DredgDikes

South Baltic Guideline for the

Application of Dredged Materials, Coal Combustion Products and Geosynthetics in Dike Construction

Edited by:
Fokke Saathoff & Stefan Cantré
Universität Rostock, Chair of Geotechnics and Coastal Engineering
Zbigniew Sikora
Gdansk University of Tecnology, Dept. Geotechnics, Geology and Maritime Engineering

South Baltic PROGRAMME
Part-financed by the European Union
(European Regional Development Fund)

Universität Rostock
gegründet 1419
Traditio et Innovatio
GDAŃSK UNIVERSITY OF TECHNOLOGY

South Baltic Guideline for the

Application of Dredged Materials, Coal Combustion Products and Geosynthetics in Dike Construction

Edited by:

Fokke Saathoff & Stefan Cantré

Universität Rostock, Chair of Geotechnics and Coastal Engineering

Zbigniew Sikora

Gdansk University of Technology, Dept. Geotechnics, Geology and Maritime Engineering

Part-financed by the European Union
(European Regional Development Fund)

South Baltic Guideline for the Application of Dredged Materials, Coal Combustion Products and Geosynthetics in Dike Construction

Edited by:

Prof. Dr.-Ing. Fokke Saathoff and Dr.-Ing. Stefan Cantré
Universität Rostock, Chair of Geotechnics and Coastal Engineering
18051 Rostock;
www.auf.uni-rostock.de; www.dredgdikes.eu

Prof. dr hab. inż. Zbigniew Sikora
Gdansk University of Technology
Department of Geotechnics, Geology and Maritime Engineering

CIP-Short Title:

South Baltic Guideline for the Application of Dredged Materials,
Coal Combustion Products and Geosynthetics in Dike Construction
Rostock, 2015

Purchasing options:

Universität Rostock, Universitätsbibliothek, Schriftentausch, 18051 Rostock
Phone: +49 381 498 8637; Fax: +49 381 498 8632

Universität Rostock, Faculty of Agricultural and Environmental Sciences
Chair of Geotechnics and Coastal Engineering
Justus-von-Liebig-Weg 6, 18059 Rostock
Phone: +49 381 498 3701; Fax: +49 381 498 3702

Gdansk University of Technology
Department of Geotechnics, Geology and Maritime Engineering
ul. Narutowicza 11/12, 80-233 Gdansk
Praca naukowa finansowana ze środków finansowych na naukę w latach 2012-2014 przyznanych na realizację projektu międzynarodowego współfinansowanego

Digital PDF versions of the guideline and annexes are available online on www.dredgdikes.eu.

ISBN: 978-3-86009-423-5

Published by Universität Rostock
www.uni-rostock.de
Print: Altstadtdruck GmbH Rostock, Luisenstraße 16, 18057 Rostock
Printed on 100% recycling paper with carbon neutral printing technology.

FOREWORD

Dredged materials research has been developing rapidly during the past decade. Although sediments that are taken on shore are generally considered a waste according to European legislation, the materials prove to have a good potential to be recovered in a variety of applications. Anthropogenic materials, such as by-products of coal combustion (CCPs), generally fall under the waste law, too. Therefore, comparable hurdles have to be taken when it comes to the recovery of the materials. The European Waste Framework Directive demands a recovery rate for these secondary materials of 70 % by 2020. This implicates research and development in all fields of sediment management and material recovery. With a growing environmental awareness all around the Baltic Sea, many debates discuss strategies on how to reduce the amount of dredged sediments dumped at sea. In addition, many ideas are being developed how to increase the possibilities for CCP recovery beyond the standard road construction and concrete production applications. Here, it is of vital importance to address the particular characteristics of the different types of materials in an environmental context.

Both types of materials face a number of barriers regarding legislation and administration as well as public acceptance. To overcome these obstacles, the stakeholders involved in civil and coastal engineering projects, including the affected public, need reliable information about the benefits and limitations regarding the recovery of dredged materials and coal combustion products.

Within the Baltic Sea Region, a large number of flood protection structures, including dikes, protect the people and properties from river flooding and coastal storm surges. In the South Baltic, this concerns Mecklenburg-Vorpommern, Germany (mainly sea dikes, river dikes at Elbe and Oder), northern Poland (river dikes), Zealand, Denmark (all kinds of dikes) and Lithuania (river dikes). In the context of climate change scenarios that predict rising sea levels and increasing extreme storms that lead to higher and more frequent inland flood events, considerable efforts in dike construction and reconstruction will be necessary during the next decades, associated with the need for enormous amounts of earth construction material. The project DredgDikes therefore aimed at combining both problems in providing alternative construction materials for future dike constructions and at the same time reducing the amount of waste for deposit.

The Chair of Geotechnics and Coastal Engineering at the Universität Rostock has been investigating the issue of dredged materials as replacement materials for dike construction since 2007. The topics of dikes, particularly with the focus on geosynthetics used in dikes and the determination of hydraulic design values, have been subject to research for a much longer time. The Department of Geotechnics, Geology and Maritime Engineering at the Gdansk University of Technology has a long-term experience with the use of fly ash in geotechnical applications and the Steinbeis Innovation Centre for Applied Landscape Planning in Rostock comes with many years of experience in dredged material research. This consortium was extended by two more partners and 16 associated organisations from the South Baltic.

In the four years of interesting investigations three large-scale research dikes were built, a large number of laboratory and field experiments were performed on material stability and environmental aspects, legal aspects were clarified, a considerable number of technical and research articles were published and two international conferences were organised. The substantial experience gained during the project is now presented in this guideline which contains recommendations on the planning and construction of dikes with dredged materials and CCPs. The guideline shall initiate the increased use of the investigated materials in dike construction. The editors would appreciate to be informed about such projects.

Prof. Dr.-Ing. Fokke Saathoff
DredgDikes Project Leader

Prof. dr hab. inż. Zbigniew Sikora
DredgDikes Director Poland

Dr.-Ing. Stefan Cantré
DredgDikes Project Coordinator

DredgDikes PARTNERS

Partner 1 and Lead Beneficiary
Universität Rostock
Chair of Geotechnics and Coastal Engineering
Prof. Dr.-Ing. Fokke Saathoff & Dr.-Ing. Stefan Cantré
Justus-von-Liebig-Weg 6
18059 Rostock, Germany

Partner 2:
Gdansk University of Technology
Department of Geotechnics, Geology & Maritime Engineering
Prof. dr hab. inż. Zbigniew Sikora & Dr inż. Remigiusz Duszyński
ul. Narutowicza 11/12
80-233 Gdansk, Poland

Partner 3:
Water and Soil Association „Untere Warnow – Küste"
Dipl.-Ing. Heike Just
Alt Batelsdorfer Str. 18a
18148 Rostock, Germany

Partner 4:
Hanseatic City of Rostock
Civil Engineering and Harbour Construction Office
Dipl.-Ing. Heiko Tiburtius, Dipl.-Ing. Ingolf Sanftleben †, Günter Lange
Holbeinplatz 14
18057 Rostock, Germany

Partner 5:
Steinbeis Innovation gGmbH
Department of Applied Landscape Planning
Dr. Michael Henneberg, Dipl.-Ing. Ricarda Neumann
Justus-von-Liebig-Weg 6
18059 Rostock, Germany

Associated Organisations:
State Agency for Agriculture and the Environment Rostock, Germany
Federal Waterways Engineering and Research Institute, Hamburg, Germany
Maritime Office Gdynia, Poland
Pomeranian Head of Melioration and Hydrotechnic Structures, Gdansk, Poland
Ekotech sp. z o.o., Szczecin, Poland
BAUGRUND STRALSUND Ing. mbH, Stralsund, Germany
Bonar GmbH & Co. KG, Obernburg, Germany
HUESKER Synthetic GmbH, distribution bureau Rostock, Germany
Heinrich Hirdes GmbH, Rostock, Germany
Danish Coastal Authority, Lemvig, Denmark
State Agency for Agriculture and the Environment Stralsund, Germany
City of Ribnitz-Damgarten, Civil Engineering Department, Germany
West Pomeranian Head of Melioration and Hydrotechnic Structures, Szczecin, Poland
Żuławski Head of Melioration and Hydrotechnic Structures. Elbląg, Poland
Latvian State Environmental Service, Riga, Latvia

Prof. Dr. Arnold Norkus, Vilnius Gediminas Technical University, Vilnius, Lithuania (External Expert)

ACKNOWLEDGMENTS

Editorial and publication team

Authors

Dr hab. inż. Lech Bałachowski, prof. PG (Gdansk University of Technology)
Dr.-Ing. Stefan Cantré (Universität Rostock)
Dr hab. inż. Marcin Cudny (Gdansk University of Technology)
Dr inż. Angelika Duszyńska (Gdansk University of Technology)
Dr inż. Remigiusz Duszyński (Gdansk University of Technology)
Dipl.-Ing. Anne-Katrin Große (Universität Rostock)
Dr. Michael Henneberg (Steinbeis Transferzentrum Angewandte Landschaftsplanung, Rostock)
Dipl.-Ing. Ricarda Neumann (Steinbeis Innovation gGmbH, Rostock)
M.Sc. Elisabeth Nitschke (Universität Rostock)
M.Sc. Jan Olschewski (Universität Rostock)
Dr inż Rafał Ossowski (Gdansk University of Technology)
Prof. Dr.-Ing. Fokke Saathoff (Universität Rostock)
Prof. Dr. hab. inż. Zbigniew Sikora (Gdansk University of Technology)
Dr inż. Mariusz Wyroślak (Gdansk University of Technology)

Technical editing

Dr.-Ing. Stefan Cantré (Universität Rostock)
Dr hab. inż. Lech Bałachowski, prof. PG (Gdansk University of Technology)
Eva-Maria Abrutat (Universität Rostock)

English proof reading

Sabine Kattge, Diplomsprachmittlerin (sprachenservice.de Hamburg)

Chapter reviewers and discussion partners

Dr. Frank Flügge (Huesker Synthetic GmbH, Rostock)
Dr. habil. Julia Gebert (HPA Hamburg, HTG Expert Panel on Dredged Material)
Dipl.-Ing. Frank Göricke (StALU MM, Rostock)
Dipl.-Ing. Michael Hering (Huesker Synthetic GmbH, Rostock)
MSc Signe Marie Ingvardsen (Danish Coastal Authority, Lemvig)
Dr.-Ing. Christian Koepke (Baugrund Stralsund Ingenieurgesellschaft, Stralsund/Rostock)
Dr.-Ing. Heino Müller (INROS Lackner AG, Rostock)
Dr.-Ing. Thomas Nuber (BAW Hamburg)
MSc Thorsten Piontkowitz (Danish Coastal Authority, Lemvig)
Dr.-Ing. Martin Pohl (BAW Hamburg)
Dipl.-Ing. Siegmund Schlie (Heinrich Hirdes GmbH, Rostock)
Mgr Inż. Anna Stelmaszyk-Świerczyńska (Maritime Office Gdynia)
Dipl.-Ing. Rica Weisz (Ministry for Economic Affairs […] M-V, Department of Waste Management)
Mgr Inż. Marcin Żywna (Zarząd Melioracji i Urządzeń Wodnych Województwa Pomorskiego w Gdańsku, Gdansk)

Funding

This guideline was produced in the frame of the DredgDikes project in the years 2010-2015, funded by the South Baltic Programme 2007-2013, EU INTERREG IV A (www.southbaltic.eu).

Contributors to the DredgDikes project

The DredgDikes consortium would like to thank all associated organisations for their contributions and discussions, the student workers in Rostock and Gdansk for their great help, the financial management, the university administrations in Rostock and Gdansk, the first level controllers, the JTS in Gdansk, the contractors and suppliers with regard to constructions, instrumentation, external laboratory analyses, dissemination tools, meetings and conferences (to name only a selection), all those who helped develop the guideline with contributions and discussions and the people who took interest in the project to spread the knowledge, namely the participants of the workshops, conferences and excursions. The DredgDikes project, and consequently also this guideline, would not have been possible without these contributions.

Special thanks go to:

Prof. Dr.-Ing. Ralf Bill and Dipl.-Ing. Matthias Naumann M.Sc. from the Chair of Geodesy and Geoinformatics at the University of Rostock for their great support with geodetic surveying equipment and knowledge as well as various measurements using unmanned aerial systems.

Elfriede Bockholt for the great help in administrative and financial affairs at the Chair of Geotechnics and Coastal Engineering, University of Rostock.

Gdańsk County in Pruszcz Gdański for the administrative support regarding the Gdansk research dike.

Dr. Antje Hiller and Dipl.-Ing. Frank Graage (Steinbeis Team Nordost) for helping to prepare the application and in their function as external financial management to the project.

Dipl.-Ing. Heike Just as the managing director of the water and soil association "Untere Warnow – Küste" für her support regarding the pilot dike.

Igor Kaniecki and Małgorzata Skołmowska from the Joint Technical Secretariat of the South Baltic Programme in Gdansk.

Dr. Kristina Koebe from Rotorwerk Project Services for the perfect proof-reading of the DredgDikes project application.

Dipl.-Ing. Martin Kresin as representative of the municipal Construction Office Ribnitz-Damgarten for the support regarding the pilot dike.

Dipl.-Ing. Heiko Tiburtius as the director of the municipal Civil Engineering and Harbour Construction Office in Rostock for his support regarding the Rostock research dike.

Dr inż. Marzena Wójcik for the financial management at the Department of Geotechnics, Geology and Maritime Engineering, Gdansk University of Technology.

CONTENTS

1. INTRODUCTION

1.1. Scope of the guideline

This guideline describes how to plan and build dikes with the use of ripened dredged materials (DMs), coal combustion products (CCPs) and geosynthetics. To receive the required permits for the recovery of DMs and CCPs as substitutes for standard dike materials such as clay, marsh clay or marl, the respective legal framework for Germany, Poland and Denmark is discussed and recommendations about the application of legal documents are given where the legislation is not clearly defined regarding the materials under consideration. Legal aspects affect both the planning process and construction work. In the future, legislation may be adjusted or gaps may be closed based on the data gained during the maintenance and monitoring of dike constructions. In Chapter 4, the required steps for the planning and design of dikes made of DMs, CCPs and geosynthetics are presented, including the required material qualities and the procedures for their characterisation while Chapter 5 gives recommendations with respect to the actual construction works on site as well as the quality control for the materials and the installation quality. General information about planning, design and construction of dikes is only repeated where necessary for completeness, however, the main focus are the additional recommendations for the materials under consideration. In Chapter 6 recommendations for the maintenance and monitoring are provided, including measurements and data collection. There are two electronic annexes: Annex I contains additional information directly connected to individual chapters and in Annex II all scientific experiments are described which are the basis for the recommendations. Figure 1.1 shows the structure of the guideline and the links between the different chapters.

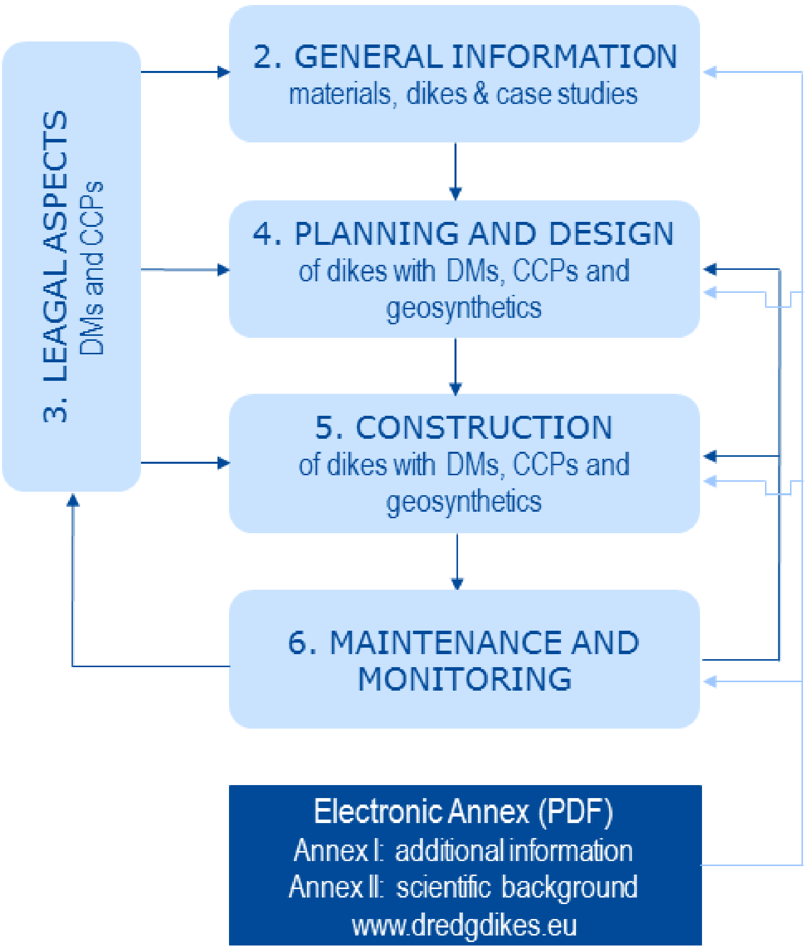


Figure 1.1. Flow chart showing the guideline structure and the links between the different chapters

1.2. Background to the guideline

1.2.1. Why this guideline

This guideline was prepared due to a lack of information in existing guidelines and regulations regarding both legal and constructive issues when building dikes with dredged materials (DMs) and coal combustion products (CCPs). The lack of guidance was also the reason why approving authorities as well as contractors repeatedly refused to implement ripened DMs in several dike construction projects in Mecklenburg-Vorpommern. Although there has been considerable experience with this technology in Bremen the recovery of fine-grained DMs in dike covers is a new approach for the German Baltic Sea coast. And it seems even newer to other South Baltic countries. Fine-grained DMs have been successfully applied in agriculture, landscaping and landfill recultivation with good experience regarding soil fertility, geotechnical stability and erosion resistance. In spite of being a useful natural resource for soil improvement and construction, the dredged materials that are taken ashore are generally considered waste material according to the European Waste Catalogue (EWC) [1]. Therefore, usually an individual case permit is required when applying the materials. This is not a problem in itself, but the procedures to receive such a permit have not been clearly described before, making an assessment difficult. This document gives comprehensive guidance on this issue for the first time.

On the other hand, there is a considerable surplus of CCPs from power plants in Poland which are often used in geotechnical engineering projects such as road construction, usually mixed with other soils. In addition, various international projects are dealing with the improvement and stabilisation of DMs for geotechnical applications by using fly ash (and other CCPs) or the improvement of ashes by adding soils and/or binders. Just like DMs, CCPs are considered waste materials according to the EWC [1] and all regulations regarding wastes for recovery apply. Therefore, the same justification regarding the recycling management and similar problems with legislation apply as for the DMs. On EU level, CCPs may also be declared construction materials in the sense of secondary materials which are certified according to the European chemicals ordinance REACH [2]. Still, the use of CCP composites in dike construction is a new concept.

Geosynthetics can be used in most geotechnical applications to serve different purposes such as filtration, separation, reinforcement and drainage while usually saving mass movement and both natural and monetary resources. They also serve a variety of functions in dike construction, which is why they are included in this guideline to show dike design options combining DMs, CCPs and geosynthetics to further reduce costs and environmental impacts.

1.2.2. The DredgDikes project

Dredged materials research has developed rapidly over the past decade. Large amounts of sediments are removed every year from water bodies in maintenance and environmental dredging projects. In the eastern Baltic Sea, large harbour projects will involve considerable dredging [3]. The major amount of these dredged materials is relocated within the water bodies [4], [5]; however, if the amount of fines in the sediment would cause turbidity at the placing area or contaminations are involved, the materials should be taken ashore. Although sediments that are taken on shore are generally considered waste according to European legislation [6], the materials prove to have a good potential to be recovered and then used in a variety of applications, particularly if they are not or only slightly contaminated. The European Waste Framework Directive [7] also demands recycling rates for wastes; for DMs taken on shore a recycling rate of 70 % shall be achieved by 2020. This implicates research and development in all fields of sediment management. With a growing environmental awareness all around the Baltic Sea, many debates discuss strategies on how to reduce the amount of dredged sediments dumped at sea.

The recycling philosophy is also a motivation force for CCP research. For a long time, CCPs were considered to be waste for disposal, thus significantly expanding the industrial waste disposal areas. First ideas to use them as secondary aggregates originate from research on road stabilisation using fly ashes and date back to the 1970s [8]. The European legislation quite recently approved CCPs as construction materials and promotes its usage in engineering and construction. The EU Regulation 305/2011 [9] lays down harmonised conditions for the marketing of construction products and particularly recommends predominantly using secondary materials in accordance with § 55 [9].

The Chair of Geotechnics and Coastal Engineering at the University of Rostock has been investigating the issue of DMs as replacement materials for dike construction since 2007. The topics of dikes, particularly with the focus on geosynthetics used in dikes and the determination of hydraulic design values, have been subject to research for a much longer time.

The Department of Geotechnics, Geology and Maritime Engineering at the Gdansk University of Technology has a long-term experience with the use of fly ash in geotechnical applications. The cooperation with the Polish Union of CCPs gives additional confidence in choosing the right kind of material in terms of the intended mechanical properties. The idea to apply fly ash in dike construction was very exciting to test under real conditions.

The Steinbeis Innovation Centre for Applied Landscape Planning in Rostock has nearly 30 years of experience in dredged material research. The scientists formerly also working for the University of Rostock, were involved in the improvement of Rostock's municipal treatment facilities as well as the setup of a sediment management system with strong focus on DM recovery in agriculture, landscaping and landfill capping.

This knowledge base of combined subjects in geotechnics and coastal engineering, DM, CCP and dike research finally lead to the project DredgDikes which was developed together with two more partners: the Hanseatic City of Rostock with its DM facilities and the Water and Soil Association "Untere Warnow – Küste" in Rostock which are responsible for two research dike investments in Germany. Additionally, 16 associated organisations from Denmark, Lithuania, Poland and Germany contributed to the project that officially started in September 2010 with a duration of 53 months. The project was co-financed by the South Baltic Programme 2007-2013 under the European Regional Development Fund (ERDF).

The project had three main objectives: The application of fine-grained DMs as a replacement for standard dike cover material or in homogenous dikes, the use of composites of ash and dredged sand to be used as dike core or dike cover materials and the use of geosynthetics to improve the functionality of these dikes and to reduce costs and environmental impacts.

The replacement of standard dike materials is of particular interest since the usual dike cover materials such as marsh clay (North Sea) and glacial marl (Baltic Sea) are becoming short and they have to be mined, usually in environmentally sensitive areas, where a permit cannot always be given.

Figure 1.2. DredgDikes research dike in Rostock

Figure 1.3. DredgDikes research dike near Gdansk

Figure 1.4. DredgDikes pilot dike construction east of Rostock

To address the different problems, three large-scale dike constructions have been built in the frame of the project to investigate installation and performance of the replacement materials under real and test conditions: The experimental dike in Rostock (Figure 1.2), composed of different DMs, was used for the analysis of construction, stability, deformation, vegetation, erosion stability, desiccation cracking, water infiltration and seepage. At the experimental dike near Gdansk (Figure 1.3), built from a composite of ash and dredged sand, a comparable analysis programme was carried out. Finally, a joint pilot construction was built at the Körkwitzer Bach near Rostock (Figure 1.4), where a 500 m long section of an actual agricultural dike was reconstructed using ripened dredged material from Rostock to show the reliability of the material. These investments will be used both for long-term monitoring and for dissemination purposes. More information about the project is provided on www.dredgdikes.eu.

1.3. Target readership and document availability

This guideline provides guidance for planners, authorities and contractors on how to deal with DMs, CCPs and geosynthetics when planning, permitting and constructing dikes. The focus and distribution area of the guideline is the South Baltic Region, which is defined in Figure 1.5. Therefore, the guideline is written in English language. However, for an easier implementation in the countries where the project was developed, the guideline is available in German and Polish, too. Furthermore, there is an electronic Annex which contains additional information for some of the chapters and the scientific background of the findings and recommendations, including a comprehensive compilation of the laboratory and field tests performed during the project. All documents are available electronically as PDFs and can be downloaded from the DredgDikes website www.dredgdikes.eu or from the website of the Chair of Geotechnics and Coastal Engineering, University of Rostock: or www.auf-gk.uni-rostock.de.

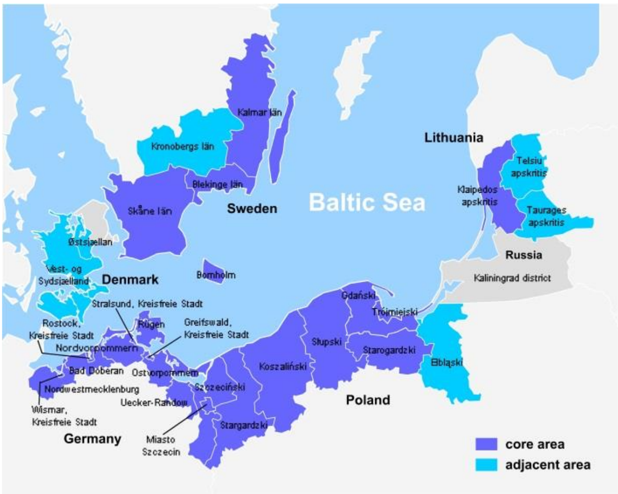


Figure 1.5. The South Baltic Programme area [10]

References

[1] EC 2000. European Waste Catalogue (EWC) 2000/532/EC.

[2] EC 2006. EU Regulation 1907/2006 of 18 December 2006 concerning the registration, evaluation, authorisation and restriction of chemicals (REACH) and establishing a European Chemicals Agency.

[3] Ecodump 2014. Website of the ecodump project „Application of ecosystem principles for the location and management of offshore dumping sites in the SE Baltic Region. http://corpi.ku.lt/ecodump [cited Nov 06 2014].

[4] Netzband, A., Christiansen, H., Maaß, B. & Werner, G. 1998. Relocation of dredged material from Hamburg harbour in the River Elbe, *Water Science and Technology*, **37**(6-7): 241-248.

[5] HELCOM 2011. Report on disposal of dredged materials at sea. Available online: http://meeting.helcom.fi/web/monas [cited Oct 23 2013].

[6] Neumann, R. & Henneberg, M. 2014. Legal aspects for the reuse of dredged material and the application in dike construction, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction, Rostock*, 10-11 April 2014, 189-194.

[7] EC 2008. EU Directive 2008/98/EC. European Waste Framework Directive, Article 11 2b.

[8] Pachowski, J. 1976. Fly-ashes and its usage in road constructions WKŁ, Warsaw (in Polish).

[9] EC 2011. EU Regulation 305/2011 of the European Parliament and of the Council of 9 March 2011 […] laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.

[10] Figure provided by the South Baltic Programme, ERDF, www.southbaltic.eu.

2. GENERAL INFORMATION

In this chapter, basic knowledge is summarised about dredged materials (DMs), coal combustion products (CCPs), geosynthetics and dikes. In addition, case studies are presented in which the materials have already been applied in dikes or embankments.

2.1. Dredged materials

Dredged materials are sediments removed from water bodies. Suspended matter and sediments are an integral component of the ecosystem. The natural sedimentation of suspended matter and bed-load lead to deposits and in consequence to restrictions of the defined water depth. These deposits have to be removed regularly by dredging. The contingent DM is composed of inorganic and organic components. The inorganic substances are composed of weathered bedrock material (sand/silt) as well as compounds reaching the water through precipitation and flood induced surface erosion of the surrounding areas. The organic matter (OM) is composed of microorganisms, remains of macrophytes and other larger organisms as well as detritus.

The characteristics of sediments and DMs are defined by hydrodynamic, morphological and hydrological processes inside a water body. Apart from this, the salt concentration and available sediment composition are of importance. The sediment transport parameters are responsible for the accumulation of sediments with differing grain-sizes.

In line with maintenance works of waterways 41 mill. m³ of DM are being dredged every year by the German federal agencies and regional government authorities in the area of the North and Baltic Seas while only 5 mill. m³ are dredged in the inland. In Denmark, about 5 mill. m³ are being dredged every year [1]. In Poland, an average yearly amount of 1.1 mill. m³ of DM has been reclaimed during the past five years (2010 – 2014) [2]. More information can be found in [1] and [3].

DMs own some interesting properties which provide good opportunities to recover them to replace natural resources and to avoid the resulting interventions of the respective raw material. A recovery strategy of marginally contaminated DM is also economical.

Figure 2.1. Dredging works at the Warnow tunnel in Rostock, dredging of fine grained organic silt

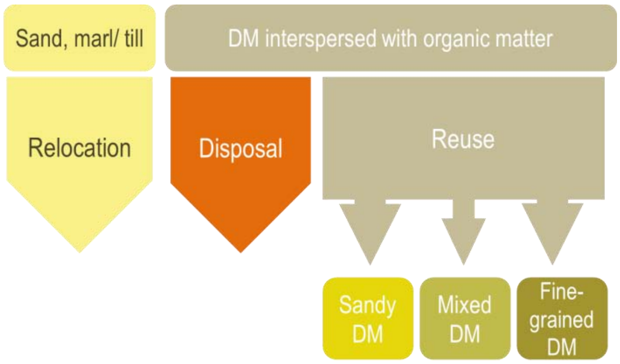


Figure 2.2. Relocation, recovery and disposal of dredged material

Sediments are primarily dredged for nautical reasons to guarantee the navigable water depth in harbours and navigation channels (Figure 2.1). According to both ecological and economic reasons the major goal is the minimisation of dredging works, thus to keep the sediments in the water body (avoidance, prevention). However, additional conditions like contaminations may also require the sediments to be removed from the water body. It is common sense that the recovery has priority over disposal/ deposition [4].

Figure 2.2 shows options on how to deal with DM. Non-organic and uncontaminated materials may be relocated in the water body, contaminated DM rich in organic matter is usually disposed (e.g. on a landfill) and uncontaminated organic DM should be recovered, while the recovery options strongly depend on the type of DM.

The ratification of international conventions regarding the protection of the marine environment, especially the Baltic Sea, resulted in a path-breaking agreement of all bodies concerned with the protection of the marine environment: for contaminated DM as well as DM containing fines and organic matter the deposition in the coastal waters of

Mecklenburg-Vorpommern (M-V) was forbidden in 1983 [5]. These materials may contain and release oxygen-depleting organic substances which would result in a degradation of the water quality in the Baltic Sea. In addition, the materials disposed under water cover the sea bed, together with the natural flora and fauna. Thus, fine-grained dredged materials would violate the principle of "equal to the same grain size" [6].

2.1.1. Definition and classification

Dredged materials can be classified according to their grain-size distribution and according to their origin. A short definition of the terms used for DMs in this guideline is given here, while a conclusive terminology can be found in the attached Glossary.

Dredged materials are materials similar to soils with different mineral and organic components, accumulated in water bodies and excavated in the course of waterway maintenance and other civil engineering projects [4]. In this guideline DM is differentiated in sandy, mixed and fine-grained DM (Figure 2.2). *Sandy DM* has a major sand fraction (d > 0.063 mm) and a small amount of fines (< 10 % of d < 0.063 mm). *Mixed DM* as defined in this guideline is dredged material having a high sand fraction and considerable contents of fines (Table 2.1). *Fine-grained DM* stands for dredged materials with at least 15 % of the finest fraction (d < 0.002 mm). The dredged material in the frame of this guideline is *rich in organic matter and lime* if the organic matter and lime contents exceed 5 % (gravimetric) respectively.

The terms *ripening* and *ripening process* are used for the drying of the DM, associated with mineralisation and soil genesis effects. The ripening process is influenced by physical, chemical and biological effects.

In case of *marine* and *brackish DMs* the salt content has to be considered. Most of the DMs investigated in the DredgDikes project were taken from brackish water bodies, thus they are indicated as *brackish sediments/ DMs* in this guideline. In Table 2.1 general parameters of treated brackish DM from the Rostock treatment plant are presented as an example. *Limnic DMs* usually contain only small contents of sodium and chloride despite possible contents of biogenic sulphur.

Table 2.1. General parameters of treated brackish DM (IAA Rostock)

Dredged material	Sand	Silt	Clay	TOC	$CaCO_3$
Mean fine-grained	40	38	24	6	8
Max. fine-grained	74	64	46	10	16
Mean mixed DM	74	16	8	3	6
Max. mixed DM	90	26	15	6	10

2.1.2. Dredged material treatment

After the dredging process, the DM is usually treated and processed before it can be recovered. This may be realised directly on the construction site or in a treatment facility, e.g. on a DM containment area. The basic treatment of most DM is dewatering. An example for a treatment facility that uses the natural sedimentation processes and self-weight dewatering is presented in Figure 2.3. In this treatment plant it is also possible to separate different grain-size classes in long dewatering polders, where the coarse particles settle close to the inlet and the finest near the outlet.

Contaminants may be chemically bonded with additives so that their elution is avoided. In Germany, this method can only be applied if the contents do not exceed the classification limits for recovery (e.g. according to [8] and [9], cf. also Chapter 4).

Other treatment options are summarised in Table 2.2 and comprehensive collections are published in [4] and [10].

Table 2.2. Treatment options for dredged materials

Treatment options for dredged materials
Grain-size classification and sorting Classification regarding weight and size, sorting according to particle properties such as density/ shape
Separation is based on grain size. It can be done e.g. by sieves or hydro-cyclones. Separation is mainly used in grain sizes ranging between 20 – 63 µm.
Dewatering Separation of water from the solid content. The time needed for dewatering depends on the fines and organic compounds in the DMs.
Biological processes/ biodegradation Decomposition of organic matter by microorganisms
Termic processes Desorption, oxidation, immobilisation with respect to contaminants and organic matter
Chemical bonding Immobilisation of contaminants by adding substances that decrease their elution

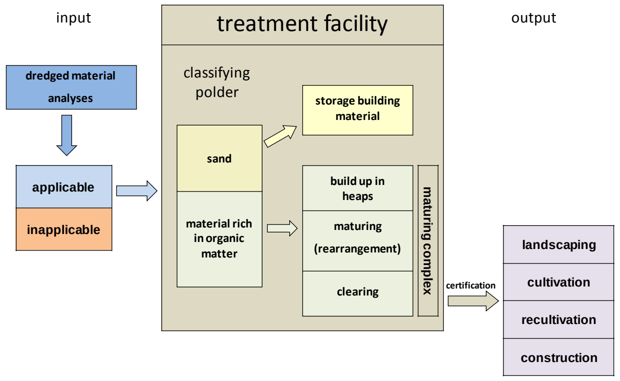


Figure 2.3. Example of a natural sedimentation treatment facility [11])

2.1.3. Contaminants

A considerable portion of the contaminants which finds its way into the water bodies is absorbed at the surface of the sediment particles. The contaminant load of the sediments can be very different and may even change over time. Contamination loads result from selective and diffuse sources via air, surface and ground water.

General information about amounts and contaminations in dredged material for disposal with data from Poland, Denmark, Lithuania and Germany can be found on the official web sites of the International Maritime Organization (IMO) [12] and the Helsinki Commission (HELCOM) [13]. Information about contaminated sediments in European river basins is provided by SedNet [14]. Brackish DMs contain large amounts of chloride and sulphate salts which have to be taken into account with respect to recovery options.

