Rostock University

DredgDikes

LEGISLATION AND POTENTIAL FOR UTILIZATION OF DREDGED MATERIAL IN DENMARK

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1. INTRODUCTION

The present report describes the potential of beneficial use of dredged material in dike construction and maintenance on selected parts of the coastline of Sealand, Denmark.

The report is a part of the DredgDikes project under the South Baltic Programme, which is part-financed by the EU. The overall focus of the project is the potential use of dredged material in construction and maintenance of dikes. The final goal of the project is to prepare a best practice guideline on the use of dredged materials in combination with geosynthetics and coal combustion products in the South Baltic Region.

In the DredgDikes project, the possibilities for application of fine-grained, organic dredged materials in dike construction are intensively studied with regard to the German and Polish Baltic Sea coast. The present technical note will add data on the Danish national legislation and procedures regarding the use of dredged materials.

In the present report, the first section will describe the Danish legislation related to disposal and utilization of contaminated and uncontaminated dredged material, with special focus on the utilization of dredged material on land for e.g. dike construction and maintenance. The second section of the report evaluates the potential for the use of dredged material in dike construction and maintenance on a short and long timescale. In the third section, sediment samples taken from six locations are evaluated specifically for suitability in dike construction and maintenance according to the Danish legislation.

2. DIKE CONSTRUCTIONS AND DESIGN

A dike is an embankment constructed to prevent flooding or confine a river to a particular course. A principal sketch of a sea dike at high tide is illustrated in Figure 1.

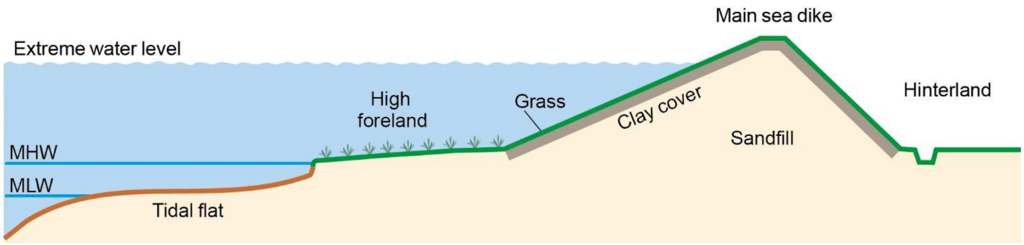


Figure 1: An explanatory sketch of how a sea dike can be constructed (Kystdirektoratet 2014).

A distinction is made between coastal and inland dikes in the form of sea and river dikes. The dimensions of a dike and the materials used to construct it will be dependent on local conditions and the desired design strength.

A sea dike should be placed back from the shoreline with a beach face/berm to minimize the risk of erosion and abrasion on the dike from direct wave action under normal and high water tidal situations. If a sea dike is installed as a protruding headland without a berm, measures should be established to protect against erosion of the dike footing, as location on the shoreline is subject to large wave impacts and abrasion.

Sea dikes should generally be established with a gently sloping seaward side, as wave energy is then dissipated over a larger area, which reduces the wave impact on the dike. This increases dike safety and reduces the risk of dike collapse and breaches. In Denmark, a sea dike is usually designed with a core of sand, overlaid with loam/clay and planted with grass or covered in asphalt.

Riverine dikes are placed directly on the river bank and are suitable along river courses and -mouths in areas with frequently elevated water levels. River dikes are typically constructed with a soil core planted with grass.

Inspection and maintenance of dikes is necessary to ensure that the designed dike strength is always present. In this regard, any damage from animals or humans should be repaired, and an intact clay cover and a closely trimmed grass cover should be maintained.

Strengthening of a dike may be necessary and will typically be conducted by raising the height of the dike, flattening the angle of the seaward side, reinforcing the landward side and/or increasing the thickness of the loam/clay cover.

Depending on the sediment characterization, dredged materials can be used as components in dike construction and maintenance.

3. LEGAL ASPECTS OF DREDGED SEDIMENT HANDLING

Danish ports and navigational channels are subject to regular maintenance in order to assure the minimum guaranteed depth. On a yearly basis, more than 5,000,000 m^3 of materials are dredged from Danish ports and navigation channels to ensure this.

The majority of dredged material in Denmark is dumped at offshore dumpsites due to practical, geotechnical or geochemical reasons. However, some utilisation of dredged material takes place and usually falls into two categories:

1) In cases where disposal of dredged material is economically or ecologically unfavourable (long distance to nearest offshore dumpsite, too high levels of contaminants)
2) In cases where both the need for dredging and the need for the materials exists.

In Denmark, the dredged material is regulated by the competent authority, which regulates the end-use of the material. The following table sets forth the applicable legislation and approving authority in relation to applications for dredging and disposal of sediment.

Thus, maintenance dredging itself -when taking place outside of harbours- is not regulated as such, but the desired end-use will determine which authority will be the regulatory body; e.g. the Danish Coastal Authority, if the dredged materials are to be used in coastal protection operations. However, construction or deepening of navigational channels on the marine territory is regulated by the Danish Coastal Authorities through the Coastal Protection Act. When the dredged material is intended for land storage, the competent municipality always has to issue a permit according to the Environmental Protection Act.

Table 1: Activities and the approving authority.

Task	Legislation	Authority
Dredging	Dependent on end-use Marine Environment Act	None, regulated by end-use of sediment
Dumping	Marine Environment Act	Danish Nature Agency
Utilization on land	Act of Raw Materials; Environmental Protection Act etc. Marine Environment Act	Danish Nature Agency; Municipalities Environmental Protection Agency
Utilization, coastal protection	Coastal Protection Act Environmental Protection Act Act of Raw Materials etc.	Danish Coastal Authority Danish Nature Agency Municipalities Environmental Protection Agency
Storage and deposit	Environmental Protection Act Storage Deposit Act, etc.	Environmental Protection Agency, Municipalities
Natura 2000	Habitat Directive	Danish Nature Agency

A list of all regulatory acts and orders that are involved when utilizing dredged sediment is presented in Table 10 in section 9.

When maintenance dredging takes place within the existing limits of a harbour, the municipality is the only authority in respect to the dredging operation. When the municipality issues permission, the municipality has to evaluate the environmental concerns in respect to the Marine Environmental Act (nr. 879 of 26/06/2010). This is especially relevant when non-contaminated sediment is intended for use as fill-material for constructions in the port.

If the dredged material is removed from the protective boundaries of the harbour, permission from the receiving authority (other municipalities, Danish Nature Agency, Danish Coastal Authority etc.) has to be obtained separately. On land, when soil (and dredged sediment) is moved between cadastres, a permit according to the Order of Soil Moving (Order no. 1479 of 12/12/2007) has to be issued.

Regardless of how the dredged material is disposed of, national and international environmental concerns are regulated by the Danish Nature Agency. In practise, this is completed when the competent authority (e.g. the Danish Coastal Authority) sends the application in an internal hearing among relevant authorities. In cases where only local concerns are of interest, the municipality is the competent authority in relation to environmental concerns according to the Environmental Protection Act (Act no. 879 of 26/6/2010).

In the following sections, methodology and possible use of dredged sediment is exemplified with respect to Danish legislation.

3.1. Methods for dredging

There are several methods to obtain dredged material. The choice of method depends on quantity of dredged material as well as on geochemical and geotechnical considerations. Practical reflections like distance to dumpsite and depth in project area are important as well.

General considerations on dredging methods are shown in Table 2.

Table 2: Selected dredging methods and applications

	Small quantities	Large quantities	Suitable for contaminated sediment	Notes
Shovel	Yes	No (slow)	Yes	Often small vessels, suitable for small volumes
Environmental grab	Yes	No (slow)	Yes	Often small vessels, suitable for small volumes
Bucket dredger	No	Yes	No	Mobilisation expensive
Trailing suction	Yes	Yes	No	

hopper dredger				
Suction dredger	Yes	Yes	No	

The number of dredging operators that operate nationally is relatively limited. Most operators work solely with hydraulic shovels and grabs from vessels either with built-in split or hopper capabilities or with an associated split/hopper barge when working in harbours and shipping channels. However, many larger operators based in e.g. Netherlands and Belgium also work on national dredging assignments.

When operating in vulnerable areas or in locations that are protected by national or international environmental legislation, environmentally friendly working practices, including the choice of equipment that has minimal environmental impact, can be set as a condition in a permit.

3.2. Disposal at sea

Disposal at sea, Dumping of dredged sediment requires regulatory approval by the Nature Agency under decree no. 32 of 07/01/2011, which is evoked under the Marine Environment Protection Act (Act. no 963 of 03/07/2013). Terms and conditions for dumping are included in manual no. 9702 of 20/10/2008.

The Marine Environment Act states, that there should only be given permission for dumping of dredged material if the compounds listed in Annex 2 of the law is present in 'insignificant quantities and concentrations". Thus, to get a permit for dumping dredged material from harbours or shipping channels, physical and chemical characteristics has to be evaluated and documented. The specific requirements are subject to an assessment by the Nature Agency, but will often include instructions for sediment sampling and directions for parameters of chemical and physical testing.
The sediment volume in the application gives an indicative number of sediment samples needed to fulfill the documentation needs. The relationship between sediment volume and sediment sampling stations is presented in the table below.

Table 3: Indicative relationship between applied quantity and number of sediment stations (manual no. 9702 of 20/10/2008)

Volume of dredged material (m^3)	Number of sampling stations
<2.500	1
2.500-10.000	2
10.000-25.000	3
25.000-100.000	4-6
100.000-500.000	7,15
500.000-2.000.000	16-30
>2.000.000	10 extra per mio. m^3

Chemical thresholds for dumping of dredged sediments are determined in the “Manual for Dumping” (manual no. 9702 of 20/10/2008). In this manual, the terms 'lower' and 'upper' action levels are essential. The lower action level indicates levels of contaminants that equals the average background level for substances and where biological effects are not expected (Class A). The upper action level indicates contaminant concentrations at which there may be preliminary biological effects (Class C). As a starting point, sediment with levels of contaminants between lower and upper action level (Class B) can be dumped, subject to a direct assessment by the Nature Agency. Action levels for contaminants are shown in Table 4.

Table 4: Indicative action levels for dumping of dredged material

Compound	Unit	Lower action level	Upper action level
As	mg/kg TS	20	60
Pb	mg/kg TS	40	200
Cd	mg/kg TS	0.4	2.5
Cr	mg/kg TS	50	270
Cu	mg/kg TS	20	90
Hg	mg/kg TS	0.25	1
Ni	mg/kg TS	30	60
Zn	mg/kg TS	130	500
TBT	µg/kg TS	7	200
Sum of 7 PCB’s	µg/kg TS	20	200
Sum of 9 PAH’s	µg/kg TS	3	30

An application for dumping is sent directly to the Nature Agency and should include:

- Applicant data (name, address, company etc.)
- Project description
- Suggestion of which dumpsite is preferred.
- Maps of dredging- and dumping areas
- Sediment volume
- Sediment characteristics
- Suitability of the sediment for beneficial use
- Time schedule
- Method

The application can be submitted in a pre-defined form, which can be downloaded through www.nst.dk or as a stand-alone application.

3.3. Utilization of dredged material

When sediment from maintenance dredging is reused, it is called utilization. When the dredging operation takes place for the sake of the material it self (use as fill-material in road construction or as a component in industrial processes etc.), the operation is termed “mining of marine raw material” or capital dredging. Both types of projects are regulated by the Nature Agency through the act on Raw Materials (Act No. 950 of 24 September 2009).

According to the Marine Environment Act (Act. no 963 of 03/07/2013) and the Act of Raw Materials (Act No. 950 of 24/09/2009), the authorities have to encourage the beneficial utilisation of dredged marine material. Furthermore, as indicated above an application for dumping has to present arguments for *not* utilizing the material for other purposes. In order to increase the quantity of utilized material from marine dredging operations, the normal fee on reclamation of marine raw materials (5 DKR per m^3) has been suspended.

For the year 2012, the production of mined marine resources (capital dredging) (fine sand, gravel, fill-sand etc.) were 7,153,987 m^3 in Denmark. In the same period, a volume of 3,371,906 m^3 were dredged through maintenance dredging operations for utilization purposes.

