially had to go through immediately after "Bodil". Julie states:

> "*We have never had those, a coastal protection project, before in the Municipality of Roskilde, so when we were hit by 'Bodil'* [...] *we had to start from scratch with 'There is a coastal protection law and what does that say? And what process must we go through?' And call other municipalities to find out 'How do you do this?'* [...] *And the dialog with the Coastal Authority all the way through. 'How do we do this?' So it was a nice collaboration in that way.*"
>
> (Interview, JNA, 6:49 – our translation, see appendix II).

Julie describes the collaboration between the Municipality of Roskilde and other municipalities and the state Coastal Authority, confirming both a vertical and horizontal collaboration on both the municipal, regional and state level, as illustrated in figure 13, in chapter 2.4.3 about ICZM in Denmark.

Upon advice and guidance from other municipalities and the Coastal Authority, the Municipality of Roskilde then made a flood risk assessment based on the standard formula:

$$Flood\ risk = Probability\ x\ Value\ loss$$

For calculating the Probability, the Municipality of Roskilde uses the statistical tool for Extreme Value Analysis (EVA) in order to "[...] *estimate the likelihood of the occurrence of extreme values based on a few basic assumptions and observed/measured data.*" (Benstock & Cegla, 2017, p. 67), in accordance with the climate adaptation plan (JNA, mail correspondence – see appendix III). The flood risk assessment is visualized with map, which gives an overview of where the biggest risks are, and thus, which areas must be prioritized. On these maps, Jyllinge Nordmark appear to be at high risk (Roskilde Kommune, 2016b).

Jyllinge Nordmark being at high risk of flood, the data for estimating flood frequency being insufficient, and the Mayor of Roskilde's promise that a suitable solution must be found and realized quickly, prompted the Municipality of Roskilde to make drastic changes to the "regular" planning process. This resulted in the Municipality of Roskilde conceiving the so-called "parallel-process", as visualized in figure 23 below. In the parallel-process, the various plan processes have been coordinated in order to align the periods of time for complaints have been, so that they occur simultaneously, cutting the waiting time down and shortening the process.