The content of heavy metals and organic contaminants in coastal sediments are very different. It varies depending on the content of fines and organic matter. The solubility of heavy metals is determined regarding the actual redox conditions and the content of lime in the DM. Sometimes there are increased values of zinc and hydrocarbons; however, they can also be of biogenic origin. In Mecklenburg-Vorpommern, there are also increased concentrations of organic tin compounds, locally bounded in small areas of harbours and shipyards. As an example, heavy metal contents of fine-grained DM in M-V are presented in Table 2.3. During dredging works (e.g. waterway Wismar) also higher contents of mercury and lead as well as copper and zinc may be found [15]. Information about heavy metals in DMs from Poland is presented in Table 2.4.

Table 2.3. Typical heavy metal contents of fine-grained DM from coastal zones; different containment facilities in M-V and Rostock municipal treatment facility (IAA) [16]

Parameter	M-V	IAA Rostock
	mg/kg dry solids	mg/kg dry solids
Arsenic	0.6 - 6.8	5 - 25
Lead	15.9 - 38.7	10 - 35
Cadmium	0.3 -1.0	0 - 0.76
Chromium	16.7 - 44.0	12 - 63.5
Copper	15.8 - 41.5	14 - 37
Nickel	15.8 - 27.7	11 - 18
Mercury	0.05 - 0.35	0 - 0.9
Zinc	55 - 178.7	36 - 177

Table 2.4. Typical heavy metal contents of fine-grained DM from coastal zones from Poland [17]

Parameter	Poland - ports	Poland shipyards
	mg/kg dry solids	mg/kg dry solids
Arsenic	n/a	n/a
Lead	2.9 - 31.4	3.3 - 865.0
Cadmium	0.1 - 1.0	0.9 - 25.9
Chromium	0.6 - 7.9	0.0 - 46.6
Copper	6.8 - 30.1	0.4 - 344.0
Nickel	n/a	n/a
Mercury	0.004 - 0.023	0.008 - 0.416
Zinc	38.4 - 156.0	9.9 - 797.0

High heavy metal charges are rather a problem of river sediments. Lentic waters show only marginal contamination of heavy metals, if any. However, higher concentrations of organochlorine pesticides may be found. Also, PCB, PAH, hydrocarbons, PCDD/PCDF and organ tin compounds (TBT) have been verified in different concentrations in lentic waters of M-V [15].

In 2008, a study on the nationwide status of the Danish marine environment summarised the status of marine sediments as follows: "*Contamination of metals was found in 20-40% of sediment samples in 2008, where concentrations were found to be above background levels according to the OSPAR assessment criteria in regard to As, Ni, Zn, Pb, Cu and Cr. Contamination of heavy metals was comprised of Cd and Hg where 70% of the sediment samples had contents above background levels, particularly in the samples from the inner Danish waters. Apart from the heavy metals, TBT and PAHs still present the largest contamination problems*" [18].

Table 2.5. Recovery options for dredged materials divided by the type of DM [20]

Applications for dredged materials	Type of dredged material				
	Rock	Gravel	Sand	Clay/Silt	Mixed soil
Road construction	x	x	x	x	x
Replacement fill	x	x	x	x	x
Dike (re)construction	x	x	x	x	x
Mounds and noise/ wind barriers			x	x	x
Land reclamation		x	x	x	x
Stabilisation		x	x		x
Sealing of confined disposal facilities				x	
Capping of confined disposal facilities, landfills and contaminated sediments		x	x	x	x
Rehabilitation of brownfields			x	x	x
Environmental enhancement (agriculture, habitat creation)				x	x

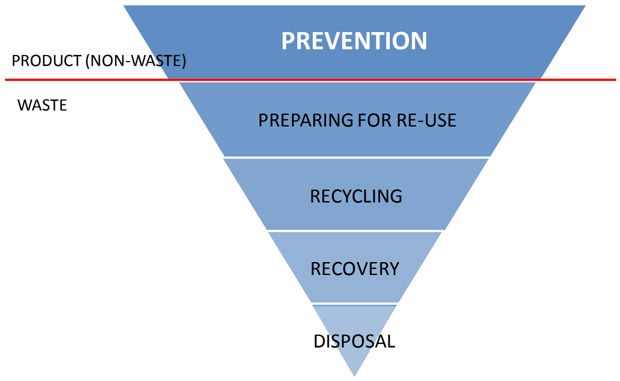


Figure 2.4. Waste management hierarchy, applied to DM manag. [19]

2.1.4. Recovery options for dredged material

If DMs have to be taken onshore they are classified as waste. Then, the general waste management hierarchy (Figure 2.4) is applied to DM management.

Dredged materials can be recovered in a large variety of applications. Extensive summaries can be found in [4], [7], [20]. In Table 2.5 a selection of recovery options for DM is presented, divided by the type of DM. Legal aspects for the recovery in geotechnical applications as well as information about the suitability are provided in the subsequent chapters of this guideline.

2.1.5. Environmental issues

When recovering waste materials (beneficial use), environmental impacts need to be analysed. Therefore, the different transport paths for substances and their potential impacts have to be determined and monitored when DM is recovered.

2.1.5.1. Leaching

Heavy metals in the leachate of DMs are no general risk regarding the main subjects of protection (soil, plants and animals). This could be proven in the DredgDikes project as well as in other projects (cf. [21] [22]). The values in both the leachate and the solid particles of DMs are usually below the limit values of the relevant regulations. Heavy metals and organic contaminants are chemically stable and hardly available. There may be the risk that reversing conditions (reduction – oxidation) may invert this status making the heavy metals available (e.g. within the first weeks of drying of freshly dredged materials). However, this is usually a short-term effect and subsequently the leachability considerably decreases, usually below the relevant classification limits [23].

No discharge of heavy metals or the nutrients N and P was detected in the leachate investigated in the DredgDikes project. In contrary to heavy metals there is an oversupply of nutrients and salt in the brackish DM. According to agricultural aspects the nutrients magnesium, potassium and calcium are at a high supply level for plants [24]; as a result, they will be subject to leaching, if the vegetation cannot absorb these nutrients.

The salt ions behave likewise. Chloride is a very soluble salt ion and therefore easily washed out in the short term. In the investigated leachate high values of chloride, sulphate and sodium were determined. In addition, the nutrients magnesium, potassium and calcium were determined in high concentrations.

It can be concluded, that the common inorganic contaminants contained in most of the DMs still comply with the requirements of the respective ordinances, but it is the discharge of salt ions from brackish DM that may be problematic for the environment [21], [25].

These previous scientific findings indicate that the discharge of salt has to be monitored when brackish or marine DM is recovered. However, when installed in a sea dike, salt ions usually play a minor role.

2.1.5.2. Contaminant transport due to particle transport

In addition to the salt and nutrient dislocation in the leachate, there is a potential risk regarding the dislocation of contaminated solid particles. This may happen due to wind or water induced surface erosion. Usually, an erosion protection cover (vegetation or constructive solution) prevents the dike surface from erosion, since the dike itself will otherwise fail. There may be an increased erosion risk in the initial period between the construction and the full effectiveness of the erosion protection; however, a considerable erosion triggered dislocation of contaminated soil particles is not likely due to the high safety requirements for newly built dikes.

2.1.5.3. Bio-degradability

Ripened DMs often contain large amounts of organic matter. In Rostock, the fine-grained DMs generally contain between 4 and 10 % TOC (6 to 17 % humus). The organic matter and lime build highly stable aggregates from organic-mineral complexes, showing a favourable sorption capacity, high water storage capacity and good soil fertility. Doubts regarding the degradation stability of the organic matter have been cleared in several investigations using the AT_4 breathability test [26]. Repeated investigations show that the organic matter in the DM is very stable, partly because they are composed of humic substances. The degradation rates in the AT_4 test of ripened DM (< 0.5-0.6 mg O_2/ g dry solids) fall significantly below the classification limit claimed of the relevant ordinance (5 mg O_2/ g dry solids, DepV) [26].

2.1.6. Further information

Further information on dredged materials as well as dredged material recovery and disposal in the South Baltic region can be found in [3], [4], [5], [7], [10], [20], [26] and [27].

2.2. Coal combustion products

General coal combustion products (CCPs) are by-products of coal-fired power plants which burn either hard or brown coal. Coal is composed primarily of carbon and hydrogen, however, both hard coal, and (especially) brown coal also contain various mineral substrates (e.g. quartz, clays, shales, calcite).The amount of CCPs produced at a power plant depends on the volume of coal burned and the amount of mineral substances in the coal. It is also dependent on the combustion techniques.

The CCPs also involve desulphurisation products obtained from the chemical reaction between sulphur dioxide (derived from the sulphur in the coal during the combustion process) and a calcium based absorbent (in all kinds of flue gas desulphurisation installations).

The total amount of CCPs produced worldwide is estimated to be about 550 million tons. In the European Union the total production is estimated to be about 95 million tons [28].

2.2.1. Definition and classification of CCPs

CCPs can be classified regarding the mineral components of the coal and the combustion technology as follows. A detailed classification based on [29] is included in Annex I.

- fly ash (FA),
- bottom ash (BA),
- boiler slag (BS),
- fluidised bed combustion (FBC) ash.

In addition, there are products from dry or wet flue gas desulphurisation:

- flue gas desulphurisation (FGD) gypsum,
- flue gas desulphurisation (FGD) wet scrubbers and semi dry absorption (SDA) products.

Fly ash (FA) is obtained by electrostatic or mechanical precipitation of dust-like particles from the flue gases of furnaces fired with coal or lignite at 1,100 to 1,400°C. It is a fine powder, which is mainly composed of amorphous or glassy aluminosilicates. Fly ash particles are fine-grained, ranging from 1 to 100 microns in diameter, with a median particle diameter of 20 to 25 microns.

Bottom ash (BA) is a granular material made of heavier particles that falls to the bottom of the furnace (Figure 2.5). It is also primarily composed of amorphous or glassy aluminosilicates, similar to fly ash, however, coarser, with a sandy texture and particles ranging from about 0.1 mm to 50 mm in diameter.

Boiler slag (BS) is a type of bottom ash collected in wet-bottom boilers (slag-tap or cyclone furnaces, which operate at very high temperatures), where the particles are cooled in a water quench and form a coarse granular material with a maximum particle diameter of about 8 mm. Boiler slag is a glassy, environmentally sound material of which about 55 wt.-% is used in road construction, e.g. as a drainage layer.

Fluidized bed combustion (FBC) ash is produced in fluidized bed combustion boilers. The technology links coal combustion and flue gas desulphurisation in the boiler at temperatures between 800 and 900°C. FBC ash is rich in lime and sulphur.

Flue gas desulphurisation (FGD) gypsum is like a natural gypsum product which is obtained by wet desulphurisation of flue gas and refining process in the FGD plant that includes an oxidation process followed by gypsum separation, washing and dewatering.

Flue gas desulphurisation (FGD) scrubbers are also produced in desulphurisation of flue gas and are the result of wet technology or *semi dry absorption* (SDA) technology with lime acting as the sorbent.

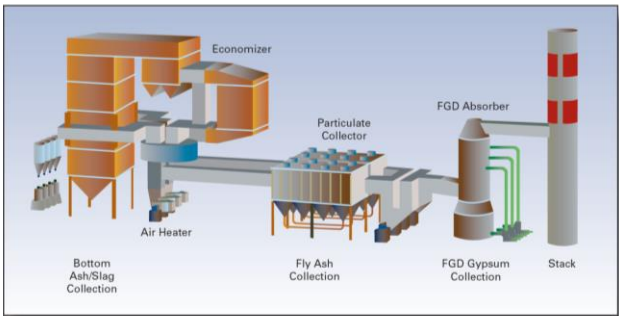


Figure 2.5. CCPs production in power plant [40]

Table 2.6. Typical chemical composition of coal ashes in Poland compared with soils (based on [30] and [31])

Compound	Fly ash from coal	Fly ash from lignite	Soil
	[%]	[%]	[%]
SiO_2	49-55	33-51	43-61
Al_2O_3	24-31	4-33	10-20
CaO	0.1-4.5	20-33	0-7
SO_3	0.0-1.0	0.0-8.5	-
Fe_2O_3	5-9	5-11	1-14
LOI	0.2-3.4	0.1-7.9	5-17

2.2.2. Chemical composition and contaminations

The chemical composition of coal ash is primarily determined by the chemistry of the source coal and the combustion process. Because ash is derived from the inorganic minerals in the coal, such as quartz, feldspars, clays, and metal oxides, the major elemental composition of coal ash is similar to the composition of a wide variety of rocks in the Earth's crust. Oxides of silicon, aluminium, iron, and calcium comprise more than 90 % of the mineral component of typical fly ash (Table 2.6).

Minor constituents such as magnesium, potassium, sodium, titanium, and sulphur account for about 8 % of the mineral component, while trace constituents such as arsenic, cadmium, lead, mercury, and selenium make up less than 1 % of the total composition. Table 2.6 provides the typical range of concentrations for major and trace constituents in fly ash and bottom ash, along with the range for rock and soil for comparison. Fly ash also contains a variable amount of unburned carbon, depending on the combustion conditions. Unburned carbon is often measured by determining the loss on ignition (LOI), ranging from < 1 % to > 20 %.

Table 2.7. Typical heavy metal contents of CCPs in Poland [32]

Parameter	Fly ash	Bottom ash
	[mg/kg]	[mg/kg]
Chromium	89 - 300	8 - 48
Lead	35 - 150	64 – 170
Cadmium	BDL – 4	3 - 15
Copper	93 - 208	94 – 242
Nickel	71 - 132	28 – 231
Mercury	BDL – 4	BDL – 4
Zinc	16 – 2,400	48 - 220

BDL: Below detection limit

Table 2.8. Typical heavy metal contents in CCP eluates in Poland [32]

Parameter	Unit	Fly ash	Bottom ash
Conductivity	µS/cm	300 – 3,200	271 – 720
Chloride	mg/l	4 – 40	2 – 47
Sulphur		25 – 357	33 – 113
Arsenic	µg/l	BDL – 400	BDL – 200
Cadmium		20 – 100	BDL - 50
Chromium		BDL – 643	30 - 130
Mercury		BDL – 10	BDL
Vanadium		BDL - 750	360 – 1,080

BDL: Below detection limit

Table 2.9. Minimum and maximum contents in the eluate of CCPs in Germany [33]

Parameter	Unit	Fly ash	Bottom ash
Conductivity	µS/cm	630 – 4500	92 – 2060
Chloride	mg/l	5 – 50	2 – 50
Sulphur		75 – 1056	10 – 419
Arsenic	µg/l	1 – 3200	0.6 – 55
Cadmium		0.5 – 100	nda
Chromium		10 – 2250	nda
Mercury		0.02 – 5	0.03 – 2
Vanadium		50 - 1050	10 – 95

nda – no data available

The relative contents of calcium, iron, and sulphur in the fly ash influence its fundamental chemical properties and reactivity. Subbituminous and lignite coal ashes typically contain relatively high concentrations of calcium, with concentrations exceeding 15 % (expressed as CaO), and produce alkaline solutions (pH 11 – 12) in contact with water. Bituminous coal ashes generally contain much less calcium, and yield slightly acidic to slightly alkaline solutions (pH 5 – 10) in contact with water.

The chemical composition of coal ash can be modified as power plants change fuels or add new air emission controls to prevent releases to the atmosphere. In Table 2.7 and Table 2.8 a selection of typical heavy metal contents of CCPs and their eluates in Poland is presented. In Table 2.9 values for CCP eluates in Germany are presented.

2.2.3. Geotechnical classification of CCPs

The basic geotechnical properties that are required to classify granular construction materials are the particle size distribution, gradation curve and liquid and plastic limits. These are to be determined in the laboratory. In case of CCPs usually only the particle size distribution and gradation characteristics are available as classification properties. Although all chemical analyses indicate the loss on ignition value, from the geotechnical point of view it is not widely used in classifying coal ashes and other CCPs.

As the fly ashes comprise predominantly silt-size particles, they are classified as fine-grained ashes. Both bottom ashes and pond ashes come under coarse-grained ashes. In most cases, they are sand-size particles. Some of the bottom ashes may contain small amounts of gravel-size fractions, too. Typical bottom ashes, pond ashes and fly ashes have been classified using the system proposed in [29] (Annex I).

2.2.4. Recovery options for CCPs

The countries of the European Union countries produced approximately 95 mill. tons of CCPs in 2009 [28]. Fly ash represents the greatest proportion of total CCP production. Within the EU, the utilisation for FA in the construction industry is currently around 48 % and for BA around 45 %, while the utilisation rate for BS is 100 %. In the majority of cases CCPs are used as a replacement for natural resources and therefore offer environmental benefits by decreasing the need to quarry or mine these resources. CCPs also help to reduce energy demand as well as emissions to the atmosphere, for example CO_2, from the manufacturing process of the products which are replaced.

CCPs are utilised in a wide range of applications in the building and construction industry. Applications for CCPs include their use as an addition in concrete as a cement replacement material and as an aggregate or binder in road construction. They can also be utilized as mineral fillers and as fertilizers. Where necessary, CCPs meet any relevant national and European building materials standard and regulation.

The primary use for fly ash is as an ingredient in concrete. FA acts as a pozzolan, a siliceous/ aluminous material that develops cementitious properties when combined with calcium hydroxide and water. FA can be used as a direct replacement for Portland cement in concrete, and has been used in a wide variety of concrete applications in the USA for more than 60 years. The use of FA can significantly improve many concrete qualities, for example strength, permeability, and resistance to alkali silicate reactivity. Numerous standard specifications establish the physical and chemical requirements of FA for use in concrete, such as ASTM C618 [34] or the Polish PN-EN 450:2007 [35].

In addition to concrete, there is a variety of applications that use more than 1 mill. tons of FA per year such as structural fills, cement production, waste stabilisation, and mine reclamation. The primary uses for the coarser BA and BS are for structural fills and road base material and as blasting grit/roofing granules [36] (Table 2.10).

Table 2.10. Recovery options for CCPs

Construction materials and improvement	CCPs					
	Fly ash	Bottom ash	Boiler slag	FBC ash	FDG gypsum	FDG/SDA scrubbers
Concrete industry	x	x			x	
Road base/sub-base	x	x	x	x		x
Railroad base/sub-base	x	x	x	x		x
Structural fills/embankments	x	x	x	x	x	x
Dikes	x	x	x	x		
Soil modification/stabilisation	x	x		x		x
Blasting grit/Roofing granules	x	x	x			
Waste stabilisation/solidification	x			x	x	x
Gypsum panel products					x	x
Rehabilitation of brownfields	x	X	x	x		
Environmental enhancement (agriculture, habitat creation)	x	x			x	

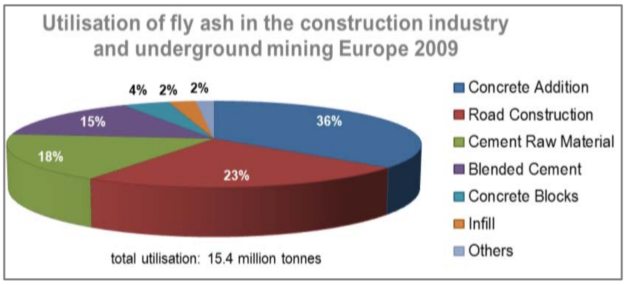


Figure 2.6. Utilisation of fly ash in the construction industry and underground mining Europe 2009 [36]

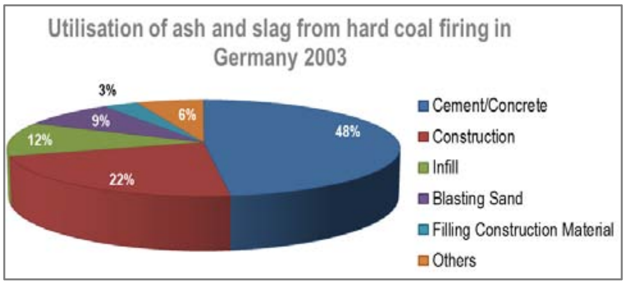


Figure 2.7. Utilisation of ash and slag from hard coal combustion in Germany 2003 [33]

The utilisation of FA in the construction industry and in underground mining in Europe in 2009 is summarised in Figure 2.6 and an example of the utilisation of ash and slag from hard coal combustion in Germany from 2003 is shown in Figure 2.7.

2.2.5. Environmental issues

2.2.5.1. Leaching

One of the primary environmental concerns regarding CCPs either in storage areas or disposal sites is leaching and release of heavy metals to ground and surface water. Extensive testing has shown that coal ash rarely, if ever, exceeds hazardous waste criteria contained e.g. in the Toxicity Characteristic Leaching Procedure (TCLP) promulgated under the Resource Conservation and Recovery Act [37] or in country specific criteria (see table 4.9 and detailed study in Annex II).

Laboratory studies have demonstrated that the leaching process is complex and depends on a number of factors, primarily chemical speciation of the constituent, solution pH, and availability of the constituent for leaching. Availability for leaching depends on whether the element resides on the surface of the ash particle, in the outer glass hull, or within the interior glass matrix.

In addition, subsequent chemical reactions and secondary mineral formation can further modify leaching characteristics of the ash. For example, because arsenic typically condenses on the surface of the FA particle, it may initially be available for leaching. However, the presence of calcium in the ash can limit the release of dissolved arsenic by the formation of calcium-arsenic precipitates [38]. Detailed leaching studies under controlled conditions should be used to elucidate the mechanisms controlling constituent release and provide the best indication of the long-term potential for release and environmental risk. Therefore laboratory investigation on leaching using CCPs based composite material is strongly advised.

2.2.5.2. Windblown ash

Because of its fine-grained texture, dry FA is susceptible to blowing under windy conditions. In a construction site the problem is not of a very high significance due to relatively short period of built-in. Most studies of the potential health effects associated with ash dust have focused on power plant workers, for whom exposure to dusty conditions is much more common than for the general public. On construction sites the standard precautions such as dust masks are recommended while working with CCPs. At disposal sites, windblown ash is generally controlled by periodic wetting of open ash areas, and by covering inactive areas with BA, soil, or vegetation. This topic is also covered in the paragraph on handling and storage in Chapter 5.

2.2.5.3. Mercury

Mercury is an element of significant environmental interest because of its toxicity and occurrence in lakes and rivers. The median mercury concentration in coal is 0.11 mg/kg while 80 % of coal samples contain less than 0.25 mg/kg. Mercury in coal-based FA generally ranges from about 0.05 mg/kg up to about 2 mg/kg, with typical concentrations between 0.1 mg/kg and 0.5 mg/kg.

One of the leading approaches to further reduce mercury emissions from power plants is the injection of activated carbon into the flue gas. The mercury particles sorb onto the activated carbon, which is then captured with the FA in the electrostatic precipitator unit or baghouse. This technique leads to higher mercury and carbon content in the FA, although research by the US Environmental Protection Agency (EPA), Electric Power Research Institute (EPRI), Building Research Institute (ITB) and others, has consistently shown that the carbon-bound mercury is very stable on the FA at ambient temperatures, with very low potential for leaching or volatilisation [32], [38].

2.2.5.4. Radioactivity

Coal contains naturally occurring radioactive constituents, such as uranium and thorium and their decay products. Uranium and thorium are each typically present in coal at concentrations of 1 to 4 mg/kg [39]. These constituents are entrapped in the fly-ash particles following combustion of the coal. Any radon gas present in the coal is released during combustion.

Although the radionuclides are enriched in the FA in comparison to the coal itself, the numerous investigations made by the US Geological Survey [39] and the Technical University of Szczecin and Central Mining Institute in Poland [32] showed that the average radionuclide concentrations in ash are within the range of concentrations found in other geologic materials. The radiation measured in decay chains of the radioactive constituents K-40, Ra-224 and Th-228 are satisfactory low (no limit values specified) and the radiation of Ra-226 and Ra-228 is three times lower than the acceptable limits allowed for soil constructions in Poland (the limit values for CCPs in Poland are only specified for: Ra-226 chain: 350 Bq/kg, Ra-228 chain: 230 Bq/kg, and the summarized weighted activity index of all radioactive constituents should be lower than 1) [32].

Experiments made on CCPs from Dolna Odra power plant proved that the integrated concentration of radioactive constituents and radon is generally below limits allowed for civil engineering materials [32]. These observations are confirmed by US EPA, US Geological Survey and EPRI; it has been shown that an exposure to radiation from coal ash or concrete products made with FA does not represent a significant health risk [39].

2.2.6. Further information

If ashes and slag from hard coal are recovered, different regulations have to be taken into account in Poland and Germany (Chapter 3). The most important documents are mainly focussing on applications in road construction and concrete production ([8], [34], [35] [40], [41], [42], [43], [44], [45], [46], [47], [48], [49]).

2.3. Geosynthetics

Geosynthetics have been increasingly used since the late 1970s to meet several functions in hydraulic and geotechnical projects. Geosynthetics act for example as filters, reinforcement, sealing, and separation layers. Geosynthetics have been developed rapidly, starting with simple non-woven and woven textiles in geotechnical and hydraulic engineering to very sophisticated composite products, combining the characteristics of different materials and production technologies.

"Geosynthetic" (GSY) is „a generic term describing a product, at least one of whose components is made from a synthetic or natural polymer, in the form of a sheet, a strip or a three dimensional structure, used in contact with soil and/or other materials in geotechnical and civil engineering applications" [50]. GSY can be subdivided into water permeable and water-impermeable planar formations [51]. In the following, the terminology of EN ISO 10318 [50] is briefly explained based on [51].

2.3.1. Types of geosynthetics

Geosynthetics are categorised in permeable and essentially impermeable products. Permeable products are geotextiles and geotextile related products, while geosynthetic barriers are impermeable (Figure 2.8). Figure 2.9 shows examples of different geosynthetics.

Geotextiles (GTX) are "planar, permeable, polymeric (synthetic or natural) textile materials, which may be nonwoven, knitted or woven, used in contact with soil and/or other materials in geotechnical and civil engineering applications" [50]. They can be woven (GTX-W), nonwoven (GTX-N, made of staple fibres or filaments and mechanically, cohesively or adhesively bonded), or knitted (GTX-K).

Geotextile related products (GTP) are "planar permeable, polymeric (synthetic or natural) material, which does not comply with the definition of a geotextile" (EN ISO 10318). These can be geogrids (GGR) and geogrid related products, such as strands, geostrips (GST), bar shaped elements, geonets (GNT), geomats (GMA), geocells (GCE) and geospacers (GSP).

The impermeable geosynthetics can be subdivided into geosynthetic clay barriers (GBR-C) (or geosynthetic clay

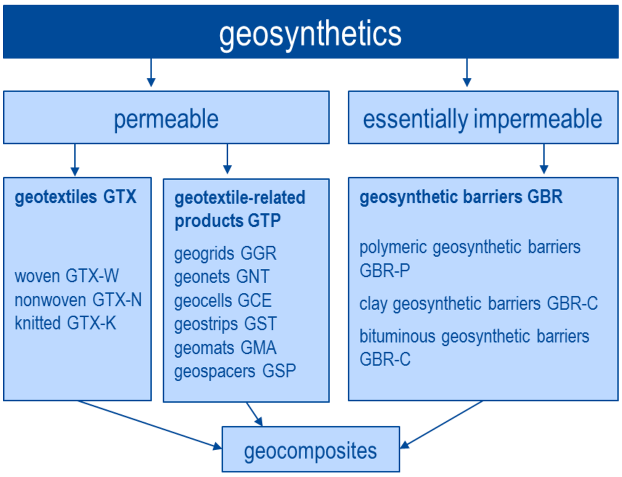


Figure 2.8. Classification of geosynthetics [51]

liners), geosynthetic polymer barriers (GBR-P) and geosynthetic bituminous barriers (GBR-B). In the GBR-C usually bentonite is used between two sheets of geotextile, functioning as very thin clay liner with low hydraulic conductivity, whereas the other two product groups are basically geomembranes made of different materials.

Finally, combinations of different geosynthetics exist, which are called geocomposites (GCO), to combine the functions of different products. An example of such a composite is the geosynthetic drainage composite, consisting of an inner drainage layer and two layers of geotextile for filtration, separation and protection on the outside.

2.3.2. Functions of geosynthetics

Geosynthetics can have one of the functions presented in Figure 2.10, or their combination, according to EN ISO 10318 [50]. Detailed information about all functions can be found in [51].

2.3.3. Further information

Further information about geosynthetics, including selection recommendations, installation guidelines, raw materials, material behaviour, testing and quality control can be found in [51] and the European and national geosynthetics standards, as well as the following documents: [52], [53], [54], [55], [56], [57], [58], [59], [60].

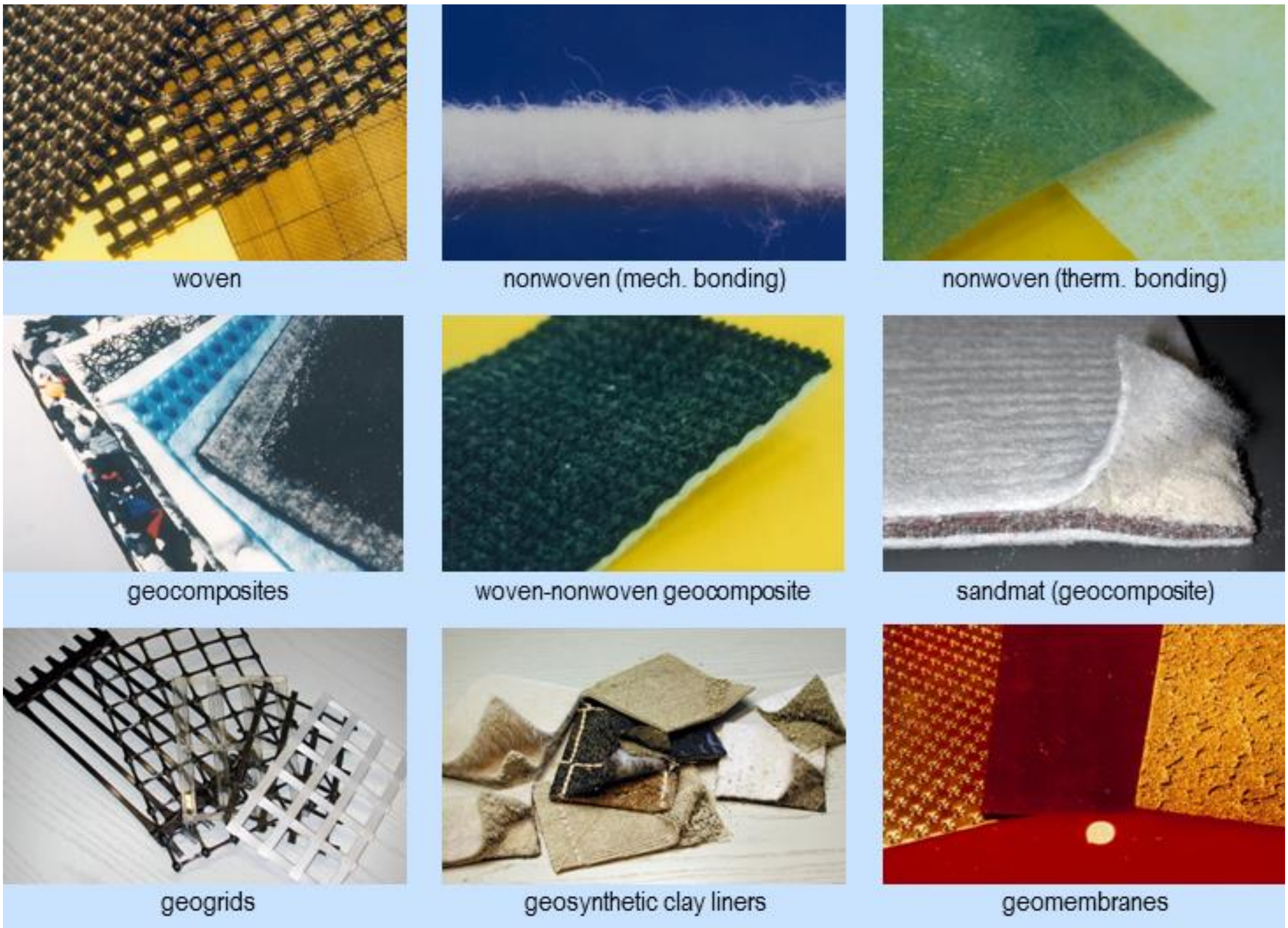


Figure 2.9. Examples of different types of geosynthetics [51]

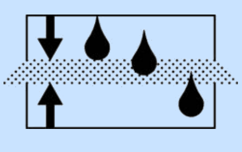
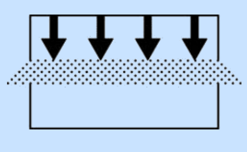
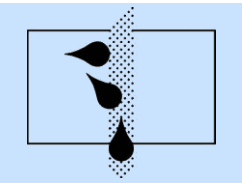
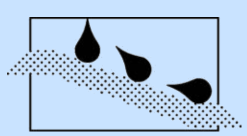
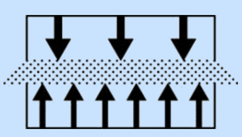
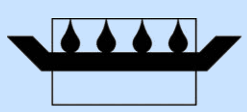
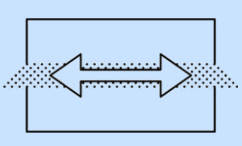
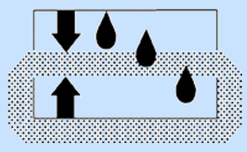
	Filtration: The retention of soil or other particles subjected to hydrodynamic forces while allowing the passage of fluids into or across a geotextile or a geotextile-related product.		Protection: The preventing or limiting of local damage to a given element or materials by the use of a geotextile or a geotextile-related product
	Drainage: The collecting and transporting of precipitation, ground water and/or other fluids in the plane of a geotextile or a geotextile-related product		Surface erosion control: The use of a geotextile or a geotextile-related product to prevent soil or other particle movements at the surface of, for example, a slope
	Separation: The preventing from intermixing of adjacent dissimilar soils and/or fill materials by the use of a geotextile or a geotextile-related product		Sealing / barrier: The control of migration of a gas or a liquid
	Reinforcement: The use of the stress-strain-behaviour of a geotextile or a geotextile-related product to improve the mechanical properties of soil or other construction materials		Wraping/ packing: In geotechnical and hydraulic engineering, earth materials in particular are "packed" in flexible tubes, sacks and containers.

Figure 2.10. Functions of geosynthetics [50]

2.4. Dikes

A dike is an embankment constructed to prevent flooding, keep out the sea or confine a river to a particular course, usually only temporarily charged by floods. Dikes are made of different soil and rock materials, supplemented by other materials, such as geosynthetics.

Dikes are generally categorised into river dikes (or levees) and sea dikes. They can be distinguished in waterside dikes (flock dikes) and set back dikes (Figure 2.11). Furthermore, there is a division into winter dikes and summer dikes. River dikes have to withstand the hydraulic load of a flooding for several weeks while sea dikes are designed to withstand shorter impact periods, including the loading by wave attacks [60], [61].

Dikes should prevent the hinterland against floods by an adequately dimensioned cubage and height. The design of the cross-section and slope inclinations is primarily determined by the local variations in wave and water attack. Also, the available area may be a limiting factor. The height of the dike crest depends on the basis of the respective design water levels, including wave run-up heights and safety factors.

The dimensioning of a dike always needs to be considered in connection with the foreshore conditions, as these have a decisive influence on the attenuation of waves and hydraulic loading and thus on the stresses in the dike. Dunes or forests on the water side of a setback dike reduce the height of the water level or the wave load. In case of a waterside dike with a direct flood loading or wave attack, the embankments are usually reinforced with a revetment.