Utilization of dredged material is regulated by the Nature Agency and through the Act on Raw Materials. Depending on how the material is intended used, permits from other authorities can be required (e.g. from Environmental Protection Agency, Municipalities and Coastal Authorities). When applying for permission for utilizing dredged material, the applicant has to include the following information:

- Applicant data and maps of where the dredging takes place
- Information on amount and composition of sediment and method of dredging,
- Expected environmental effects of the dredging, expected spills and relevant countermeasures to reduce the environmental impact.
- The intended use of the dredged material

In principle, the utilization of dredged material can be divided into three categories based on how it is intended to be utilized:

1) Coastal protection (band nourishment, beach nourishment)
2) As building material (fill-material in road constructions, dikes, landscape projects etc.).
3) Industrial purposes (extraction of silica)

Dike construction and maintenance with dredged material in principle fall into both first and second category. When a dike is constructed in or near the coastal zone it is a coastal protection project and when further away, it is considered fill-in in construction work. However, in the present document, dike construction etc. is only considered in the section relating to the use of dredged material as building material.

In the following sections, legislation and practical considerations for each of the above-mentioned points are reviewed separately.

3.3.1 Coastal protection

Non-contaminated dredged sediment with the proper sediment characteristics can be utilised in coastal protection for e.g. beach nourishment.

In Denmark, coastal protection is regulated under the act on Coastal Protection (act no. 267 of 11/03/2009), which is managed by the Danish Coastal Authority. However, as stated in the previous sections, all utilization of dredged material is regulated by the Danish Nature Agency under the act of Raw Material (Act No. 657 of 27/05/2007). Moreover, the owner of the beach has to give consentient and the applicant will need an exemption from the Coastal Setback Line. Consequently, a number of applications have to be submitted in order to get permission for coastal protection projects using dredged materials.

The different acts that regulate coastal projects are summarized in Figure 2.

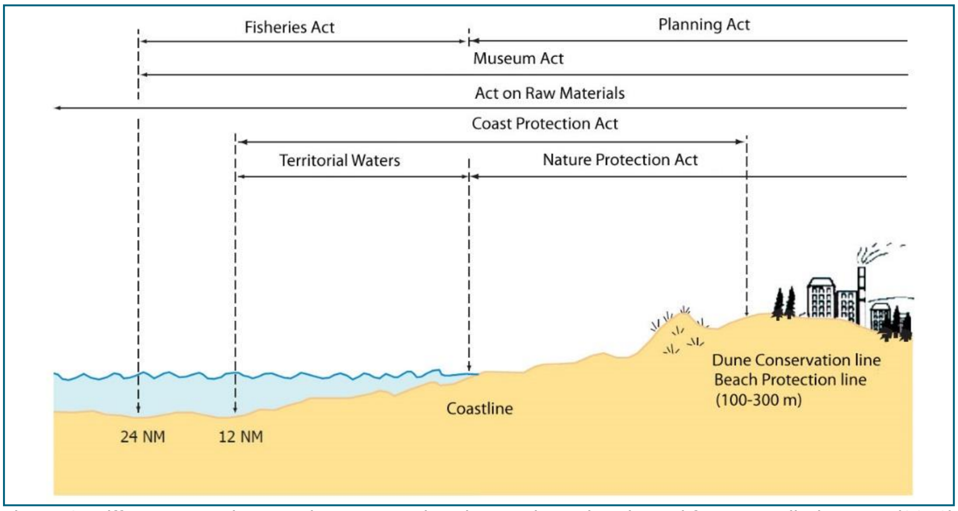


Figure 2: Different Acts that regulates coastal projects. Figure is adapted from Kystdirektoratet (2013).

When using dredged sediment for coastal protection (not in dike construction) it has to be non-contaminated. However, documentation needs are assessed individually and the use of dredged sediment from pristine areas is rarely met with demands for chemical analysis. Geochemical testing is, however, mandatory because coastal protection (beach nourishment etc.) is only allowed with sediment types, which are similar to those naturally present in the given area. This does not apply when sediment is utilized in dike construction. In this case, geotechnical parameters have to apply to the specifications lined up by the Danish Coastal Authority (Kystdirektoratet, 2014).

In Denmark utilization of marine resources in coastal protection projects, are primary related to sand bar feeding, beach nourishment or to direct build-up of coastlines or beach sections after storms etc.

3.3.2 Utilization of dredged material as building material

If non-contaminated dredged material has the correct geotechnical characteristics, it can be used in constructions. Examples of how dredged material can be utilized as building material includes land-fills when developing harbours, land-fills in landscaping, as fill material for large infrastructure projects (highways, bridges) but also when dredged material is incorporated into dike constructions. Separate permit for this must be obtained from the relevant authorities.

The legal basis for handling dredged material as a component in building projects is rather complex as the material may or may not need to be transported, may or may not need further handling (dewatering, cleaning) before it can be utilized (re-use) and may or may not be contaminated. The municipality in which the activity takes place regulates the use of soil in a construction project (Environmental Protection Act) as they do when soil is moved between cadastres (order of soil moving, no. 1479 of 12/12/2007).

The overall use of soil (and sediment) as building material is regulated within the Environmental Protection Act. However the Environmental Protection Act (no. 879 of 26/06/2010), § 19 makes no provision for soil but is a general provision stating that materials that can contaminate soil and groundwater should not be buried, stored or diverted without permission. Thus, in each case it must be determined whether the applied project is under this provision or not.

Furthermore, it should be evaluated if the application can be considered in relation to the provisions in the executive Order of Reuse (no. 1662 of 21/12/2010) which partly have authority in § 19, or if the soil perhaps can be reused without permission. Finally, it should be evaluated if the construction is under the provisions in § 33 in the *Environmental Protection Act* concerning approval of listed activities (Executive order no. 669 of 18/06/2014).

In some cases, slightly contaminated soil can be used freely as it is considered not to cause any contamination of the environment or other impact on the environment. This applies to soil that classified as Class 1 soil after the Zealand guideline (Zeealand Guidelines, 2001) and soil categorized in category 1 in *executive order of Reuse*. The soil can be used in construction works such as dikes unless otherwise stipulated by the *Environmental Protection Act* and other legislation.

Permission to reuse contaminated soil according to the *executive order Reuse* requires permission according to the *Environmental Protection* Act § 19 or environmental approval according to § 33. The reuse of soil is regulated in the order of Reuse if the soil is only contaminated with heavy metals and listed in Annex 6 in the executive order.

Recent decisions from the Environmental Board of Appeal on two cases (Cases NMK-10-00087/NMK-10-00308 and case NMK-10-00346) of reuse of contaminated soil in dikes indicates that reuse of contaminated soil in dikes generally shall be applied as an environmental approval according to the Environmental Protection Act § 33.

Levels of contaminants that are included within category 1 of the Zealand guideline (Zeealand Guidelines, 2001) and executive Order of Reuse (no. 1662 of 21/12/2010) is pictured in Table 8.

The utilization of dredged material as fill material is often preferred when larger quantities of dredged material has to be disposed of within harbours. The big advantage occurs if the harbour already has expansion plans, as this will minimize the cost of purchasing natural raw material for fill and at the same time reduce the cost of transporting the dredged material to an offshore dumpsite for marine disposal.

If dredged material is contaminated, it can still be used as fill material in marine construction projects, but then the construction is considered as an end-storage facility for contaminated soil and is regulated under the Environmental Protection Act (no. 879 of 26/06/2010). See the next section.

3.3.3 Treatment and storage of dredged sediment

If dredged material cannot be utilized directly due to excessive water content or contaminants, the dredged material can be treated to make it more suitable for its utilization purpose. After the appropriate treatment, the material can be re-used. When the sediment has been treated, the sediment is subject to the same legislative conditions as explained in the previous chapter.

Dewatering

Dewatering of sediment is often needed before storage or further treatment can take place. For fine-grained sediments, the water content can often be 200-300 %, which provides an economic motivation for dewatering, as disposal and treatment fees are often paid per m^3.

Sediments are generally dewatered in dedicated dewatering facilities (using gravitational dewatering), in geosynthetic tubes or by mechanical dewatering processes. Several harbours in Denmark have permanent dewatering facilities to meet their continuous dredging needs. These operations are engaged prior to landfill, utilization in construction projects or storage and are in Denmark usually based on gravitational dewatering as this is less expensive. Geosynthetic tubes are a mobile solution, which most often is used in minor harbours with dredging needs before end-storage. The principle is that the sediment is pumped through a water-permeable tube, allowing excess water to seep through for collection.

Mechanical dewatering can be conducted in centrifuges, belt presses or chamber filter presses but these processes are significantly more expensive than the above-mentioned methods.

It is up to each municipality to decide the procedure regarding authorization of dewatering facilities. When taking place within the protective boarders of a harbour, this is often considered a part of the normal harbour operations and does not require a separate permission. However if the water leaving the facility is discharged into the recipient, a permission has to be issued by the municipality under the Environmental Protection Act (no. 879 of 26/6/2010), the Sewage Executive Order (no. 1448 of 11/12/2007) and Order on environmental quality standards for water bodies and requirements for the discharge of pollutants into rivers, lakes or the sea (no. 1022 of 25/08/2010).

If the water is discharged to a public treatment plant, the local municipality must grant the application. If water is collected in tank cars and driven to a suitable treatment plants in another municipality, the receiving municipality has to grant the application. The same legislation is applicable as above.

If the dewatering site is established as a permanent facility, the municipality has to grant an environmental permit before construction. If the sediment remains at the facility after drainage, the plant must be approved as a landfill facility according to Order on Approval of Listed Companies (Order no. 669 of 18/06/2014) and the Order on Landfill (Order no. 1049 of 28/08/2013). The municipality decides (based on an EIA screening from the developer) wither a full EIA has to be prepared. If the facility is located on land, the municipality authorize the facility according to the Planning Act (Order no. 587 of 27/05/2013). The Environmental Protection Agency is responsible for all regulatory aspects related to the establishment and monitoring of disposal facilities.

Special concerns are addressed in relation to e.g. groundwater protection and the marine environment. When requirements for a permit are specified, factors of importance are: geotechnical conditions in the area, groundwater interests, environmental interests, level of contaminants, contaminants in leachate and recreational interest in the area. Facilities included as storage facilities for dredged sediment include inland settling pits and sediment spoil areas and land fill areas. Optimally, the storage facility is constructed on an impermeable surface (clay or geotextile) and is subsequently covered with uncontaminated soil to reduce chemical reactions with acidic rainwater. Specific requirements for construction, permeability of sheet piles and installation of wells for testing and draining may be included in a permit.

If the sediment is dewatered and then transported to either landfill somewhere else or other re-use, the facility is defined as a waste treatment facility and not as a storage facility. This type of plant is not included in the Order on Landfill (Order no. 1049 of 28/08/2013) which exclude the facility in the EIA procedures. Re-used material is subject to regulation according to the Order on the use of residues and soil for construction works and the use of sorted, uncontaminated construction and demolition waste (Order no. 1662 of 21/12/2010).

If the same sediment is present in the facility more than one year, the facility must be considered a storage facility in accordance with the Order on Landfill (Order no. 1049 of 28/08/2013) and is thus subject to the same regulations as the permanent facilities.

Treatment of sediment

Dredged material that cannot be dumped at offshore dumpsites or utilized in construction due to exceedance of chemical threshold can be treated using chemical and physical processes. This is not often performed in Denmark due to the economic aspects of the handling and treatment. Treatment of sediment usually involves higher costs than other types of sediment handling.

The value of the recovered usable fractions rarely correspond to the cost of the treatment and the motive for treatment is therefore often not of economical nature. Thus the motivation for sediment treatment is usually not to reduce the total costs of handling the sediment, but often to reduce the environmental impact of the sediment and therefore to make landfill and storage possible.

Treatment of sediment usually includes one or more of the following methods:

1) Mechanical
2) Thermic
3) Biological

Treatment of dredged sediment is regulated by municipalities by the Environmental Protection Act (Order 879 of 26/6/2010) Furthermore treatment of sediment is subject to all of the above-mentioned regulations which are mention in relation to construction of treatment plants, discharge of sewage and following landfill orders.