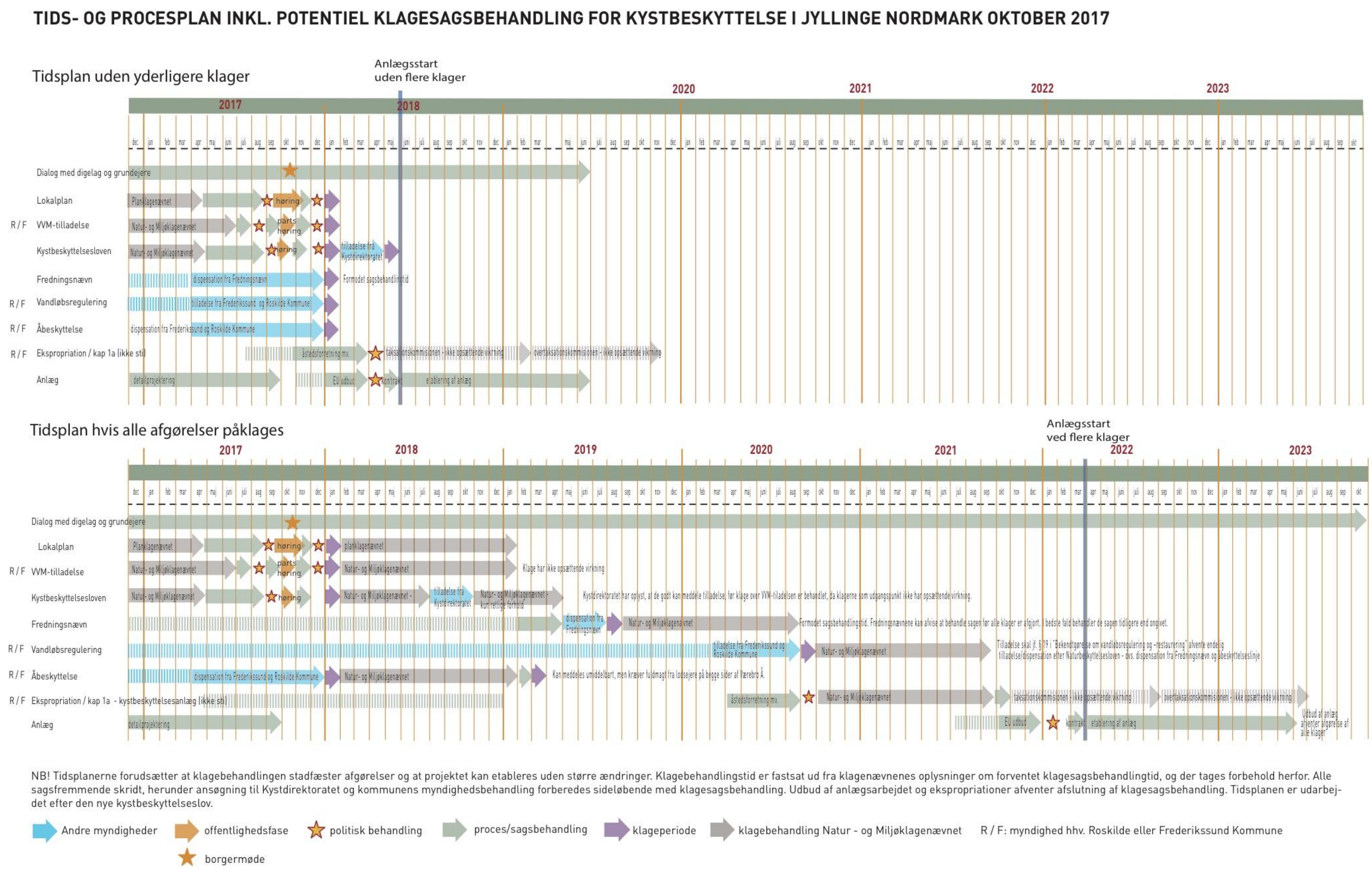

Figure 23: Side-by-side timeline comparison of the regular process and the parallel-process (Roskilde Kommune, 2017).

The idea seemed great in theory, however, it proved difficult in praxis. Hans Christian Jensen explains that every time an adjustment is made to the project, the process has to, more or less, start over. Hans states:

> "*The thing that has burdened this project, also its progress, has been* [...] *all the adjustments. Because there are authority evaluations and plan documents and public debates at various times in the process. So, we have fallen into those traps sometimes, that we have had a project drawn up and then we have been through a formal hearing in regard to VVM and VVM-report and such, and then time runs out. Then feedback is received which has resulted in us making changes to the project, and then we have sent an application to the Coastal Authority and then it is all of a sudden, a different project that has been VVM-assessed that has been applied for.* [...] *According to the coast protection law we must account for the project and the costs. And then account for a project which is slightly different than the one that is going to be realized, and at a slightly different price.* [...] *And that is the kind of thing boards of complaints just sit and wait for.* [...] *Then you are back to square one."*
>
> (Interview, HCJ, 19:35 - our translation, see appendix II).

4.3.1 Mobilization summary

"Bodil" has affected the recognition of the vulnerability of Jyllinge Nordmark, which in turn has expedited the generation of physical geographical knowledge about the area. Furthermore, "Bodil" has affected the organizational structure of the departments of the Municipality of Roskilde, which has led to increasingly integrated work between the departments and an extensive collaboration between the Municipality of Roskilde, other municipalities and State Authorities. In addition, the urgency of the situation has prompted the development of a new, time-saving planning process, where plans are produced and processed simultaneously.

4.4. Analysis summary

Despite the available physical geographical knowledge about Jyllinge Nordmark, which show that the area historically has been characterized as wet and the despite the local plans mentioning frequent floods in the area, Jyllinge Nordmark nonetheless, underwent an urban development. Jyllinge Nordmark was officially converted from rural- to urban zone in 1989, and houses were built on the low-lying parts of the area. As evident from the newspaper articles the frequent floods of the area were not reported on much before people started permanently residing in Jyllinge Nordmark.

After "Bodil", it became apparent that Jyllinge Nordmark had a high vulnerability to floods, and future climate change would cause increasingly frequent flooding. Therefore, the Municipality of Roskilde immediately initiated a flood adaptation project in collaboration with the residences. For this, two pilot projects were produced in the first year after "Bodil", in which a massive amount of knowledge was rapidly generated. Furthermore, the new local plan for Jyllinge Nordmark included extensive information about the floods in the area contrary to the previous ones.

In relation to the floods experienced as a result of "Bodil", the Municipality of Roskilde made structural changes to the organization of the departments. The establishment of a Steering Group and a Task Force should ensure more integrated solutions. Furthermore, the urgency of the Jyllinge Nordmark situation required a quicker planning process that usual, which lead to a compressed time schedule for the planning process being devised.

5. Discussion

The analysis of the pre-Bodil knowledge clearly shows that physical geographical knowledge about Jyllinge Nordmark existed in various forms before the conversion of Jyllinge Nordmark from rural- to urban zone. Whether decision makers were unaware of the knowledge or the knowledge was purposely ignored is unclear. However, there has been a conspicuous coincidence between politicians in both the Municipality of Gundsø and the Danish Parliament at the time of the approval of the conversion to urban zone. This coincidence of politicians could have caused a conflict of interest. Especially with Marianne Jelved, who was a member of the City Council of the Municipality of Gundsø 1982-1989 and also a member of the Danish Parliament for Radikale Venstre in the Roskilde County (Roskilde Amtskreds) from September 8th, 1987 to December 12th, 1990 (Folketinget, 2017). Jelved, then a resident of Jyllinge, was thus both on the City Council and in the Danish Parliament when the permit to convert Jyllinge Nordmark to an urban area was issued. It would seem that the available physical geographical knowledge did not reach the decision makers.