As a general rule, dikes are not totally watertight; depending on the situation and type of construction a considerable amount of seepage water flows through the construction. For stability reasons, the seepage should always exit the dike cross-section at the land side toe or in a controlled filter and drainage area (e.g. drainage prism). All aspects of dike design and construction are comprehensively summarised in [62]

Sea dikes are usually stressed by storm surges for a very limited amount of time (one to several days). Due to the temporary water stress in the dike body transient flow conditions dominate the system. The flow through the dike section can be influenced by the choice of materials and their arrangement. The dike cover needs to be protected against surface erosion triggered by different phenomena such as rainfall, current, wave attack and overtopping as well as internal erosion such as piping and contact erosion (Figure 2.15). The natural mineral dike cover must therefore be carefully installed with sufficient quality and compaction [60], [61] and where necessary with an additional revetment.

The characteristics of a river dike are different since it is usually exposed to high flood water levels over a longer period of time (up to several weeks). Inside the dike body, stationary conditions may occur [63], particularly in historical dikes where the sealing is weak compared to the quality required for newly built river dikes.

The following paragraph defines the dike terminology for this guideline, describes important issues of sea and river dikes in Germany, Poland and Denmark and gives a short overview on failure modes as a basis for Chapter 4.

2.4.1. General dike terminology

A dike cross-section is characterised by the slope inclination, the width and height of the crest and the arrangement of berms (Figure 2.12). A dike needs to be designed regarding all relevant load cases including the subsoil and the dike itself.

The height and width of the *crest* and the construction of a possible revetment must be chosen for all relevant loads. In most cases the crest width exceeds 3 m. If a road is planned on the crest, its width should be at least 4 m. The crest is designed with an inclination to the outer slope (usually > 2 %) [64], [65].

The choice of the dike *embankments* is a question of stability, repair and maintenance accessibility and the embedding into the landscape. The permissible slope inclination depends on the type of earth material and should always be confirmed in a stability analysis. Typical slope inclinations vary, particularly between sea and river dikes. There are also differences based on the constructions' historical development [60], [63].

The *dike toe* is the lower part of the embankment, including a possible vertical integration into the underground. Due to its position, the dike toe on the outer slope is more frequently stressed by floods, wave attacks or moisture. For this construction detail the frequency of flood events is more important than the design flood level.

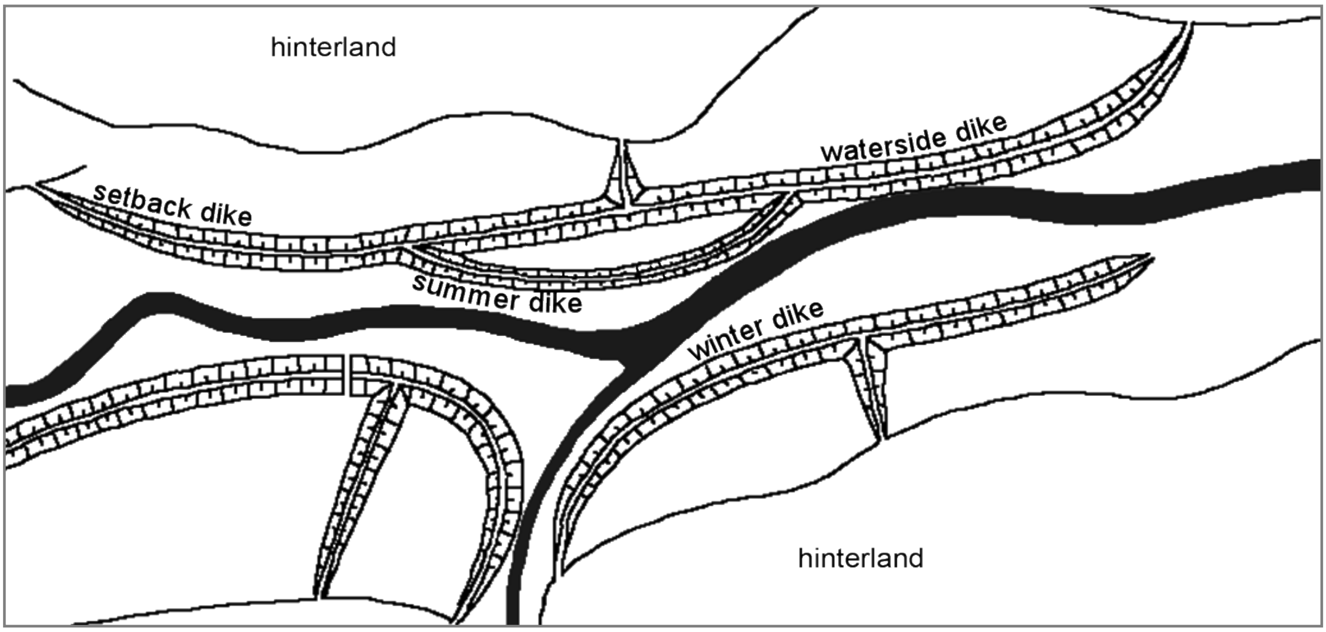
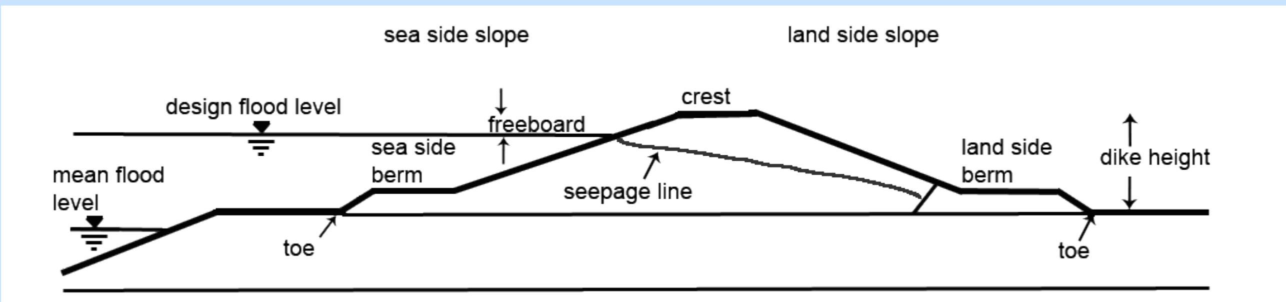


Figure 2.11. Basic classification of dikes [64]

Summary of important aspects to be considered in the dimensioning of a dike



Available area	Properties of the foreshore	Foundation conditions	Settlement of the underground
Design flood level (DFL)	Wave run-up level	Freeboard (FB)	Design height - crest (DFL+FB)
Dike stability reg. shear strength	Seepage, erosion	Elevations for residential, commercial and industrial development	
Available dike materials	Available construction equipment	Flood zone boundaries	Material deformation

Figure 2.12. Terminology and dike dimensioning aspects ([63], [64], [66])

The best protection for the toe of the outer slope is a foreland. In case of a waterside dike, the toe should be vertically integrated into the underground [60], [63].

Berms facilitate the repair and maintenance of dikes and increase the stability of the cross-section. The width of the berms and their location on the embankment are designed in accordance to the requirements.

The freeboard is the vertical distance from the design flood level to the dike crest and serves as a safety factor. It is mainly calculated from wind data and wave run-up data and if necessary other parameters [63].

Access roads are adjusted to the type and means of transport allowing carriage of all necessary equipment and materials during construction and maintenance. Roads should be constructed parallel to the dike on a berm at the inner slope or on the crest, and should have connections to public roads at least every 4 km [64].

2.4.2. Sea dikes

The dikes of the North and Baltic Seas and along the tidal rivers are historically built of regionally typical materials, which make the major difference. In case of floods sea dikes are usually stressed by direct wave attack at the outer embankment and sometimes even by wave overtopping with impacts on the inner embankment. Sea dikes can be categorised into setback dikes (foreland dikes) and waterside dikes (flock dikes) [61], [60]. In general, two different types of dikes can be found at the German North and Baltic Sea coasts: dikes with a supporting body made of sand, covered with clay or marl (Figure 2.13) and homogenous dikes [60].

In the following, Baltic Sea dikes from Germany and Denmark are described in more detail. Poland does not have sea dikes due to the high elevation of the coasts. The lowlands are usually associated with river deltas (Paragraph 2.4.3).

2.4.2.1. German Baltic Sea dikes

Information about design, construction and monitoring of sea dikes in the German federal states at the Baltic Sea coast (Schleswig-Holstein; Mecklenburg-Vorpommern) are comprehensively included in EAK 2002 [60].

Generally, the foreland dike at the Baltic Sea coast of M-V is only one part of a complex coastal protection system, including beach, dunes and coastal woods as primary protection system on the sea side of the dike. However, there are also dikes along the backwater lagoons (Bodden) and some dikes on the islands of Rügen and Hiddensee which are flock (waterside) dikes.

The sea dikes in M-V are usually made of a sand core (supporting body) covered with regional marl as erosion resistant, low permeability layer, and a top soil to establish vegetation. In case of flock dikes the water side is usually protected by a revetment. General properties of German Baltic Sea dikes are summarised in Table 2.11.

In general, the responsibilities for the German dikes are regulated by the water laws of the federal states (Landeswassergesetze der Länder). In M-V the dike associations (Deichverbände) are responsible for the planning, construction and maintenance of the sea dikes. Due to the small number of dike associations, the State Agencies for Agriculture and Environment (StÄLU) take the responsibility.

Table 2.11. General properties of German Baltic Sea dikes

Relevant guidelines	EAK 2002 [60]	
Design flood level DFL	With foreland	No foreland
Inclination of dike toe	1V:15H	1V:3H - 1V:4H
Crest width	2.5 m to 3 m	
Incl. of sea side slope	1V:3H to 1V:6H	
Incl. of land side slope	1V:3H	
Thickness of cover layer	0.5 m to 1.2 m sea side slope 0.5 m to 0.7 m land side slope	

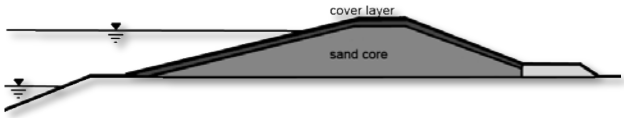


Figure 2.13. Example cross-section of a German sea dike with sand core and cover layer

2.4.2.2. Danish Baltic Sea dikes

In Denmark, flood protection and particularly sea dike construction is municipality or private concern. While the Danish Coastal Authority will advise the land owners in their coastal protection projects, there is no central responsibility like there is in Germany. Coastal dikes are generally built in the same way as in Germany, either with a supporting sand core covered with an erosion resistant clay layer or as homogenous clay dikes. Usually, the German EAK [60] is used for the design and construction of Danish sea dikes. A comprehensive Danish guideline on dike construction is currently being prepared [67].

2.4.3. River dikes

2.4.3.1. German river dikes

German river dikes have to be designed according to DIN 19712 [63] and DWA-M 507 [64] usually as a multi (three) zone dike and constructed under consideration of ZTV-W-205 [68] and ZTV-W-210 [69]. The design cross-sections consist of a supporting body, a barrier system to seal the embankment against seepage water - either on the upstream face (e.g. clay liner or geosynthetic barrier) or as a core sealing - as well as a drainage body at the downstream toe.

Existing river dikes, however, may not have been built according to this standard. There is a variety of homogenous dikes, made of locally available materials. Many of these dikes have been subject to reconstruction, additional sealing and other improvement during the past years.

A selection of construction aspects is provided in Table 2.12. More information can be found in [63] and [64].

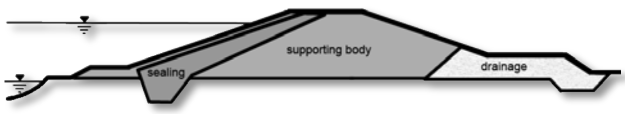


Figure 2.14. Example cross-section of a German river dike section with three zones (sealing, supporting body, drainage)

Table 2.12. General properties of German river dikes

Relevant guidelines	DIN 19712 [63] / DWA-M 507 [64] / ZTV-W 205 [68] / ZTV-W 210 [69]
Crest width	3 m (min 2 m)
Incl. of upstream slope	1V:3H
Incl. of downstream slope	1V:3H
Recommended hydraulic conductivity for sealing elements	2 orders of magnitude lower than the supporting body [63] According to ZTV-W 210 [69]: $q_s < 2.5 \cdot 10^{-8}$ m³/s/m²

2.4.3.2. Polish river dikes

Flood protection in Poland is regulated under the Water Law (WL) [70]. According to art. 81 WL, flood protection is the duty of public administration. The general construction rules for flood protection structures are given in §1 art. 63 WL. Technical requirements to be met by flood protection structures are defined in a ministerial directive [65]. According to this directive there are temporary and long-term hydraulic structures. Dikes are long-term structures and they are classified according to the area protected by the dike (Table 2.13).

The dikes are designed for the debits of high water which appear with a certain probability p%. There are two types of debits: the corresponding debit Q_m (miarodajny),

Table 2.13. Dike classification in Poland

Dike class	I	II	III	IV
Protected area F [km²]	F>300	150<F≤300	10<F≤150	F≤10

Table 2.14. Probabilities of debits for a given class of the dike

Structure	Debit	Probability of the debit in p % for a given dike class			
		I	II	III	IV
Dike	Q_m	0.5	1.0	2.0	3.0
	Q_k	0.1	0.3	0.5	1.0

Table 2.15. General properties of Polish river dikes

Relevant guidelines	Water law [70] / Directive [65]/ [71]
Crest width for dikes higher than 2 m	Min 4.5 m (in case of transport on the crest), 3.0 m in other cases
Inclination of upstream slope	1V:2H to 1V:2.5H [1)]
Inclination of downstream slope	1V:2H to 1V:2.25H [2)]
Recommended hydraulic conductivity for sealing elements	No specifications

[1)] for non-cohesive soils
[2)] for non-cohesive soils without drainage system.

and the control debit Q_k (kontrolny). The probabilities p of debits for given dike classes are provided in Table 2.14.

The highest water level H_m used in the calculation is established based on observation data or the analysis of possible hydraulic events (incl. wind action in the deltas). Details of static and hydraulic calculations are given in [65]; they have to be performed for standard and exceptional load combinations. The required height of the dike crest above high water level is determined with a function based on the dike class for a static water level increased by an addend considering wave action [65]. The calculations have to prove that the dike satisfies the requirements concerning stability and filtration. There are no requirements concerning the sealing layer in the Polish guidelines.

The most typical shape of a dike is a trapezoid with the maximum slope inclinations given in Table 2.15. The crest width depends on whether traffic is allowed (road, pathway). In order to increase the stability of river dikes berms can be used on both sides of the dike the surface of which should be inclined at 5 % to assure drainage.

Apart from very regular cross-sections there are also ideas to construct irregularly shaped dikes which fulfil ecological needs. Here, the dike is composed of an inner part which satisfies hydraulic and stability conditions and an outer part for flora and fauna. The thickness of the outer part should exceed 1 m. It should be sufficiently elevated above the design water level. Such a solution could reduce the risk of deterioration by animals, improve the general dike stability and lower maintenance costs. It needs, however, a larger dike section, more space and more earthworks.

Generally local materials are used to construct dikes. Mineral soils to build the dike core should meet the following conditions:

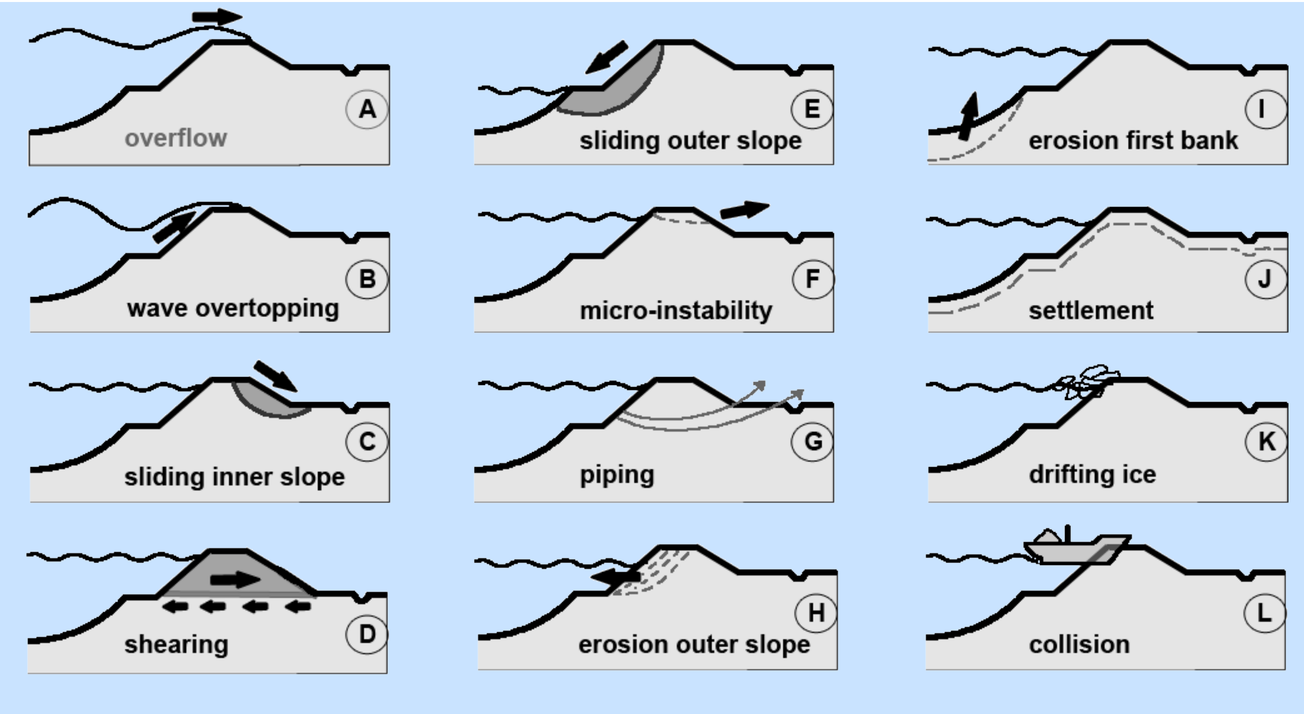
- for cohesive soils 0.95 ÷ 1.15$\cdot w_{opt}$,
- for non-cohesive soils $w > 0.7 \cdot w_{opt}$.

Extremely swelling and soluble soils and clays with a liquid limit LL > 65 % are not recommended to be used, unless special improving techniques are applied. Organic soils can be used under geotechnical supervision in special cases, e.g. when the dikes are constructed on weak organic subsoil and no local mineral soils are available. Anthropogenic materials including CCPs can be used with additional testing (Chapters 3, 4, 5).

Typical existing river dikes are constructed from local mineral soils which are often very heterogeneous (e.g. local inclusions or sand lenses). Their compaction is generally low and does not meet the usual requirements for earth constructions (e.g. concerning the degree of compaction). That is why many dikes were subjected to improvement works concerning the construction of impervious vertical barriers or sealing liners on the slope. The vertical barriers are constructed in the central part of the dike core and subsoil or at the toe of the outer slope and connected to the sealing liner on the slope.

2.4.4. Dike failure modes

During dike design the stability analysis is a central task. Usually, sophisticated geotechnical and geohydraulic models are applied to perform these analyses. The main issues for which the stability has to be proven are: internal erosion, slope failure, hydraulic heave and surface erosion with respect to wave run-up, and overtopping. A compilation of dike failure modes according to [72] is presented in Figure 2.15. More information can be found in [62].



A	High water level and wave overflowing leads to inundation of the area behind the dike, but without destruction of the dike
B	Overtopping water leads to erosion of the inner slope (caused by a high water level and wave overtopping)
C	High water level and wave overtopping leads to infiltration of overflowing water on the inner slope. This may leads to sliding of the inner slope (loss of stability). Also water pressure against the dike with increased water pressure in the underground may lead to such a failure.
D	Shearing of the dike body caused by a high water pressure against the construction and a increased water pressure in the underground.
E	A rapid fall of the water level at the outer slope after a period with a high water level may leads to sliding of the outer slope.
F	A leakage of seepage water of the inner slope may lead to failures such as under C, but at lower water levels (micro instability).
G	Piping may occur caused by seepage flow in the subsoil. The erosion starts behind the dike and soil is borne along (sand boils).
H	Wave movement may lead to erosion of the outer slope, the toe of the dike.
I	Wave movement may lead to erosion the foreshore.
J	Settlements lead to a lower defence structure.
K	Mechanical threats like ice and ice movement leads to damage of the construction.
L	Mechanical threats like shipping leads to damage of the construction.

Figure 2.15. Dike failure modes [72]

2.4.5. Internal erosion

Internal erosion phenomena are major triggers for dike failure. Therefore, this topic is intensively investigated worldwide. This guideline also discusses the stability of DMs and CCP-soil composites against internal erosion. Therefore, a basic understanding and classification is helpful.

A comprehensive overview about the state of the art in internal erosion with regard to dikes is provided in [73]. Here, four different types of internal erosion are defined: Concentrated leak erosion, backward erosion (incl. piping), contact erosion and suffosion.

Concentrated leak erosion may occur in cracks, e.g. caused by differential settlements or desiccation. *Backward erosion* can occur in two different ways: *Piping* starts at a point where the seepage water exits the ground or the inner embankment, eroding non-cohesive soil so that an actual pipe develops in or underneath the dike body. In case of a cohesive dike cover this may also happen in combination with hydraulic heave of the cohesive material. *Global backward erosion,* on the other hand, leads to a near vertical pipe in the dike core [73]. *Contact erosion* occurs at the interface of a coarse and fine soil where the fine particles erode due to interface parallel flow in the coarse material while *suffosion* is triggered by water flowing through widely graded or gap-graded non-cohesive soils. This topic is also discussed in [62], [65], [74], [75].

2.5. Case studies of dikes made of dredged materials

2.5.1. Norddeich CT 4 Bremerhaven, Germany

As part of the expansion of the container terminal in Bremerhaven, a 900 m long dike was built (Figure 2.16). The dike core was built up with sandy DM from Bremerhaven harbour and covered with a layer of 1 m thickness of marsh clay. According to the results of the chemical analyses the dewatered DM was characterized based on the classification limits for solids and eluate of LAGA-M20 [8] and classified as a Z1.2 material, while the majority of eluate parameters even fell below the Z1.1 threshold. The main exceptions exceeding the LAGA thresholds were the parameters conductivity, chloride and sulphate, which is natural due to the brackish water of the dredged area. A comprehensive presentation of the project can be found in [4] and [76].

Figure 2.16. Norddeich CT4 Bremerhaven [76]

2.5.2. Weser dike in Bremen, Germany

In Bremen, the dike association responsible for the left banks of the river Weser (Deichverband am linken Weserufer) installed DM in the tidal Weser river dikes (Figure 2.17). The DM was processed in the bremenports treatment plant. In the years 2009–2014 a total of 156,000 m³ of dried, processed DM with TBT contaminations and LAGA [8] classification limit Z2 (with single contaminants slightly exceeding the Z1 threshold [79]) was used to increase the height of the Weser dikes. The DM was encapsulated in marsh clay by removing only part of the existing clay cover which was placed on top of the DM as final layer (Figure 2.18).

In Bremen, there is even a special framework for the recovery of DM in dike construction. In an official note, the Senator for the Environment, Construction, Traffic and European Affairs demands for every dike construction project to check whether DM is available in the required quality. Then this material has to be recovered before other resources are considered [77].

Figure 2.17. Dike reconstruction in Bremen with slightly contaminated dredged material (Z2 + TBT), DM placement summer 2014.

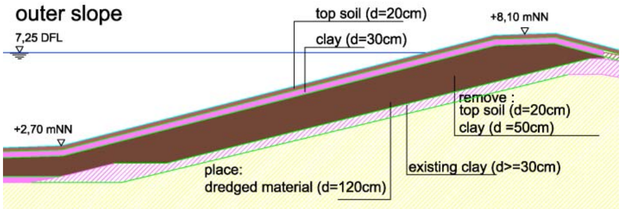


Figure 2.18. Dike reconstruction in Bremen with slightly contaminated dredged material (Z2 + TBT), standard cross-section [78]

2.5.3. River Scheldt, Netherlands and Belgium

Dredged material has been traditionally used for flood protection along navigation channels and in polder dike construction in the Netherlands and in Belgium [20]. Here, clean and slightly contaminated dredged sediment can be placed on the banks of rivers and channels according to strict rules. Not only the suitability is restricted but also the distance of the placement area from the waterway (20 m in the NL, 5 m in Flanders). Also, the necessity for ripening is seen as a precondition.

In the particular example at the river Scheldt, the dikes for a controlled flood area were constructed with sand dredged during a harbour construction project, covered with a layer of polder clay. The polder clay, however, seems to be more like a German North Sea marsh clay than a ripened, fine-grained dredged sediment.

Figure 2.19. Placement of dredged material on banks of waterways in the Netherlands [20]

Figure 2.20. Dike construction at Hoek van Holland [20]

2.5.4. Hoek van Holland, Netherlands

PIANC [20] also reports that "dredged material has been used in the United States and the Netherlands to build land dikes for interior waterways or at the coast in order to control flooding, either by channelling the waters (dikes located alongside the channels), or protecting sensitive areas (ring dikes)". As an example, the dike at Hoek van Holland is mentioned, where dredged material was placed in the cover layer.

References

[1] Köthe, H. 2010. Dredging and the Environment – international guidance for best practice, *PIANC 125th Anniversary Celebration in ASIA*, Nagoya JAPAN, www.pianc.org [cited 13 Jan 2015].

[2] Maritime Office Gdynia 2014. Information from the office gathered by Dr. Duszynski, Gdansk University of Technology.

[3] CEDA 2015. Website of the Central Dredging Association, www.dredging.org [cited 13 Jan 2015].

[4] HTG 2006. Verwertung von feinkörnigem Baggergut im Bereich der deutschen Küste, Fachbericht der Hafentechnischen Gesellschaft Fachausschuss Baggergut, 37 pp. Available online: www.htg-baggergut.de/Downloads/HTG%20Verwertungsbericht%200906.pdf [cited 16 Dec 2014].

[5] HELCOM 2007. Guidelines for the Disposal of Dredged Material at Sea – adopted in June 2007, 37 pp. Available online: http://helcom.fi/ [cited 16 Dec 2014].

[6] Kibbel, E. & Henneberg, M. 2004. Dredged material management in Rostock, Handout, Hanseatic City of Rostock, 6 pp. Available online: www.dredgdikes.eu/wp-content/uploads/iaaE.pdf.

[7] SMOCS 2011. Sustainable Management of Contaminated Sediments – Guideline. 32 pp. Available online: www.smocs.eu.

[8] LAGA 2003. Länderarbeitsgemeinschaft Abfall, Anforderungen an die stoffliche Verwertung von mineralischen Abfällen – Technische Regeln. Allgemeiner Teil, Teil II (TR Boden), Teil IV (Aschen aus Kohlekraftwerken); as per version of 6 Nov 2003 as note M20. Erich Schmidt, Berlin 2004, 128 pp. Available online: http://laga-online.de/servlet/is/23874/ [cited 13 Jan 2015].

[9] DepV 2009. Deponieverordnung - Verordnung über Deponien und Langzeitlager. 27 April 2009 (BGBl. I p. 900) last change in article 7 of the ordinance of 2 May 2013 (BGBl I p. 973), 63 pp. Available online: www.gesetze-im-internet.de [cited 16 Dec 2014].

[10] DGE 2002. Dutch-German Exchange on Dredged Material Part 2 - Treatment and Confined Disposal of Dredged Material, Sept. 2002, coord. by A. Netzband, A.L. Hakstege & K. Hamer, 39 pp.

[11] Henneberg, M. 2004. Lysimeter- und Praxisversuche zur Verwertung von gereiftem Baggergut als Bodenverbesserungsmittel in Landwirtschaft und Landschaftsbau, unpublished lecture at the State Office for Environment, Nature Protection and Geology, Güstrow.

[12] IMO 2015. Website of the International Maritime Organisation, www.imo.org [cited 13 Jan 2015].

[13] HELCOM 2015. Website of the Helsinki Commission, www.helcom.fi, relevant publications www.helcom.fi/Lists/Publications/BSEP120A.pdf [cited 16 Dec 2014].

[14] Salomons, W. & Brils, J. 2004. Contaminated Sediments in European River Basins; *Summarising Report of the European Sediment Research Network SedNet*. Available online: www.sednet.org /download/Sednet_booklet_final.pdf.

[15] LUNG 2002. Bodenbericht des Landes Mecklenburg-Vorpommern, Phase 1 des Bodenschutzprogrammes M-V. Available online: www.lung.mv-regierung.de/wasser_daten/Dateien/Start.htm [cited 13 Jan 2015].

[16] LUNG 1999. Verwertungsstrategien für aquatische Sedimente in Mecklenburg-Vorpommern, Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern, 175 pp.

[17] Zadroga, B. & Olańczuk-Neyman, K. 2001. Ochrona i rekultywacja podłoża gruntowego, Wydawnictwo Politechniki Gdańskiej.

[18] Hjort, M. & Josefson, A. 2008. Marine omrader 2008. Novana. Tilstand og udvikäng i miljo- og aliteter. Faglig rapport fra DMU nr. 760. Aarhus Universitet.

[19] EC 2008. EU Directive 2008/98/EC on waste (Waste Framework Directive).

[20] PIANC 2009. Dredged Material as a Resource: Options and Constraints. PIANC report no. 104. EnviCom Working Group 104. Available online: www.pianc.org.

[21] Gebert, J., Gröngröft, A. & Eschenbach, A. 2010. Eignung von Baggergut im Deichbau, *6. Rostocker Baggergutseminar – Kompetenztreffpunkt Baggergut*, Universität Rostock: 65-78.

[22] Gebert, J.; Gröngröft, A. & Eschenbach, A. 2014. Eignung von Baggergut im Deichbau, *8. Rostocker Baggergutseminar – Kompetenztreffpunkt Baggergut*, Universität Rostock, *Schriftenreihe Umweltingenieurwesen* **47**: 95-102.

[23] Stephens, S.R., Alloway, B.J., Parker, A., Carter, J.E. & Hodson, M.E. 2001. Changes in the leachability of metals from dredged canal sedimentsduring drying and oxidation, *Environmental Pollution* **114**: 407-413.

[24] Düngung 2004. Hinweise und Richtwerte für die landwirtschaftliche Praxis – Leitfaden zur Umsetzung der Düngeverordnung, Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz M-V, Schwerin,182 pp.

[25] Henneberg, M. & Neumann, R. 2011. 10 Jahre Lysimeterversuche zum Einsatz von gereiftem Baggergut zur Bodenverbesserung in der Landwirtschaft, report, 37 pp. Available online: www.htg-baggergut.de.

[26] Morscheck, G. & Henneberg, M. 2012. Einsatz von gereiftem Nassbaggergut als Rekultivierungssubstrat in Oberflächen-abdichtungssytemen, report for the Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern, 78 pp.

[27] SedNet 2015. Website of the European Sediment Research Network SedNet, www.sednet.org.

[28] vom Berg, W. & Feuerborn, H-J. 2006. Coal Combustion Products in Europe - valuable raw materials for the construction industry. *Concrete Plant International*, Special Print 04/06.

[29] Prakash & Sidharan 2006. A geotechnical classification system for coal ashes, *Geotechnical Engineering* **159**(GE2): 91-98.

[30] Ostrowski M. 2011. Charakterystyka morfologii popiołów lotnych ze spalania węgli brunatnych. *Prace Instytutu Ceramiki i Materiałów Budowlanych*.

[31] Galos K. & Uliasz-Bocheńczyk A. 2005. Źródła i użytkowanie popiołów lotnych ze spalania węgli w Polsce. *Gospodarka Surowcami Mineralnymi, no.* 21.

[32] Sybilski D. & Kraszewski, C. 2004. Ocena i badania wybranych odpadów przemysłowych do wykorzystania w konstrukcjach drogowych, IBDiM Warsaw, 278 pp. Available online: www.gddkia.gov.pl/userfiles/articles/p/prace-naukowo-badawcze-zrealizow_3435//documents/tn-233.pdf.

[33] Dehoust, g., Küppers, P., Gebhardt, P., Rheinberger, U. & Hermann, A. 2008. Aufkommen, Qualität und Verbleib mineralischer Abfälle, final report of the research project contracted by the German Umweltbundesamt, UBA, 153 pp.

[34] ASTM C618. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. ASTM standard, DOI: 10.1520/C0618-12A.

[35] PN-EN 450:2007. Popiół lotny do betonu (Fly ash for concrete applications), Polish standard.

[36] ECOBA 2015. Website of the European Coal Combustion Products Association, www.ecoba.com [cited 13 Jan 2015].

[37] EHSO 2008. The EPA TCLP: Toxicity Characteristic Leaching Procedure and Characteristic Wastes (D-codes). Available online: www.ehso.com/cssepa/TCLP.htm

[38] EPRI 2010. Comparison of Coal Combustion Products to Other Common Materials - Chemical Characteristics, Electric Power Research Institute (EPRI), 66 pp. Available online: www.epri.com.

[39] USGS 1997. Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance. US Geological Survey Fact Sheet FS-163-97, Oct 1997.

[40] EPRI 2009. Coal Ash: Characteristics, Management and Environmental Issues, Electric Power Research Institute, 12 pp. Available online: www.epri.com.

[41] FGSV 1993a. Merkblatt der Forschungsgesellschaft für Straßen- und Verkehrswesen über die Verwendung von Schmelzkammergranulat im Straßenbau, M624, 8 pp.

[42] FGSV 1993b. Merkblatt der Forschungsgesellschaft für Straßen- und Verkehrswesen über die Verwendung von Steinkohlenflugasche im Straßenbau, M625, 10 pp.

[43] FGSV 1994. Merkblatt der Forschungsgesellschaft für Straßen- und Verkehrswesen über die Verwendung von Kesselasche im Straßenbau, M626, 10 pp.

[44] FGSV 2001. Richtlinie der Forschungsgesellschaft für Straßen- und Verkehrswesen für die umweltverträgliche Anwendung von industriellen Nebenprodukten und Recycling-Baustoffen im Straßenbau, M642, 38 pp.

[45] LAB 1998. Anforderungen des Länderausschusses Bergbau an die stoffliche Verwertung von Abfällen im Bergbau über Tage.

[46] FGSV 2003. Hinweise der Forschungsgesellschaft für Straßen- und Verkehrswesen zur Verwendung von Braunkohlenflugasche aus Kraftwerken mit Kohlenstaubfeuerung, M627, 15 pp.

[47] PN-S-02205. Drogi samochodowe. Roboty ziemne. Wymagania I badania, 1998.

[48] PN-S-06102:1997 Drogi samochodowe. Podbudowy z kruszyw stabiliziwanychmechanicznie.

[49] PN-S-96012:1997 Drogi samochodowe. Podbudowa i ulepszone podłoże z gruntu stabiliziwanego cementem.

[50] ISO 10318-1:2013. Geosynthetics – Part 1: Terms and definitions.

[51] Saathoff, F. 2003. Geosynthetics in geotechnical and hydraulic engineering, *Geotechnical Engineering Handbook*, Berlin: Ernst&Sohn, 507-597.

[52] MLUV 2012. Uferlängswerke – Geotextilwälle. *Regelwerk Küstenschutz Mecklenburg-Vorpommern*, 3-9-4 / 2012.