Mechanical treatment is relatively simple and hence relatively inexpensive, but the cost still exceeds landfill consolidation and final sand covering. The principal mechanism behind mechanical treatment is that the sediment is separated into fractions. It is known from experience, that metals, organic contaminants and TBT adhere to fine-grained sediment fractions and organic components. Consequently, it is therefore possible to remove a considerable portion of the contaminants by a physical separation of coarsely and fine grained sediment fractions. There are numerous ways to size separate the dredged sediment, but the most often used is separation over a grate (as used by the aggregate industry), by sand traps, by settling pools or by a Hydrocyclone. A Hydrocyclone is a device which by centripetal forces sorts particles in liquid suspension according to their density.

In **Thermal treatment** the sediment metals are immobilised and organic pollutants are destroyed when exposed to high temperatures. When sediment is incinerated at temperatures above 1.300 ºC, the resulting product is a crystalline product that can be further used in industrial processes. However, the method is relatively expensive due to its large energy consumption.

There are several types of **biological treatments** of contaminated soil. One type is based on microbiotic degradation. In this method, specialised bacteria are mixed with the soil and degrade contaminants within the sediment. Another method involves cultivating trees and other vegetation in contaminated soil/sediment. The principle of this method is that contaminents e.g. PAHs, PCBs and certain metals are assimilated into the plant tissues when the vegetation grows in the contaminated soil. The plant matter is subsequently incinerated, which breaks down the contaminants as described above. Common for both methods is that they are time and space consuming.

3.3.4 Industrial utilisation for further processing

There are several examples of industrial utilisation of dredged material as an ingredient in chemical processes or products. Regardless of how the dredged material is utilised in industrial processes, the economic incentive is of significant importance.

In the following, two examples of industrial use of dredged material is described. In general, the municipality where the activity takes place has to issue permit for the use of the dredged material.

Aalborg Portland: In an effort to reduce environmental impact, Aalborg Portland has a resource strategy that includes the utilization of dredged sediment from the Port of Aalborg and from shipping channels in Løgstør Bredning and at Hals Barre. The areas are subject to massive annual maintenance dredging operations due to eastward water movements and sediment transport in Limfjorden. Material in the dredged areas is mainly coarsely grained, but not exclusively. Aalborg Portland informs that they utilize all received material but they are not interested in very fine grained material. They utilize between 40,000 and 75,000 tons per year but the plant can increase production, and thus the need for dredged material further, if necessary.

The dredged material is used in the production of cement and the sand is utilized for its content of Silicon. Minor amounts of contaminants are not problematic in the production system, but volatile heavy metals like cadmium and mercury cannot be allowed in significant quantities.

Aalborg Portland has a permit in relation to both utilization of dredged material and in relation to mining of marine resources. Both are subject to approval by the Nature Agency through the Act on Raw Material (Act No. 657 of 27/05/2007), but Aalborg Portland informs that the permission on Mining of Marine resources have not been used, as the utilization volumes has been sufficient for the production.

The utilization is a mutually beneficial arrangement. Aalborg Portland informs that they will be happy to receive more material from other areas as long as the sediment characteristics are favourable for environment and production.

Usage of sediment in incineration processes: This is a project idea, which has not yet been realised. The basic concept is that when dredged materials with high contents of organic compounds and salts such as e.g. aluminium oxides are incinerated, the resulting ashes will be of high value as ingredients in industrial products. As the incineration processes remove metals and organic contaminants, sediment can be both contaminated and non-contaminated (Miljøministeriet 2013).

Before incineration of dredged material can be authorised, both the municipality where the dredging operation takes place (if within a port) and where the incineration plant is situated, has to issue a permit.

4. POTENTIAL USE OF DREDGED SEDIMENT IN DIKE PROJECTS

4.1. Method

The objective of this section of the report is to describe the potential for the use of dredged material in constructing, repair works and improvements of dikes.

The geographical area in question is the light blue-colored area on Figure 3 (Adjacent area).

Figure 3: Illustration of the focus area of the report

To facilitate the analyses, the areas will be examined region by region as specified in Figure 4.

The analysis will start in the eastern and southern regions and end with the western and northern regions.

In each of the regions, potential known dredging areas, known dike constructions, known future dike projects and an examination of usable landing facilities are reviewed for each municipality present in the region. Overlaps between projects etc. may occur.

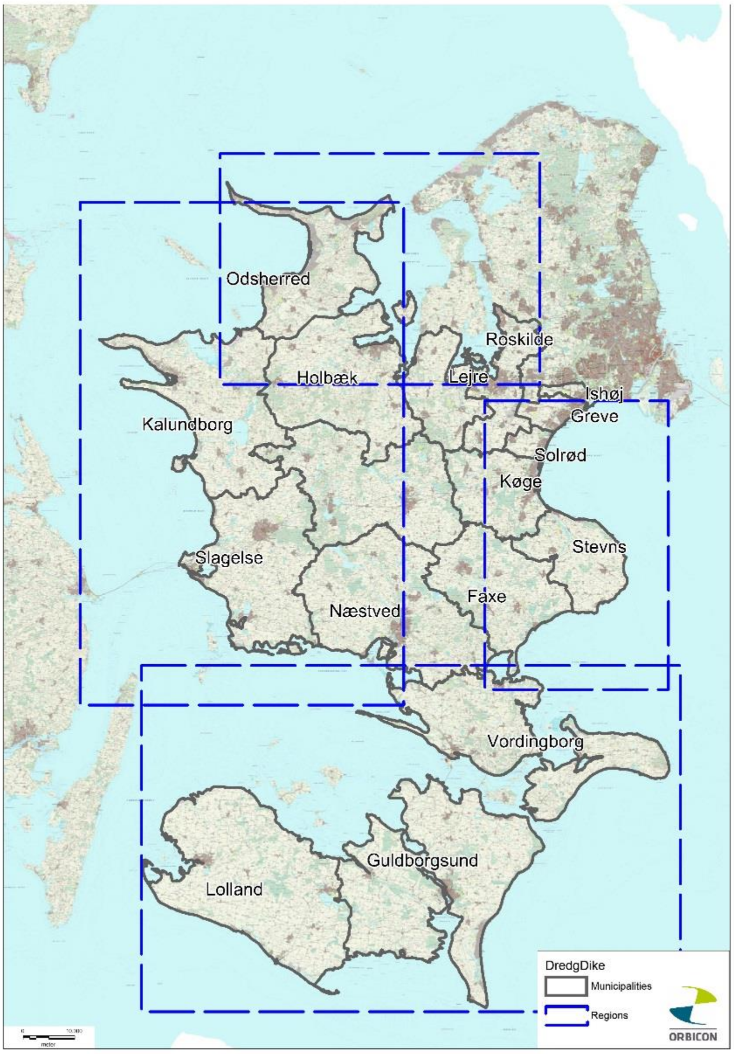


Figure 4: Illustration of the four regions, which will be the focus of the discussion

Whether there is a potential for the utilization of dredged sediment for dike construction, is determined by a complex of several factors, including:

- The distance between the dredging zone and the project area
- Whether there is a suitable port facility within range
- The characteristics of the material (chemical and physical), and
- Whether there is a specific need for the material in a project.

Several other parameters may be important in specific projects, but the above-mentioned points are considered the most central and will be used further in the text.

In the following text, the potential of utilization of dredged material for the use in dike constructions are evaluated with reference to the geographical regions presented in Figure 4; eastern region; southern region; western region and the northern region.

For each of the four areas, the above mentioned considerations will be evaluated. In order to do so, a geographical analysis for each area has been performed to clarify distances to appropriate port facilities, distances to potential project areas for dike construction works.

The geographical analysis was performed on general data from public databases and information from municipalities, but also with the use of a GIS-database kindly provided by the Danish Coastal authorities.

Selected municipalities were contacted to obtain general and specific information regarding potential dike projects in the region.

4.2. Eastern part – Køge Bugt

In the eastern region, there are several existing sea dikes, and usable landing facilities. On Figure 5, the municipalities (blue line) and known dike constructions (red line) are shown.

Figure 5: Municipalities and known dike constructions in the eastern region.

Ishøj, Greve and Køge

The largest exciting dike constructions in the region are the dikes that represents “Køge Bugt Strandpark” which is present on the shorelines of Ishøj, Vallensbæk and Brøndby on the north of the region. Dredged material can be transported to local harbors (Hundige, Ishøj or Brøndby Harbor) but no established handling facilities are available. As an alternative, a pipe-system could be installed.

“Køge Bugt Strandpark” informs that they regularly perform maintenance on the 6 km long sand sea dike. This is primarily necessary between Valensbæk and Brøndby, which is approximately 9 km from Mosede Harbor. Køge Bugt Strandpark furthermore informs that they, as an experiment, has utilized material from embankments of the coast and the navigational channels from Ishøj/Vallensbæk Harbor to strengthen dikes between Vallensbæk and Brøndby. Hundige Harbor is interested in a similar corporation, but this has not been formalized yet. The method for the dredging operation is mainly from land with excavator. These dikes are constructed mainly by sand with planted Lyme Grass to restrain sand. Therefore the coarsely grained material that is excavated from the navigational channels and harbours can be utilized directly on the dikes.

The port of Mosede is dredged regularly to maintain guarantied depths. The dredging operation mainly takes place in the outer port, which receives material that is transported through the outer breakwater due to a failing geotextile in the construction. Thus, the material is only slightly contaminated.

Further to the south, the port of Køge is positioned. This area consists of a marina and a commercial port, which both are subject to regular dredging operations. Inside Køge commercial port, there is a facility for handling marine raw material operated by the company NCC Raw materials.

The port of Køge is currently expanding and a landing facility for marine and land based raw material has been established for the major landfill operation.

There are a few minor dikes in Køge Kommune, which are owned by private owner groups. In the Climate Adaptation Strategy (Køge 2013), some areas are listed as prone to flooding and dike constructions are identified as a tool to protect rural and urban areas. However, no action plans have been adopted.

Stevns and Faxe
Only a few dikes are present in the municipalities of Stevns and Faxe. However there are several usable sites for dredging material for utilization in dike construction. According to the climate adaptation plan for Stevns Municipalities (Stevns Municipality, 2014), there are only few areas that needs protection from the sea. However specific sites such as Strøby Egede, Strøby Ladeplads and Rødby are pointed out as places where construction of dikes may be recommended. In the municipality of Faxe, sea dikes and secondary are considered a part of the coming climate adaptation strategy (Faxe Climate adaptation strategy, 2013) for coastal areas.

The ports of Rødby, Faxe Ladeplads and Præstø are all subject to regular dredging operations. Furthermore, the Coastal Authorities dredge approximately 15.000 m^3 per year from the narrow navigational channel at Sandhage to keep it clear from sand. There are several suitable landing facilities in this area but the facility at Præstø is considered best for the purpose, as there is a dedicated port for landing marine raw materials from marine mining areas.

4.3. Southern part – Lolland, Guldborgsund and Vordingborg

This region includes a number of islands that vary in size. Most of the region is positioned very low having led to the construction of several dike constructions that have been in operation for hundreds of years. A large part of the municipalities of

Guldborgssund and Lolland has a level that is close to sea level and would be flooded without dikes. Municipalities and existing dikes can be seen in Figure 6.