In 2007 the EU issued the Floods Directive (Directive 2007/60/EC), which requires all member states to plan for an extreme flood event. In this regard, the Ministry of Environment, the Nature Agency, the Ministry of Transport, and the Danish Coastal Authority carried out an analysis of flood risk of all of Denmark. The flood risk analysis consists of two factors: (1) Probability of flood and (2) potential consequences to people and value. The probability of flood is assessed on the basis of historical flood data, either measured data or flood events described in detail in historical documents. Despite Jyllinge Nordmark's history of flood events, Roskilde Fjord was not identified as a flood risk area (Miljøministeriet/Naturstyrelsen og Transportministeriet/Kystdirektoratet, 2011, p. 24). The fact that Jyllinge Nordmark is a relatively newly developed area means that there is insufficient data about floods in the area, as the floods that occurred when it was a leisure house area caused only minor damages and inconveniences and the high frequency of floods in the area meant that they were not sensational enough to be reported on. This has resulted in Roskilde Fjord not being identified as a flood risk area. The systematic approach to identifying the flood risk areas failed to recognize the flood risk of Roskilde Fjord and Jyllinge Nordmark, which a more in-depth research could have determined.

The municipalities that were identified as flood risk areas were obligated to make a danger and risk map of the identified area before the end of 2013. Furthermore, the municipalities were obligated to make a risk management plan for the identified area before October 22nd 2015. Since Roskilde Fjord was not identified as a flood risk area, the Municipality of Roskilde was not obligated make either and consequently did not. This is evident from Roskilde's pre-Bodil water- and climate adaptation plan (2013-2016) that flood risk from the sea was regarded. It only mentions rain- and wastewater management for Jyllinge Nordmark and contains nothing about storm surge risk (Roskilde Kommune, 2013, p. 8). Since then "Bodil" has occurred, and consequently the new, current, post-Bodil water- and climate adaptation plan (2016-2019) now has a section about the coastal protection project in Jyllinge Nordmark (Roskilde Kommune, 2015, p. 6-7). If Roskilde Fjord had been recognized as a flood risk area the municipality could have been better prepared to an extreme flood event like "Bodil".

When the Municipality of Roskilde experienced "Bodil" it had to start from scratch with the coastal protection project of Jyllinge Nordmark. This meant figuring out what laws apply, which stakeholders have an interest in the area, and which permits and dispensations to apply for etc., in order to take all the relevant interests in the area into account. The case in Jyllinge Nordmark, however, highlights the difficulties of implementing an Integrated Coastal Zone Management. This is due to the structure of the Danish Plan System, which has several overlaps in laws and jurisdiction of authorities in the coastal zone, as evident in figure 15 in chapter 2.4.3. Consequently, the structure of the Danish Plan System seems to complicate the process of implementing an Integrated Coastal Zone Management, as is required by the EU in Directive 2014/89/EU.

6. Conclusion

Jyllinge Nordmark is situated directly on the right bank of Roskilde Fjord, bounded to the north and east by the watercourse Værebro Å and to the south by the town of Jyllinge. The northern part of Jyllinge Nordmark along the fjord and watercourse is low-lying under elevation level 1.5 meters. Jyllinge Nordmark has a history of being a rural area used for agricultural purposes with fishing activity and a few, small sheds situated on big plots of land. The small sheds eventually developed into larger leisure houses, and more leisure houses were built. Gradually the area became more populated, and eventually people started living there permanently.

Jyllinge Nordmark's low elevation level means that the area has been frequently flooded, which is evident in the old local plans for the area. Furthermore, historical maps show that the area has been characterized as "wet" since at least 1896. Moreover, soil maps indicate that the soils in the northern part of Jyllinge Nordmark could consist of some degree of river deposits and sedimentations, not suitable for building. Despite all of this knowledge about the area being available, the area was still officially converted from rural zone to urban zone in 1989, which meant that people could now legally live there permanently. The only regard to the physical geographical knowledge was a requirement for terrain regulation when building new houses on the low-lying areas. Newspaper articles show that before the area became a permanent residential area, the regular flooding of the area was not reported on, but as more people took up residency there the frequent flood became a bigger problem. Nevertheless, a solution to the flood problem was never realized.

In 2013 the storm "Bodil" caused severe flooding in Jyllinge Nordmark, which served as a symbol of the impending climate change, with rising sea levels and increasingly frequent and severe extreme weather events. "Bodil" emphasized the vulnerability of Jyllinge Nordmark, which the Municipality of Roskilde became aware of and consequently the process of organizing a coastal protection project was initiated. The coastal protection project launched a massive generation of physical geographical knowledge about Jyllinge Nordmark's soil, groundwater, and the water flow of Værebro Å, in order to design the best possible flood protection solution.

As a result of "Bodil", structural changes were made to the organizational framework of the departments of the Municipality of Roskilde. In order to better share and utilize knowledge between different sub-projects, of which the flood protection project of Jyllinge Nordmark was one, a Task Force and a Steering Group was formed to coordinate the efforts. Furthermore, collaborations with other municipalities and state authorities were established in the Jyllinge Nordmark flood protection project. This has resulted in an Integrated Coastal Zone Management in the area, where knowledge is constantly produced and shared, and where all the stakeholders' interests are taken into consideration, as required by the EU in Directive 2014/89/EU. However, the structure of the Danish Plan System has proven to complicate the process of Integrated Coastal Zone Management due to several overlaps of laws and authority jurisdiction.

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