[53] FGSV 2005. Merkblatt über die Anwendung von Geokunststoffen im Erdbau des Straßenbaues (M Geok E-StB).

[54] BAW 1993. Merkblatt Anwendung von geotextilen Filtern an Wasserstraßen MAG.

[55] BAW 1994. Richtlinie für die Prüfung von Geotextilien im Verkehrswasserbau RPG.

[56] DVWK 1992. Merkblatt 221 Anwendung von Geotextilien im Wasserbau. Deutscher Verband für Wasserwirtschaft und Kulturbau e.V. (DVWK), Hamburg/Berlin: Parey, 31 pp. Currently being updated in the frame of the DWA recommendations. Also available in English as DVWK Guideline 306.

[57] Heerten, G., Achmus, M., Boley, C., Grabe, J., Katzenbach, R., Meyer, N., Oumeraci, H., Richter, T., Saathoff, F., Savidis, S. & Scheffer, H.J. 2009. Bauwerke und Bauwerksertüchtigung im Küsten- und Verkehrswasserbau, Unsere Gewässer – Forschungsbedarf aus Sicht der Praxis – Eine Dokumentation von HTG und DGGT, Schiffahrts-Verlag Hansa C. Schroedter & Co Hamburg, 65-72.

[58] DIN-EN ISO 10318-1:2013-07. Geokunststoffe – Teil 1: Begriffe. Beuth: Berlin, 24 pp.

[59] PN-EN ISO 10318. Geosyntetyki – Terminy I definicje.

[60] EAK 2002. Empfehlungen für Küstenschutzwerke, korrigierte Ausgabe 2007, *Die Küste* **65**, KFKi (Kuratorium für Forschung im Küsteningenieurwesen), 589 pp.

[61] MLUV 2009. Regelwerk Küstenschutz Mecklenburg-Vorpommern, Übersichtsheft, Ministerium für Landwirtschaft Umwelt und Verbraucherschutz.

[62] CIRIA 2013. The International Levee Handbook, 1350 pp. Available online: www.ciria.org.

[63] DIN 19712-2013. Hochwasserschutzanlagen an Fließgewässern (Flood protection works on rivers). Beuth: Berlin, 68 pp.

[64] DWA-M 507. DWA Regelwerk, Merkblatt DWA-M 507-1, Deiche an Fließgewässern Teil 1: Planung, Bau und Betrieb, Dec 2011.

[65] Polish Directive of the Ministry of Environment of 20 April 2007 on the technical requirements to be met by hydrotechnical structures and their location (Journal of Laws 07.86.579).

[66] TAW 1998. Technical Report on Soil Structures, Delft, 248 pp.

[67] Piontkowitz, T. 2014. Personal information by Mr. Thorsten Piontkowitz, Danish Coastal Authority, Lemvig.

[68] ZTV-W-205 1992. Zusätzliche Technische Vertragsbedingungen – Wasserbau für Erdarbeiten.

[69] ZTV-W-210 2006. Zusätzliche Technische Vertragsbedingungen – Wasserbau für Böschungs- und Sohlensicherung, 14 pp.

[70] Polish Water Law 2005. (Journal of laws 05.239.2019).

[71] Borys, M., Mosiej, K. & Topolnicki M. 2006. Projektowanie i wykonawstwo pionowych przegród przeciwfiltracyjnych z zawiesin twardniejących w korpusach i podłożu wałów przeciwpowodziowych, *Wydawnictwo IMUZ*, Falenty 64 pp.

[72] TAW 2000. Fundamentals on Water Defences, *Technical Advisory Committee on Water Defences (TAW)*, Road and Hydraulic Engineering Division, Delft.

[73] Bonelli, S. (ed.) 2013. Erosion in Geomechanics Applied to Dams and Levees. ISTE Ltd. London, 388 pp.

[74] BAW MSD 2011. Merkblatt Standsicherheit von Dämmen an Bundeswasserstraßen (MSD). [Code of Practice - Stability of dams at federal waterways], Bundesanstalt für Wasserbau.

[75] BAW 2011. Merkblatt Standsicherheit von Dämmen an Bundeswasserstraßen – Ergänzende Hinweise zur Berechnung der Dammdurchströmung im Bereich von Bauwerken (Ergänzung MSD).

[76] Umtec 2008. Verwertung von Bremischem Baggergut im Deichbau, Machbarkeitsstudie im Auftrag der bremenports GmbH & Co. KG. 136 pp.

[77] SUBVE-B 2008. Verwendung von Baggergut im Deichbau. Mitteilung des Senators für Umwelt, Bau, Verkehr und Europa (Bremen), 20. Mai 2008, cited in [76].

[78] Planungsgruppe Grün 2014. Original CAD drawing provided by the planning company Planungsgruppe Grün, Bremen.

[79] Tarner 2014. Personal note by Mrs. Tarner, Deichverband am linken Weserufer, Bremen.

3. LEGAL ASPECTS

The European Directive on the assessment and management of flood risks [1] was drawn up in 2007 to implement a policy of flood risk assessment and prevention in the EU. All member states are invited to assess and map flood risks in order to prepare flood risk management plans that outline the need to improve and reconstruct coastal and river dikes for various flood risk areas. In this context, the demand for dike construction materials steadily increases. Often the soils have to be transported over large distances to the construction site, causing considerable environmental impacts. The general flood, soil and water protection and waste legislation is therefore both triggering and influencing the use of dredged materials in flood protection embankments such as dikes. In this chapter, however, focus is set on the legal framework to be considered when planning dikes with dredged materials (DMs) and coal combustion products (CCPs) while geosynthetics are generally unproblematic regarding legislation.

3.1. Legal aspects of DMs

3.1.1. Legal background

At international and national levels the conventions for protection of the marine environment e.g. London (1972), HELCOM (1992) and OSPAR (1992) ([2], [3], [4]) regulate the general handling of DM in different recommendations and guidelines, however, mostly regarding water and waterways (Figure 3.1). In the field of dredging and DM management a variety of European framework directives are affected (Figure 3.2).

In Germany the application of the existing regulations depends on whether the DM stays in the water body or an onshore recovery / disposal is considered. Based on this decision, different remedies take effect depending on the way of disposal/ recovery and the responsibilities [5].

The complexity of the legal situation (Figure 3.3) and the special requirements may cause considerable costs in a project and the use of DM in dike construction is only possible in specific individual cases [6]. However, it is important to define the ways on how to come to a solution in conformity with the law and to give a clear guidance on how to receive a permit. Objective decisions demand an understanding for the characteristics of sediments and the

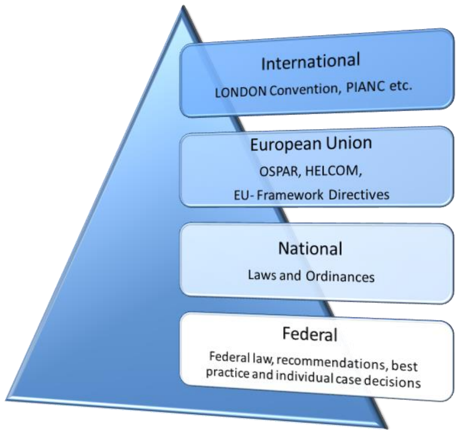


Figure 3.1. Hieratic structure of regulations and recommendations concerning DM

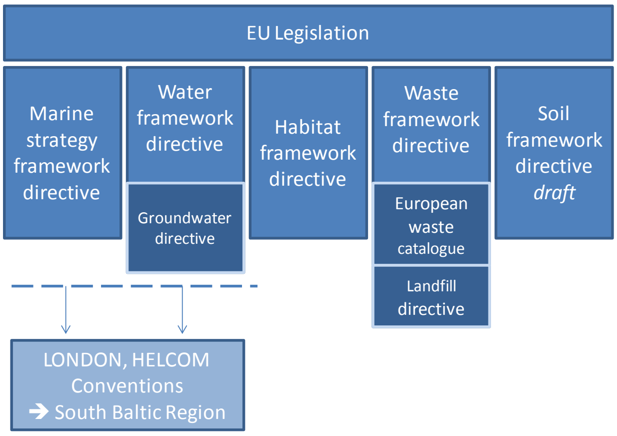


Figure 3.2. EU framework directives concerning the handling of DM with subordinated directives

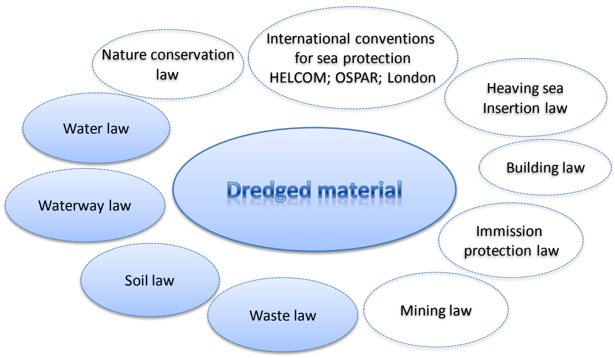


Figure 3.3. Different legal aspects concerning DM (based on [5])

system they came from, inasmuch as DM applications are as yet individual case decisions based on an extensive environmental assessment. The intended recovery of DM as substitute material in dike constructions creates complexities, which have to be clarified legally.

According to the European Waste Catalogue [7] DM is classified in group 17 (construction and demolition wastes including excavated soil from contaminated sites). The general code is 17 05 (soil […], stones and dredging spoil), further divided into two groups:

- 17 05 05* dredging spoil containing dangerous substances,
- 17 05 06 dredging spoil other than those mentioned in 17 05 05.

A comprehensive compilation of international and particularly European regulations about dredging and the recovery of DMs with regard to sustainability and ecology is provided in [8].

3.1.2. Relevant legislation for the recovery of dredged materials in dike construction

The legislation to be considered when recovering DMs in dike construction differs within the South Baltic region. Therefore, tables have been prepared to give an overview about the legislation and responsible authorities for the countries Germany, Poland and Denmark.

3.1.2.1. Recovery of DM in dike construction – Germany

In Germany, dike construction measures have to be carried out based on the water law because they are hydraulic measures according to § 67 WHG [9]. Therefore, the application of DM in dike construction has to comply with the requirements of the water law. A permanent change in the condition of the water bodies has to be avoided. The planning permission is regulated in § 68 WHG [9]. However, classification limits for construction materials are not listed in these paragraphs. „An explicit regulation tailored for the application of DM in dike construction in the soil conservation or waste management law does not yet exist, or rather, there are no classification limits for the application of DM“ [6].

The type of permit that is required for a recovery measure depends on the kind of recovery (e.g. approval according to construction law). For the recovery of DM according to waste law no special waste law permitting procedure is needed.

Some individual characteristics of DMs are completely different to those of other earth materials which has to be considered when comparing the classification limits. This issue is discussed in Chapter 4.

Sandy DM with almost no organic matter can be applied in a construction (underneath the rooting layer) if it complies with the waste regulations (e.g. harmless recovery). The supreme waste authority in Mecklenburg-Vorpommern recommends using the LAGA M20 recommendations [10] as implementation tool. If evidence is provided that the common property is not in danger, the transgression of classification limits shall be allowed in individual cases [10]. Fine-grained DMs are generally not covered by the LAGA recommendations, nor is there any other regulation directly concerned with these materials. Due to the lack of guidance, the recommendation of this guideline is to use LAGA M20 also for fine-grained materials rich in organic content as an implementation help to come to a sound decision and permit (unless the permitting authority agrees on a separate procedure to prove the environmental harmlessness of the concerned DM). If the DM is recovered to fulfil a technical function (such as a dike) the LAGA M20 classification limits for Z1 shall be used as reference values to give guidance for the decision [11]. For the application of fine-grained DM which is also rich in organic matter, the individual case decision of the responsible authorities should be based on this procedure under consideration of the possibility to exceed individual classification limits (such as TOC) if the common property is not in danger.

For the greening or rooting layer (top soil), recovery of DM is also possible according to the German federal soil protection regulation BBodSchV [12] if it complies with its classification limits. The recommendations for application of §12 BBodSchV [13] restrict the layer thickness to 15-30 cm in case of an increased organic matter content.

3.1.2.2. Recovery of DM in dike construction – Poland

Water protection is considered in the Water Law [31]. According to art. 81 Water Law, water protection lies in the responsibility of public authorities. The general rules for the construction of water protection structures are provided in art. 63.1 Water Law [31]. In the design, construction and maintenance of water protection structures one should respect the rules of sustainable grow, and particularly to maintain good water conditions including the characteristic biocenosis, to conserve the existing ground relief and biological conditions in the water environment and wetlands or marshes.

Technical conditions to be fulfilled by water protection structures are defined in a ministerial directive [35]. This directive defines the technical conditions to be fulfilled by the constructions and the necessary calculation methods.

Table 3.1. German (regional M-V) legal framework concerning the recovery of DM in dike constructions

Task	Legislation	Authority
Dredging	German Waterways Act (WaStrG § 4, 7, 14, 48) [14] German Environmental Impact Assessment Act (UVPG §1, 2, 3b, 5, 6, 36) [15] German Water Management Act (WHG) [9] German Federal Nature Conservation Act (BNatSchG) [16] M-V: NatSchAG M-V [17], LWaG M-V [18] EU FFH directive (92/43/EEC) [19] EU Wild Birds directive (79/409/EEC) [20] EU Water Framework directive (2000/60/EC) [21] EU Marine Strategy framework directive [22]	Personal responsibility Federation (Bund WSD) for federal waterways Municipalities outside federal waterways
Treatment	Federal Recycling Management and Waste Law (KrWG) [23] Federal Immission Control Act (BImSchG) [24] Approval of treatment facilities according to 4th BImSchV [25]	Lower waste authority (State Offices of Agriculture and Environment – StÄLU)
Quality and applicability	Federal Recycling Management and Waste Law (KrWG) [23] As yet: Material evaluation acc. to LAGA M20 [10] and EAK 2002 [6] as individual case decision for a technical construction Federal Soil Protection Act (BBodSchG) [26] Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV) [12] for DM recovered in the rooting soil layer: For DM (ECC/170506) [7] no waste law approval is required.	Lower waste authority / lower water authority (StALU) Coastal authority
Planning approval and permission	German Water Management Act (WHG § 67, 68) [9] (Dikes as hydraulic measures) Water Act of the federal state M-V (LWaG M-V) [18]	Upper water authority (§107, LUNG) Lower water authority (StALU) Coastal authority
Construction	Construction Law (incl. BauGB [27], LBauO M-V [28]) Nature Conservation Law (incl. BNatSchG [16]) Construction of federal costal protection structures M-V / 1st order dikes (§83 LWaG) [18] Construction of dikes for the protection of agricultural areas, 2nd order dikes (§83 LWaG) [18]	Lower water authority (StALU) Lower water authorities (Municipalities) and water and soil associations (WBV)
Environmental impacts / dike specific environmental aspects	Environmental Impact Assessment Acts (UVPG[15], LUVPG M-V [29]) Nature Protection Acts (BNatSchG [16], NatSchAG M-V [17]) Federal Soil Protection Act (BBodSchG) [26]	Lower nature authority

Table 3.2. Danish legal framework concerning the recovery of DM in dike constructions with focus on Zealand

Task	Legislation	Authority
Dredging	Danish Marine Environment Protection Act [52] (new law is on the way – it will be executed on 1 July 2015 and administrated by the Danish Coastal Authority)	Regulated by end-use of sediment (e.g. harbours, municipalities) Danish Nature Agency
Treatment	Danish Coastal Protection Act [53] Danish Act of Raw Materials [54] Danish Environmental Protection Act [45] (e.g. for storage and deposits and utilisation of DM on land; treatment of DM is regulated by municipalities through this act)	Danish Nature Agency Municipalities Environmental Protection Agency Danish Coastal Authority
Quality and applicability	Instructions for handling contaminated soil on Zealand (Zealand Guidelines) [48] Provisions in the Danish Order of Reuse [46] Environmental Protection Act [45]	Municipalities Danish Nature Agency Environmental Protection Agency
Planning approval and permission	Municipal plan	Municipalities
Construction	Danish Act of Raw Materials [54] Danish Environmental Protection Act (for utilisation on land) [45] Danish Order of Soil Moving [44] Provisions in the Danish Order of Reuse [46] Instructions for handling contaminated soil on Zealand [48]	Municipalities Danish Nature Agency Environmental Protection Agency
Environmental impacts / dike specific environmental aspects	Coastal Protection Act [53] Environmental Protection Act [45] Act of Raw Materials [54] EU FFH directive (92/43/EEC) [19] EU Wild Birds directive (79/409/EEC) [20]	Danish Coastal Authority Danish Nature Agency Municipalities Environmental Protection Agency

Table 3.3. Polish legal framework concerning the recovery of DM in dike constructions

Task	Legislation	Authority
Dredging	Polish Geological and Mining Law [30] Polish Water Law [31] EU FFH directive (92/43/EEC) [19] EU Wild Birds directive (79/409/EEC) [20]	Authority responsible for water management
Treatment	-	Ministry of Environment
Quality and applicability	Polish Waste Act [32]	Ministry of Environment
Planning approval and permission	Polish Directive of the Minister of Environment on the technical requirements to be met by hydraulic structures… [33] Polish Act on spatial planning and development [34]	
Construction	Polish Building Law Act. [35] Polish Water Law [31] Polish Directive of the Minister of Environment on the technical requirements to be met by hydraulic structures… [33]	According to art. 81 water protection is the responsibility of public authorities
Environmental impacts / dike specific environmental aspects	Polish Environmental Protection Law Act [36] Polish Nature Preservation Act [37] Polish Law on the prevention of damages in environment and their repairing [38] Polish Ministry Act on the forms and methods of monitoring of superficial and underground waters [39]	Ministry of Environment

The present Ministry Act on the recovery of wastes outside landfill installations [40] will be replaced in the near future (projected Ministry Act [41]). According to these projected regulations, different procedures should be fulfilled according to DM classification.

- 17 05 05* dredging spoil containing hydrocarbons should be decontaminated and the results should be approved by a certified laboratory.
- 17 05 06 dredging spoil other than 17 05 05* can be used for construction of hydraulic structures like harbours, dikes, artificial islands, port infrastructure and shore protection provided that this action is in conformity with a decision concerning the spatial planning [34] or building law [35] and does not induce any direct damage in the environment as stated in [38]. According to technical requirements the DM may be subjected to dewatering and stabilisation using different materials and binders. The requirements for contamination levels of heavy metals and organic compounds are given in [42], [43]. Special procedures for sampling and analyses are described in [41]; for inorganic materials, the recycling and recovery procedure R5 is used.

3.1.2.3. Recovery of DM in dike construction - Denmark

In Denmark, non-contaminated dredged material can also be recovered in dike construction with an individual case permit to be obtained from the relevant authorities.

The legal basis for handling DM as a component in construction projects is rather complex as the material may need to be transported and require further handling (dewatering, cleaning) before it can be recovered. Moreover, it may also be contaminated. The municipality in which the activity takes place regulates the use of soil in a construction project according to the Environmental Protection Act (EP-Act) as they do when soil is moved between cadasters [44].

The EP-Act [45] regulates the overall use of soil and sediments as building material. EP-Act § 19 is a general provision stating that all 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 applicable project is under this provision or not. Furthermore, it should be evaluated whether the application can be considered in relation to the provisions in the Danish Order of Reuse [46] which partly has authority in § 19 EP-Act, or whether the soil may perhaps be recovered without the need of a permission. Finally, it should be evaluated whether the construction is under the provisions of § 33 EP-Act concerning the approval of the listed activities [47].

In some cases, slightly contaminated soil can be used freely as it is considered to be harmless to the environment. This applies to soil classified as class 1 soil after the Zealand guideline [48] and soil categorized in category 1 in the Danish Order of Reuse [46]. The soil can be used in construction works such as dikes unless otherwise stipulated by the EP-Act and other legislation.

Permission to recover contaminated soil according to the Order of Reuse requires permission according to § 19 EP-Act or environmental approval according to § 33 EP-Act [45]. The recovery of soil is covered by provisions in the Order of Reuse if the soil is only contaminated with heavy metals, listed in the Order of Reuse, Annex 6 [46].

Recent decisions from the Danish Environmental Board of Appeal on two cases where contaminated soil was recovered in dikes ([49], [50]) indicate that the recovery of such soils in dikes will generally need an environmental approval according to § 33 EP-Act. Information about category 1 levels for contaminants and additional information about Danish legislation is provided in [51].

3.2. Legal aspects of CCPs

3.2.1. Legal background

The CCPs in Europe are considered either as waste material or as a by-product of coal combustion. The legal status of CCPs directly depends on the classification to one of the mentioned groups. In general, coal combustion products are handled under the European waste legislation and therefore, the Waste Framework Directive *2008/98*/EC [56] applies, among other EU guidelines. The procedures for recovery of CCPs when classified as waste are quite different in the European countries. In some countries and only under special circumstances, the CCPs can be certified as legal products, following the REACH [57] regulations. This by-product status can simplify the usage considerably.

According to the European Waste Catalogue ashes are classified in group 10 (wastes from thermic processes). The general code is 10 01 (wastes from power stations and other combustion plants except 19). In the detailed classification there are the following groups of products related to power plants:

- 10 01 01 – Bottom ash, slag and boiler dust […],
- 10 01 02 – Coal fly ash,
- 10 01 80 – Ash and slag mixtures from wet furnace waste disposal,
- 10 01 81 – Microspheres of fly ash (PL).

The classification of the products coming from wood, peat, liquid fluids, desulphurisation of gas, acid sulphur, cooling water, and others is not relevant for this guideline.

Combustion by-products are also analysed within the EU REACH system due to their varying chemical composition. REACH [57] is the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals. It regulates the safe use of chemicals through registration and assessment and, in some cases, by granting permits or limiting the trade and application of some chemicals.

The status of standardisation in Europe, in the scope of using combustion by-products, allows a wide spectrum in using ashes and slag as independent road material or in combinations with mineral materials in cement stabilisation technologies. Depending on the use in road structure, these can be earthwork mixtures and mixtures for improvement and stabilisation with hydraulic binding agents.

3.2.2. Relevant legislation for the recovery of CCPs in dike construction

The legislation to be considered when recovering CCPs in dike construction differs among the South Baltic region. Therefore, an overview about the legislation and responsible authorities are presented separately for the countries Poland and Germany in tabular form.

3.2.2.1. CCPs in dike construction – Poland

The main legislation act that relates to CCPs in Poland is the Waste Law [32]. It specifies the "procedures for handling of wastes in a manner that ensures the protection of human health and the environment in accordance with the principle of sustainable development, in particular the principle of waste prevention or reduction of waste production, and its negative impact on the environment, as well as the recovery or disposal of waste." It is supplemented by the Polish Waste Catalogue [58].

The provisions of the Waste Law [32] stipulate to carry out recovery or disposal of CCPs in constructions that meet certain requirements. Derogations from this rule are the types of waste listed in [40]. A new law will be introduced for the recovery or disposal of wastes outside landfill installations taking into account new types of wastes and some amendments [41]. This regulation addresses waste subgroup 10 01. Moreover, some wastes from the above subgroups (ex 10 01 01, 10 01 08 only) are identified in [59]. Here, they can be used in recovery procedure R14 to hardening surfaces, storage places and roads under the condition that they will not produce dust, and also as a foundation layer according to hydraulics and construction regulations.

According to Waste Law [32] there are three kinds of wastes: dangerous, neutral and other than neutral or dangerous. The dangerous wastes are those which exhibit properties listed in Appendix 3 (Waste Law) such as for instance: Harmful (H5), Toxic (H6), Carcinogenic (H7), Harmful to reproduction (H10), Mutagenic (H11), and Ecotoxic (H14).

The wastes can be classified as above if they meet the criteria enclosed in Appendix VI of the EU Directive 67/548/EEC [60] concerning the harmonisation of legislation […] on classification, packaging and labelling dangerous substances. For certain cases the admissible levels of substances are given in Appendix II and III of the EU Directive 1999/45/EC concerning harmonisation of legislation […] on classification, packing and labelling dangerous substances [61]. Test methods are described in [62] and in the appropriate CEN notes. The substances which lead to the wastes to be considered dangerous are listed e.g. in Appendix 4 of the Polish Waste Law [32].

The owner of wastes may change the classification of a dangerous waste when proving that the waste does not have dangerous properties. A certain procedure needs to be fulfilled and tests performed in a certified laboratory (cf. [42], [43]). It is obligatory that the owner of the waste informs the Marshal of Voivodship about the changes in waste classification from *dangerous* to *other than dangerous*. This should be approved by the Marshal of Voivodship, who informs the Ministry of Environment. The Ministry informs the European Commission about the change regarding the waste status. This process is also described in Chapter 4.

Material being the result of industrial processes but not intended as its principal product can be considered as by-product if the following four conditions are satisfied simultaneously:

- Further use of this material is assured,
- The Product or substance can be used directly subjected to typical industrial practice,
- The Product or substance is produced in an integral part of the industrial process,
- The Product or substance fulfils all the environmental requirements including also those related to law.

The producer of the material or substance is obliged to request the Marshal of Voivodship to change the classification from wastes to by-product. The results of the laboratory tests performed by a certified laboratory should be attached. In this case the material goes through the certification process (carried out by REACH standards [62]) and is licensed by governmental institutions, such as the Polish Building Research Institute. The Marshal of Voivodship transmits the information about the status changes of wastes to by-products to the Ministry of Environment. This is the easiest way to recover, and eventually use CCPs.

3.2.2.2. CCPs in dike construction – Germany

The application of CCPs (rust and boiler slag 100 101 and fly ash from coal combustion 100 102) is generally regulated under the German Recycling Act (KrWG [23]). The CCPs have to be harmless and useful. Recommendations are provided by the interstate working group LAGA [63]. These technical rules also define classification limits for the recovery of CCPs for solids and eluates (Chapter 4).

The application of mineral wastes (ashes and slag) can be carried out in areas with favourable hydrological conditions up to the classification Z1.2. If these areas are not subject to authority regulation, the convenient characteristics have to be proven by certificate. The materials can be used for road construction, attendant earth works, industrial and other storage spaces or mining recultivation measures and other excavations, whereas the waste will have to be covered with a sufficient layer of top soil or cultivable soil.

Materials with contaminations that fall below the classification limits of Z2 can be recovered in areas with favourable hydrological conditions (e.g. in noise barriers) if the waste is covered with a mineral liner of $d > 0.5$ m thickness and a hydraulic conductivity (sat.) $k_s < 1 \cdot 10^{-8}$ m/s covered by an additional recultivation layer.

The application in dike constructions is not explicitly mentioned as an option in the LAGA recommendations. Areas with frequently occurring flood events, on the other hand (e.g. flood control reservoirs, diked foreland), are excluded from the recovery. Based on these recommendations, it is not clear whether a recovery of CCPs in dike constructions is possible in Germany. However, since the LAGA recommendations are not a binding legal document (unless a federal state issues a respective decree), it should be possible to prove the environmental harmlessness in a particular project in the frame of an individual case decision.

Table 3.4. Polish legal framework concerning the recovery of CCPs in dike constructions

Task	Legislation	Authority
Waste/ material production	Polish Waste law [32] Polish Environmental Law [36]	Marshal of Voivodship Ministry of Environment
Treatment	Projected Polish Environmental Ministry Act of 15 June 2015 [41] For inorganic material the recovery procedure R5 used.	Local administration (Starostwo)
Quality and applicability	Polish Waste Law [32] EU REACH Directive [57] Polish Environmental Law [36] For detailed information on classification of wastes and the procedures for a change in waste status (from official waste to REACH by-product) Chapter 4.	Marshal of Voivodship Ministry of Environment Certified Laboratories e.g. Building Research Institute Institute of Ceramics and Building Materials
Planning approval and permission	Polish Act on Spatial Planning and Development [34] Polish Building Law Act [35] Polish Environmental Law [36] Polish Water Law [31] Polish Directive of the Minister of Environment on the technical requirements to be met by hydraulic structures… [33]	Local administration (Starostwo)
Construction	Polish Building Law Act [35] Polish Water Law [31] Polish Directive of the Minister of Environment on the technical requirements to be met by hydraulic structures… [33]	Local administration (Starostwo)
Environmental impacts / dike specific environmental aspects	EU FFH directive (92/43/EEC) [19] EU Wild Birds directive (79/409/EEC) [20] Polish Environmental Law [36] Polish Water Law [31]	Local administration (Starostwo)

Table 3.5. German legal framework concerning the recovery of CCPs in dike constructions

Task	Legislation	Authority
Waste production	Approval of treatment facilities according to 4th BImSchV [25]	
Treatment	Federal Recycling Management and Waste Law (KrWG) [23] Approval of treatment facilities according to 4th BImSchV [25]	
Quality and applicability	Federal Recycling Management and Waste Law (KrWG) [23] LAGA M20 TR Ashes and Slag – in different applications with compliance of classification limits [63]	Lower waste authority
Planning approval and permission	German Water Management Act (WHG § 67, 68) [9] (Dikes as hydraulic measures) Water Act of the federal state M-V (LWaG M-V) [18]	Upper water authority (§107) (LUNG) Lower water authority (StALU) Coastal Authorities
Construction	Construction Law (incl. BauGB [27], LBauO M-V [28]) Nature Conservation Law (incl. BNatSchG [16]) Coastal protection constructions: M-V (§83 LWaG) Dikes for agricultural purposes: WBV (§83 LWaG)	Lower water authority(StALU) Lower water authority (Municipalities) Water and soil associations (WBV)
Environmental impacts / dike specific environmental aspects	Environmental Impact Assessment Acts (UVPG[15], LUVPG M-V [29]) Nature Protection Acts (BNatSchG [16], NatSchAG M-V [17]) Federal Soil Protection Act (BBodSchG) [26]	Lower nature authority

If the contents of the specified parameters of the CCPs are below the classification limits for Z0, no constrictions regarding dike construction are listed in the German regulations. However, an individual case decision of the responsible authorities is still needed in analogy to the recovery of dredged materials.

References

[1] EC 2007. European directive on the assessment and management of flood risks (2007/60/EC).

[2] LC 2000. London Convention (1972). Guidelines for the assessment of dredged material.

[3] HELCOM 2007. HELCOM Guidelines for the Disposal of Dredged Material at Sea - Adopted in June 2007.

[4] OSPAR, 2009. Guidelines for the Management of Dredged Material (Ref. no. 2009/4).

[5] Köthe, H. 2002. Baggergut im Kontext nationaler und europäischer Regelungen, *2. Rostocker Baggergutseminar*. Available online: www2.auf.uni-rostock.de/ll/baggergut/rbs2/pdf/Koethe.pdf.

[6] EAK 2002. Empfehlungen für die Ausführung von Küstenschutzwerken durch den Ausschuss für Küstenschutzwerke der Deutschen Gesellschaft für Geotechnik e.V. und der Hafenbau-

technischen Gesellschaft, aktualisierte Fassung 2007, *Die Küste* **65**, 589 pp.

[7] EC 2000. The European Waste Catalogue (2000/532/EC).

[8] SMOCS 2011. Legislation on dredged material. Report from the SMOCS project. Available online: http://smocs.eu.

[9] WHG 2009. German Water Management Act (Deutsches Gesetz zur Ordnung des Wasserhaushalts). Available online: www.gesetze-im-internet.de.

[10] LAGA 2004. Technische Regeln der Länderarbeitsgemeinschaft Abfall – Anforderungen an die stoffliche Verwertung von mineralischen Abfällen, Teil II (LAGA M20 TR Boden).

[11] Weisz, R. 2014. Die LAGA M20 - was geht und was geht nicht in Bezug auf die Verwertung von Baggergut, *Proceedings of the 8th Dredged Material Seminar*, Rostock.

[12] BBodSchV 1999. German Federal Soil Protection Ordinance (Bundesbodenschutz- und Altlastenverordnung), 32 pp. Available online: www.gesetze-im-internet.de.

[13] LABO 2002. Implementation Aid regarding §12 BBodSchV 1999 (Vollzugshilfe zu den Anforderungen an das Aufbringen und Einbringen von Materialien auf oder in den Boden, §12 BBodSchV), 42 pp. Available online: www.labo-deutschland.de/documents/12-Vollzugshilfe_110902_9be.pdf.

[14] WaStrG 1968. German Federal Waterways Act (Bundeswasserstraßengesetz). Online: www.gesetze-im-internet.de.

[15] UVPG 2010. German Environmental Impact Analysis Act (Gesetz über die Umweltverträglichkeitsprüfung). Available online: www.gesetze-im-internet.de.

[16] BNatSchG 2013. German Nature Protection Act (Bundesnaturschutzgesetz). Available online: www.gesetze-im-internet.de.

[17] NatSchAG M-V 2010. Nature Protection Impolementation Act of the federal state of Mecklenburg-Vorpommern (Gesetz des Landes M-V zur Ausführung des Bundesnaturschutzgesetzes). Available online: www.landesrecht-mv.de.

[18] LWaG M-V 1992. Water Act of the federal state of Mecklenburg-Vorpommern (Wassergesetz des Landes M-V). Available online: www.landesrecht-mv.de.

[19] EC 1992. Flora Fauna Habitate Framework Directive (FFH) (92/43/EEC).

[20] EC 2009. Directive on the conservation of wild birds (2009/147/EC) [codified version of Bird Protection Directive (79/409/EEC)].

[21] EC 2000. The Water Framework Directive (2000/60/EC).

[22] EC 2008. The Marine Strategy Framework Directive (2008/56/EC).

[23] KrWG 2012. German Federal Recycling Management and Waste Law (Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen), Bundesministerium der Justiz, 45 pp. Available online: www.gesetze-im-internet.de.

[24] BImSchG 2013. German Federal Immission Control Act. Available online: www.gesetze-im-internet.de.

[25] BImSchV 2013. German Federal Immission Control Ordinance. Available online: www.gesetze-im-internet.de.

[26] BBodSchG 2012. German Federal Soil Protection Act. Available online: www.gesetze-im-internet.de.

[27] BauGB 2004. German Construction Act (Baugesetzbuch), BGBl. I S. 2414. Available online: www.gesetze-im-internet.de.

[28] LBauO M-V 2011. Construction Ordinance of the federal state of Mecklenburg-Vorpommern (Landesbauordnung M-V). Available online: www.landesrecht-mv.de.

[29] LUVPG M-V 2011. Environmental Impact Analysis Act of the federal state of Mecklenburg-Vorpommern (Gesetz über die Umweltverträglichkeitsprüfung in Mecklenburg-Vorpommern), GVOBl. M-V S. 885. Available online: www.landesrecht-mv.de.

[30] Polish Geological and Mining Law (Journal of Laws 11.163.981).

[31] Polish Water Law from 18 July 2001 (Journal of Laws 05.239.2019 with later amendments).

[32] Polish Waste Act of 14 December 2012 (Journal of Laws of 2013 item 21 with later amendments). The full text is published in Journal of Laws of 2013 items 1238 and 888 and in Journal of Laws of 2014 item 695.

[33] Polish Directive of the Ministry of Environment of 20 April 2007 on the technical requirements to be met by hydraulic structures and their location (Journal of Laws 07.86.579).

[34] Polish Act of 27 March 2003 on Spatial Planning and Development (Journal of Laws 03.80.717 with later amendments).

[35] Polish Building Law Act of 7 July 1994 (Journal of Laws 2000.106.1126 with subsequent amendments).

[36] Polish Environmental Protection Law Act of 2001 (Journal of Laws 01.62.627, as amended).

[37] Polish Nature Preservation Act (Journal of Laws 04.92.880 as amended).