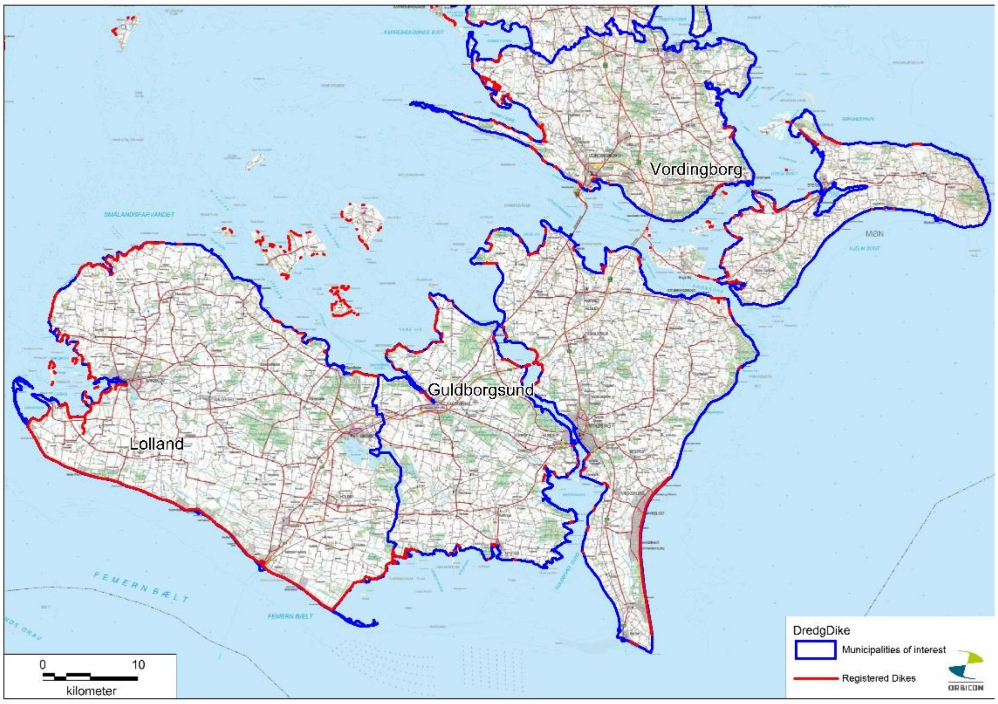


Figure 6: Municipalities (blue line) and known sea dikes (red line) in the region.

Several historical dike constructions exists in the region. Some of these historical dikes are regulated under special acts like the “Act on Dike Works of Lolland and Falster” which was founded in 1873. In this act, which is still valid, the rules and obligations of authorities in relation to construction and maintenance of this up to five meter tall and 63 km long dike called “Det Falsterske Dige” (The Dike on Falster) is listed. The dike protects more than 70 km^2 of rural and urban areas.

Vordingborg

In the municipality of Vordingborg, several marinas and commercial ports exists. In Præstø and Vordingborg Commercial ports, dredged material can be landed, but only few existing dikes are present in the immediate vicinity of these facilities.

In the action plan for the Climate Protection Plan (2012-2020) for the municipality of Vordingborg, protection of urban areas by reinforcing or constructing dikes is mentioned for Vordingborg, Masnedø, Ore and Nordhavn. The municipality clarifies, that dikes at Masnedø and Ore have the highest priority.

Where reclaimed and dike-secured areas exists, the municipality may be included as an motivator where additional security is needed. However, it will be the Danish Coastal Authority as authority, and the owners of the underlying land, which must bear the cost of the reinforcement.

Several additional areas are to be protected from protruding sea water in the long-term action plan (>2020), but which measures to implement is unsettled. The realization of these measures is appointed as the responsibility of the municipality.

The municipality informs that dike construction are solely the responsibility of private owner groups. However, there are some public owner groups, which have a yearly budget.

Guldborgsund

There are several leisure harbors in the Municipality of Guldborgsund, but no known handling facilities of mined raw marine materials exists. There are several harbors and navigational channels where regular dredging operations are necessary to maintain navigability. The navigation channel at Grønsund is maintained by the Coastal Authorities and is subject to yearly dredging of approximately 40.000 m^3, which is dumped at a nearby dumpsite. Most harbors in the municipality are dredged regularly and most of the material is disposed at dumpsites. The harbors in the municipality are responsible for exploring the possibilities for utilization of the dredged material themselves.

In the municipality of Guldborgsund, private owner groups possess all dike constructions which means that all maintenance and construction work is initiated and financed based on the landowners' needs for protection of their property. The Coastal Authorities perform early inspections on the dikes in the municipality and sends the municipality a status report for information.

In the Climate protection plan of the municipality of Guldborsund, two sea dikes are mentioned; Sakskøbing and Guldborg. Before the construction can begin the implicated land-owners has to reach an agreement on location, financing and maintenance.

The municipality informs that most dredged material from marinas within the municipality is disposed at dumpsites due to its content of silt. Most of the material is slightly contaminated by harbor related activities (heavy metals, TBT etc.) and is not considered suitable for dike constructions. There is no overall coordination of dredging operation in the municipality.

Furthermore the municipality informs that clay has been utilized on the dike around Falster when excavating channels in Bøtø Nor. The distance between dredging area and the dike was 5-8 km.

Lolland

A considerable part of the municipality of Lolland is in a historical context reclaimed and is below sea level, which necessitates massive dike constructions and drainage systems.

Potential projects where dredged material can be utilized for dike constructions include maintenance of the depths in harbors and navigational in Nakskov and Rødby ports. Clay and sand from the navigational channel to Nakskov was utilized for dikes at Unsevig. Sailing depths for both Rødby and Nakskov ports are maintained on a regular basis. The material from the regular dredging operations are mainly sandy material.

Several projects have tried to utilize material from construction sites etc. for reinforcements of dikes. However, it is a concern that material from building sites include another seed pool of grass and other plants than what is present on the dike. As most dikes in the region are protected according to § 3 of the environmental protection act, projects that change the species composition cannot be accepted. Therefore it is preferred that material for dike construction and reinforcement is found close to the project site and the procedure is to excavate the material from holes immediately behind the dike.

In Kragenæs Marina, a project for the utilization of dredged material is in progress. The dredged material, which is produced when widening the port entry, will be used to create a beach on the outside of the breakwater. From Kragenæs Marina there are about 4 km by water and 8 km by land to the nearest dike construction. This particular dike is not mentioned by the municipality as a prioritized dike construction.

Dredged material can be landed at several port facilities (old ferry quays, commercial ports etc.) but they are located relatively far away from dikes.

As yet there there is no climate adaptation plan for Lolland, but the municipality informs that reinforcements of dikes will be a part of the coming plan. In general, no new constructions of dikes are planned, but it is a long-term objective to ensure that all dikes are minimum 2.5 meters in height. In Nakskov, dike reinforcements will become a part of the emerging risk management plan. The municipality informs that the construction of the tunnel under Fehmarn Belt will create large quantities of sediment from the dredging operations. However, the material is thought utilized in a large reclamation projected. Dredged material that is in surplus can be utilized for other purposes, but the municipality does not consider this as a realistic option in relation to dike maintenance as the distances will make it economically unfavourable.

4.4. Western region – Kalundborg and Slagelse

This western region consists of three large municipalities that all face “Store Bælt” on the coastline. Municipalities and known dike constructions are illustrated in Figure 7.

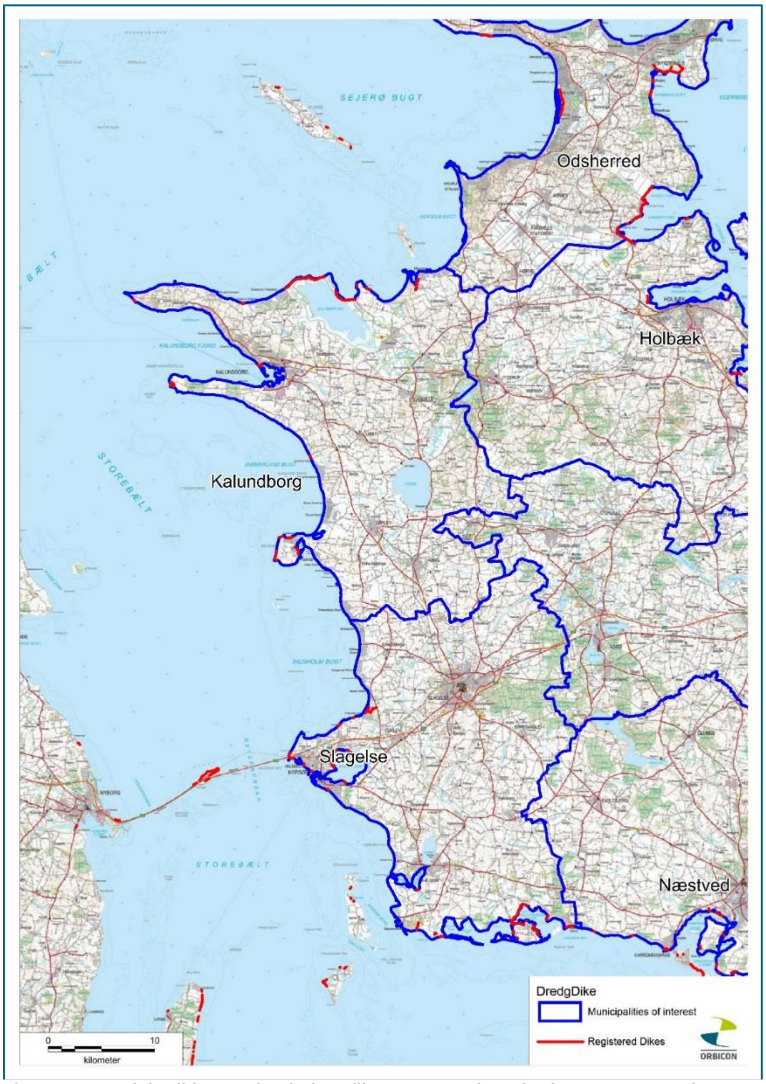


Figure 7: Municipalities and existing dike constructions in the western region.

Næstved

In the municipality of Næstved, several ports and marinas exist which all have recurrent dredging needs. The Port of Næstved is situated at the end of a long inland channel and is subject to recurring dredging operations (app. every five years). At the outside of the channel, two marinas are present at Karrebæksminde. These marinas are also prone to dredging operations.

Only few dikes are registered in the municipality of Næstved. There are some at Karrebæksminde. If landing of the material is possible, material from the channel and marinas should be relatively close to the dikes that are present at Karrebæksminde. However, the material is normally disposed at offshore dumpsites and is fine grained.

In the climate adaptation plan (Næstved 2012) there are several dike construction projects that could protect valued inland areas. More specifically, it is mentioned that the construction of a dike along the island of Enø, Enø overdrev and Dybsø could protect inland properties in case of flood. Alternatively, dikes should be constructed throughout the coastlines of Dybsø Fjord. The Municipality will be responsible or partly responsible for the construction of this dike.

A computer simulation shows that a dike should be constructed at Mindegab within a short period of time. The responsibility lies with the land owners.

In the climate adaptation plan, areas for temporary storage for clean soil is pointed out so that there will be building materials when the construction works begins. There are no plans to utilize dredged material.

Slagelse

There are several ports and marinas on the 180 km coastline in the municipality of Slagelse, which are subject to recurring dredging operations. In the south, several marinas are present, including Bisserup, Agersø and Omø. As there are several islands in the municipality, several ferry ports exists. Furthermore there is a larger commercial port facility at Stigsnæs, which could serve as a handling facility of dredged material.

The navigational channel to Skælskør has to be maintained on a regular basis to maintain the guarantied depths. The materials from the navigational channels are mainly coarsely grained while fine particular sediment is present within the protected waters of the marinas. Contamination levels vary considerable within marinas but also between different marinas. Dredged sediment is disposed at offshore dumpsites.

The port of Korsør includes a commercial port, a marina and a navy facility in addition to a navigational channel to Korsør Nor. Access to all facilities are maintained by dredging operations. In Korsør, there are an old ferry facility, which could be usable for the landing of dredged material.

There are several dikes in the municipality (see Figure 7). In the southern part of the region (close to Bisserup Marina) a number of dikes protect inland resources. Landing of dredged material in this area is however problematic due to a lack of qualified landing facilities. Pumping of dredged material can be a solution.

On the island of Omø, a dike project has just been finished, thereby protecting a large part of the islands populated area. Clay and soil for the construction was excavated near the dike. In Korsør Nor several dikes are present. In the climate adaptation plan for Slagelse, an extension of the dikes are mentioned. In this particular area.

The municipality of Slagelse has produced a coastal protection plan (Slagelse, 2009), where the coastline is classified according to a risk analysis. According to this plan, 50 areas will be affected by the rising sea level and 13 of these areas are considered high-risk areas with an acute need for dike construction/reinforcements.

In the climate protection plan, a value mapping has been performed. This mapping showed that the costs of constructing dikes or reinforcing existing dikes to a height of 2.25 would be significantly less than what a flood would cost in damaged property.