[38] Polish Law of 30 April 2007 on the prevention of damages in the environment and their repairing (Journal of Laws 14.75.493).

[39] Polish Ministry Act of 15 November 2011 on the forms and methods of monitoring of superficial and underground waters (Journal of Laws 11.258.1550 and Journal of Laws of 2013 item 1558).

[40] Polish Ordinance of the Minister of the Environment (Ministry Act) of 21 March 2006 on the reuse or disposal of waste outside landfill installations (Journal of Laws 06.49.356).

[41] Projected Polish ordinance of the Minister of the Environment (Ministry Act) of 15 June 2014 on the reuse or disposal of waste outside landfill installations.

[42] Polish Ordinance of the Ministry of Environment on Soil Quality Standards (OSQS) of 9 September 2002 concerning the quality standards of for soil and ground (Journal of Laws 02.165.984).

[43] Projected Polish Ministry of Environment Act from 15 February 2014 on the estimation of contamination of the ground surface.

[44] Danish Order of Soil Moving (no. 1479 of 12/12/2007).

[45] Danish Environmental Protection Act. EP-Act (no. 879 of 26/06/2010).

[46] Danish Order of Reuse. Danish Order on the use of residues and soil for construction works and the use of sorted, uncontaminated construction and demolition waste (no. 1662 of 21/12/2010).

[47] Danish Order on the approval of a listed company (no. 669 of 18/06/2014).

[48] Zealand guidelines 2001. Frederiksberg Kommune, Frederiksborg Amt, Københavns Kommune, Københavns Amt, Roskilde Amt, Storstrøms Amt og Vestsjællands Amt (Eds.). Vejledning i håndtering af forurenet jord på Sjælland [Instructions for handling

contaminated soil on Zealand], 26 pp. Available online: www.regionsjaelland.dk.

[49] Danish Environmental Board of Appeal, decision on cases NMK-10-00087 and NMK-10-00308.

[50] Danish Environmental Board of Appeal, decision on case NMK-10-00346.

[51] Orbicon 2014. Report on the reuse possibilities of dredged materials in dike construction at the Danish Baltic Sea coast (Zealand). Available online: www.dredgdikes.eu.

[52] Danish Marine Environment Act (no. 963 of 03/07/2013).

[53] Danish Coastal Protection Act (no. 267 of 11/03/2009).

[54] Danish Act of Raw Materials (no. 657 of 27/05/2007).

[55] Danish Order on the use of residues and soil for construction works and the use of sorted, uncontaminated construction and demolition waste (no. 1662 of 21/12/2010).

[56] EC 2008. The Waste Framework Directive (2008/98/EC).

[57] EC 2006. EU Regulation 1907/2006 of 18 December 2006 concerning the registration, evaluation, authorisation and restriction of chemicals (REACH) and establishing a European Chemicals Agency.

[58] Polish ordinance of the Minister of Environment of 27 September 2001 on waste catalogue. (Journal of Laws 2001.112.1206).

[59] Polish ordinance of the Minister of the Environment of 19 December 2008 on the list of the types of waste that the waste holder may delegate to individuals or agencies who are not enterprises, and acceptable methods of reuse (Journal of Laws 2008.235.1614).

[60] EC 1967. EU Directive 67/548/EEC on classification, packaging and labelling of dangerous substances (EC Diary L 196 of 16.08.1967).

[61] EC 1999. EU Directive 1999/45/EC concerning the approximation of the laws, regulations and administrative provisions of the Member States relating to the classification, packaging and labelling of dangerous preparations (EC Diary L 200 of 30.07.1999).

[62] EC 2008. EU Directive 440/2008/EC of 30 May 2008, fixing test methods according to EU Directive 1907/2006 (REACH) (EC Diary L 142 of 31.05.2008).

[63] LAGA 1997. Technische Regeln der Länderarbeitsgemeinschaft Abfall – Anforderungen an die stoffliche Verwertung von mineralischen Abfällen, Teil IV (Aschen aus Kohlekraftwerken) [technical rules for ashes and slag from hard coal combustion power plants, combined heating and power plants, heating plants] (LAGA M20).

4. PLANNING AND DESIGN

This chapter contains recommendations for the planning and design of dikes with dredged materials (DMs), coal combustion products (CCPs) and geosynthetics. This includes the information/ inclusion of stakeholders in the planning process, the actual design process, information about subsoil and other boundary conditions on the construction site as well as the characterisation of the materials to be chosen for the construction.

The general design criteria for coastal and river dikes need to be considered. However, for the use of DM and CCPs special criteria apply additionally. The general design criteria are comprehensively documented in different national and European standards, regulations and recommendations. This chapter outlines only the most important issues and gives an overview of the topic. The particular focus of this chapter, however, lies on the peculiarities when designing with DMs and CCPs.

The application of geosynthetics in dikes is documented in a variety of standards and manuals. The focus of this guideline is to present the most important applications and the additional experience from the DredgDikes project.

4.1. Planning process

The planning process when recovering DMs or CCPs in dike construction is generally equal to the standard dike planning procedure. The main planning stages include the basic evaluation, preliminary planning (incl. cost estimation), basic design (incl. cost calculation), approval planning and (detailed) execution planning. However, some important tasks and parallel steps will have to be considered when recovering DMs and CCPs and summarized in the Table 4.1 below. This additional information particularly focuses on the early inclusion of the responsible permitting authorities and other stakeholders as well as recommendations about the necessary investigations, treatment steps, etc. to be performed with regard to the planning stages.

Most of the DM and CCP related questions have thus to be clarified during the basic evaluation and the preliminary design stage. This includes the pre-definition of the way on how to come to an individual case decision with the responsible authorities. Figure 4.1 and Figure 4.2 outline the possible options to come to an agreement when recovering DMs and CCPs in a dike construction.

Table 4.1. Planning process

Planning stages	Tasks to be considered when recovering DMs and CCPs
Basic evaluation	▪ Include permitting authorities, land owners, and other important stakeholders (see stakeholder tables) ▪ Choose possible treatment plants (or similar) to get material from ▪ Collect information about materials ▪ Collect information about protected areas (Natura 200, etc.) in the dike construction area ▪ Collect information about landownership (if applicable)
Preliminary planning / design	▪ Alternative plan evaluation, including the comparison between different materials ▪ Collect more information about materials ▪ Request the permitting authority, define the necessary frame of material testing and proof of qualities ▪ If needed (e.g. for DM not certified in the treatment facility): test materials according to national requirements ▪ Determine problematic issues, start necessary treatment (particularly dewatering) of materials early ▪ Determine the dike section and the ownership (if not yet known), inform owners about recovery plans ▪ Consider transportation of the materials (e.g. route through protected area with CCPs and DMs) ▪ Clarify interim storage depots ▪ Clarify important issues regarding the execution phase, such as issues that may directly influence (e.g. delay) the construction, the material delivery and construction technology (e.g. regarding the trafficability on the DM / CCP) ▪ Cost estimation including all material related points (treatment, transport, storage, installation, etc.) ▪ Define the necessary construction oriented accompanying planning, such as landscape conservation plan and environmental impact analysis
Basic design / design engineering	Here the preferred version is in focus, thus all issues regarding the materials (DMs, CCPs) have to be clarified before.
Approval planning	Submit request to the responsible authority based on the basic design version. The responsible permitting authorities are listed in the stakeholder tables.
Execution planning / detail planning	Here, the detailed requirements for the technology and the construction site will be specified for procurement and contracting.

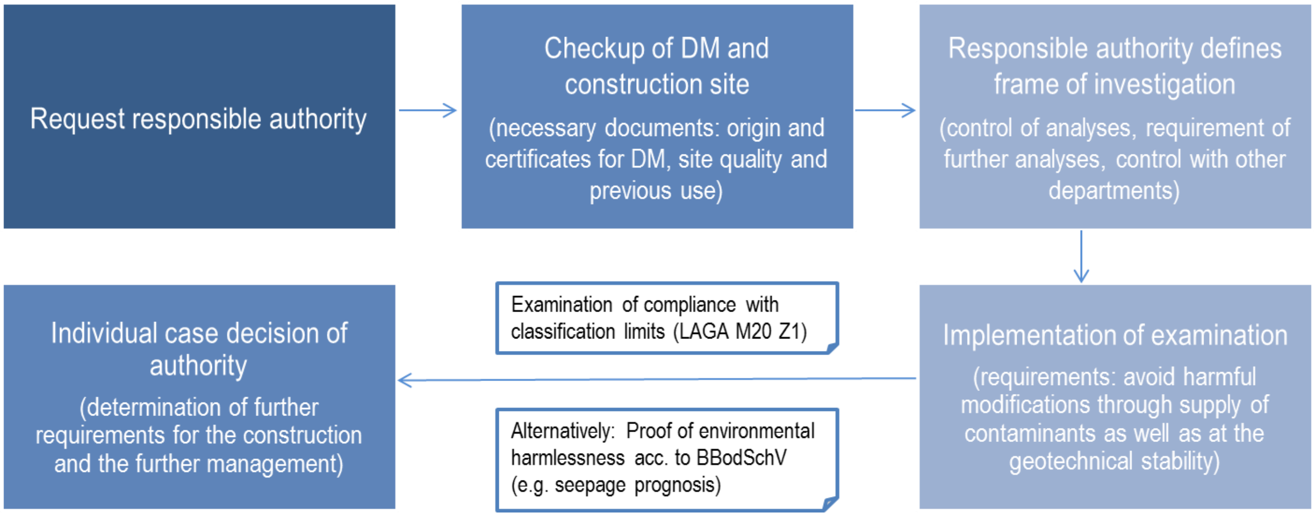


Figure 4.1. Flow chart how to receive the permit when DMs are used in dike construction in Mecklenburg-Vorpommern

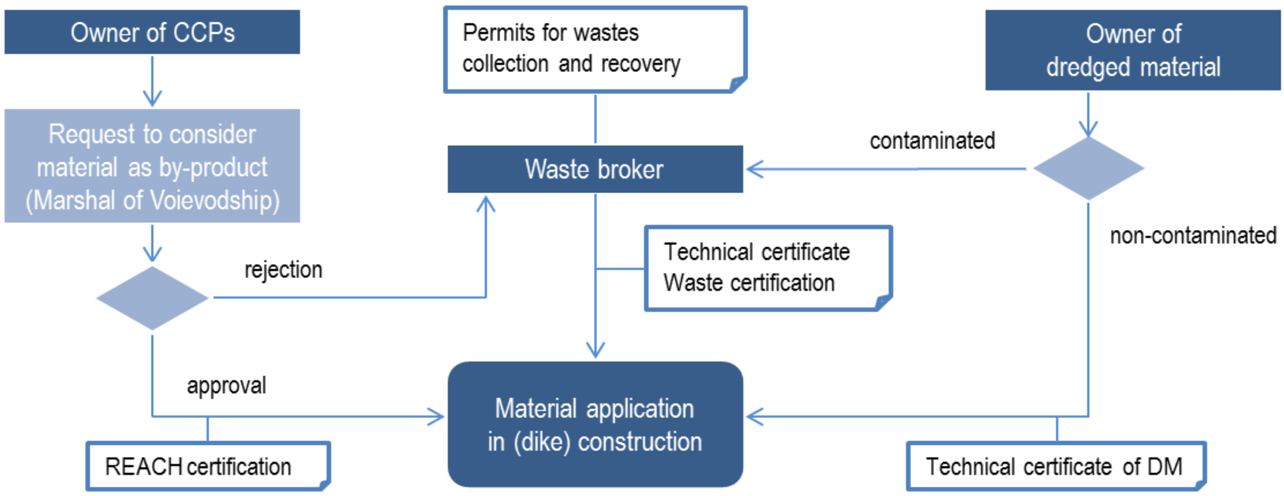


Figure 4.2. Flow chart how to recover CCPs and DMs in dike construction in Poland

4.2. Stakeholders

A variety of stakeholders should be informed and included in the decision making process from the beginning of a dike construction project in general and even more so if alternative materials such as DMs and CCPs are used. In the following Tables 4.2, 4.3 and 4.4 the most important stakeholders, such as permitting authorities, are listed. In addition, local solutions for material extraction, storage and transport are sometimes needed, which are controlled by the local administration. Other project stakeholders may be responsible for material extraction and handling or the design, construction, maintenance and monitoring of the constructions. The general public is always one of the most important stakeholder groups, particularly when planning flood protection structures and when recovering waste materials in construction. Finally, the concerned municipalities, the construction industry and research institutions should be involved in different stages to develop good recovery solutions.

Table 4.2. General stakeholders

Topic	Institution / stakeholder	Relevance/function in the planning process
All topics	General public	Concerned inhabitants
	Construction industry, dredging companies and local businesses	Dredging works, dike construction, experience, public-private partnerships, know-how
	Research institutions	Scientific experts

Table 4.3. German stakeholders (focus on Mecklenburg-Vorpommern)

Topic	Institution	Relevance/function in the planning process
Dike construction	BAW (Federal Waterways Engineering and Research Institute)	Federal expert and research institution for all waterways projects
	StÄLU (State Agencies for Agriculture and the Environment)	Permission of 1st order dikes
	Water and soil associations	Responsible for 2nd order dikes (e.g. agricultural dikes, etc.)
	Lower water agencies	Regulatory approval for water bodies and constructions 2nd order
Dredged Materials	StÄLU (State Agencies for Agriculture and the Environment)	Permission and expert authority for application of waste materials; soil conservation, water conservation
	Lower water agencies	regulatory approval for water bodies and constructions 2nd order Mecklenburg-Vorpommern inspection authority for water and soil associations (e.g. lower Warnow River and coast department)
	WSA (Water and shipping boards)	Responsible for the maintenance of navigable waterways Owners of DM containment facilities
	Hanseatic City of Rostock	Operates own DM treatment facility
CCPs	StÄLU (State Agencies for Agriculture and the Environment Central Mecklenburg), departments 4 and 5	Permission and expert authority for application of waste materials; soil conservation, water conservation
	Lower water agencies	Regulatory approval for water bodies and constructions 2nd order Mecklenburg-Vorpommern
	Coal combustion plants	Producers and owners of CCPs

Table 4.4. Polish stakeholders

Topic	Institution	Relevance/function in the planning process
Dike construction	Local Administration and Municipality	Permission authority for demand according to legislation
	Regional Water Management Authority	Authority for multicriterial process of legislation
	Regional Water Equipment Authority and Melioration Office	Strategies and planning of flood protection
	Regional Environmental Authority	Approval for environmental impact
Dredged Materials	Local Administration and Municipality	Permission authority for demand according to legislation
	Regional Water Management Authority	Owners of DM
	Regional Environmental Authority	Approval for environmental impact
CCPs	Local Administration and Municipality	Permission authority for demand according to legislation
	Polish CCPs Association	An advisory group of experts
	CHP plants and power plants	Producers and owners of CCPs

Table 4.5. Danish stakeholders

Topic	Institution	Relevance/function in the planning process
Dike con-structino	Danish Coastal Authority	Permission authority according to Coastal Protection Act
	Municipality	Part in the public hearing procedure
	Landowners	Applicant body
DM	Danish Nature Agency	Permission authority, regulation depends on the end-use of the sediment

4.3. Subsoil and construction site

4.3.1. Subsoil

The subsoil forms the foundation for the dike and the soil layering should be considered in the analysis of seepage, settlements and general stability. The dike has to be stable with regard to water forces and traffic and to keep its design height; this requires the load-bearing capacity. The hydraulic conductivity is another important quality of the dike base to mitigate underflow effects and to protect the ground when slightly contaminated materials are recovered replacing standard construction materials. A ground consisting of a thick and closed layer of cohesive soil is therefore beneficial. In addition, the underground needs to be sustainable to hydraulic and hydrodynamic stress. Thus, it is important to perform detailed soil investigations to get comprehensive information on:

- Soil layering including soft / organic deposits and coarse grain strata with respect to deformations and increased hydraulic conductivity,
- Physical soil parameters like density, water content, grain-size distribution, grain shape and mineralogy,
- Mechanical soil parameters estimated with field and subsequent laboratory tests, including strength, deformability and hydraulic conductivity and
- Additional requirements for environmental aspects (see below).

The extent of ground investigation is usually set by the following regulations and methods:

- **Germany**: DIN 4020 [1] or DIN 1054 [2] DIN ISO/TS 22476 [3] as well as requirements set by geotechnical experts hired for the project.
- **Poland**: Eurocode 7 [4] and the Ordinance on the determination of the geotechnical conditions of the foundation of structures [5].
- **Denmark**: DS/EN ISO 22476-1/AC:2013 [6].

The ground investigation should at least cover the area of the planned dike. Comprehensive geotechnical information should be prepared regarding the dike foreland, the dike base and the hinterland. Therefore, additional tests shall be performed here. The grid size for the investigation shall be adjusted according to the dike importance and the subsoil heterogeneity. An example for the soil investigation efforts in the different planning phases is provided in Annex I.

Since both the subsoil investigation and the subsoil requirements for dike constructions are generally independent of the earth materials used to construct the dike, the respective standard literature on dike construction should be consulted. Some additional information on subsoil is also provided in Annex I.

4.3.2. Required space on the construction site

On the construction site, space is needed for the actual construction works and for the job site installations. The job site installations may include considerable space for DM or CCP storage, handling, treatment, improvement, etc. The amount of space for DM is particularly dependent on the technology for homogenisation and drying and whether this is performed in a plant (e.g. on the treatment / containment facility) or in place (on the construction site).

4.3.3. Environmental aspects

Requirements to the construction site are particularly influenced by the quality of the building materials used. The usually low heavy metal and organic contaminations in DMs are relatively uncritical (Paragraph 2.1.3). Changing redox conditions, e.g. during installation (reduced when extracted, oxidised when put on storage heaps) or during flood events on the construction site, may unintentionally mobilise heavy metals in the stored materials, even if the contents of heavy metals are meeting the requirements for recovery in constructions. Therefore, the actual hydraulic and hydrological conditions on the building site may be of interest.

In marine and brackish DMs salt ions (chloride and sulphate) may be mobilised. These DMs should rather be used in a marine / coastal environment where the wash-out of salts will not negatively influence the subsoil and ground water.

In the project DredgDikes, no discharge of heavy metals or the limiting nutrients nitrogen and phosphorus could be detected in the leachate analyses during the first two years after construction, although there were permanent wet-dry phases during the field tests. Both clay particles and organic matter possess high sorption capacities to bind and stabilise heavy metals. Still, in changing redox conditions monitoring may be needed.

Composite soils based on CCPs should be investigated with regard to heavy metal leaching. It is important to understand that the problem is not the quantity of heavy metals in the solids, but in the eluate (comparable to fine-grained DMs). Numerous researchers showed that a matrix built using CCPs has binding properties regarding heavy metal particles in alkaline conditions [7]. In particular cases it is advisable to add small quantities of lime (1-3 %) to keep the alkalinity in a safe margin to bind heavy metal particles. The most appropriate procedure of eluate investigation is described in the German standard DIN 38414-4 [8]. In Poland, PN-EN 12457-4:2006 [9] should be used.

For the protection of soil and groundwater from possible leakages from stored and installed materials, the construction site / subsoil has to be checked for:

- Vertical distance of the storage place to the groundwater,
- Horizontal distance to nature reserves (protected areas),
- Hydraulic conductivity of the underground (the lower the better),
- Leachate prognosis (e.g. according to [10]),
- Horizontal distance to the coastline/ the receiving water.

In addition, a seepage prognosis should be performed regarding both the temporarily stored and the installed recovered materials.

Depending on the contamination level of the building materials, the above requirements may apply to the construction base and to areas where the construction materials are temporarily stored (e.g. regarding slightly contaminated DMs or CCPs that will have to be encapsulated between other (clean) earth materials in the actual dike construction).

4.4. General selection criteria for dike construction materials

In a dike construction project, usually considerable earth masses are involved. Therefore, the selection, characterisation and availability of materials represent the most important factors for the construction. In this guideline, particular focus is given to the availability of DMs and CCPs and the procedures to choose a suitable dike construction material. While the general selection criteria such as availability, economic issues and basic environmental issues are compiled in this paragraph, the actual environmental and geotechnical classification criteria for the final selection is discussed in the following paragraphs on the characterisation of DMs and CCPs.

4.4.1. How to select dredged materials

4.4.1.1. Availability

Generally, there are three different possibilities of DM availability:

(1) The sediment on the river bed or sea floor is immediately available during dredging works. However, this DM is inevitably wet. Basically only sand may be directly placed after dredging. The hydraulic filling of a sand core is even a standard technology in coastal dike construction [11]. But there are also ideas to use fine-grained DMs rich in organic matter directly in embankment construction by improving the materials using additives inside the dredging pipeline or in a mobile plant on the construction site.

(2) Often DMs are stored in containment facilities over a long period of time without further processing (drying, homogenisation, etc.). These DMs can be described as raw and wet materials. Depending on the dredging technology, more or less water is added during the dredging operation and thus the actual water contents of the materials in containment facilities vary considerably. However, due to the generally high water contents in the materials further treatment will be needed.

(3) There are also containment and treatment facilities such as the municipal DM treatment plant of Rostock [12] and similar plants in Bremen and Hamburg, in which the DMs are dried, processed and stored to produce certain material qualities. The water contents of fine-grained DMs rich in organic matter may still be high compared to usual soils and also on the wet side of the materials' optimum water contents, however, much lower than that of the freshly dredged or untreated stored materials.

DMs may be available from permanent maintenance works, such as those performed by the water and shipping authorities (e.g. Water and Navigation Board WSA in M-V), and from other hydraulic construction works (directly available from the client, the contractor or from a treatment facility they deliver the DMs to).

4.4.1.2. Economic aspects

When DMs are recovered, the economic viability plays an important role. Practical experience in Rostock has shown that the treatment of DMs to gain a material that can be recovered as replacement material in different agricultural and geotechnical applications can be performed at comparably low cost. As an example Table 4.6 shows the costs for the DM management in Rostock.

The fee for pumping DM into the treatment facility IAA covers the treatment costs and part of the transport. The materials are "sold" for a total of 2.50 €/m³ including the transport to a distance of up to 40 km from the plant. This enables the beneficial use of the treated DM, however, it refers to relatively clean materials only. For these materials the transportation cost is a major factor, particularly because in dike construction often very large amounts of earth materials are needed.

The distance from the construction site to the storage place of the available material is a limiting factor and has already led to the exclusion of DMs in dike construction projects [14]. Transportation distance is not only a monetary but also an environmental issue. However, if the dike construction site is close to a DM treatment facility, the material costs may be kept at a very low level. This also implies that more containment facilities should treat and process their materials to make them available for recovery in the proximity of potential construction sites.

For materials with higher contamination levels the transportation distance may play a less important role, because disposal of contaminated materials, e.g. in a landfill, is usually very costly and long travel distances may

Table 4.6. Example of treatment costs per m³ ripened DM in a treatment facility for clean DM (2014) [13]

Position	Description	€/m³
Fee for DM to be pumped into the IAA	Treatment (polder clearance and building material heaps)	2.40
	Transport/delivery (until 40 km to end-user incl. proceeds from selling the material)	4.30
	Management of treatment facility (staff costs, certification, repair services, maintenance, research & development, marketing)	2.00
Net Sum (excl. VAT etc.)		**8.70**

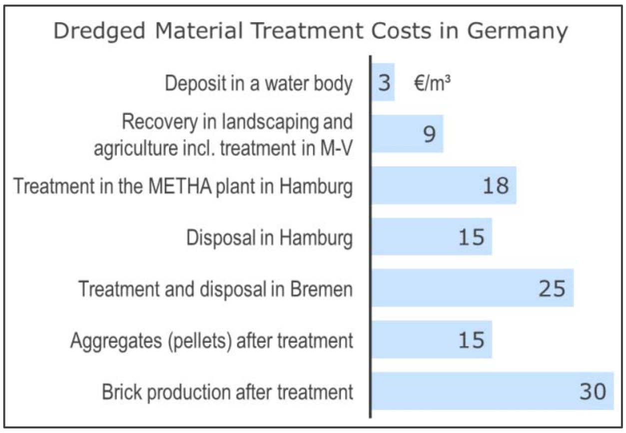


Figure 4.3. Approximate costs for DM treatment in €/m³ (2006) [14]

have to be considered in DM disposal projects. In addition, treatment and processing usually generate higher costs and since the materials permanently accrue, the recovery is the best option, if the contamination level will allow it.

There are different possibilities to recover DMs, the costs of which should be compared to the application in a dike construction. A selection of costs for DM treatment is compiled in Figure 4.3

4.4.1.3. Environmental aspects

The DMs available from Rostock are all comparably clean, meeting the classification limits of §12 BBodSchV [10] resp. LAGA Z0 and Z1 [15] with the exception of total organic carbon (TOC), conductivity and salt ions. Since the organic matter is highly stable (Paragraph 4.5.1) and eutrophication problems through eluates can basically be excluded, the salt content is the only critical parameter here.

Since the Rostock materials are usually dredged from brackish waters, the high salt contents are the standard condition. Since salts are easily soluble, an application in a geotechnical construction is usually only possible on a ground which is invulnerable against these salts, usually in proximity to the coast where the ground water is directly influenced by the sea water. This example shows how materials may be chosen with regard to their composition, availability and building site.

In many dredging projects, there are fine-grained DMs with slightly higher contamination levels, while often only individual values exceed the regional or national classification limits for the recovery of wastes. This issue is discussed in Paragraph 4.5.

4.4.2. How to select CCPs

The selection of CCPs for a project should be based on the availability of local materials for a construction and detailed geotechnical laboratory analysis. Usually, CCPs are only applied in hydraulic constructions in mixtures with other granular materials such as (dredged) sand for different reasons (Paragraph 4.6.2). Therefore, not only the materials themselves but also the mixtures need to be investigated to find an optimal composite material.

4.4.2.1. Availability

The main source of CCPs are coal-fired power plants and closed ash disposals. In Poland there is a dense "mesh" of closed coal ash disposals as a remnant of decades of coal-based energetics. It is a safe assumption that in Poland one may find either a coal-fired power plant selling CCPs as a by-product or an ash-disposal site as a source of CCPs in an average distance no larger than 50-70 km. A third possibility is to purchase a certified coal-ash product from a specialized and certified company. Choosing one of these sources is closely connected with the amount of evaluation and treatment needed before application.

4.4.2.2. Economic aspects

In general the application of CCPs in dike construction is closely related to economic aspects. The different sources of CCP availability (Paragraph 4.4.2.1) can be rated economically as follows:

- CCPs from a closed ash-disposal are often the least costly solution, however, the longest legal path to gain a building permit among the three options an extensive and time consuming evaluation and possibly also treatment before application.
- When CCPs are directly purchased from a power plant, the direct costs are higher, while there is usually a chemical analysis provided and no additional treatment may be needed. In addition, the legal path to receive a building permission is less time consuming.
- When CCPs are purchased as a ready-to-use product from a certified company or waste broker, the products themselves may be costly; however, they are already certified products. This may be of particular advantage when the CCPs are used as additives to treat DMs, where smaller amounts are needed compared to a dike built mainly from CCPs.

4.4.2.3. Environmental aspects

The environmental aspects of CCPs are mainly related to their chemical composition and heavy metal contents, the details are given in Paragraphs 2.2 and 3.2.

4.5. Selection and characterisation of dredged material

Dredged materials are usually characterised prior to the dredging works using underwater sampling techniques and laboratory tests. These tests are mandatory regardless of what subsequently happens to them [16], [17]. These analyses include the geochemical analysis and a basic soil analysis, such as grain-size distribution, organic and lime content; however, they are not sufficient to determine the option of DM recovery in dike construction. Therefore the pre-characterisation is not issued in this guideline while part of the discussion on the characterisation of the treated materials, such as the determination of the grain-size distribution or the organic matter content, also generally applies here.

The characterisation of DMs to be recovered in dike construction can be divided into the environmental/ geochemical analysis with respect to environmental regulations, and the geotechnical analysis, necessary to evaluate the stability and installation characteristics of the materials. However, some parameters need to be covered in both subjects since they are either intimately connected with other parameters or the recommended analysis methods depend on certain characteristics.

4.5.1. Environmental characterisation

For the environmental characterisation of DM, potential contaminations in the material are of major importance. The composition of the materials should adhere to the specifications of the national and regional requirements on soil contaminations which are defined below.

For DM treatment plants it is of advantage if they include the environmental analysis in their quality management system. This ensures that the analysis is always performed in the same way and all treated material can be certified according to a consistent analysis programme.

4.5.1.1. Environmental characterisation in Germany

In Germany, the environmental characterisation for soil materials to be recovered follows two regulations, depending on the actual type of use. If a soil is installed in the rooting zone (down to ca. 30 cm below the surface) the Soil Conservation Ordinance (§12 BBodSchV) [10] applies, while for the installation in a technical construction underneath the rooting layer the recommendations of LAGA M20 [15] can be applied to prove the environmental harmlessness (which again links to BBodSchV regarding the rooting zone). However, there is no officially binding document available for fine-grained DMs which are rich in organic content to be recovered in technical constructions, particularly because LAGA M20 is restricted to soils with a total organic carbon (TOC) content below 5 % and with less than 10 % fines. In spite of this fact, DM to be recovered in technical constructions (such as dikes) should be characterised following LAGA M20 until a binding document will be available, and where legally necessary, BBodSchV shall be applied. Alternatively, the environmental harmlessness of the DM may be proven based on an individual expert opinion, e.g. with a seepage prognosis after BBodSchV.

In Mecklenburg-Vorpommern a general agreement has been established together with the Ministry for Economy, Construction and Tourism/ Department Waste Management and the State Agency for Agriculture and the Environment (StALU M-M), Departments Soil & Water and Coastal Engineering to proceed in this way when using DMs in dike construction (Chapter 3).

For the vegetation rooting horizon, the classification limits and the additional notes of §12 BBodSchV [10] apply and the materials should keep the limits of Annex 2, BBodSchV.

For an open application of DMs in a technical construction, the classification limits according to LAGA M20 with the assignment criteria Z0 or Z1 are recommended to be used, while the Z0 criteria are basically equal to those for loamy soils in BBodSchV.

The sampling as well as the storage and treatment of the samples have to follow the recommendations for laboratory tests in BBodSchV and LAGA M20.

Additional laboratory analyses may be necessary if there is a specific suspicion (e.g. with respect to the origin of the DM). Here, a query at the responsible authority may be needed and evaluation limits need to be defined.

The recommended process for an environmental investigation of DMs to be recovered in dike construction as recommended in this guideline is shown in Figure 4.4.

In Table 4.7 the minimum environmental classification limits are composed which are recommended to be analysed at first. However, there is no requirement to analyse eluates when a DM is classified as Z0 material or according to BBodSchV.

The TOC content in the fine-grained DMs often exceeds the maximum values of the LAGA classification (while there is no limit in BBodSchV), the allowed mineral fines fraction is often exceeded and in marine and brackish sediments the salt contents are often high. Therefore, an individual case decision of the responsible authority is needed (Chapter 3). Therefore, it is not included in Table 4.7. However, as a parameter to describe the organic matter content, the TOC according to ISO 10694 [18] should always be determined in the frame of the environmental analysis; it may be used as an indicator for different chemical processes in the soils. The organic matter / humus content OM may be approximated using the following formula: OM = 1.724 TOC.

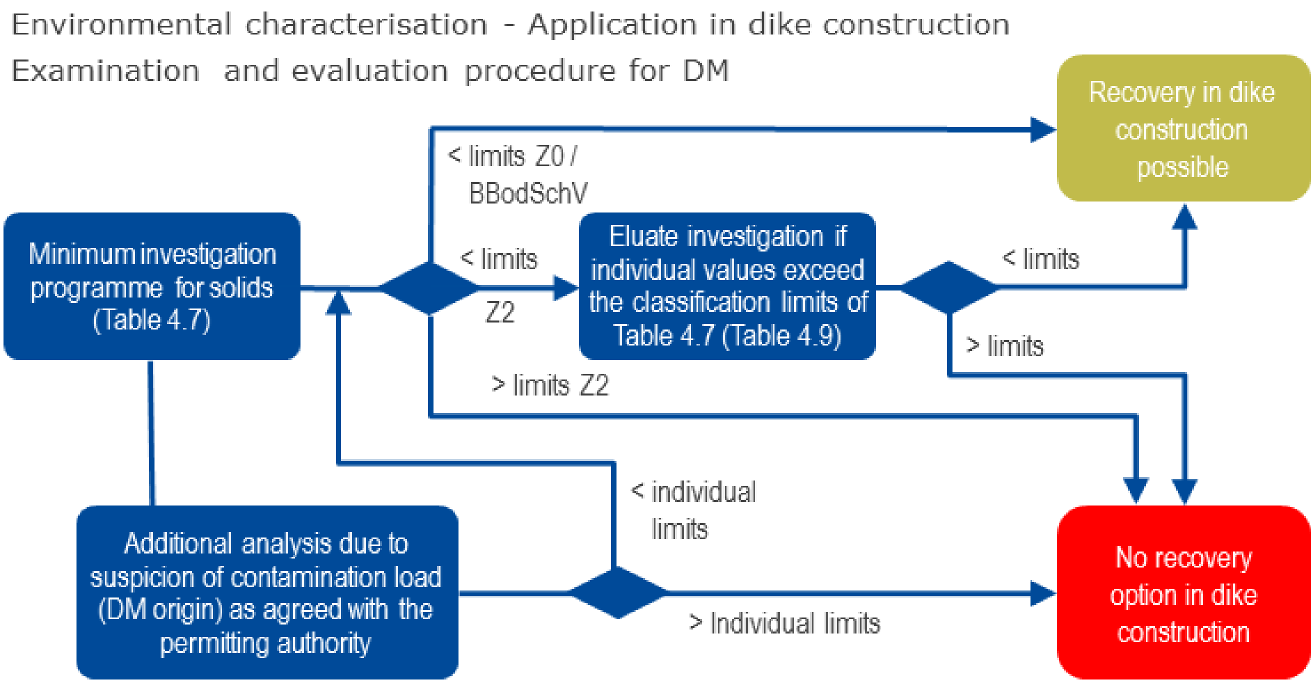


Figure 4.4. Recommended procedure for planning laboratory tests to evaluate the environmental characterisation for DM recovery, German example

Table 4.7. Minimum investigation programme and classification limits for loamy DM in soil-like applications in Germany [10], [15]

Parameters	unit	BBodSchV	LAGA (Z0)
Lead	mg/kg dry solids	70	70
Cadmium		1	1
Chromium		60	60
Copper		40	40
Nickel		50	50
Mercury		0.5	0.5
Zinc		150	150
Arsenic			15
Hydrocarbon			100
PAH		3.0	3.0
PCB		0.05	0.05
EOX			1

For the geochemical analysis according to BBodSchV, a basic soil classification (at least grain-size analysis) is needed, since the classification limits depend on the type of soil. Therefore, reliable information about the actual fine fraction in a DM is needed. For DM rich in organic matter and lime content, a method has to be chosen with which the fine fraction and particularly the clay fraction (< 0.002 mm) can be determined more realistically than with a standard wet sieving and sedimentation analysis (e.g. DIN 18123 [19]). One suitable method is described in ISO 11277 [20]. More details are provided in Paragraph 4.5.2 on geotechnical testing.