Kalundborg

In the municipality of Kalundborg, several minor marinas are present (Mullerup, Reersø, Røsnæs and Havnsø) together with a larger commercial port (Port of Kalundborg). All harbors are dredged on a regular basis, but it is only the Port of Kalundbor, which have facilities that may serve useful for receiving raw materials.

In the municipality of Kalundborg, dikes are constructed to protect several areas. Places with the most dikes are centered around Reersø and Saltbæk vig, but several other minor dike constructions exists. At Reersø, a dike enforcement project has been scheduled, but not completed yet. As Reersø marina is subject to regular dredging operations to maintain navigability of the marina entry, there should be a potential for utilization.

The protection of Kalundborg and Reersø are characterized as a matter of importance in the climate adaptation plan (Kalundborg, 2012). In this plan it is stated that the municipality will facilitate larger dike constructions, but costs are to be held by the owners themselves.

4.5. Northern region – Odsherred and Isefjord

This northern region consists of the municipality of Odsherred, Holbæk, Lejre and Roskilde. The latter three municipalities are situated within the Isefjord System.

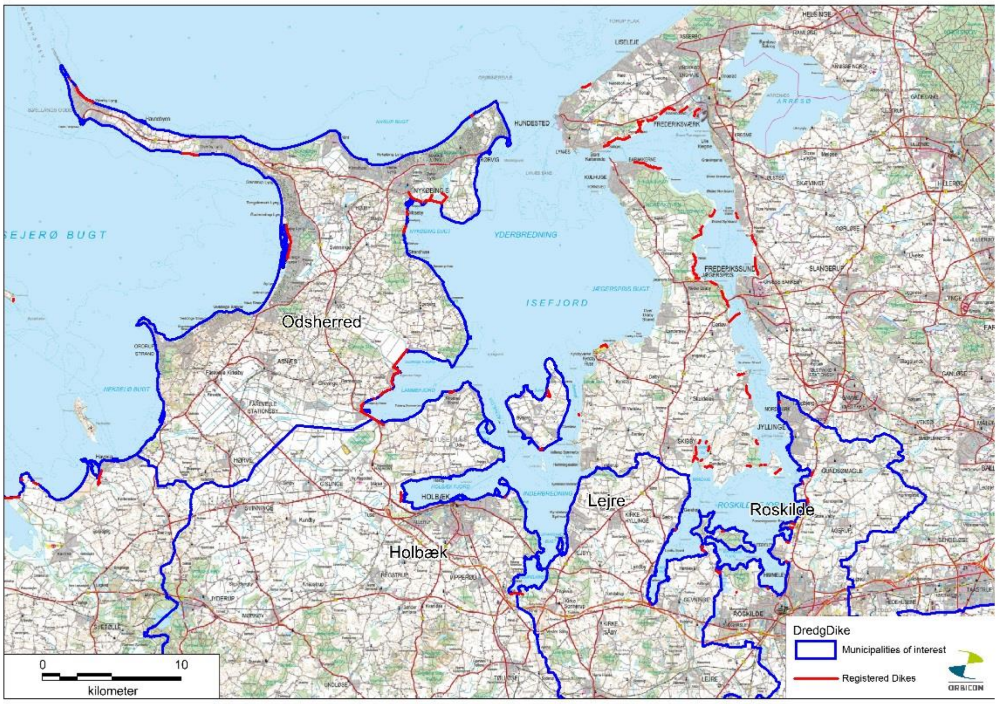


Figure 8: Municipalities (blue) and known dike constructions (red) in the northern region.

Odsherred

Within the municipality of Odsherred, several dike constructions are present thereby both indicating a rather wave exposed region, but also a region with a general low – lying region.

In the municipality there are a number of marinas, minor ports, commercial ports, ferry terminals and navigational channels. The material dredged from the ports on the western and northern shores of Odsherred is often coarsely grained sediment, which has been transported by the large waves that exists when the wind is in north or west. The regular dredging operations for Odden Havn (~every year) has to cover two types of substrate; the coarsly grained sediment from the port entry (uncontaminated) and sediment from the outer basin, which is slightly contaminated. Depending of the mixing of sediment within the outer basin, all material is usually fit for disposal at off-shore dumpsites. There could be a potential for the utilization of sediment from this area, but contamination levels are highly variable. The base layer of the harbor is clay which should be directly usable in dike constructions. However, no dedicated landing facilities are present. Landing of dredged sediment on the beach could be possible.

In Rørvig and Nykøbing marinas, the sediment is fine grained as it is a more protected area. Sediment from these areas are disposed at offshore dumpsites.

In "Sejerø Bugten" and on "Sjællands Odde" several dikes are present. The first mentioned dike is protecting an area with private holiday homes, which is situated more or less on sea level. On “Sjællands Odde” the dike is protecting agricultural land and private land. Within Isefjorden, there are several minor dike constructions protecting Nykøbing Sjælland. In the climate protection plan for Odsherred (Odsherred 2013), Nykøbing is considered a place which will be flooded by in the event of flood-event. Existing dikes may therefore be reinforced and new dikes constructed.

A large part of the area behind the Lammefjord is reclaimed seabed which is situated in sea level or below. The area has great importance for local agriculture and is protected by massive dike constructions. In the Climate protection plan, these dikes are to be reinforced considerable. However, there are no harbors or navigational channels within 20-30 km, so the sediment has to be pumped directly to the dike area from dredging projects in other areas.

Holbæk

The municipality of Holbæk has one minor commercial port and several minor marinas. The municipality of Holbæk is maintaining sailing depths of all marinas in the municipality.

The island of Orø has a marina and two ferry terminals. Holbæk Marina is the largest marina in the municipality, but is not dredged on a regular basis. The navigational channel to Orø Ferry terminal is dredging approximately 6.000 m^3 every 5 years. The material is fine-grained and is by the municipality, not considered suitable for utilization.

The municipality informs that the material usually is “relatively polluted” and all dredged material is placed in a permanent storage facility.

The port of Holbæk is considered usable for landing marine raw materials, even though it is situated in the middle of Holbæk city, which may make further transportation to project sites difficult. The dredging vessel that are operating within the Isefjord are generally flat bottomed and may be able to come close to potential dike projects.

There are a number of larger dike constructions in the municipality of Holbæk. As in the municipality of Odsherred valued agricultural land is reclaimed seabed and being kept dry by pumps, channels and dikes. Other dikes are placed at the end of narrow fjords.

In the climate protection plan, most risk-areas are concentrated within the town of Holbæk. The basis for this priority is a risk-analysis where public and private property has been capitalized. However there are no immediate plans of constructing dikes to protect the properties on land.

There are no plans on reinforcing existing dike constructions on Orø and in the Tempelkrog where minor dikes are present. Presently, the municipality is preparing a strategy for mitigation measures in relation to rising seawater.

Lejre

There is only one marina in the municipality of Lejre and no navigational channels exists. There are only minor dike constructions in the municipality. However, in the climate protection plan for the Municipality of Lejre, the construction of sea dikes is mentioned, in combination with high-level locks that will stop saltwater protrusion into the streams, are characterized as an instrument to protect urban areas in the vicinity of the Fjord.

There have been several cases of flooding in the Isefjord System, which caused substantial damage.

Roskilde

The municipality of Roskilde is present in the inner part of Roskilde Fjord and is subject to frequent flooding events, which has caused substantial damage to private property. There are three marinas in the municipality (Jyllinge, Himmelev and Roskilde), but none of them has facility to handle dredged material.

Only Jyllinge Marina has a regular need for dredging in order to maintain the guarantied sailing depths in the navigational channel. The marina has a permit to dump 3000 m^3 per year at an offshore dumpsite.

A qualified landing facility is placed on the other side of the fjord at Østby Havn. This port is closed but may be useful for the purpose. The municipality of Frederikssund is currently finalizing a climate adaptation strategy, which may include construction of dikes. There are no existing dikes in the vicinity of Jyllinge Marina.

The municipality is preparing a climate adaptation strategy to counteract the rising sea levels and the increase in flooding events. The municipality informs that they presently are considering the construction of a sea dike at Jyllinge Nordmark, but they have not decided on specific design and location yet. They inform that the municipality presently has no intentions of using dredged material for this construction.

5. ASSESMENT OF SAMPLE ANALYSIS

5.1. Method

During May 2014, sediment from six different locations (harbors and navigation channels) was sampled:

- Køge Harbour
- Tårs Ferry Port
- Mosede Harbour
- Vordingborg South Harbour
- Grønsund – Navigation route
- Sandhage – Navigation route

A total 36 of sediment samples, six from each of location, were collected. The sediment samples were taken with a PVC tube from Orbicons survey ship Warrior 175.

Each sediment sample was described by colour, odor, grain characteristics and length of the sample as well as the water depth were the sample was taken. These information were noted in a logbook (see Appendix 1).

Some samples were analysed for geotechnical parameters and some were analysed chemical concentrations such as heavy metals, PCBs, PAHs and TBT (Table 5).

The sediments from the navigation routes were not analyzed for chemicals, as it is assumed non-contaminated by heavy metals etc.

10 l of sediment was collected from each location to reassure 5 kg of dry-matter for the geotechnical analysis. Where more than one type of sediment was present in a location (etc. both silty and coarsely grained), one bucket was collected with each of the registered sediment types.

The chemical analyses were conducted at Kiwa Control GmbH, FB Umweltanalytik in Germany whereas the geotechnical analyses were conducted at the University of Rostock, Chair of Geotechnics and Coastal Engineering.

Table 5 Overview of the samples and mixing of samples for geotechnical and chemical analyses of sediment from four different harbours and two navigation routes. No chemical analysis were performed on the samples from Sandhage and Grøndsund.

Location	Sample	Sample for geotechnical analyses	Mixed sample for chemical analyses (heavy metals, PCBs and PAHs)	Mixed sample for chemical analyses (TBT)
Køge Harbour	Koge1		A	MP Koge A+B+C
	Koge2	Køge Havn 2		
	Koge3	Køge Havn 1		
	Koge4		B	
	Koge5			
	Koge6		C	
Tårs Ferry Port	Taars1	Tårs 1		
	Taars2		B	MP Tars Faergehavn B + C
	Taars3			
	Taars4		C	
	Taars5			
	Taars6	Tårs 2		
Mosede Harbour	Mos1		A	Mosede A
	Mos2			
	Mos3			
	Mos4			
	Mos5	Mosede Havn		
	Mos6			
Vordingborg South Harbour	Vord1	Vordingborg I	A	
	Vord2		B	
	Vord3			
	Vord4		A	
	Vord5	Vordingborg II	B	
	Vord6			
Sandhage	Sand1			
	Sand2			
	Sand3	Sandhage		
	Sand4			
	Sanf5			
	Sand6			

Grønsund	Gron1	Grønsund		
	Gron2			
	Gron3			
	Gron4			
	Gron5			
	Gron6			

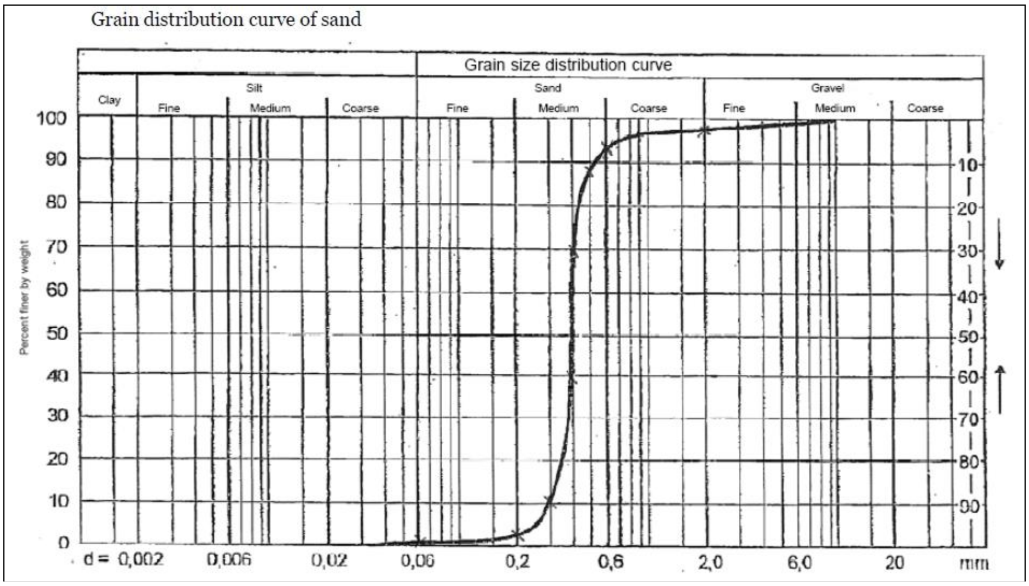
When applying the Danish Coastal Authority for a permit for the construction of a sea dike, the material applicability in a dike construction is evaluated by the authority after the guidelines given in
'Figure 9, Table 6 and Table 7 (Kystdirektoratet 2014). All other parameters are evaluated by the staff in the evaluation process.