In Table 4.8 the recommended classification limits for the possible open (Z1) or encapsulated (Z2) installation of soils in technical constructions according to LAGA M20 are presented. The LAGA classification limits listed in Table 4.7 and Table 4.8 give guidance for the evaluation of the solid dredged material and they are also recommended in the frame of this guideline (with the exception of TOC and salt ions), although LAGA M20 is no binding legal document in the meaning of a regulation.

If individual parameters determined in the solids are increased, the eluates can provide more clarity about the actual availability or mobility of the contained substances. In case of suspicions, the responsible authority can again claim additional analyses (cf. above). Additional analyses may also be necessary if the in-situ investigations show individual high contamination values (e.g. TBT).

Table 4.8. Classification limits for soils to be installed in technical constructions in Germany after LAGA M20 – dry solids [15]

Parameters	unit	LAGA (Z1)	LAGA (Z2)
Arsenic	mg/kg dry solids	45	150
Lead		210	700
Cadmium		3	10
Chromium		180	600
Copper		120	400
Nickel		150	500
Thallium		2.1	7
Mercury		1.5	5
Zinc		450	1,500
Cyanide		3	10
EOX		3 1)	10
Hydrocarbons		300 (600) 2)	1,000 (2,000) 2)
BTX		1	1
VHH		1	1
PCB_6		0.15	0.5
PAH_{16}		3 (9) 3)	30
Benzo(a)pyrene		0.9	3

1) check the cause if exceeded
2) classification limits for hydrocarbons with chain length of C_{10} to C_{22}. Limit in brackets: total value (C_{10}-C_{40}) according to E DIN EN 14039
3) soil material with classification limit > 3 mg/kg and ≤ 9 mg/kg should only be applied in areas with hydraulically favourable conditions

Table 4.9. Classification limits for the eluate of soils to be installed in technical constructions in Germany after LAGA M20 [15]

Parameters	Unit	Z1.1	Z1.2	Z2
pH	-	6.5-9.5	6-12	5.5-12
Cyanide	µg/L	5	10	20
Arsenic		14	20	60
Lead		40	80	200
Cadmium		1.5	3	6
Chromium		12.5	25	60
Copper		20	60	100
Nickel		15	20	70
Mercury		< 0.5	1	2
Zinc		150	200	600
Phenole index		20	40	100

For dike construction, the eluate quality is important because there is usually seepage water involved that could mobilise contaminants. Materials meeting the classification limits Z0 and Z1.1 are uncritical for recovery. If these values are exceeded, an individual proof of environmental harmlessness, e.g. using a seepage prognosis according to BBodSchV may still allow the fine-grained DMs with often high sorption capacities to be recovered in a dike construction without an elaborate encapsulation. The classification limits for eluates according to LAGA M20 are given in Table 4.9.

4.5.1.2. Environmental characterisation in Poland

In Poland, the geochemical characterisation of DM should be performed according to the projected Law from 15 July 2014 [21]. The upper limits of contamination with heavy metals and organic compounds for DM to be recovered are given in Table 4.10. The number of samples to be taken is related to the volume of DM:

- up to 25,000 m^3 of DM: 3 sampling points,
- up to 100,000 m^3 of DM: 4-6 sampling points,
- up to 500,000 m^3 of DM: 7-15 sampling points,
- up to 2,000,000 m^3 of DM: 16-30 sampling points,
- more than 2 mill. m^3 of DM: 10 sampling points for each 1 mill. m^3 of DM.

4.5.1.3. Environmental characterisation in Denmark

In Zealand, Denmark, the Zealand Guidelines [23] contain information on the classification of soils / DMs and classification limits for contaminants. In addition, the Danish Order of Reuse [24] provides classification limits. Category 1 materials can be applied in geotechnical projects in general. In Table 4.11 the classification limits for the contamination categories 1 (after [23] or [24]) and for “slightly contaminated” materials according to [22] are listed. This list also stands for the minimum investigation programme for DMs in Denmark.

4.5.1.4. Environmental recommendations regarding humus stability and suitability for vegetation

Sometimes, environmental authorities are concerned about high humus contents in the substrates, because they are concerned that the organic matter may gradually decompose. To prove the stability of the organic matter (often mainly humic substances) and therefore the safety with regard to the eutrophication risk, a so-called breathability test (AT_4 test) is recommended. This test is also required in Germany for the deposition of wastes [25] and has already been applied when DMs were recovered in the recultivation layers of landfills. The recommended limit value is 5 mg/g dry solids.

Table 4.10. Classification limits for heavy metals and organic compounds in dry solids for soils to be installed in technical constructions in Poland after [21]

Parameters	Unit	Max. contamination level
Arsenic	mg/kg dry solids	30
Lead		200
Cadmium		7,5
Chromium		200
Copper		150
Nickel		75
Mercury		1
Zinc		1000
WWA		
Benzo(a)antracen		1,5
Benzo(b)fluoranten		1,5
Benzo(k)fluoranten		1,5
Benzo(ghi)perylen		1,0
Benzo(a)piren		1,0
Dibenzo(a,h)antracen		1,0
Indeno(1,2,3-c,d)Iren		1,0
PCB[1]		0,3

1) Sum of PCB 28, 52, 101, 118, 138, 153 and 180

Table 4.11. Classification limits of clean and slightly contaminated soils in Denmark

Parameters	Slightly contamin.[1)]	Zealand [2)] category 1	Category 1[3)] non-cont.
	mg/kg dry solids	mg/kg dry solids	mg/kg dry solids
Arsenic	≤20	20	0-20
Cadmium	0.5-5	0.5	0-0.5
Chromium	500-1,000	500	0-500
Copper	500-1,000	500	0-500
Mercury	1-3	1	0-1
Nickel	≤30	30	0-30
Lead	40-400	40	0-40
Zinc	500-1,000	500	0-500
TBT	2.44	n/a	n/a
PAH	4-40	n/a	n/a
Benzo(a)pyrene	0.3-3	0.1	n/a
Dibenz(a,h)antracene	0.3-3	0.1	n/a
Naphthalene	n/a	0.5	n/a

[1)] Danish Order on the definition of slightly contaminated soil [22]; [2)] Zealand Guidelines [23]; [3)] Danish Order of Reuse [24]

The investigation of DM should also take care of the high nutrient and salt contents in some of the materials. The knowledge of the parameters chloride, sulphate, sodium as well as potassium and magnesium give information of possible discharge amounts and may influence the decision of an application near subjects of protection. The nutrients phosphor and nitrogen will not discharge in critical amounts documented by experiments [26]. Recommendations for maximum nutrients (e.g. Na, Cl, N, P) in the seepage are given for instance in the German Soil Conservation Ordinance [10].

Apart from the standard chemical analysis, a germination test is recommended to evaluate the germination capacity of the investigated and chosen material prior to application. Since there is no standardised test, the evaluation of a good germination quality should be performed, e.g. on the DM heaps before choosing the materials for construction. It should be considered, that the heaps / storage piles may not be as well compacted as the dike surface. Therefore, the germination test area should be compacted before performing the test. Alternatively, a lab / glass-house test may be performed on at least 3 samples, considering compaction and the planned surface preparation. Recommendations about the seeding and vegetation establishment are included in Chapter 5.

4.5.2. Geotechnical characterisation of DM

During the planning phase, the required characteristics of the construction materials may be defined in accordance with the planned section. Conversely, if locally available materials (such as marsh clay or marl) or DMs shall be used, the section may have to be designed taking into account the available material qualities. Usually, the DMs need to be characterised regarding their geotechnical properties prior to or at the beginning of the planning phase, following the minimum testing programme recommended in this guideline.

Regarding the material availability and the intention to use specific DM to build a dike, two main strategies may influence the investigation:

(1) In case of a general intention to use DMs among other materials, required limit values for the properties need to be defined in the planning and procurement documents. Then, the contractor needs to choose a material meeting these requirements. If he decides in favour of DMs, the contractor will have to provide the full geotechnical characterisation.

(2) In case of a definite decision (e.g. by the municipality or the responsible authority) to use DMs in a dike construction project, the full geotechnical characterisation should be known at the beginning of the planning phase so that the sections may include the respective material qualities to full extent. Then, the client will have to contract the geotechnical analysis separately or demand it from the owner of the DM to choose suitable batches for the construction.

All soil materials used for dike construction require certain minimal qualities. For standard dike construction materials, including dredged sand, the quality requirements are defined in the respective design guidelines and standards for sea and river dikes (Chapter 2). For fine-grained DMs and DMs rich in organic and/or lime content recommendations for classification limits as well as extent and peculiarities of the analyses are presented in the following. The most important characteristic parameters are also used as quality control parameters (they are also discussed in Chapter 5).

When DMs are planned to be used in dike construction, they may either already be treated or they may need treatment before they can be used. The following recommendations are valid for treated materials (in Rostock, this mainly refers to classification and ripening). However, for raw/ fresh materials which are basically untreated (e.g. in containment polders), the quality after treatment will have to meet the same criteria. Then, a suitable way to prove the material quality after treatment has to be defined between the client and the DM owner.

The extent of the laboratory tests is presented and recommendations on how to perform the tests are given. In addition, information is provided about tests that may not deliver reliable results.

4.5.2.1. Standard laboratory testing programme for the geotechnical characterisation of DMs

The standard laboratory programme for the geotechnical characterisation of DMs should at least consist of the tests compiled in Table 4.12. The list includes standard tests to describe the DMs regarding their geotechnical behaviour with respect to dike construction.

Table 4.12. Geotechnical parameters to be determined for DMs used in dike construction – minimum required testing programme

Parameters	Standards	
	Germany	Poland
Granulometry [1)]	ISO 11277 & DIN 18123	ISO 11277 & ISO/TS 17892-4
TOC	DIN 18128	PN-B-04481:1988
Carbonate content	DIN 18129	PN EN ISO 14688-1
Liquid limit LL	DIN 18122-1 or ISO/TS 17892-12	ISO/TS 17892-12
Plastic limit PL	DIN 18122-1 or ISO/TS 17892-12	ISO/TS 17892-12
Shrinkage limit SL	DIN 18122-2	ISO/TS 17892-12
Plasticity index PI	DIN 18122-1	ISO/TS 17892-12
Liquidity index LI	DIN 18122-1	ISO/TS 17892-12
Volumentric shrinkage rate Vs	Paragraph 4.5.2.4	
Undrained shear strength $c_{u,r}$ (w_{nat}) [3)]	DIN 4094-4 [2)] DIN 18137	PN EN 1997-2
Water permeability k_s	DIN 18130-1	ISO/TS 17892-11
Additional parameters if needed		
Friction angle φ	DIN 18137	ISO/TS 17892-10
Cohesion c	DIN 18137	ISO/TS 17892-10
Elastic moduli E	DIN 18135	ISO/TS 17892-5

[1)] Both with and without the removal of organic matter. Alternative methods to remove the organic matter may be considered.
[2)] In the pre-investigation the lab vane shear test should be used for ripened materials based on this standard. For pre-determination of in-situ quality of untreated materials the field vane shear test applies.
[3)] $c_{u,r}$ as determined on samples with natural water content w_{nat}. Sample preparation in the Proctor device with standard Proctor energy. The test can also be used to determine the water content for which a recommended c_u can be reached.

4.5.2.2. Pre-testing and certification

A pre-test during the basic evaluation phase as well as the quality certification in the treatment plant should include the granulometry, TOC (total organic carbon), carbonates, water content and Atterberg limits. With these parameters, promising material batches may be chosen for further analysis.

4.5.2.3. Untreated materials

For untreated materials, the sample should be dried before performing the geotechnical analysis. Therefore it has to be estimated to which water content the materials may be dried during the ripening process (e.g. the soil hydrological equilibrium) and how long this may take. Ripening may also include soil genesis processes, which have to be neglected.

4.5.2.4. Recommended geotechnical limit values for DMs used as cover layer in sea dikes

The limit values that should be met for DMs used as cover layer in sea dikes are summarised in Table 4.13. They are based on the investigations in the DredgDikes project. Soils with a medium to high plasticity are considered suitable if some additional parameters are also met, such as a low to medium shrinkage rate and a certain TOC value. The plasticity is estimated to be more reliable than the grain-size analysis and it describes the characteristics of a soil as a whole, including its erosion stability (plastic soils are usually more erosion resistant than non-plastic soils; this complies with a larger fraction of fines or organic matter). The grain-size distribution of DMs rich in organic matter and lime content is often difficult to determine (see below) and therefore, classification limits should not be based on this analysis (which may lead to the exclusion of an actually suitable material). However, it is a standard parameter to be determined and the geotechnical expert will also use this information to judge the material quality.

The grain-size dependent evaluation of suitable DMs for dike cover layers provided in EAK 2002 [11] is not recommended for different reasons:

- A sand fraction > 40 % (which is the upper limit in [11]) improves the stability and cracking resistance. However, a reliable maximum value was not determined in the DredgDikes project.
- The grain-size analysis is difficult: without removing organic matter OM and carbonates; the required clay fraction can often not be determined, even if contained. The removal of OM and carbonates, however, considerably changes the soil characteristics, and in case of the chemical sample preparation, the mineral particles may be influenced.
- It has not been defined how the evaluation of a sample should be performed, since the required clay fraction is only considered for the mineral fraction in the sample. In case of 20 % OM and 10 % carbonates, 30 % of the sample is non-mineral and a value of 15 % of clay in the mineral fraction compares to only ca. 10 % in the total sample. Thus it would very much depend on the determination method whether the criteria of EAK are met or not.

The organic matter in a DM is usually very stable (cf. above) and thus the mechanical behaviour of the DM should not change much with regard to this parameter. Therefore, the shear strength and plasticity (incl. information about erosion resistance) is considered more reliable in this context.

The total organic carbon (TOC) should be less than 9 % to reduce irreversible shrinkage effects. Information on the determination of the characteristic parameters is provided in Paragraph 4.5.2.9.

Table 4.13. Geotechnical selection criteria for DM used as sea dike cover material (Baltic Sea dikes)

Parameters	Unit	Limit
TOC	%	≤ 9 [1)]
Plasticity index PI	%	≥ 15 [2)]
Liquidity index LI	-	≤ 0.3 [3)]
Undrained shear strength $c_{u,r}$	kPa	≥ 50 [4)]
Volumetric shrinkage rate Vs	%	class 1 - 2 Table 4.14

[1)] Higher values should be subject to individual case decision. Then, the AT4 test (cf. above) should be mandatory and Vs should be strictly below 40 %. Installation water content should be close to the optimum (w_{opt}) to allow a high Degree of Compaction.
[2)] At least medium plasticity. Provides information on soil types in the plasticity diagram: TM, TA, TL, OM, UM, UA, OT, UA.
[3)] Installation water content slightly above PL, preferably semi-solid state.
[4)] As determined with a vane shear tester in a sample with LI ≤ 0.3 or to define the minimum installation water content.

Table 4.14. Shrinkage classification - volumetric shrinkage rate Vs for DM used as sea dike cover material (Baltic Sea dikes)

Shrinkage class	Vs [%]	Comment
1 (low)	≤ 20	low cracking tendency
2 (medium)	21 - 40	medium cracking tendency (unproblematic for sea dike covers at the Baltic Sea)
3 (high)	> 40	high cracking tendency (problematic particularly with high natural water content, requires monitoring and/or additional actions)

During installation, the undrained shear strength should be c_{fu} ≥ 50 kPa (as determined with a vane shear tester), which is also a quality control parameter. Therefore, this value should be achieved in the characterising laboratory tests using samples of achievable field compaction.

The volumetric shrinkage rate is a good measure of the tendency of a soil to crack when it dries. In spite of the generally good experiences with cracked materials, a classification regarding the shrinkage rate proved to be useful (Table 4.14). The volumetric shrinkage rate is defined as follows (equation 1):

$$Vs = \frac{Vi - Ve}{\mathrm{Vi}} \times 100 \qquad (1)$$

With Vs = shrinkage rate [%], Vi = initial sample volume, Ve = sample volume at the end of the test

In the DredgDikes investigations regarding the flow through the dike sections and the (mostly stationary) overflowing tests no stability problems were observed with the materials that showed considerable desiccation cracking during the first summer. There was no erosion related to cracks and the crack flanks proved to be stable, since the seepage water did not contain sediment. Even in the sections where the cover layer was saturated very quickly due to the many fissures, no loss of stability could be observed. The grass cover is very well established and extremely stable and the roots strongly reinforce at least the upper 20 cm. Field vane shear tests directly after the drawdown of the water inside the test dike polders showed high strength values of c_{fu} ≥ 60 kPa in a depth of 20 cm and increasing with additional depth. In addition, the materials did not show a considerable loss in strength during in-situ saturation. Thus, the cracking is judged to play a less important role for Baltic Sea dikes made of DM rich in organic content than originally feared. This judgment is made without having investigated the influence of transient overflowing conditions and hydraulic shock from breaking waves. However, according to Führböter [27] the stability of a sea dike cover against hydraulic shock can be estimated with regard to the undrained shear strength c_u. For a significant wave height of Hs = 1.50 m (a common design value for Mecklenburg-Vorpommern) a c_u ≥ 60 kPa would be needed for a dike with a slope inclination of 1V:3H. This limit can be achieved and was usually exceeded by the DMs investigated, even when fully saturated. For flatter embankments (usual water side inclination of a Baltic Sea dike embankment is 1:3 - 1:6) the required c_u is even lower.

Table 4.15. Geotechnical selection criteria for DM used as supporting body or in a homogenous dike section (Baltic Sea and river dikes)

Parameters	Unit	Limit
TOC	%	≤ 6
Plasticity index PI (homogenous)	%	≥ 10
Plasticity index PI (supp. body)	%	≤ 30
Liquidity index LI	-	≤ 0,1*
Volumentric shrinkage rate Vs	%	≤ 20 (40)
Undrained shear strength $c_{u,r}$	kPa	≥ 50

* Installation water content only slightly above PL, semi-solid state

Table 4.16. Geotechnical selection criteria for DM used as mineral sealing in river dikes

Parameters	Unit	Limit
TOC	%	≤ 3
Plasticity index PI	%	≥ 15*
Liquidity index LI	-	≤ 0,0**
Volumentric shrinkage rate Vs	%	≤ 10
Undrained shear strength $c_{u,r}$	kPa	≥ 50
Hydraulic conductivity k_s	m/s	***

* At least medium plasticity. Provides information on soil types in the plasticity diagram: TM, TA, TL, OM, UM, UA, OT, UA.
** Installation water content w ≤ PL, semi-solid state
*** The hydraulic conductivity of a sealing depends on national and regional regulations as well as local peculiarities and individual case decisions. Fine-grained DMs often meet these requirements.

The hydraulic conductivity always needs to be determined, however, it is an issue of the design and stability analysis and not a selection criterion. The hydraulic conductivity is connected to the amount of seepage water that is predicted and which has to be dissipated at the land side toe. For sea dikes no limit value regarding the hydraulic conductivity exists.

Another important issue is the internal erosion, including concentrated leaks, piping and suffosion (Chapter 2). In different experiments of the DredgDikes project, no sediment transport was observed when seepage water seeped through cracks or vole burrows in stationary conditions. Transported sediment would be visible, for instance, as a small sand pile underneath the well. The standard pin-hole test did not show any erosion because of agglomerations of mineral fines, carbonates and organic matter (Paragraph 4.5.2.10). Therefore, it is recommended to perform further investigations regarding internal erosion, but at the same time the observations together with the high plasticities partly caused by stable organic matter lead to the assumption, that fine-grained DMs rich in organic matter meeting the above requirements are not particularly vulnerable to internal erosion.

4.5.2.5. Recommended geotechnical limit values for DMs only used as vegetation layer

If the DMs are used to replace the fertile top soil only, they should still be fit for processing. A mixed soil with some organic matter and a high sand fraction is advantageous for nutrient and oxygen supply of the vegetation. The environmental requirements for the top soil and the additional recommendations regarding germination testing apply according to Paragraph 4.5.1.

4.5.2.6. Recommended geotechnical limit values for DMs used as homogenous construction or as cohesive supporting body of sea or river dikes

Mixed dredged soils may be used as supporting body of both sea and river dikes if they prove to have a low tendency to cracking and dispose of a high stability. Therefore, a lower TOC, a lower PI, a lower shrinkage rate Vs and a higher shear strength are recommended compared to sea dike cover material. If a hydraulic conductivity required for a homogenous river dike in the respective country will not be met by the material, additional sealing elements have to be considered (Chapter 2).

4.5.2.7. Recommendations for DMs used as mineral sealing elements in river dikes

Desiccation cracking is an important point in river dike construction, much more than for Baltic Sea dikes. The quality of the materials used as barrier (watertight blanket or impermeable core) usually underlie strict rules, in Germany, e.g. according to [44], [28], [29]. Here, the barrier material should have a k_s value at least two orders of magnitude lower than the supporting body [44] and a maximum specific discharge $q_s < 2.5 \cdot 10^{-8}$ m³/s/m² [29]. The hydraulic conductivity needs to be contained for a long period of time. DMs may be used as river dike sealing elements if they have a particularly low tendency to shrinkage and if they are installed with a water content close to the optimal (Proctor) water content w_{opt} (see also Paragraph 4.7.4.1).

4.5.2.8. Actions to be considered if the DMs do not meet the requirements for recovery in sea dikes

Top layer cracking itself may not be as problematic for Baltic Sea dikes as for North Sea dikes; however, deep cracks may cause flow-paths that increase the hydraulic conductivity too much. If there are open flow paths through to the sand core, a concentrated leak erosion problem may occur. If the DMs show a high tendency of shrinkage / cracking (class 3, Table 4.14) and the water content is high, the following actions may be considered to enable the use of the materials.

The thickness of the cover layer can be increased so that the cracking may not go through to the sand core (if applicable). However, in some cases the high capillary suction of fine-grained DMs may lead to a dewatering and thus fissures even in larger depths.

A nonwoven geotextile may be placed between sand core and cover layer to guarantee the stability of the layered system. Then, larger cracks are not critical with respect to material transport out of the (sand) core. In addition, large cracks may fill over time and thus may be nearly closed (although not totally healed).

The treatment method may be adjusted to further homogenise the materials and at the same time reduce the water content (e.g. by windrow turners).

4.5.2.9. Recommendations for the laboratory testing

Proctor test: The Proctor test should generally be performed according to the applicable standard. Germany's relevant standard is DIN 18127 [30]. The general procedure is to dry a soil sample to a water content between the shrinkage SL and plastic limit PL and then add moisture step by step to perform the actual Proctor tests.

If the DMs contain organic matter, the drying temperature should never exceed 60°C; the lower the temperature, the better. The most reliable results should be gained by air drying; however, this usually takes too much time. Therefore, this guideline recommends an oven drying between 40°C and 50°C.

The DM samples should never be dried completely since this will change the sorption capacity of the fine fraction and organic matter. For fine-grained DM rich in organic matter it is recommended to use a lower target value of 25 % water content during the drying.

The exact method used for the Proctor test needs to be documented in the geotechnical report together with the results. Since both the drying method and the water content to which the sample is dried influence the results of optimal density and water content, it is important to perform this test in the same way during characterisation and quality control.

Sometimes, this standard procedure does not work properly, since DMs may have an optimal water content w_{opt} as determined in the Proctor test that is very close to or even below the shrinkage limit SL as determined after DIN 18122 [31]. There will not be a peak value in the Proctor curve and thus result evaluation is impossible. Then, the DMs should be air dried down to w = 25 % before rewetting, to avoid the colour change of the soil (unless the colour change is already noticed above w = 25 % together with a w_{opt} >> 25 %).

The recommended compaction values in Chapter 5 are based on the results using the air drying method. With oven drying the OD is sometimes higher, resulting in lower computed degrees of compaction (with the same actual density). Therefore, the quality control parameters need to be adjusted in the required installation testing field prior to the construction (Paragraph 5.4.1).

Grain-size analysis: For the grain-size analysis of fine-grained materials rich in organic matter and/or lime content at least the organic matter should be removed before performing a sieving and sedimentation analysis. Lime and organic particles form agglomerations with the mineral fines, and thus the fine fraction (and particularly the clay fraction d < 0.002 mm) is considerably underestimated using the standard geotechnical test (e.g. DIN 18123 [19]).

In the project the grain-size analysis was performed according to ISO 11277 [20] to receive a more realistic picture of the mineral grain distribution. In this test, the wet sieving and sedimentation analysis is performed after removing organic matter and carbonates from the sample using H_2O_2 and HCl respectively. The sample preparation may take several weeks (depending on the amount and type of organic matter and lime), which has to be taken into account while planning the analysis. Still this method is highly recommended for soils with an organic matter and/or lime content of > 3 % respectively.

In the project DredgDikes, a possible overestimation of the clay fraction in the tests according to ISO 11277 was also discussed as well. The very time consuming sample treatment with chemicals may also affect the mineral grains. However, this has not been proven. In marine and brackish DMs the lime content often represents mussel shells and their granular fragments. These may not add to the agglomerations much and may rather be geotechnically interesting. Therefore, another method may be equally suited: Before performing the wet sieving and sedimentation analysis, only the organic content may be destroyed by burning (e.g. in a muffle furnace). Then the dried samples need to be carefully pestled (broken up) before testing.

Hydraulic conductivity: In sea dike projects the hydraulic conductivity is often assessed by the geotechnical expert regarding the soil type or by computed values based on the grain-size distribution. These are very approximate values, which may even be sufficient for the stability analysis since there are usually high safety factors, which are often even increased by using stationary instead of transient seepage calculations in the stability analysis. Since there is little expert experience with the hydraulic conductivity of DMs, however, the parameter should always be determined in the geotechnical laboratory.

For DMs with $k_s < 10^{-7}$ m/s, triaxial permeability cells are often used because the saturation pressure is usually very high. Then, the steps during saturation have to be kept very small and also pressure controlled, comparable to the procedure in a triaxial shear test (b test).

Since the laboratory values usually result in considerably lower hydraulic conductivities than the materials have in the field after installation (and particularly fissuring), the geotechnical expert needs to judge these values before including them in the geotechnical expert statement from which the parameter is then directly used for computations. Since the DMs which are rich in organic matter showed an even higher discrepancy between lab values and in situ measurements than other soils by trend, it is recommended to multiply the lab values generally with the factor 10 for computations.

Organic matter and lime content: Generally, it is recommended to use the TOC value (total organic carbon) determined in an elemental analyser as the parameter to describe the organic matter content. The organic matter content (approximation) can be computed using the factor 1.724.

The loss on ignition (LOI) is often used to determine the organic matter content. However, in DMs rich in lime content, the LOI value may considerably exceed the actual humus content, because some of the lime (but not necessarily all) may burn in the muffle furnace. For the reason of comparability, all DMs should be characterised using the TOC rather than the LOI. More information can be found in Annex II.

Stability of the organic matter: The stability of the organic matter OM is not only important with regard to the environmental impact (e.g. eutrophication) but also for the geotechnical behaviour of the materials. In DMs rich in OM, the plasticity is often mainly influenced by the organic substances.

A high plasticity generally indicates a high stability against erosion, which is important for a dike material. This quality should not get lost over time due to the degradation of the OM. The brackish DMs in Mecklenburg-Vorpommern show a very high stability of the OM both in long-term lysimeter experiments [26] and according to the AT_4 breathability test [25]. If the stability of the organic matter is questioned, the AT_4 test should be performed (Paragraph 4.5.1).

4.5.2.10. Notes on erodibility testing

Disintegration test: In some publications, disintegration tests are recommended to evaluate the erodibility of dike cover materials. An intensive study was performed on these tests; however, none of them gave reliable results regarding the material erodibility, particularly because the data evaluation method did not work for any of the data gained with the investigated DMs. This issue is discussed in Annex II. Based on these results, the use of a disintegration test as proposed by [32] and [33] cannot be recommended for DM analysis so far.

Pin-hole tests: The erodibility of cohesive soil may also be determined using pin-hole tests, e.g. after [34]. For DMs rich in organic matter, however, the standard pin-hole test does usually not work because the pin-hole in the sample is too small and the comparably large aggregates (agglomerations of organic matter, carbonates and mineral fines) will immediately block the hole. Therefore, the standard pin-hole test cannot be recommended for DM analysis so far. The results of an enhanced pin-hole test with a larger sample are still pending. This may, however, be a solution in the future.

4.6. Selection and characterisation of CCPs

For the selection of a suitable CCP it is necessary to decide whether it is used directly or in a composite material mixed with soil. In addition, as discussed in Paragraph 4.4.2, CCPs may either be found in an old disposal facility, directly in a power plant or as ready-to-use certified by-products at a CCP seller.

Today, CCP products are usually submitted to chemical certification already in the production plant. In this case the recipient of CCP based products should be provided with the chemical data necessary to characterise the materials for different applications. The process is more difficult if a CCP from a disposal facility shall be recovered.

For the classification as a by-product the CCP needs to fulfil the requirements of the Waste Law [35]. If the requirements are not met the CCP can be sold to a waste broker. After a defined treatment process (R5), the broker can apply for a Technical Certificate and sell the CCP as a construction material. Defined chemical analyses need to be performed by a certified laboratory for such cases. The certificate considers chemical properties only.

While the issue of environmental characterisation is generally the duty of the owner of the CCPs, the geotechnical characterisation may have to be performed case specific, particularly if a deposited material is used.

4.6.1. Environmental characterisation

The chemistry of CCPs depends mainly on the fuel used in the power plant. There are substantial differences between hard coal and lignite CCPs; moreover, the chemistry of CCPs depends on the stage of technological processes from which it originates (Chapter 2).

In Poland, the usage of CCPs as an element of soil composite is subjected to the Waste Law [35] and the projected Ordinance of July 2014 [21] on the treatment of waste outside landfill installations. The limit values of several groups of contaminants such as heavy metals, inorganic & organic compounds and carcinogenic ones are listed there.

With a product certified as a construction material (no longer labelled as waste) and purchased from a CCP seller the characterising data will always be available. In this case no further analysis is needed.

If one wants to apply CCPs deposited in a disposal facility, the owner of CCPs should follow the path indicated in Figure 4.2 and request all necessary chemical tests in a certified laboratory. In Poland, the information about the required test procedures and classification limits can be found in the Waste Law [35] and the projected Ordinance of July 2014 [21], while in Germany the LAGA M20 (part IV technical rules for CCPs) [15] is recommended to be applied. This means, in both countries the procedures of certification of a waste for recovery need to be applied.

4.6.2. Geotechnical characterisation of CCPs and composite materials

The geotechnical characterisation of CCPs should follow, in general, the requirements for soils as described in EC 7 [4]. The minimum investigation programme should involve the determination of basic physical soil properties such as water content, density, specific gravity, dry density, grain-size distribution, soil strength and compressibility, compaction and permeability parameters [37], [38], [39]. The tests should be performed separately for the CCP, a possible soil in a composite and for CCP-soil composites.

The CCPs can be applied in dike constructions as: (1) supporting body, (2) sealing element on the slope, and (3) vertical barrier system constructed in the central part of the dike or at the water side toe.

The supporting body should be constructed with a CCP-soil composite. It is not allowed to use only CCPs such as bottom ash to construct the dike body due to their low dry density, which impairs the dike stability during high water. The addition of soil to the mixture shall assure the specific gravity of the supporting body to be larger than 12 kN/m^3. The proportion of the mixture needs to be chosen based on the laboratory test results and verified in field trials.

The sealing liner on the slope can be made from a mixture of soil and hydraulic binders based on CCP products. The properties of the hydraulic binder should satisfy the technical certification requirements (in Poland [36]) for a given product. The proportion of the soil-binder mixture should be chosen based on field trials.

In a vertical barrier system (Paragraph 4.7.4.3) the mixture prepared in mixing plant may contain CCP based hydraulic binders or fly ash. The proportion of the mixture should be examined to satisfy the required strength and permeability coefficient of the constructed barrier.

The main issue for dike design with CCP composites is to ensure three essential aspects for dike stability, namely its compactability, strength and hydraulic conductivity. The geotechnical characterisation of the material should be performed

- At the initial stage of the study (laboratory),
- During the construction phase (field tests),
- After construction (field and laboratory tests).

During the initial laboratory tests the properties of the CCPs or of mixtures from CCPs and (dredged) soil with different proportions need to be evaluated. The procedure of preparing and mixing the components and sample reconstitution should be fixed. The large fractions (> 6 mm) should be excluded from the soil and bottom ash samples and each component should be well mixed to get homogenised samples of each material. Either the volumetric or weight proportions of the soil-CCP composite have to be chosen for comparison. In addition, the water content of the components to be mixed has to be defined.

Good compactability of the CCP-soil mixture is an important issue, especially when bottom ash is used. Therefore, the standard Proctor test is recommended to define the maximum dry density.

When the uniformity coefficient of both ash and sand is small ($U < 3$), it is recommended to add a small amount of fly ash to increase the compactability of the mixture.

The strength parameters of the composite should be determined in a series of triaxial or direct shear tests. The tests should be performed either on remoulded or undisturbed samples taken from a dike body or installation testing field. The residual drained shear strength should be used for stability analysis. An eventual development of cementation with time may increase the composite shear strength and decrease its hydraulic conductivity. Therefore, in addition to standard geotechnical investigation, research on the ageing process of an ash-soil composite together with the observation of the variability of strength and hydraulic properties with time is recommended [40].

The dike body made of the chosen optimal ash-sand mixture should be installed close to the optimal water content. When CCPs are used in barrier systems, the proportion of the mixture should be examined to satisfy the required strength and hydraulic conductivity of the constructed barrier. The standard recommendations for slurry walls should be satisfied [41].

4.7. Dike design

This paragraph contains information on how to design dikes made of DMs, CCPs and geosynthetics in the South Baltic region, with particular focus on Germany, Poland and Denmark. Both river and sea dikes are addressed. Reference is provided on which regulations and guidelines need to be consulted when designing dikes in the region. A comprehensive collection of all kinds of topics related to dikes, including design, construction and maintenance, has been published in the International Levee Handbook [42].

The most important steps when designing a dike are the definition of the design flood level, the choice of the general section including the materials, the choice of drainage facilities, additional facilities (e.g. access roads and crest pathways) and the stability analysis under consideration of the ground. General information about dikes including definitions, the subsoil, typical cross-sections and failure modes is provided in Chapter 2. For more information on standard design issues (e.g. determination of load parameters and stability analysis) reference is provided to the respective national and international standards and recommendations. The actual design recommendations strongly focus on sea and river dikes made of DMs and CCPs and the use of geosynthetics in dike construction.

4.7.1. General design issues

4.7.1.1. Design flood level

The first step when designing a dike is to determine the flood scenario the dike shall prevent the hinterland from.

Table 4.17. Determination of design flood levels for sea and river dikes

Sea dikes	River dikes
Germany	
EAK 2002 (2007) [11]	DWA M507 [28] DIN 19712 [44]
Mecklenburg Vorpommern (regional)	
Regelwerk Küstenschutz M-V 2-5 / 20012 [43]	See above
Poland	
n.a.	Polish Water Law, article 63
n.a.	Directive of Ministry of Environment 2007 [46]
Denmark	
Extreme Sea Level Statistics Based on recommendations by the Danish Coastal Authority	River discharge and river level

This implies the correct choice of flood design for the dimensioning of the dike. A decision must be made, taking into account economic, technical, environmental and urban aspects. The determination of the design flood level differs within the South Baltic region and also for sea and river dikes (Table 4.17). In Mecklenburg-Vorpommern there is even a special regional manual to determine the design flood level.