Table 6: Requirements for clay used as dike revetment (EAK, 2002)

Soil property	**Threshold**
Sand content (d > 0.06mm)	< 40%
Clay content (d < 0.002mm)	> 10%
Liquidity Limit	$W_L > 25\%$
Plasticity Limit	$W_P > 15\%$
Undrained Shear Strength	> 20 KN/m^2
Dry density	$0.85 < \rho_d < 1.45$ t/m^3
Water content	80% > w > 30%

Table 7: Classification of clay erosion resistance (TAW, 1996)

Clay category	**Water content w [%]**	**Plasticity Index**	**Sand content [%]**
Erosion resistant	> 45	$> 0.73 \cdot (w - 20)$	< 40
Moderate erosion resistance	< 45	> 18	< 40
Low erosion resistance	< 45	< 18	< 40



'Figure 9: Prefered grain size distribution of sand for dike constructions (Kystdirektoratet 2014).

The Danish Coastal Authority informs, that they make a case-to-case evaluation of the applicability of the given material in relation to design, location and expected impact from waves (Pers. com. Thorsten Piontkowitz).

5.2. Field observations

Field observations, including positions, sample size and sample description from the sediment sampling is presented in appendix 1.

5.3. Chemical analyses

Eight mixed sediment samples from four harbours (Table 5) were analysed for:

- Heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn)
- PCBs
- PAHs

Whereas sediment from two harbours were analysed for:

- TBT

The analyses were conducted by KIWA Control GmbH. The analytical results are presented in Appendix 3.

Table 8 compiles the results and compares them with soil contamination criteria from the executive order on definition of slightly contaminated soil (no. 554 of 19/05/2010), List of quality criteria in relation to contaminated soil and quality criteria for drinking water (Miljøstyrelsen, 2014) and Guideline on handling of contaminated soil in Zealand

(Zeeland Guidelines, 2001). The results from the chemical analyses are compared with the criteria in order to assess whether the sediment can be reused in dikes and which applications is required.

The results represents the upper part of the sediment (20-45 cm). Below this layer are older geological types of material. The deeper parts of the sediment are considered to be outside the direct influence of anthropogenic impact and therefore generally have a lower content of heavy metals and pollutants.

Table 8 Chemical analytic results from sediment samples from four different Danish harbours compiled with the lower and upper action levels from the Nature Agency (for explanation see the text).

		Sediment sampling May 2014 Station:												
		Køge A	**Køge B**	**Køge C**	**Køge A+B+C**	**Tårs Færgehavn B**	**Tårs Færgehavn C**	**Tårs Færgehavn B+C**	**Mosede A**	**Vordingborg A**	**Vordingborg B**			
		3 subsamples mixed	**2 subsamples mixed**	**1 sample**	**6 subsamples mixed**	**2 subsamples mixed**	**3 subsamples mixed**	**5 subsamples mixed**	**6 subsamples mixed**	**2 subsamples mixed**	**4 subsamples mixed**	**Sligthly contaminated**	**Zealand guidline[5] Category 1**	**Executive Order of Reuse[6] Category 1 Non-contaminated**
As	mg/kg TS	<5	<5	<5		<5	<5		<5	<5	<5	≤20[3]	20	0-20
Cd	mg/kg TS	0.3	<0.1	0.1		0.2	0.3		0.7	<0.1	<0.1	0.5-5[1]	0.5	0-0.5
Cr	mg/kg TS	6.8	18	9.8		7.6	11		8.4	2.2	0.92	500-1000[1]	500	0-500
Cu	mg/kg TS	9.5	12	8.7		7.9	12		44	2.1	0.91	500-1000[1]	500	0-500
Hg	mg/kg TS	<0.1	<0.1	<0.1		<0.1	<0.1		<0.1	<0.1	<0.1	1-3[1]	1	0-1
Ni	mg/kg TS	5.6	14	7.8		6.2	9.6		6.7	1.6	0.58	≤30[1]	30	0-30
Pb	mg/kg TS	6.4	8.4	5.8		6.2	10		13	2.1	<2	40-400[1]	40	0-40
Zn	mg/kg TS	49	42	29		34	49		100	9.6	4.1	500-1000[1]	500	0-500
TBT	mg/kg TS				0.008			0.009	0.62			1 (measured as Sn)[3] =2.44 (meas-ured as TBT)	n.a.	n.a.
DBT	mg/kg TS				0.003			0.003	0.190			n.a.	n.a.	n.a.
MBT	mg/kg TS				0.002			0.003	0.050			n.a.	n.a.	n.a.
PCB (sum of 7)	µg/kg TS	0	0	0		0	0		0.0057	0	0	n.a.[4]	n.a.	n.a.
Benzo(a)pyrene	mg/kg TS	0.08	<0.02	0.05		0.05	0.08		0.42	0.08	<0.02	0.3-3[1]	0.1	n.a.
Dibenz(a,h)antracene	mg/kg TS	<0.02	<0.02	<0.02		<0.02	<0.02		0.1	<0.02	<0.02	0.3-3[1]	0.1	n.a.
Naphthalene	mg/kg TS	<0.02	<0.02	<0.02		<0.02	<0.02		<0.02	<0.02	<0.02	n.a.	0.5	n.a.
PAH (sum of 6)[2]	mg/kg TS	1.42	0	1.03		0.69	0.49		2.65	0.31	0	4-40[1,2]	n.a.	n.a.

Note

[1]Executive order on definition of slightly contaminated soil no. 554 of the 19th of May 2010

[2]Sum of fluoranthene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenz(a,h)antrachene, Indeno(1,2,3-c,d)pyren.
Executive order on definition of slightly contaminated soil no. 554 of the 19th of May 2010 requires sum of these 6 PAHs plus benzo(j)fluoranthene

[3]List of quality criteria in relation to contaminated soil and quality criteria for drinking water announced by the Environmental Protection Agency May 2014

[4]No soil quality criteria for PCBs according to the soil quality criterias announced by the Environmental Protection Agency per May 2014

[5]Guideline on handling of contaminated soil on Zealand, July 2001

[6]Recycling ordinance no. 1662 of 21/12/2010

Signature

(green) = Non-contaminated

(yellow) = Slightly contaminated material

5.3.1 Heavy metals

The concentrations of heavy metals are below the levels for slightly contaminated soil on all locations except 'Mosede A' (Table 8). The concentrations of cadmium (0.7 mg/kg DW) in sediment from Mosede Harbour just above category 1 (non-contaminated soil) and the sediment is thus slightly contaminated.

The level of heavy metals in the sediment from Køge Harbour, Tårs Ferry Port and Vordingborg Harbour can be characterised as being at the level of background concentrations in sediment in Danish waters.

The concentration of heavy metals does not restrict the reuse of sediment in fx. dikes in Køge Harbour, Tårs Ferry Port and Vordingborg Harbour.

5.3.2 Polyclorinated bisphenyls (PCBs)

Analysis are made for 7 PCB's and the sum of the 7 is illustrated in Table 8. In general, none of the analysed samples showed signs of PCB contamination. The only sediment sample where PCB concentration were above the detection limit were in Mosede Marina. According to the guidelines sketched in Table 8 there are no quality criteria concerning these compounds. However, in the Order of dumping of dredged material (Order no. 32 of 07/01/2011) criteria for the sum of PCBs are listed (see Table 4). In Mosede marina, a concentration of 0.0057 µg/kg dry matter was registered. The action levels in relation to dumping of the material is 20 (lower action level) and 200 (upper action level) µg/kg dry matter. Accordingly, there is a substantial margin to the lower action levels in relation to the measured concentrations.

5.3.3 Polyaromatic hydrocarbons (PAHs)

PAH compounds, polycyclic aromatic hydrocarbons (tars), which is formed by incomplete combustion of organic material (coal, oil and wood). PAHs are widespread and are found in all environments.

According to Table 8 the sum of six specific PAH compounds are below the level f contaminated soil in Køge Harbour, Tårs Ferry Port and Vordingborg harbour whereas the concentration of the PAH benzo(a)pyrene in Mosede Harbour is slightly above category 1 and thus slightly contaminated.

The concentrations of PAHs in the sediment of Køge Harbour, Tårs Ferry Port and Vordingborg harbour can be reused freely in fx. dikes.

5.3.4 Butyltin

Butyl compounds include TBT (tributyltin), DBT (dibutyltin) and MBT (monobutyltin). Butyltin is the active component of marine paints to prevent fouling. Butyltin can be found anywhere in the marine environment both in the water phase and in the sediment.

TBT is the most toxic, while the degradation products DBT and MBT are less toxic. TBT degrades fastest at biological metabolism and under the presence of oxygen. The half-lives are of the range of weeks to years, the longest in sediments.

The use of paints with TBT was phased out after the conclusion of an international agreement in 2001 (AFS Convention). The content of TBT in Danish marine areas is decreasing as a function of the gradual turnover to less toxic compounds.

The concentrations of TBT in all four harbours are way below the quality criteria for soil (Table 8). Thus, the TBT concentration does not restrict the reuse of sediment in dikes.

5.4. Geotechnical analyses

To evaluate the sediment samples' suitability for a component in dike constructions, the geotechnical consultants firm Jysk Geoteknik was engaged to perform the geotechnical evaluations.

The results of the Geotechnical analysis are presented below.

Table 9 Overview of results from analyses of geotechnical parameters.

Material	Køge Havn I	Køge Havn II	Grønsund	Mosede Havn	Sandhage	Tårs I	Tårs II	Vordingborg I	Vordingborg II
Coarse sand (%)	6.49	3.15	1.25	4.99	14.04	5.25	10.79	8.15	9.25
Medium sand (%)	29.39	15.20	84.09	24.36	86.61	33.88	19.27	81.04	65.04
Fine sand (%)	47.93	65.12	14.13	64.01	1.69	47.16	45.72	6.55	23.53
Coarse silt (%)	4.8	5.98	0.04	2.49	0.17	5.03	7.95	1.32	0.49
Miedium silt (%)	4.02	4.08	0.04	1.31	0.20	2.59	7.29	0.74	0.32
Fine silt (%)	2.46	1.95	0.12	0.70	0.01	1.72	3.15	0.59	0.24
Clay (%)	4.91	4.52	0.33	2.14	0.28	4.37	5.83	1.61	1.13
TOC (%)	1.67	1.70	-	2.10	-	1.24	2.11	3.49	0.18
OS (%)	2.88	2.93	-	3.62	-	2.14	-	3.64	0.31
LOI (%)	4.1	5.0	0.2	4.0	0.2	3.4	9.9	1.5	0.6
Lime content LC (-)	8.3	21.8	0.4	0.6	0.4	7.3	7.5	0.8	0.9
Liquid Limit LL (%)	37.7	41.6	-	37.7	-	36.8	72.8	-	-

Plastic Limit LL (%)	30.2	31.9	-	35.7	-	28.4	49.0	-	-
Plastivity Index PI (%)	7.5	9.7	-	1.0	-	8.4	23.8	-	-
Consistency Index CI (%)	-6.1	-7.8	-	-76.55	-	-8.5	-6.5	-	-
Oversized grain (%)	14.2	8.0	-	4.0	-	21.6	4.1	-	-

Based upon the above listed results, Jysk Geoteknik performed the following analysis in relation the potential use of dredged material for the use as core-material and cover-material in dike constructions. The below listed assessment as translated and adapted from Danish. The geotechnical note is presented in appendix 1.

5.4.1 Cover material

For the use of dredged material as protective cover-layer, the clay (material less than 0,002mm) has to be over 10 %. The highest measured clay content from the sediment samples were 5.8% in the sample named Tars II. Thus, it is found that none of the analyzed samples reflects material that is suitable for use in the protective layer of a dike.

5.4.2 Core material

For the use of material in the dike core, the Danish Coastal Authority recommends a well-graded grain size distribution with a steep curve (which is well draining) and a mean grain size D50 of 0.4mm (Kystdirektoratet, 2014). There is no specified tolerance for the recommended curve and some personal evaluation must therefore be performed.

It is assessed that material from Vordingborg I and II, Grønsund and Sandhage will be suitable for implementation in the core of dike constructions, as their grain size distributions are fairly close to the optimum curve (see appendix 2).

Whereas for the material from Køge I and II, Mosede port and Tars I and II their mean grain size D50 is between 0.1 and 0.2. This is below the optimum curve presented by the Danish Coastal Authority.

There should be an assessment of whether the stability of the core of these materials will be sufficient.

6. SUMMERY OF THE UTILIZATION POTENTIAL

In the following sections, the six areas in question will be evaluated in relation to sediment characteristics, dredging needs, suitable port facilities and known dike constructions in the vicinity of the dredging area.

6.1. Køge Port

Description

The port of Køge is a commercial port and is located in the southern part of Køge Bugt. The port of Køge has a mixture of berths, which range from bulk cargo, landing of marine resources and a ferry terminal. The port of Køge is in the middle of a major expansion project, where an area is reclaimed to create a larger harbour with better facilities. The port and sediment sampling positions can be seen in Figure 10.

Figure 10: Port of Køge with the sediment sampling positions

Distance to appropriate ports

There is a dedicated landing facility for the handling of marine resources within the port of Køge.

Dredging needs

The port of Køge has a continuous need for dredging of the navigational channel and of the outer basin of the harbour. Presently, the harbour has a permit for the dumping of 9,000 m3 from the outer basin.

The inner port is subject to moderate sedimentation from a local stream, but the material from this area is highly contaminated by TBT and cobber from an old shipyard.

Sediment characteristics

The chemical analyses of environmental contaminants from all samples from the port of Køge were at the level of the background concentrations.

From a chemical perspective, the sediment from Køge Bugt is thus suitable for reuse in dikes and other constructions.

Due to its low content of clay (< 5%), it is not considered usable for cover material in dike constructions.

However, during sediment sampling, several of the original sampling positions had to be changed due to a layer of clay, which cannot be sampled by Cayak tube. However, the clay can only be dredged if sailing depth is increased above what is guaranteed.

Dike constructions

There are several minor dike constructions in the vicinity of the port of Køge as can be seen on Figure 11. The area south of Køge is located very low and may be subject to dike construction and reinforcements. There are presently no plans of creating new dikes on the coastline, even though it is mentioned as a mitigation measure in the Climate Adaptation plan for the municipality.

Figure 11: Dikes in the vicinity of the port of Køge.

6.2. Tårs Ferry Port

Description

Tårs Ferry terminal is placed in the western Lolland and maintain the traffic to Langeland. There is a minor marina within the immediate vicinity of Tårs Ferry port in this relatively shallow bay.

Figure 12: Tårs Ferry Port and sediment sampling locations

Dredging needs
Tårs Ferry Port and the navigational channel to the bay, has regular dredging needs due to sand movement in the area.

Tårs Ferry Port has a 5-year permit for dredging material from within the harbour. The marina has a 5-year permit for dredging of 3,000 m^3.

Sediment characteristics
The chemical analyses of environmental contaminants from all samples from Tårs Ferry Port were at the level of the background concentrations. From a chemical perspective, the sediment from Tårs Ferry Port is thus suitable for reuse in dikes.

As more than one of the sediment samples contained clay (which could not be sampled and hence is not a part of the evaluation in appendix 2) there could be a potential for dredging of clay for dike constructions. In relation to utilization of the dredged material for the core of dikes, samples have to be evaluated further, as the grain size deviated from the official guidelines from the Danish Coastal Authorities. As these guidelines are the only evaluation criteria used by the Danish Costal Authorities, the potential utilization of material from this area as core material in dike constructions has to wait for the full evaluation by the Danish Coastal Authorities.

Distance to appropriate ports
There are suitable port facilities in the commercial port of Nakskov which is situated 10 km from Tårs. Material may be landed in the Ferry Port itself, as only half of the port is used presently.

Dike constructions

There are several dike constructions within short distance of Tårs (see Figure 13). Furthermore there are several dike construction projects where there may be use for reinforcements.

Figure 13: Dikes in the vicinity of Tårs Ferry Port.

Overall assessment

There seems to exist a potential for the utilization of dredged material from Tårs Ferry Port at adjacent dikes.

6.3. Mosede Harbour

Description

Mosede Harbour contains primarily leisure vessels and is self-owned by the users. Only a few commercial fishing ships are located here. Depths vary between 2 and 2.5 meters. Dredging of the navigational channel to the harbour is only rarely maintained (< 10 years).


Figure 14: Mosede harbour and the sediment sampling locations.

Dredging needs
Mosede harbor has an existing permit for dumping dredged material from the outer basin. No regular dredging is required from the inner basins. The material in the dredging area is primarily coarsely sediment that is transported through the breakwater due to failing sand seal. The sand is relatively uncontaminated.

Sediment characteristics
According to the Order on slightly contaminated soil (no. 554 of 19/05/2010), Order on Reuse (no. 1662 of 21/12/2010) and the *Zealand Guideline*, the sediment in Mosede Harbour is slightly contaminated with cadmium. Furthermore, the sediment is slightly contaminated with benzo(a)pyrene according to the *Executive order on slightly contaminated soil* and the *Zealand Guideline.*

The concentrations of the contaminants is very close to the lower limit for slightly contaminated soil. However, the exceedances are very small. The source to the contaminations might be local and it is recommended to analyse the different subsamples to localize the source. The non-contaminated sediment can be used freely if the contamination is local. The reuse of contaminated sediment from Mosede Harbour should be applied as an environmental approval according to the *Environmental Protection* Act § 33.

Distance to appropriate ports
Closest port facility that can accept dredged material is the port of Køge, which has a facility for the handling of mined sediment. The port facility is considered ideal for receiving dredged material. The distance to the port of Køge is 13.5 km. The port facility is handled by a mining company (NCC raw materials) which has great expertise in handling raw materials.

Alternatively, dredged material has to be transported directly to the place of use and pumped to land in pipes. However this will increase costs considerable.

Dike constructions

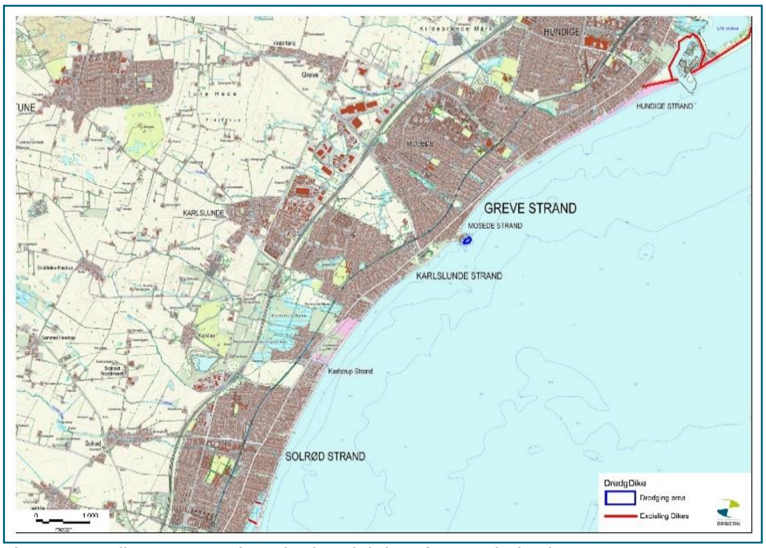


Figure 15: Dike constructions in the vicinity of Mosede harbour.

The closest existing dike construction in the vicinity of Mosede Harbor are the dikes that represents “Køge Bugt Strandpark” which can be seen in Figure 15 north of Mosede Harbor. 4-5 km. Dredged material can be transported to the local harbor (Hundige Harbor) but no handling facilities are available, so pipes etc. have to be established.

“Køge Bugt Strandpark” informs that they regularly perform maintenance on the 6 km long dike. This is primarily necessary between Valensbæk and Brøndby, which is approximately 9 km from Mosede Harbor. Køge Bugt Strandpark furthermore informs that they, as an experiment, have utilized material from embankments of the coast and the navigational channels from Ishøj/Vallensbæk Harbor to strengthen dikes between Vallensbæk and Brøndby. Hundige Harbor is interested in a similar corporation, but this has not been formalized yet. The method for the dredging operation is mainly from land with excavator.

South of Mosede Harbour a set of minor inland dikes are present (distance ~8 km, see Figure 15). No handling facilities are present at this site.

Overall assessment

There seems to exist a potential for the utilization of dredged material from Mosede Harbor in projects at adjacent dikes.

6.4. Vordingborg Navigational Channel

Description

The navigational channel outside Vordingborg, connects several minor harbours and ports within the main waters of Denmark (see Figure 16). Vordingborg southern harbour has expansion plans that include widening of the navigational channel, but nothing is finalized presently. There are several harbours and ports in the immediate vicinity of the navigational channel.

The area is subject to powerful currents, which remobilizes the sediment.

Figure 16: Dredging area and sediment sample locations.

Dredging needs

Vordingborg Port has a permit for dumping about 4,000 m^3 per year. The other harbours in the municipality have similar dredging needs. Vordingborg Port have plans on expanding the southern port, which will include landfill and widening of the navigational channel.

Sediment characteristics

The chemical analyses of environmental contaminants from all samples from Vordingborg Harbour were at the level of the background concentrations. From a chemical perspective, the sediment from Vordingborg Harbour is thus suitable for reuse in dikes.

According to the geotechnical report (see appendix 2) the material from Vordingborg navigational channel is not suitable for protective material in dike constructions. However the material is found suitable as core-material.

Distance to appropriate ports

The closest appropriate port that can handle dredged material is Vordingborg Commercial Port (distance 500 m).

Dike constructions

In the immediate vicinity of Vordingborg navigational channel there are only minor dike constructions. However more dikes are planned as a part of the climate adaptation strategy.

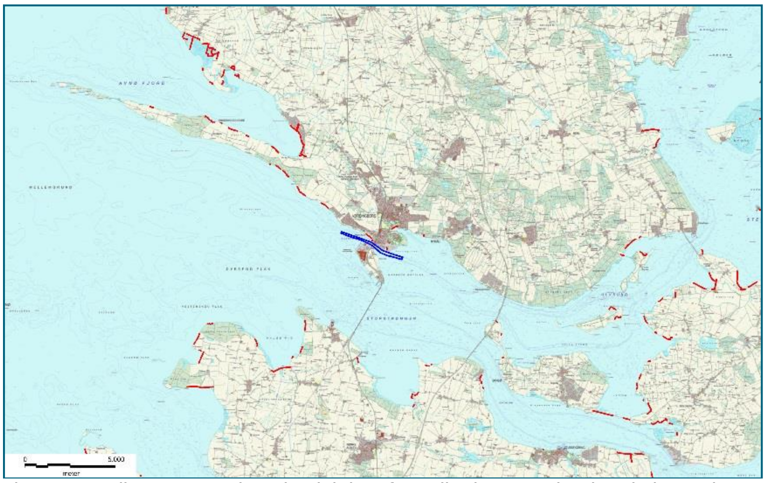


Figure 17: Dike constructions in vicinity of Vordingborg navigational channel.

Overall assessment

There seems to be a potential for utilization of dredged sediment from Vordingborg navigational channel as the material is considered suitable as core material in dikes (but not as cover material) and there are both dikes and suitable port facilities nearby.

6.5. Grønsund Navigational channel

Description

The navigational channel at Grønsund (also called Nytløb and Hestehoved dyb) excavated through a shallow barrier east of Falster. Only minor harbours are present at the immediate vicinity. The navigational channel is present within a Nature 2000-area. Location of dredging area and sediment locations are shown in Figure 17.