4.7.1.2. General dike cross-sections

The design of dike cross-sections primarily needs to comply with the loading to which the dike is exposed to, depending on its location, its purpose and its height, the dike construction material and the ground conditions. A cross-section is characterised by the water and land side slopes, the height and width of the crest and the possible arrangement of berms and dike defence infrastructure. In addition, the material combination (homogenous dike, multi/three zone dike, sand core with cover layer) needs to be chosen.

To reduce the current load inside the dike body as well as to improve the overall and local stability dikes are usually constructed with some kind of sealing. However, the sealing function is more important for river dikes than for sea dikes. The dimensioning of the cross-section must specify a maximum allowable hydraulic conductivity.

Both the sealing and dike cover materials have to be resistant against erosion, suffosion, aging and weathering. Other relevant requirements may arise with regard to the resistance against mechanical, chemical and biological impacts as well as plasticity and strength.

Particularly for newly built river dikes but also in sea dike design, drainage elements are used in the dike section to drain the seepage water without compromising the construction. Standard elements are filter loads made of armourstone at the downstream toe and drainage pipes inside a sand core.

Specific information about the general dike design in Germany is provided in [11], [28], [44], information for the general design, construction and maintenance of water protection structures in Poland is provided in [45] and the technical conditions to be fulfilled by the structures including calculation methods in [46].

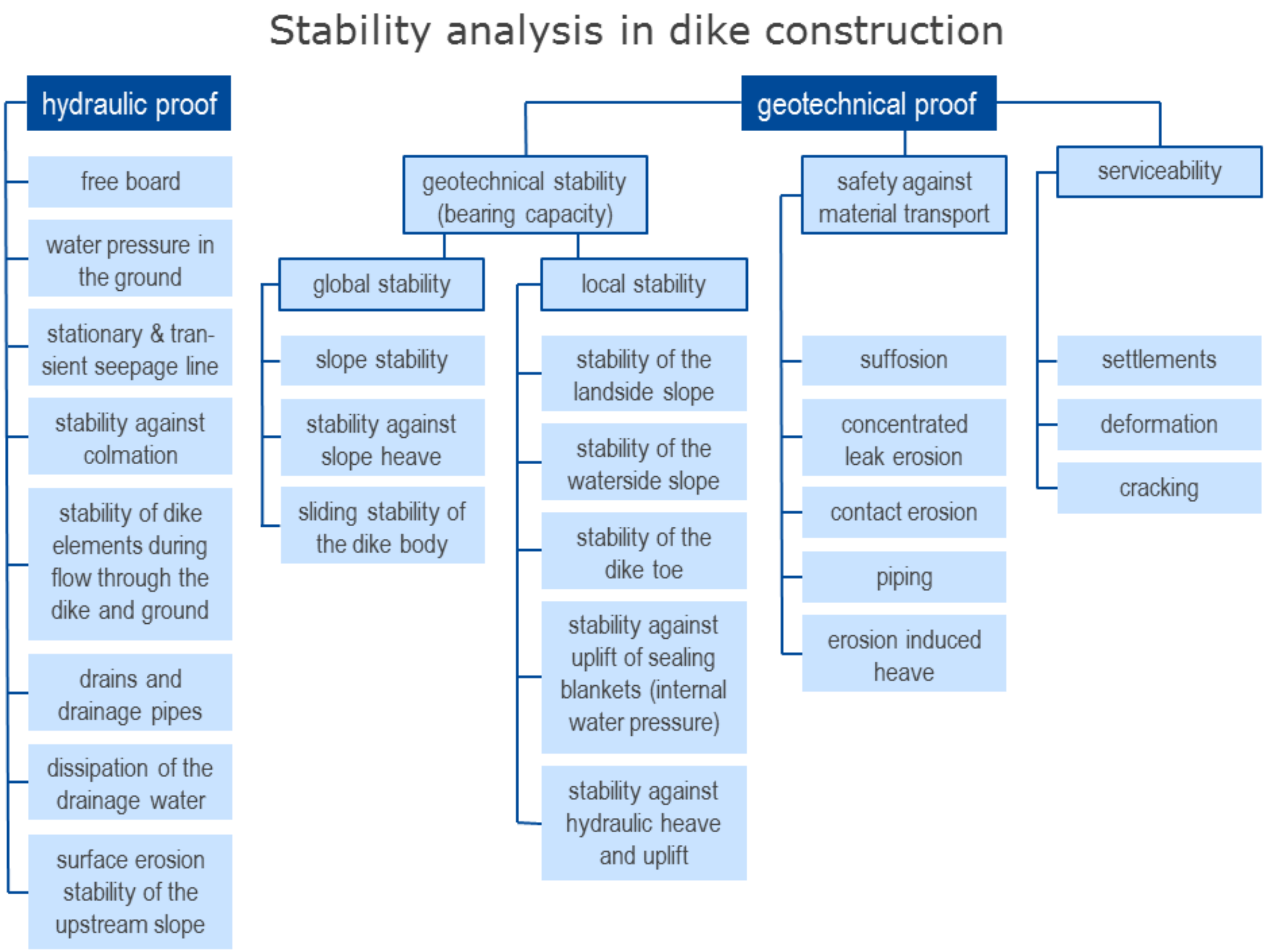


Figure 4.5. Hydraulic and geotechnical stability analysis for (river) dike design based on [28]

4.7.2. Stability analysis

In case of floods, the dike and the underground are considered one unit. Therefore, the stability analysis always has to include the subsoil. Figure 4.5 exemplarily shows the structure for a stability analysis in dike construction based on [28]. The stability analysis has to be documented in form of geotechnical certificates according to EC7 [4] (and the respective national application documents, i.e. [2], [47], [48]).

Since the stability analysis of dikes with the materials covered in this guideline is generally not different to any standard dike construction, this paragraph shall only give a basic overview. Detailed information is provided in the respective handbooks, guidelines and standards. Standard design issues are covered for instance in [44], [11], [42], [46], [49] and information about overflowing is collected in [50] while internal erosion of dams and dikes is comprehensively covered in [49], [51].

In Figure 4.5, which is based on a river dike manual, special issues for sea dikes are missing such as the hydraulic shock dimensioning. Since this is an intensively discussed topic, particularly with respect to dike surfaces that show desiccation cracks, similarly to some of the dredged materials under investigation, the subsequent paragraph is covering this issue.

4.7.2.1. Notes on cracks and hydraulic shock

Desiccation cracks in the dike cover made of DM are often discussed to be problematic, because they were identified to contribute to the failure of dike surfaces during storm surges. The results of the DredgDikes project are only based on two years of investigations, however, the high stability during extremely turbulent overflowing tests, the high undrained shear strength of the saturated material and the observations during all experiments lead to the assumption that the cracks in a dike cover made of a fine-grained DM with some organic matter content may be of less importance regarding the sea dike stability when the grass cover is well developed. This should be particularly considered under the premises of many Baltic Sea dikes that are not directly attacked by waves (no flock dikes) because they are protected by foreland, dunes and coastal forest and for dikes along the backwater lagoons (Bodden). The maintenance of a strong and intact vegetation cover on a fertile fine-grained DM is usually possible throughout the year (Chapters 5 and 6). As an additional support during in the stability analysis, the method of Führböter [27] results in a required shear strength to withstand possible loads from hydraulic shock.

A general fear of cracks in a dike cover material concerns the large destructive forces during a wave induced hydraulic shock. In theory, the hydraulic shock would cause water to infiltrate into the crack, the quick and strong pressure of the hydraulic shock would be concentrated in the crack and in this way stress the dike cover horizontally, leading grass sods to be torn out of the surface [52]

The cracked surfaces on the German DredgDikes research dike lead to increased average hydraulic conductivities compared to the laboratory values, however, still sufficiently low for a standard Baltic Sea dike. During the overflowing tests no erosion could be detected. Existing cracks showed no negative influence on the erosion stability in case of overflowing water. In addition, the cracks were usually filled with sediment (externally or by eroding crack edges due to weathering) and the grass roots spanned and reinforced the cracks. Furthermore, most of the cracks, even those originally several centimetres in width, closed due to swelling. Moreover, the crack edges are comparably erosion resistant regarding flowing water (Paragraph 4.5.2.4).

4.7.2.2. Notes on soil strength estimation

The shear strength estimation based on the liquidity index LI after Pohl & Vavrina [53] cannot be recommended for the fine-grained dredged materials under consideration.

Pohl & Vavrina [53] propose to estimate the strength of a marly dike cover of a Baltic Sea dike according to its consistency index $Ic = 1 - LI$, based on the assumption of Kiekbusch [54] regarding a strong logarithmic dependency of undrained shear strength c_u and Ic for these materials. However, this proved not to be valid for the DMs because the calculated density based saturation water content w_{sat} is partly below PL leading to high saturated strength values $c_{u,sat}$. The $c_{u,sat}$ of the DMs measured in situ was high, however, did not compare to the values computed with the above estimation method.

4.7.3. Design recommendations for sea dikes

In this paragraph, the design recommendations for sea dikes made of DMs are summarised from the experience gained in the DredgDikes project. The recommended standard dike sections for the different material combinations are presented in a simple and general way, showing the most important elements to be looked at regarding this guideline. They are not complete standard sections to be directly applied in a project, since each project requires a particular dike design depending on the boundary conditions of the site. The following recommendations do not include revetments, berms, flood defence roads, a supporting body embedded in the ground, slope and crest inclinations and the foreland.

There are no sea dikes in Poland and consequently no recommendations about their design and construction. Thus, the Polish research dike was only intended to give results regarding river dikes. Therefore, this paragraph is restricted to the use of fine-grained DMs.

Based on the experience of the DredgDikes project as well as projects in Hamburg [55] and Bremen [14] the following general recommendations for dike sections made of DMs can be made:

Fine-grained and mixed DMs can be used as dike cover material and in homogenous dikes. A dike cover made of fine-grained DM should generally have a thickness of at least 1.0 m, with an additional thickness of up to 0.5 m (safety layer) to account for the estimated extent of desiccation cracking based on the volumetric shrinkage rate Vs, in analogy to the recommendations regarding North Sea marsh clays as recommended in [56], [57]. Here, it should be noted again that some of the DMs show considerable shear strength even when saturated which may reduce the need for an additional safety layer.

In Mecklenburg-Vorpommern, the issue of using fine-grained DM in dike construction was discussed with the responsible ministry and permitting authorities, leading to the following recommendations with respect to the building permit. Since the installation of DM in a dike is always a single case decision, the evaluation should be performed on the basis of LAGA M20, taking into account a separate agreement about acceptable levels of salts and TOC as explained above. A dike is a technical construction, therefore DM classified as Z0 and Z1 is recommended to be installed in the dike cover (Figure 4.6) also in the rooting zone. However, LAGA also refers to BBodSchV regarding the recovery of mineral wastes in the rooting zone. Therefore the issues summarised in Table 4.18 have to be clarified with the respective permitting authority.

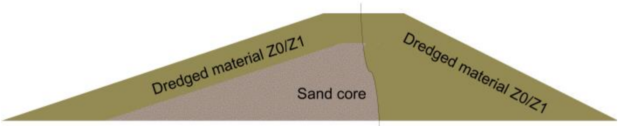


Figure 4.6. Recommended general sea dike section for Germany using DMs with LAGA classification Z0 and Z1

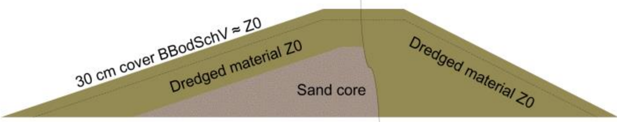


Figure 4.7. Double classification of one and the same DM after both ZAGA and BBodSchV is not recommended.

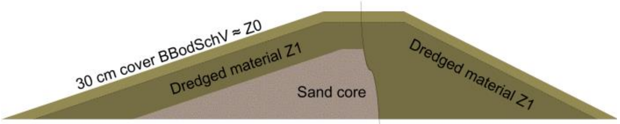


Figure 4.8. General sea dike section for Germany using DMs with low contamination levels (LAGA class Z1), considering BBodSchV

Table 4.18. Planning the cross-section according to material classification

Classification of DM	Recommendations
LAGA Z0	**Install Z0 material in one layer** (Figure 4.6). Classification limits of LAGA Z0 compare to the limits of BBodSchV for fine-grained soils. If strictly applied: double classification of one DM (rooting zone after BBodSchV, below rooting zone after LAGA) Agreement with permitting authority: **NO double classification** (Figure 4.7)
LAGA Z1 (Z1.1)	Agreement with permitting authority: **Install Z1 material in one layer** (Figure 4.6). This may be discussed regarding the often low eluate contaminations (high sorption capacity of the DMs – Z1.1). Alternative: Cover the Z1 material with 15-30 cm of clean soil / DM according to BBodSchV (Figure 4.8).
LAGA Z2	cf. case study Weser dike Bremen (Paragraph 2.5). Alternative 1: encapsulate the material according to LAGA Alternative 2: prove the environmental harmlessness (e.g. through a seepage prognosis according to BBodSchV) and install the material according to the recommendations for Z1 material including a clean cover.
> LAGA Z2	These materials are generally not found suitable for recovery (Figure 4.4.). However, if only single limits are exceeded, an exception may be negotiated with the permitting authority if the environmental harmlessness, particularly regarding the seepage quality, is separately proven.

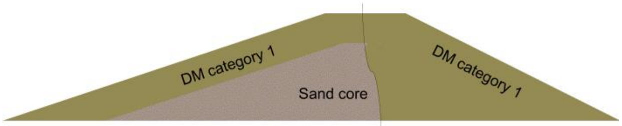


Figure 4.9. Recommended general sea dike sections for Denmark using DMs with low contamination levels (category 1)

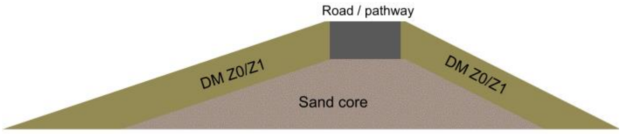


Figure 4.10. Recommended general sea dike section for DMs with a road or pathway on the crest (German case example)

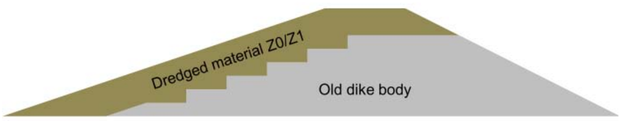


Figure 4.11. Example dike section for the raising of a sea dike using DMs (German case example)

In the case of an additional cover soil on the DM (only recommended for classification limits > LAGA Z1.1), the total thickness of the dike cover may have to be increased, depending on the material quality and installation technology for this layer.

In Denmark, clean DMs meeting category 1 according to the Danish Order of Reuse [24] and the Zealand Guidelines [23] can be recovered in geotechnical applications. There is no information of a differentiation of soil protection and construction law, thus the installation of the DM according to Figure 4.9 is recommended. If slightly contaminated DM shall be used it is subject to an individual case decision whether a clean soil cover is sufficient or whether an encapsulation is demanded.

If a touristic pathway on the dike crest is planned, the DM on the crest may have to be replaced by a material meeting the criterion to carry the road construction. The road is thus founded directly on the supporting body (sand core) of the dike (Figure 4.10).

Usually the touristic pathway on the crest of a newly built dike is not the dike defence road, since this element should rather be positioned on a berm on the land side slope. The fine-grained DMs investigated in the DredgDikes project have low elastic moduli. Thus, even the foundation of a touristic pathway on top of the DM is difficult and may not be permitted, since the deformation requirement on the planum is usually E_{V2} > 45 MN/m².

When fine-grained DMs with at least some organic matter are installed at the surface, an additional top soil for the vegetation layer is not needed. More information about this issue is provided in Chapter 5.

The above recommendations apply to a dike renovation accordingly. An example for fine-grained DM recovered in a dike raising project is shown in Figure 4.11.

4.7.4. Design recommendations for river dikes

River dike design generally follows a different concept than sea dike design (Chapter 2). This has to do with the limited space along river banks and longer flood waves. Therefore, the sealing elements usually have a much bigger importance and so has the drainage of seepage water. The very general recommended cross-sections in this paragraph do not include drainage elements, berms, dike defence installations, etc.

4.7.4.1. River dikes made of dredged materials

Dredged materials meeting the requirements of mineral sealing elements (surface or core sealing) should be treated in analogy to standard mineral sealing materials such as loam and clay. Generally, the k_f value should be at least two orders of magnitude below that of the supporting body [28]. In Germany, the ZTV-W – 210 [29] even demand a permittivity of $q_s = 2.5 \cdot 10^{-8}$ m³/s/m² (specific seepage discharge).

The fine-grained DMs rich in organic matter investigated in the DredgDikes project were not found suitable as mineral sealing material for large river dikes without conditioning due to the high shrinkage tendency and an in situ hydraulic conductivity above the requirements of a river dike. For the sealing material in large river dikes usually the hydraulic conductivity of the sealing system has to be guaranteed for the long term. However, since DMs are composed very differently, they should not generally be excluded but judged individually.

Fine-grained or mixed DM with or without high amounts of organic matter may be used as supporting body of river dikes or even as a homogenous river dike (although large dikes today are usually not built with a homogenous section to ensure a faster dewatering of the dike body after a flood event). The high stability of the organic matter in DMs supports this recommendation.

In Germany DIN 19712 [44] judged soils with an organic matter content of more than 4 %grav. generally unsuitable for this purpose. However, there is no reason provided for this statement and since the organic matter in a ripened DM is usually stable (Paragraph 4.5.1) an individual case permit should be pursued if the concept of a supporting body made of mixed DM is otherwise efficient. This may also apply to homogenous dikes.

For small agricultural dikes a homogenous structure made of a fine-grained DM or a "mixed soil" type DM (flat grading curve) may be chosen. In low-lying regions of Mecklenburg-Vorpommern, Denmark and western Poland, a large number of small summer dikes protect agricultural land from both upstream river floods and floods induced by the backwater of high sea water levels. Ripened fine-grained or "mixed soil" DM with or without organic compounds can be a favourable solution to build such dikes since the materials should be available at low cost reducing the construction costs considerably.

Finally, on large river dikes ripened DMs rich in organic content may be used as vegetation top soil layer on top of the sealing blanket and as erosion protection layer on the downstream face due to their favourable soil fertility and usually high water holding capacity. The field capacity is often FC > 50 % with usually 35-50 % of the FC being active for the plants; this means there is an active storage capacity of 20-30 %vol. [26]. However, particular care has to be taken on the downstream face in order not to reduce the dike toe drainage capacity by low-permeability materials.

Since there are no specific standards or requirements concerning the use of DM in dike construction in Poland, the above recommendations for Germany should also be applied here, taking into account the general Polish requirements concerning the use of material in river dikes (Chapter 2) and the stability of such structures have to be checked according to [46].

4.7.4.2. River dikes newly built with CCPs

For a river dike that is newly built (or reconstructed from base), the following recommendations are given:

The supporting body can be built using bottom ash (BA) mixed with a (dredged) sand in different proportions. The mixture usually has a high shear strength, however, the compactability needs to be tested intensively, particularly if one of the materials of the mixture has a low uniformity coefficient (U < 5).

A low permeability cover can be built with a composite of a mineral soil and hydraulic binders based on fluidized and fly ash to be applied both on upstream and downstream slopes.

In order to minimize potential threats to the environment and to prevent potential leaching of heavy metals in the long term, it is recommended to construct an impermeable horizontal liner below the dike construction which may also be made with CCPs. If this barrier is made of an earth material (or CCP composite), it should be at least 0.50 m thick. Based on the experimental dike of the DredgDikes project, the recommended general cross-section of a new dike made with CCPs is given in Figure 4.12., showing a BA-sand-composite dike core covered with a low permeability composite including a CCP based hydraulic binder. For greening, an additional top soil layer is needed. The slope inclination should not exceed 1V:2H.

4.7.4.3. River dikes renovated with CCPs

In renovated dikes CCP products can be used to form an impervious barrier in the existing dike core using the trench mixing technology or vibratory mixing. Fly ash can be used as a component for the sealing composite which is prepared in a mixing plant. The barrier that reaches into the ground to be embedded in underlying impermeable soil layers can be constructed as a vertical barrier in the middle of the dike core (Figure 4.13) or at the dike toe (Figure 4.14), where it is combined with the sealing blanket on the embankment. Some hydraulic binder mixtures based on fluidized ash can be used for temporary roads or working platforms during the dike construction as well.

If existing dikes have to be raised, CCP composites can be used as stable fill material on top of the old dike cross-section and covered with low permeability composites with the use of CCPs, similar to a newly built dike (Figure 4.15).

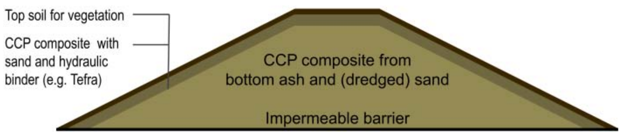


Figure 4.12. Recommended general cross-section of the dike constructed made with CCP composites

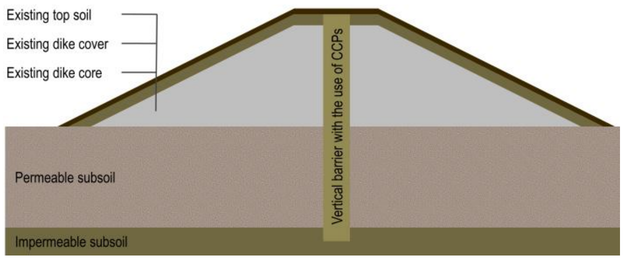


Figure 4.13. Recommended general cross-section of a river dike improved with a vertical toe barrier using CCPs

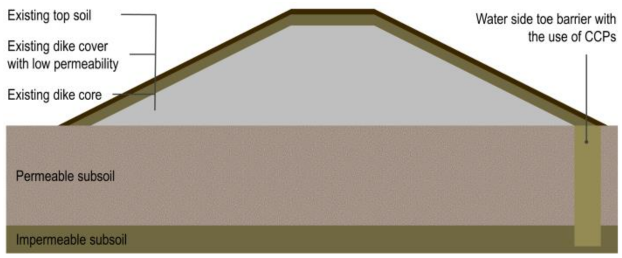


Figure 4.14. Recommended general cross-section of a river dike improved with a vertical core barrier using CCPs

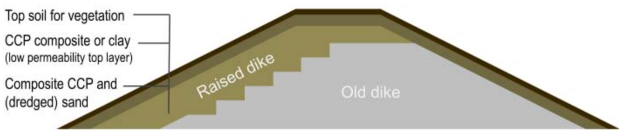


Figure 4.15. Recommended general cross-section of a raised renovated dike using CCPs

4.7.5. General aspects on dike design using geosynthetics

Historical flooding along rivers in Germany has led to the significant incorporation of geosynthetics in dike construction [58]. The German state of the art for safe dike sections is characterized by the successful use of geosynthetics. Integrated into flood defences, geosynthetic technologies provide structural strength against floods and additional time for emergency responders to react and to notify and evacuate residents at risk. After the Elbe River floods of 2002 - 2007, approximately 160 flood protection projects were carried out in Germany in which approximately 2.4 mill. m² of geotextile filter fabrics, 330,000 m² of geogrids, and 770,000 m² of geosynthetic clay liners (GCLs) for dike sealing were used [59].

Geosynthetics are also widely used in dams and dikes along navigation channels and in sea dikes. The good experience with geosynthetics in dike construction resulted in a number of ideas how to improve the safety of a dike when DMs are used as well as systems that can be used with standard dike material to enhance the global or local stability [59], [60].

There are a variety of geosynthetic solutions that have become standard elements in dike construction. When it comes to sealing elements, geosynthetic clay liners are often applied, the dimensioning of which is comprehensively covered in [61]. Geomembranes (geosynthetic polymer barriers), on the other hand, are not recommended to be used in dike sealing, due to their lack in intimate contact between the geomembrane and the earth material (water may seep around the system).

To reduce and level settlements and deformations, the reinforcement of the dike base using geogrids is a standard solution. The German EBGEO [62] is becoming the European standard document on geosynthetic reinforced constructions.

Often, non-woven geotextiles are used for filtration and separation in dike constructions. In Germany, geotextile filters are usually designed according to [63], however, there is an intensive discussion on this topic and a new guideline is being developed which shall have significance for the whole of Europe. Similar products with a lower class of robustness can be used for simple separation purposes.

Other systems, such as geosynthetic container or tube elements for dike core protection, are still comparably new and still developing.

4.7.6. Dike design with geosynthetics based on the experience of the DredgDikes project

The systems investigated in the DredgDikes project at the Rostock research dike include the reinforcement of the dike cover material to reduce cracking, the protection of the dike surface against rain or overflowing induced erosion and drainage composites to control the seepage line. In addition, a geosynthetic barrier system was applied to seal the research dike against the subsoil and at the pilot dike (Körkwitzer Bach), the construction road to access the dike section on the very weak peat ground was reinforced with a geotextile. However, these last two geosynthetics solutions have not been investigated in the project since they are standard construction elements.

The DMs used to build the research dikes in the DredgDikes project performed so well that the mechanical strengthening by the use of geosynthetics (reinforcement and erosion control) was not generally necessary. However, the investigated systems may be more suitable in constructions with weaker materials.

The drainage composites performed well; however, there are some important points to be considered if using these systems for dike drainage.

In addition to the systems investigated in the project, non-woven filter geotextiles can be used for filtration and separation between different construction materials, the so-called wrap-around method with geotextiles or geogrids can be used to permanently stabilise the dike core and geotextile tubes may be used when comparably wet DM is applied in the dike core.

Finally, in case of slightly contaminated DMs (e.g. LAGA classification Z2 [15]), the wrap-around method or even geosynthetic barrier systems can be used to encapsulate the materials.

In the following, experience is compiled and recommendations for the planning with geosynthetics are presented for surface erosion control, drainage and separation.

4.7.6.1. Surface erosion control

There are different geosynthetic products and systems to protect an embankment or slope against water induced surface erosion. The DredgDikes project investigated two types of surface erosion control products. The following experience and recommendations are strongly connected to the use of fine-grained dredged materials used in the DredgDikes project.

At first, a decision has to be made whether an erosion protection product is necessary at all. In case of the cohesive, medium to highly plastic DMs rich in organic matter used in the project, an initial erosion protection may not be necessary, since the DMs are usually erosion resistant against standard rainfall events and particularly stable as soon as vegetation is established.

An initial (temporary) erosion protection may be chosen if flood water levels are expected shortly after the construction, if a top soil with a lower erosion resistance is used (e.g. sandy silt or silty sand) and if the slopes are built unusually steep. In these cases a temporary erosion control product made of an organic material (coconut fibre, jute, straw, etc.) may be preferred, depending on the time needed for protection (different lifetimes of the natural fibres) and the required strength.

A permanent erosion control product made of UV stabilised synthetic material may be chosen, if the erosion stability of the vegetated soil surface is assessed to be permanently low or if particularly high action forces are predicted. This may particularly apply to sandy top soil on top of a supporting body or sealing liner that does not contribute to the water and nutrition supply of the vegetation (e.g. on clay with very low hydraulic conductivity, stiff CCP mixtures or marl). In this combination of soils, the vegetation often dries out during the summer and the roots may not be well established in the top soil.

In addition, the root reinforcement of the top soil in the layers underneath may be weak (and often even undesired). In this case, the friction between top soil and dike cover / sealing / supporting body can be permanently increased using geomats.

Drawings of the different installation methods and protection functions can be found in Chapter 5.

4.7.6.2. Drainage

There are different possibilities to construct drains in a dike. General information on the arrangement of drainage elements is provided in [11], [28], [42], [44], [46]. General information on the dimensioning of geosynthetic drains is provided in [49].

In addition to the standard drainage options, the following recommendations can be made based on the experience from the DredgDikes project to control the phreatic line inside the dike core using geosynthetic drainage composites. However, these drainage solutions are independent of the earth material used, thus not restricted to the use of DMs or CCPs. The dimensioning should follow the guidelines for drainage composites in landfill construction [64], since dikes should be functioning at least as long as landfills.

A drainage composite can be placed in the dike core and connected to a drainage pipe with outlets in defined distances (Figure 4.16), based on the seepage calculations. The use of drainage composites on the level of the drainage pipe adds safety to the system. The phreatic line can be forced down further inside the dike while on the same time the drainage pipes can be installed near the dike toe for eventual maintenance access.

Drainage composites can also be placed in a way that they drain freely at the dike toe (Figure 4.17). It is important to consider a trench to dissipate the seepage water. The drainage should exit the landside toe 20-30 cm above the ground, so that the free outflow can be guaranteed. If the product is placed directly at the base, the product can easily be clogged or covered by soil material either during the construction or during the lifetime of the dike.

The third recommendation is to use a gravel rigole inside a homogenous dike cross-section to guarantee the dissipation of the seepage water inside the dike body before it flows out of the dike through the drainage composite (Figure 4.18). The recommendations for installation of the

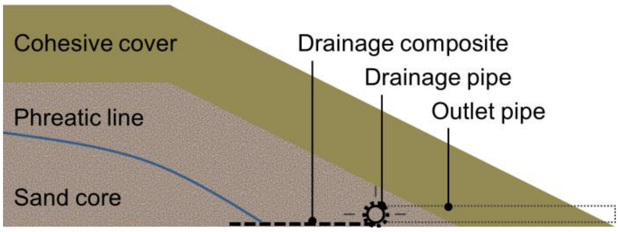


Figure 4.16. Recommended example for the use of a geosynthetic drainage composite attached to a drainage pipe to control the phreatic line inside the dike core.

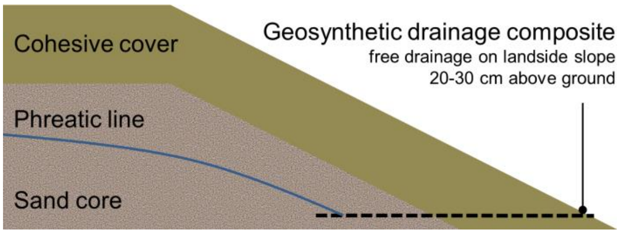


Figure 4.17. Recommended example for the use of a geosynthetic drainage composite that freely drains at the landside toe.

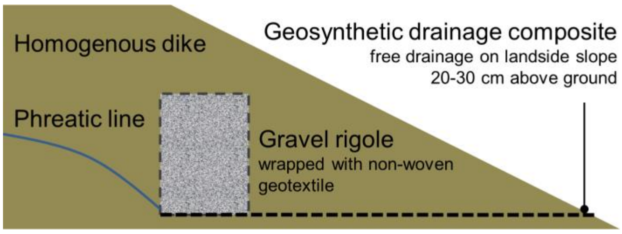


Figure 4.18. Recommended example for the use of a freely draining geosynthetic drainage composite with a gravel rigole for additional safety.

second example apply accordingly. The advantage of the system is that even in the unlikely case that parts of the drainage composite will be clogged during the long service time, the seepage water entering the rigole will be quickly distributed and led to sections of the drainage composite which are still intact. This only applies to homogenous dikes made of earth material with comparably low hydraulic conductivity. In case of a sand core, the distribution of the seepage water inside the dike body is always guaranteed.

These are only three examples of a variety of possibilities how drainage composites can be applied. They have all been tested in the DredgDikes project and proved to be functioning. The first two examples can also be applied in homogenous dikes.

4.7.6.3. Separation and filtration

Geotextiles can be used for filtration and separation. Usually, non-woven geotextiles are used for these purposes. The supporting body (e.g. sand core) and the dike cover or sealing have to be stable against internal erosion, particularly at the boundary between the materials.

The filter stability should be determined based on [63]. At the same time, the two problematic earth materials are permanently separated. This will considerably increase the safety against internal erosion in case of desiccation cracks in the cover layer, because the seepage water cannot wash out material from the supporting body (Paragraph 4.5.2.8). Also, an additional overall stability is provided.

Separation may also be used between different materials on the construction site and when constructing drainage elements such as filter loads and rigoles (see above).

References

[1] DIN 4020. Geotechnische Untersuchungen für bautechnische Zwecke, 2010 - Ergänzende Regelungen zu DIN EN 1997-2.

[2] DIN 1054. Baugrund- Sicherheitsnachweise im Erd- und Grundbau, 2010.

[3] DIN ISO/TS 22476. German national annex to ISO 22467. Geotechnische Erkundung und Untersuchung, Parts 1 – 12.

[4] EN 1997-1. Eurocode 7- Geotechnical design - Part 1: General rules, 1997.

[5] Polish Ordinance of the Minister of Transport, Construction and Maritime Economy of 25 April 2012 - On the determination of the geotechnical conditions of the foundation of structures (Journal of Laws 2012 item 463).

[6] DS/EN ISO 22476. Danish National Annex to ISO 22467.

[7] Sybilski D. & Kraszewski (Ed.) 2004. Ocena i badania wybranych odpadów przemysłowych do wykorzystania w konstrukcjach drogowych, IBDiM Warsaw, 278 pp. Available online: www.gddkia.gov.pl [Tests of industrial wastes for application in road construction].

[8] DIN 38414-4. Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung; Schlamm und Sedimente (Gruppe S); Bestimmung der Eluierbarkeit mit Wasser (S 4).

[9] PN-EN 12457-4:2006 Characterisation of waste. Leaching.

[10] BBodSchV 1999. Bundes-Bodenschutz- und Altlastenverordnung of 12 July 1999 (BGBl. I S. 1554). Last change through Art. 5 § 31 of 24 February 2012 (BGBl. I S. 212). 34 pp. Available online: www.gesetze-im-internet.de/ [cited 16 Dec 2014].

[11] EAK 2002. Empfehlung für Küstenschutzwerke, korrigierte Ausgabe 2007, *Die Küste* **65**, KFKi (Kuratorium für Forschung im Küsteningenieurwesen), 589 pp.

[12] Kibbel, E. & Henneberg, M. 2004. Dredged material management in Rostock, Handout, Hanseatic City of Rostock, 6 pp. Available online: www.dredgdikes.eu/wp-content/uploads/iaaE.pdf.

[13] IAA 2014. Kostenaufstellung der Industriellen Absetz- und Aufbereitungsanlage für Nassbaggergut der Hansestadt Rostock. Unveröffentlichter interner Bericht.

[14] HTG 2006. Verwertung von feinkörnigem Baggergut im Bereich der deutschen Küste, Fachbericht der Hafentechnischen Gesellschaft Fachausschuss Baggergut, 37 pp. Available online: www.htg-baggergut.de/ [cited 16 Dec 2014].

[15] LAGA 2003. Länderarbeitsgemeinschaft Abfall, Anforderungen an die stoffliche Verwertung von mineralischen Abfällen – Technische Regeln. As per version from 6th of November 2003 as note 20. Erich Schmidt, Berlin 2004, 128 pp. Available online: www.laga-online.de/ [cited 16 Dec 2014].

[16] GÜBAK 2009. Joint Transitional Arrangements for the Handling of Dredged Material in German Federal Coastal Waterways (GÜBAK-WSV), 59 pp. English version. Available online: www.bafg.de/Baggergut/DE/04_Richtlinien/guebag_en.html.

[17] Danish Marine Environment Act (no. 963 of 03/07/2013).

[18] ISO 10694. Soil quality - Determination of organic and total carbon after dry combustion (elementary analysis), 1995.

[19] DIN 18123. Baugrund, Untersuchung von Bodenproben - Bestimmung der Korngrößenverteilung, 2011.

[20] ISO 11277. Soil quality - Determination of particle size distribution in mineral soil material - Method by sieving and sedimentation, 2009.