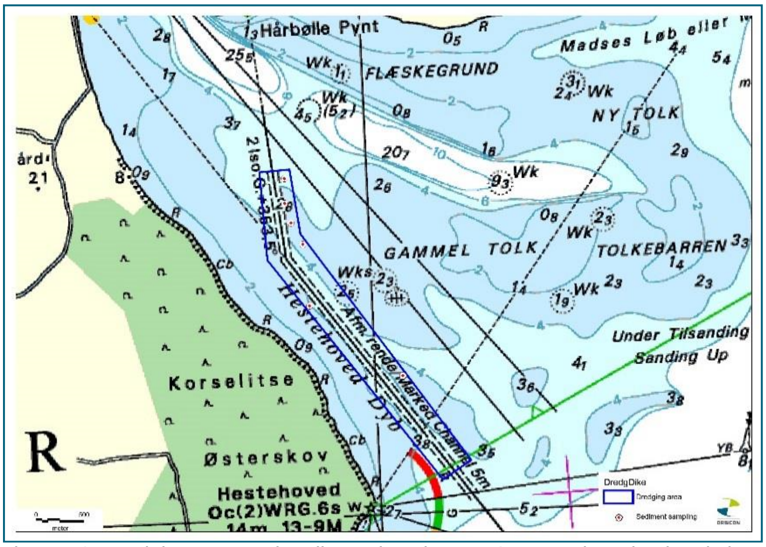


Figure 18: Dredging area and sediment locations at Grønsund Navigational channel.

Dredging needs

The navigational channel is subject to massive and repeated dredging and the Danish Coastal Authorities (that has the dredging obligations of the navigational channel) has a permit for dredging approximately 40,000 m^3 per year. Furthermore, Hesnæs Hav, which is located approximately 5 km from the navigational channel, is dredging material from the harbour.

Sediment characteristics -

The material from Grønsund is considered suitable for core material for dikes but not as cover material.

Distance to appropriate ports

Closest port is Vordingborg commercial port which is 25 km from this location.

Dike constructions

There are several dike constructions close to Grønsund, but the present constructions are only of minor size. Existing dikes are pictured in Figure 19.

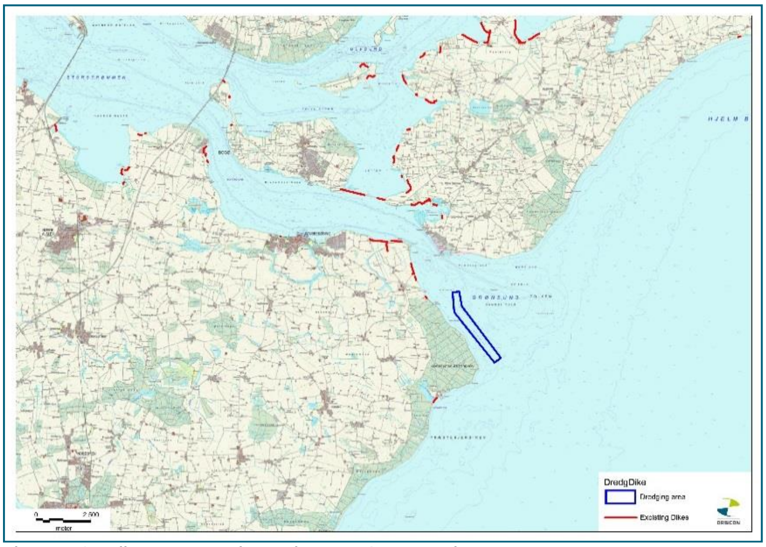


Figure 19: Dike constructions close to Grønsund.

Overall assessment
There seems to be a potential for utilization of dredged material from Grønsund (volume, presence of suitable harbour, material suitable) but no larger dike projects are present in the vicinity of the navigational channel and the distance to landing facilities is high.

6.6. Sandhage Navigational Channel

Description
The navigational channel is present in an area called "Bøgestrømmen" which is a complex of sand barriers. Sandhage navigation channel pierces this area with barriers with an approximately 30 meter wide route.

The navigational channel is present in the Natura 2000-area no. 168 "Havet og kysten mellem Præstø Fjord og Grønsund", which also includes the coastal areas and coastlines in the region. Location is pictured on Figure 20. There are several harbours in the vicinity of "Bøgestrømmen" but the closest are located in Sandvig, Præstø, Kalvehage and Stege.

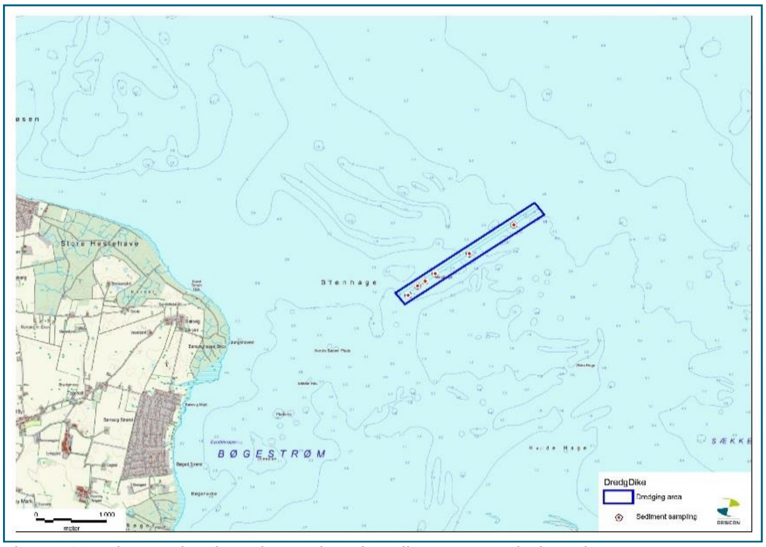


Figure 20: The navigation channel and sediment sample locations.

Dredging needs

There is a permit for dredging 15,000 m^3 per year (75,000 m^3 per 5 years) from the navigation channel. The Danish Coastal Authorities Danish Coastal Authorities informs that there presently is being investigated wither the sediment from the channel is suitable for a beach nourishment project at Kalvehave Havn. However, no permits have yet been issued.

Sediment characteristics

The material is primarily coarse and middle sand and is thus considered suitable for utilization in dike constructions as core material (se appendix 2).

Distance to appropriate ports

There are two ports with suitable landing facilities. Towards north Præstø has a dedicated landing facility for landing marine resources. Towards the south Stege commercial port is present. There is no dedicated landing facility for landing dredged material. Of the two mentioned ports, Præstø is considered the best alternative. For local projects, temporary pipelines may be a solution.

Dike constructions

There are a number of dike constructions in the immediate vicinity of Bøgestrømmen. Closest dikes are situated at Kindvig Hoved and around Stege Bugt.

Established dikes are pictured in Figure 21

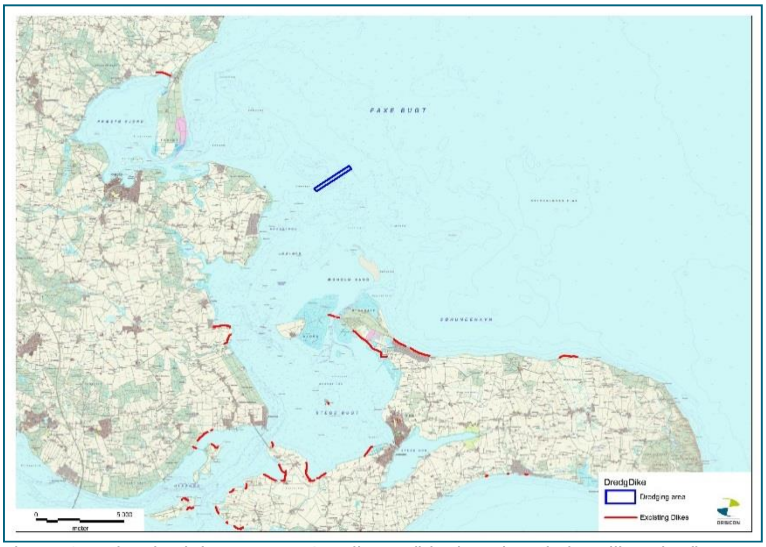


Figure 21: The dredging area at Sandhage (blue) and excisting dikes (red)

No projects for new dike constructions are known.

Overall assessment

From the characterization of the sediment and from the distance to ports and dike projects, there should be a potential for utilization of the dredged material in dike constructions and dike maintenance. However, the distance to landing facilities may show to be too long and temporary landing facilities close to project area may be the best solution.

7. CONCLUSION

The utilization of dredged sediment is regulated by a number of authorities and based on the end-use of the material. In several cases, more than one authority has to give its consent before dredging can begin. A full list of orders and acts involved is listed in Table 10.

The sediment samples all showed low levels of contaminants and was from a chemical perspective, suitable for utilization. The geotechnical analysis showed that the sediment from all locations were suitable as core material in dike constructions. As the level of clay was low in all samples, the sediment may not be suitable for protective cover on dikes. However, during the sediment sampling, no samples of clay could be taken due to the chosen sample-method. In the field observations in appendix 1, a short description of each sediment sample is given.

There is no regional or national coordination of dike construction or maintenance in Denmark. As the common practise is today, utilization of dredged material is taking place where there is both a need for dredging and a need for dike constructions or reinforcements. As dike constructions are solely (with few exceptions) the responsibility of the landowners that may benefit from the dikes, it may be a matter of coincidence where the two needs can be combined.

As mentioned above, dike projects are exclusively financed and initiated by the needs of landowners. However, in some municipalities, the coordination of dike construction lies within the technical management of the municipality. In general, municipalities are only financing dike construction and maintenance in areas where they are landowners.

It seems as though the produced climate protection plans - which are mandatory for all municipalities in Denmark - in many coastal areas include construction and/or reinforcements of dikes. If the right material is present in the vicinity of the project and there is a suitable landing facility, there might be a potential for an increased utilization of dredged sediment. However, this will require a better coordination of dike projects (construction and reinforcements) and an intensive mapping of dredging operations within an area. This may be a task for a municipality, but the coordination has to be on a regional scale.

A regional coordination of dike projects and dredging operations could increase the utilization of dredged material through mapping of local needs on a short and long timescale. Furthermore, regional storage facilities could be established to work as a buffer for construction works. This would make the legislative work regarding treatment-, storage and dewatering facilities less comprehensive for each municipality.

In general, no fine-grained material is utilized in dike projects presently, except for few exemptions where clay has been used. The reason for this is perhaps that there is no central authority that coordinate dike constructions, which means that private dike owner-groups need to have a high degree of insight in an areas' potential in relation to utilization of where dredging takes place and where the sediment has the appropriate geochemical and geotechnical specifications.

The overall conclusion is that there seems to be a greater potential for utilizing dredged material in construction works than what is presently being exploited. However this cannot be accomplished without an intense regional coordination of project.

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9. LEGISLATION CITED

Table 10: List of acts and orders involved when utilizing dredged sediment.

Description	No.
Environmental Protection Act	(Order 879 of 26/6/2010)
Act of Raw Materials	(Act No. 657 of 27/05/2007)
Marine Environment Act	(Act. no 963 of 03/07/2013)
Order of Soil Moving	(Order no. 1479 af 12/12/2007)
Order of dumping	(Act No. 32 of 07/01/2011
Dumping manual	(Manual no. 9702 of 20/10/2008)
Act on coastal protection	Order no. 267 af 11/03/2009
Sewage Order	(Order no. 1448 of 11/12/2007)
Order on environmental quality standards for water bodies and requirements for the discharge of pollutants into rivers, lakes or the sea	(Order no 1022 of 25/08/2010
Order on Landfill	(Order no. 1049 of 28/08/2013)
Order on approval of listed company	(Order no. 669 of 18/06/2014)
Act on planning	(Order no. 587 of 27/05/2013)
Order on the use of residues and soil for construction works and the use of sorted, uncontaminated construction and demolition waste	(Order no. 1662 of 21/12/2010)
Order on dumping of dredged material	(Order no. 32 of 07/01/2011)