[21] Projected Polish Ordinance of the Minister of the Environment of 15 July 2014 on the treatment of waste outside landfill installations.

[22] Danish Order on the definition of slightly contaminated soil (no. 554 19/05/2010).

[23] Zealand guidelines 2001. Frederiksberg Kommune, Frederiksborg Amt, Københavns Kommune, Københavns Amt, Roskilde Amt, Storstrøms Amt og Vestsjællands Amt (Eds.). Vejledning i håndtering af forurenet jord på Sjælland [Instructions for handling contaminated soil on Zealand], 26 pp. Available online: www.regionsjaelland.dk.

[24] Danish Executive Order of Reuse - Recycling ordinance (no. 1662 of 21/12/2010).

[25] DepV 2009. Deponieverordnung - Verordnung über Deponien und Langzeitlager. Deponieverordnung of 27 April 2009 (BGBl. I S. 900) with last change through Art. 7 2 May 2013 (BGBl I S. 973) 63 pp. Available online: www.gesetze-im-internet.de/. [cited 16 Dec 2014].

[26] Henneberg, M. & Neumann, R. 2011. 10 Jahre Lysimeterversuche zum Einsatz von gereiftem Baggergut zur Bodenverbesserung in der Landwirtschaft, report, 37 pp. Available online: www.htg-baggergut.de.

[27] Führböter, A. 1966: Der Druckschlag durch Brecher auf Deichböschungen, *Mitteilungen des Franzius-Instituts der Technischen Universität Hannover*, **27**.

[28] DWA M507. DWA Regelwerk Merkblatt DWA-M 507-1, Deiche an Fließgewässern Teil 1: Planung, Bau und Betrieb, Dec 2011.

[29] ZTV-W 210. Zusätzliche Technische Vertragsbedingungen – Wasserbau, für Böschungs- und Sohlensicherungen (Lb 210), EU notification no. 2006/0628/D of 1 Dec 2006.

[30] DIN 18127. Baugrund, Untersuchung von Bondenproben – Proctorversuch, 2012.

[31] DIN 18122. Baugrund, Untersuchung von Bondenproben – Zustandsgrenzen (Konsistenzgrenzen) – Teil 1: Bestimmung der Fließ- und Ausrollgrenze, 1997.

[32] BAW RPW 2006. Richtlinien für die Prüfung von mineralischen Weichdichtungen im Verkehrswasserbau, 21 pp.

[33] Weißmann, R. 2003. Die Widerstandsfähigkeit von Seedeichbinnenböschungen gegenüber ablaufendem Wasser. *Institute of soil mechanics and foundation engineering*, University Duisburg-Essen, issue **30**.

[34] ASTM D4647-13. Standard Test Methods for Identification and Classification of Dispersive Clay Soils by the Pinhole Test, 11 pp.

[35] Polish Waste Act of 14 December 2012 (Journal of Laws of 2013 item 21 with later amendments). Full text in Journal of Laws of 2013 items 1238 and 888 and in Journal of Laws of 2014 item 695.

[36] Aprobata techniczna ITP.AT/18-2012-0052-01.

[37] Batog, A. & Hawrysz, M. 2010. Przydatność mieszanek popiołowo-gruntowych do budowy nasypów komunikacyjnych, *Górnictwo i Geoinżynieria* **34**(2), pp.69-75.

[38] Batog, A. & Hawrysz, M. 2011. Stateczność nasypów drogowych formowanych z mieszanek piaskowo-popiołowych w rejonie Wrocławia, *Biuletyn PIG* **446**: 445-452.

[39] Zabielska-Adamska, K. 2008. Laboratory compaction of fly ash and fly ash with cement additions, *Journal of Hazardous Materials* **151:** 481–489.

[40] Balachowski L. & Sikora Z. 2013. Mechanical properties of bottom ash – dredged material mixtures in laboratory tests, *Studia Mechanica et Geotechnica*, **35**(3): 3-11.

[41] PN-EN 1538: 2010: Performance of special geotechnical works, slurry walls.

[42] CIRIA C731. The International Levee Handbook. London, 2013. 1350 p. Available online: www.ciria.org.

[43] MLUV, 2012. Regelwerk Küstenschutz Mecklenburg-Vorpommern, Bemessungshochwasserstand und Referenzhochwasser (2–5 / 2012), 20 pp.

[44] DIN 19712. Hochwasserschutzanlagen an Fließgewässern. [Flood protection works at streams and rivers], 2013.

[45] Polish Water Law (Journal of Laws 2005.239.2019).

[46] Polish Directive of the Ministry of Environment - Technical conditions to be met by flood structures defined in the Regulation of the Minister of Environment of 20 April 2007: On the technical conditions to be met by hydraulic structures and their location (Journal of Laws 2007.86.579).

[47] PN-EN 1997-1:2008. Eurokod 7 Projektowanie geotechniczne, Polish national implementation of the Eurocode 7, 152 pp.

[48] DS EN 1997-1. Danish National Annex to Eurocode 7: Geotechnical design - Part 1: General rules, 33 pp.

[49] BAW MSD 2011, BAW Merkblatt- Standsicherheit von Dämmen an Bundeswasserstraßen (MSD), Bundesanstalt für Wasserbau.

[50] EurOtop 2007. Wave Overtopping of Sea Defences and Related Structures: Assessment Manual, *Die Küste* **73.** 193 p.

[51] Bonelli, S. (Ed.) 2013. Erosion in Geomechanics Applied to Dams and Levees. John Wiley, Hoboken. 388 p.

[52] Pohl, C. 2009. Witterungsbedingte Gefügebildung bei See- und Ästuardeichen und ihr Einfluss auf die Deichsicherheit, Doctoral Dissertation Universität Duisburg/ Essen, 178 pp.

[53] Pohl, C. & Vavrina, L. 2008. New Approaches for Geotechnical Design of Baltic Sea Dikes, *Proceedings of the 11th Baltic Sea Geotechnical Conference*, Gdansk, Poland, 1005-1012.

[54] Kiekbusch, M. (1999). Beziehung zwischen Konsistenzzahl und undränierter Scherfestigkeit, *Die Bautechnik* **76**(9): 775-784.

[55] Gröngröft, A., Gebert, J. & Eschenback, A. 2014. Water Balance of Dikes Constructed with Dredged Material – Results From a Long-Term Field Test, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 61-66. Available online: www.dredgdikes.eu.

[56] Weißmann, R. & Richwien, W. 2004. Funktionale und statische Bemessung der Abdeckung von Deichbinnenböschungen. *HANSA*, **141** (6): 69-75.

[57] Temmler, H. 2009. Sickervorgänge in Deichen und ihre Auswirkungen auf die Sturmflutsicherheit. *Fachausschuss Küstenschutzwerke*, 20 pp.

[58] Saathoff, F. & Cantré, S. 2014. Geosynthetics and Dredged Materials in Dike Construction, *10th International Geosynthetics Conference, Berlin*, paper 143, 7 pp.

[59] Heerten G., Achmus, M., Boley, C., Grabe, J., Katzenbach, R., Meyer, N., Oumeraci, H., Richter, T., Saathoff, F., Savidis, S. & Scheffer, H.J. 2009. Bauwerke und Bauwerksertüchtigung im Küsten- und Verkehrswasserbau, Unsere Gewässer – Forschungsbedarf aus Sicht der Praxis – Eine Dokumentation von HTG und DGGT, *Schiffahrts-Verlag Hansa* C. Schroedter & Co Hamburg, 65-72.

[60] Saathoff, F. 2006. Beispiele zur Sanierung und Ertüchtigung von Deichen mit Geokunststoffen, *2. Symposium Sicherung von Dämmen, Deichen und Stauanlagen*, Universität Siegen, 9./10.2.2006.

[61] BAW EAO 2002. Empfehlungen zur Anwendung von Oberflächendichtungen an der Sohle und Böschung von Wasserstraßen, *Mitteilungsblatt der Bundesanstalt für Wasserbau* **85**, 30 pp.

[62] DGGT (Ed.) 2010. Empfehlungen für den Entwurf und die Berechnung von Erdkörpern mit Bewehrungen aus Geokunststoffen (EBGEO), 2. vollst. überarb. u. erw. Auflage April 2010, Ernst & Sohn, 327 pp.

[63] DVWK 1995. DVWK-Guideline 306–1995, Application of Geotextiles in Hydraulic Engineering, 36 pp. Based on the German guideline: DVWK 221/1992, Merkblatt Anwendung von Geotextilien im Wasserbau, Deutscher Verband für Wasserwirtschaft und Kulturbau.

[64] BAM 2014. Richtlinie für die Zulassung von Kunststoff-Dränelementen für Deponieoberflächenabdichtungen, Bundesanstalt für Materialforschung und –prüfung, 31 pp. Available online: ww.bam.de [cited 23 Jan 2015].

5. CONSTRUCTION

This chapter covers the requirements on the construction site for the utilisation of dredged materials (DMs), coal combustion products (CCPs) and geosynthetics; namely the handling and storage of the materials, quality control parameters and methods as well as recommendations for the construction technology and the establishment of a high quality vegetation cover, which is the standard erosion protection on dikes. The recommendations on how to choose suitable materials are presented in Chapter 4.

5.1. Material and installation quality

On the construction site, the quality of the installed materials is of importance in addition to the general material quality as discussed in Chapter 4. If the requirements are not met during the pre-analysis, the DM may be treated or improved. The requirements for the installation quality of DMs and CCPs recovered in dike construction are presented in the following.

5.1.1. Quality requirements for DM installation

The following recommendations are valid for fine-grained and mixed-soil type ripened DMs which may contain organic matter and carbonates. For pure dredged sand/ gravel, the standard recommendations for dike construction apply and no recommendations need to be given in this guideline.

There are no particular environmental requirements that directly influence the installation quality. General environmental and particularly geochemical requirements are presented in Chapter 4 and the same parameters are used for the different levels of quality control (Paragraph 5.4.1). Therefore, the following paragraphs focus on the geotechnical quality requirements for the installation of DMs in dikes.

Table 5.1. Installation quality requirements for DMs in sea dike covers

Parameter	Unit	Value
Undrained shear strength (field vane shear test)	kPa	≥ 50
Water content	%	1)

1) The water content should be close to the optimum or only minor on the wet side. It shall only be as high as a c_u > 50 kPa or in addition a DoC > 83 % can be achieved. Furthermore, for installation purposes the water content should not exceed the plastic limit PL much (LI ≤ 0.3).

5.1.1.1. Geotechnical quality requirements for DMs in sea dike covers

The recommended quality control parameter for fine-grained and/ or organic DMs used as dike cover materials is a minimum undrained shear strength as determined with a field vane shear tester of c_u > 50 kPa (this corresponds to a medium strength according to [2]). This value can be determined in a large number of repetitions in the field, easier than compaction control (unless an automatic compaction control device in the compactor is used).

The water content is also closely connected with compactability and shear strength. The general recommendations of Chapter 4 should be applied accordingly as requirements on the construction site. For sea dike covers, the installation water content should not exceed the plastic limit considerably; the recommendation is LI ≤ 0.3. For fine-grained DM with at least some organic matter, a water content on the dry side of the Proctor curve is not generally recommended, although it would considerably reduce the danger of desiccation cracking. Such a low water content usually implies considerable additional energy effort for the drying of the originally wet materials, which produces additional costs and, more importantly, these materials tend to raise dust when the water content is this low so that their installation is impeded.

Usually, the quality of the compacted soil, represented by the Degree of Compaction (DoC) with respect to the Proctor density (ρ_{Pr}), is used as the quality control parameter when installing DMs and other materials in dikes. The closer the water content to the optimal water content, the better.

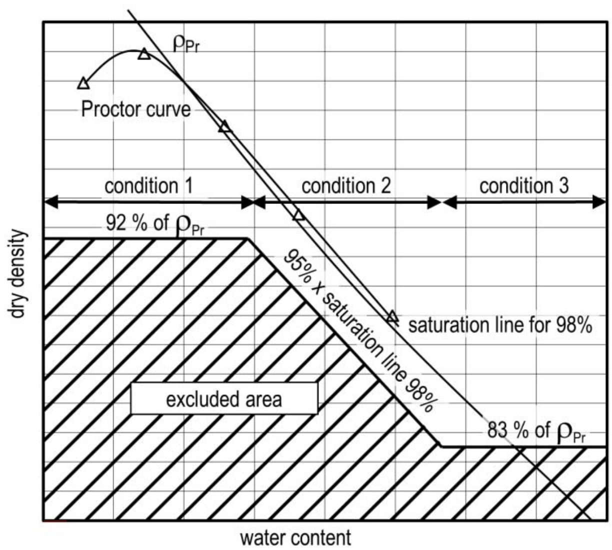


Figure 5.1. Compaction recommendation (based on [3])

This refers to an optimal compaction as well as a lower danger of desiccation cracks. However, it is recommended to use this parameter only for comparison and to assess the c_u value, particularly in the installation test field (Paragraph 5.4.1.1). Then, in accordance with [1] and [3] and the experience from the DredgDikes project, three conditions for a sufficient compaction (Figure 5.1) are recommended:

- Condition 1 (water content close to the optimum): DoC > 92 % (of ρ_{pr} = OD),
- Condition 2 (higher water contents): The dry density at 98 % water saturation is used instead of the Proctor density. Sufficient compaction: DoC_{98} > 95 %,
- Condition 3 (always): DoC > 83 %.

If the DMs are homogenous or homogenised and the client requests compaction control as the main quality parameter (although not recommended here) this procedure should be used. However, it is often difficult to determine a representative Proctor density in the laboratory without considerable effort (e.g. many tests to compute a reliable medium value). Additionally, small deviations of the measured dry densities can significantly impair the DoC result due to the low optimal dry density of DMs rich in organic matter (Annex II).

In case of inhomogenous DM, the Proctor density may vary considerably making the choice of a reference density difficult. These wide variations directly affect the DoC result. Therefore, only the c_u control is recommended then, which may also show variations but can be performed using a denser raster.

5.1.1.2. Geotechnical quality requirements for DMs in supporting bodies and homogenous sections

For pure (dredged) sand to be installed in the core of a sea dike, the geotechnical requirements in EAK 2002 [1] apply in Germany and Denmark. However, in Chapter 4, the use of (sandy) mixed-soil type DMs for supporting bodies and homogenous dikes is discussed. For these solutions the compaction and strength requirements are higher than for sea dike covers and recommendations are presented here.

The supporting body of a sea dike usually requires sandy material. If the water permeability requirements will allow, a small amount of fines and may even be advantageous for compaction, strength or stability. The Degree of Compaction should generally be DoC ≥ 93 % (sea dikes [1]) and DoC ≥ 97-100 % (river dikes [4]) as for standard sand cores. This implies water contents close to the optimum. In case of inhomogeneous materials not homogenised before installation (not recommended) a minimum shear strength should be defined in a test field prior to the construction depending on the required DoC.

For DMs installed in homogenous sea dikes -which is not very common but in case of a large amount of DM surplus may be useful- the method shown in Figure 5.1 is recommended with the following modifications:

- Modification for condition 1 : DoC ≥ 93 %,
- Modification for condition 2: DoC_{98} ≥ 97 %,
- Modification for condition 3: DoC ≥ 86 %.

5.1.1.3. Geotechnical quality requirements for DMs replacing standard river dike sealing materials

For river dikes, the quality requirements of mineral sealing materials are included in national standards and guidelines:

- Germany: DIN 19712 [5], DWA M 507 [6], EAO [7], ZTV-W 205 [4], ZTV-W 210 [8].
- Poland: Regulation on the technical conditions to be met by hydraulic structures and their location [9].

For DMs used as mineral sealing (surface or core sealing), the installation requirements of standard sealing materials (loam, clay) need to be met together with the requirements from Paragraph 4.5.2.7. If a DM with the required low volumetric shrinkage rate is installed close to the optimal water content with high compaction, an increased amount of organic matter compared to the above documents may be allowed due to the long-term stability of the organic matter (Paragraph 4.7.4.1).

5.1.2. Quality requirements for CCP installation

If bottom ash (BA) is used, it should be generally mixed with mineral soil or DM in different proportions and used for the supporting body. The use of BA-soil (DM) mixtures for Polish class I dikes is only recommended in case of renovation (e.g. raising) of existing dikes.

It is necessary to establish a plan for the preliminary laboratory tests of the mixtures including basic soil physical parameters, compactability, shear strength and hydraulic conductivity. A small amount of fines like fly ash or silt is advantageous for compaction, strength and stability.

The degree of compaction should generally be DoC ≥ 93 % as for standard sand cores when no heavy traffic load is considered. This implies water contents close to the optimum. The tests should be performed in the standard Proctor test with energy corresponding to the compaction technology in-situ. The recommended minimum bulk weight of the mixture should always exceed $\gamma = 12$ kN/m^3 to prevent buoyancy and liquefaction.

The maximum ash content in the composite should not exceed 70 %. The appropriate content of ash in the composite should be decided on the results of the preliminary laboratory tests and the design conditions. A content of bottom ash in the range of 30-70 % is recommended based on the DredgDikes experiments. The laboratory shear tests should be performed on reconstituted samples at water content close to the optimum.

In case of a BA-sand composite with relatively high hydraulic conductivity, this parameter should be determined in the constant water head apparatus.

Low permeability barriers can be produced using hydraulic binders containing fly ash or fluidized fly ash. The mixing units should provide a homogeneous medium that can be pumped over long distances. The bulk density and viscosity of the mixture as well as the volume of the decanting water during 24 hours have to be controlled regularly. Quality control of these low permeability barriers should satisfy the requirements of PN-EN 1538 [10].

There are also special mixtures already prepared for application, such as hydraulic binders based on CCPs. These products have to fulfil special requirements, e.g. [11].

The most important parameters are the compression strength and hydraulic conductivity of the mixture. The unconfined compressive strength of the hardened mixture after 28 days has to exceed 0.5 MPa in laboratory conditions and 0.3 MPa for samples taken in-situ. The hardened mixture after 28 days should have a hydraulic conductivity of $k_s < 10^{-8}$ m/s in laboratory conditions and $k_s < 10^{-7}$ m/s when installed in-situ. Before applying CCP-based hydraulic binders in organic or anthropogenic materials (e.g. mixtures with other CCPs or DMs), suitability tests should be performed in a specialized geotechnical laboratory [11].

5.2. Treatment and beneficiation

If the DMs or CCPs (incl. composites) do not immediately meet the environmental or geotechnical requirements for dike construction materials as defined in Chapter 4, different treatment and beneficiation methods may be applied to reduce the water content, to homogenise the materials, to change the compaction curve, improve the strength or fix contaminations in the sediments. It is even possible to mix fine-grained DMs rich in organic content with different ashes to reach one or several of these goals; however, this was not subject to investigation in the DredgDikes project.

5.2.1. DM treatment and beneficiation

Treatment and beneficiation of DMs includes both the improvement of the geotechnical characteristics and the removal or fixation of contaminants.

The most important issue regarding the geotechnical usability is the water content of the materials. If the water content is too high, the required shear strength and recommended compaction cannot be achieved. Therefore, drying should be the first step in a DM treatment procedure. Often, even ripened (basically dried) DMs possess high water contents far above the plastic limit. However, only actual installation tests (5.4.1.1) including the kneading effect of the compactor will show if the materials meet the installation criteria. Only if the criteria are not met, further drying is recommended. To speed up the initial drying, particularly in geosynthetic tube dewatering projects [12], flocculants can be used. However, the economic efficiency should be carefully evaluated.

The homogeneity of the DMs after drying depends both on the quality of the DM itself and the processing technology used in the containment facilities. Usually, as little effort as possible is made regarding the homogenisation, since in standard applications such as landscaping and landfill recultivation, inhomogeneities of the materials play a minor role. In dike construction, however, the reliability regarding the quality of the (cover) material is important and thus homogenisation seems to be an important issue.

Homogenisation can be realised on the drying fields of a containment facility using windrow turners (Figure 5.2) to rebuild drying heaps several times. This also speeds up and intensifies the drying process. Another option are screeners used on the construction site which can be fixed to excavators (Figure 5.3).

A promising possibility to improve the geotechnical characteristics and to fix contaminants in the materials is the conditioning with different additives including hydraulic binders is [13], [14]. The mixing with fibres can also improve the stability and bearing capacity of the materials. Natural fibres, such as coconut fibres, can be used for temporary effects, while permanent solutions may require synthetic fibres; although their use is not recommended due to their environmental impact regarding soil conservation. Another way to improve a DM is to add mineral grains that are missing in the particle distribution.

If the DMs are stored on heaps (piles), they usually become vegetated very quickly due to the intrinsic seeds. The large leaf mass and even more the often thick roots (e.g. reed) need to be removed prior to installation in a dike. Both foliage and roots have a negative effect on compaction. Additionally, the foliage will quickly decompose inside the DMs and thus further reduce the compaction quality. The roots will not decompose as quickly, however, they may function as predetermined seepage flow-paths.

Figure 5.2. Heap piling and homogenisation with windrow turner [15]

Figure 5.3. Homogenisation of DM with screener fixed to an excavator

Figure 5.4. Mixing plant (courtesy Moebius Polska)

5.2.2. CCP treatment and beneficiation

Generally, CCPs should only be applied in dike construction as composite materials, e.g. mixed with sand, soils or DMs or used as hydraulic binders for different purposes. Therefore, the beneficiation of the CCPs includes mixing and homogenisation, in a plant or on location.

Low permeability barriers made with binders containing fly ash or fluidized fly ash can be produced with the trench mixing technology or a vibro injected thin wall technology (WIPS) [16]. The mixture is prepared in a mixing plant (Figure 5.4) and pipelined to the working area. The existing Vistula dike near Gdansk, for instance, was improved by such a low permeability WIPS barrier (Figure 5.9, p. 79).

If the CCPs do not directly meet the required parameters to be certified as a construction material (either according to waste legislation or REACH, cf. Chapter 4), they may be treated to reduce contamination levels or to fix contaminants permanently.

5.3. Handling and storage

5.3.1. Handling and storage of dredged material

When constructing dikes with fine-grained DMs rich in organic matter, the handling and storage is basically similar to any other earth construction material. In order to enable their recovery on site also at a later stage, DMs need to be stored in temporary stockpiles to minimise the occupied surface area and to prevent weather induced damage (e.g. erosion) or negative impacts (e.g. wetting) and damages caused by other construction activities. Recommendations for the layout of a DM depot are provided in Table 5.2.

Table 5.2. Recommendations for dredged material depots

Recommendations for laying out a DM depot
DMs of different quality have to be stored (e.g. [17], [18]).
Avoid mixing of DM with the subsoil in the storage area.
No storage or mixing of other materials/ wastes in the DM depots.
Protect the depots from leaking liquids (oil, lubricant or propellant).
Prevent the temporarily stored soil from compaction and wetness.
Depots should be sited on dry ground, not in hollows and should not disrupt local surface drainage.
4 % surface inclination for the dissipation of precipitation water.
Size and height of the stockpiles depend on several factors: amount of space available, nature and composition of the soil, prevailing weather conditions at the time of excavation.
No traffic on the depots / stockpiles (e.g. by wheeled loaders).

5.3.2. Handling and storage of CCPs

If the material is certified as by-product it should be stored in a way that it is not mixed with subsoil and other materials. CCP products of different quality have to be stored separately. They should be protected against wetness or water run-off. The material should be stored and handled in a way to reduce the dust problem. Depots should be located on dry ground, not in hollows, should not disrupt local surface drainage and should generally not be run over.

Hydraulic binders based on CCPs are transported unpacked in special trucks, pneumatically transferred for storage in tight silos on the construction site. They should be protected against wetness and atmospheric conditions. It is not recommended to use CCP-based hydraulic binders in soil temperatures below 5°C [19].

5.3.3. Handling and storage of geosynthetics

Handling and storage of geosynthetics has to be done carefully. Damages of the materials may reduce their functionality and should therefore be avoided. This applies to physical damage by machines during transport and loading / unloading as well as UV light. Therefore, geosynthetics need to be covered for UV protection while stored on the construction site.

For the handling and storage of geosynthetics on earth construction sites the M Geok E-StB including its check lists [20], [21], [22] applies in Germany, while in Poland general recommendations are given in [23]. For geosynthetic clay liners, EAG-GTD [24] is valid and for geosynthetic drainage composites the BAM guideline [25] contains comprehensive information.

5.4. Quality control

Quality control on the construction site is needed for DMs, CCP composites and geosynthetics as delivered and installed. The recommendations for DMs are restricted to comparably fine-grained materials installed in the cover layer or in homogenous dike sections. For DM installed in the dike core recommendations are given in [1], [9]. Quality control of CCP composites is recommended according to [23], [26] concerning in-situ testing. For the quality control of geosynthetics, reference is given to existing documents. An overview about the quality control systems is provided in Table 5.6 (p. 76).

Generally, the quality control system for all materials used in a construction is based on different levels of control: The suitability test during product development or prior to the installation, the reception control on the construction site, the internal and external quality monitoring (in the production plant and / or on the construction site) and the control inspections by the client on the construction site.

5.4.1. Quality control for the installation of DMs as dike construction material

This paragraph is based on the German recommendations “LAGA M20 TR soil” [27] and “Quality control for marsh clay installation” [3], adapted to the use of DMs. Although based on German documents, the recommendations for quality control are equally valid within the South Baltic Region.

For a functioning quality control system the soil mechanical characterisation needs to be controlled in the internal quality control of the producer/ supplier of the DM, the internal quality control of the contractor and the external quality control contracted by the client. An additional step when recovering DMs in dikes is the installation test field which can be compared to a suitability test.

5.4.1.1. Installation test field – suitability test

Before starting the installation of the DM, a test field shall be prepared with the proposed installation and compaction technology to verify the suitability of the whole installation chain. The test field may be part of the actual construction. The boundary conditions have to comply with those of the actual construction. Therefore, the DM with the highest installation water content has to be tested at least. If there is considerable variation in the water content (e.g. different drying times) it is recommended, however, to choose DMs with three different water contents (highest, lowest, intermediate) to compare the results with the strength and/ or compaction requirements.

The recommended sampling on the test field to define the boundary conditions and soil characteristics as good as possible is summarised in Table 5.3.

The number and locations of the control points need to be adjusted to the chosen installation method. The results of the test field have to be documented and evaluated in a summary report. Particularly the field vane shear test (later used for quality control) and the Degree of Compaction should be compared and evaluated.

Table 5.3. Recommended analyses and sampling on the installation test field and associated field and laboratory tests

Recommended analyses and sampling on the installation test field and associated field and laboratory tests
Undisturbed samples (cylinder samples) to determine density and water content (e.g. DIN 18125-2 and DIN 18121), compute DoC
Field vane shear test (ISO 22476-9)
Lab vane shear test on undisturbed samples
Grain-size analysis (both with and without removal of OM and carbonate, e.g. using DIN 18123 and ISO 11277)
TOC and lime content
Atterberg limits (DIN 18122-1 & 18122-2; alt: ISO-TS 17892-12)
Proctor test (e.g. DIN 18127)
Dry density of the installed material (Degree of Compaction)
Uniaxial compression test (e.g. DIN 18136)

If the requirements of this guideline will not be met with the chosen DM and technology, either the DM can be further treated / improved or the technology has to be varied before a definite decision can be made. For each chosen combination a test field shall be set up.

5.4.1.2. Delivery control, internal and external quality monitoring, control inspection

For the quality control of earth materials classified as waste and used in earth constructions, the requirements of ZTVE-StB 09 [28] apply in Germany, substantiated regarding the chemical characterisation according to LAGA M20 [27]. The precondition for a functioning quality control implies that the DM has been classified according to national regulations (Chapter 4). The travel path of the materials should be completely documented from dredging to installation and included in the material certificate.

When the materials are delivered, a delivery note has to be provided for every batch of material with similar characteristics. A batch can be maximum 2,000 m³; that means that at least every 2,000 m³ a delivery note needs to be provided by the seller. The delivery note should always contain the following information to ensure a required consistent material quality:

- Type of dredged material and waste code
- Delivered amount
- Classification
- Characteristic geotechnical parameters
- Official material certificate (if available)
- Origin of the material
- Date of the delivery

Table 5.4. Recommended quality management and analysis programme during the installation of certified DMs

Recommended quality management and analysis programme during the installation of certified DMs
Continuous visual checks of the delivered materials (including finger test) and control of delivery notes with every delivery
Field vane shear test every 500 m³ of installed material
Sample taking of cylinder samples to determine water content and dry density and thus the DoC every 2,000 m³ of installed DM (client / representative of the client)
Every 5,000 m³ of installed DM the following laboratory analysis should be performed: - Grain-size analysis (after removal of organic carbon and carbonates, e.g. after ISO 11277) - Atterberg limits and Proctor test - LOI, TOC, lime content - Laboratory vane shear test
1 mixed sample every 4,000 m² surface per 1 m layer thickness (at least 1 mixed sample every 200 m dike length and 1 m layer thickness) for chemical analysis (sampling: client / representative of the client; analysis: external lab chosen by client)

Table 5.5. Recommended quality management and analysis programme during the installation of all other DMs

Recommended quality management and analysis programme during the installation of all other DMs
Continuous visual checks of the delivered materials (including finger test) and control of delivery notes with every delivery
Field vane shear test every 500 m³ of installed material
Sample taking of cylinder samples to determine water content and dry density and thus the DoC every 2,000 m³ of installed DM (client / representative of the client)
Every 5,000 m³ of installed DM the following laboratory analysis should be performed: - Grain-size analysis (after removal of organic carbon and carbonates, e.g. after ISO 11277) - Atterberg limits and Proctor test - LOI, TOC, lime content - Laboratory vane shear test
1 mixed sample every 2,000 m² surface per 1 m layer thickness (at least 1 mixed sample every 100 m dike length and 1 m layer thickness) for chemical analysis (sampling: client / representative of the client; analysis: certified testing body)
1 mixed sample per day Sampling and analysis by a certified testing body

The first control of the material quality on the construction site is needed as soon as the materials are delivered (delivery control). Generally, the DMs have to be stored on stockpiles on the depot before they can be installed in the dike. Here, the construction supervisor will order an analysis (both geotechnical and geochemical) to make sure that the delivered material has the desired quality before it is installed in the dike. The recommended minimum analysis programme is provided in Table 5.4.

Only if the materials are delivered from a certified organisation and the material certificates are provided with the delivery, the construction supervisor may decide to renounce an additional analysis.

The internal and external quality control on the construction site should also be distinguished regarding these two basically different boundary conditions. In case of a certified ripened DM from a treatment facility, such as that run by the municipality of Rostock (e.g. certification according to the criteria of the German soil ordinance BBodSchV [29] Annex2), the continuous quality control on the construction site can be limited to the analysis programme provided in Table 5.4.

If the DM is not yet certified (e.g. directly dredged for the purpose of dike construction or simply stored in containment basins or on drying fields, treated or untreated), the material selection is usually based on the analysis of a small number of samples, sometimes even taken under water. These materials need to be controlled more intensively on the construction site (Table 5.5).

The extent of sampling depends on the boundary conditions of the construction site and has to be fixed in a quality control plan. If there is a particularly high quality control standard on the DM delivery side, the intensity of the lab analysis programme for installed material may be reduced. Additionally, quick tests may be permitted. The mixed samples should be produced from 10 evenly distributed samples taken from the test area. The test area has to be documented. If there is obvious evidence about a contamination then this area has to be sampled separately. For continuous compaction control an automated compaction control vehicle (roller compactor) is preferable.

5.4.2. Quality control for CCP composites

The quality control in the power plant mainly focuses on the chemical compounds and the grain size distribution. The quality control regarding the geotechnical parameters should be performed at the construction site.

5.4.2.1. Quality control during CCP production

The requirements for the analysis, evaluation, installation and other recoveries of wastes from power plants need to be quality controlled. In Germany, fly ash and bottom ash from hard coal are controlled according to a quality monitoring system defined in [30] consisting of an internal and external quality control. Before the quality monitoring is started, a proof of qualification has to be documented, consisting of an initial control and a company assessment (initial inspection).

For the internal quality control analyses are performed:

- In the original substance: visual appearance, colour, smell (continuously) and
- In the eluate: colour, turbidity, smell, pH, el. conductivity (once per week).

The classification limits for pH and conductivity are provided in LAGA M20 (tables II.4-1 and II.4-2 [27]).

The external quality control has to be performed every three months for hard coal bottom ash and fly ash. The extent of the analyses and the classification limits are again given in [27].

In Poland, construction products produced from CCPs, such as CCP-based hydraulic binders, are regularly controlled during the production process in the factory. Additionally, there is external constant and periodic control (at least every three years) of the final product.

5.4.2.2. Quality control on the construction site

On the construction site, the CCPs and soils for the composites may either be delivered and stored separately or prefabricated composites are delivered from a plant. In every case, a regular visual control of the homogeneity of the CCPs, soils and composites is recommended.

During installation of CCP composites as dike body or cover, the quality of the compaction should be regularly checked in-situ using typical tests like the plate loading Test or the dynamic plate test in each compacted layer. It is also recommended to check the compaction in the total profile of the dike core using dynamic soundings. Continuous compaction control installed on the compactor is also possible. The compaction should satisfy the general requirements in [1], [4], [9] (GER) and [23], [31] to [37] (PL). The chosen optimal ash-sand mixture for the dike body should be installed close to the optimal water content.

When CCPs are used in barrier systems, the pre-determined optimal mixture needs to be controlled which is needed to satisfy the strength and hydraulic conductivity requirements. Samples should be taken from the mixing plant and from the constructed barrier. The standard recommendations for diaphragm walls should be met [10].

The quality control on the construction site is comparable to that of the DMs, including a delivery control, internal and external quality control and control inspections. Table 5.4 and Table 5.5 can be applied accordingly, under consideration of the relevant parameters of the different CCPs (Chapter 4).

Table 5.6. Quality control measures on the construction site and during material production

Quality control	Dredged material	CCP composites	Geosynthetics
Suitability test	Test field with DM and chosen installation/ compaction technology, using at least DM with the highest possible installation water content (recommendation: 3 different water contents)	Test field with CCP composites and chosen installation/ compaction technology, using at least the CCP with the highest possible installation water content (recommendation: 3 different water contents, two different compositions of the mixture)	Suitability tests during product development or in case of new applications before installation
Delivery control	Field and laboratory analysis performed by the contractor according to this guideline. May be renounced for certified DMs.	Field and laboratory analysis performed by the contractor according to this guideline. May be renounced for certified CCPs.	Analysis e.g. according to CEN TR 15019 and in analogy to ZTVE-StB 09 [28]
Internal quality control External quality control Control inspections on the construction site	Field and laboratory analysis performed by the contractor according to this guideline.	Field and laboratory analysis performed by the contractor according to this guideline.	According to geosynthetics standardisation, ISO EN 9001, documents listed above CEN TR 15019

5.4.3. Quality control for geosynthetics

There are different guidelines and regulations that have to be applied for quality control when installing different geosynthetics in dikes. This paragraph mainly provides reference to the respective documents. General remarks for the quality control of geosynthetics in geotechnical and hydraulic engineering can be found in [38]. The quality control system for geosynthetics consists of an accreditation of the manufacturer, having a certified quality management system (e.g. ISO EN 9001 [39]), the initial type or suitability test proving the suitability of a product for the desired type of use, internal and external quality monitoring and control inspections on the construction site. The general standard for quality control of geosynthetics on the construction site is CEN/TR 15019 [40]. There is a variety of other documents for the different geosynthetics and different levels of quality control and product certification, some of which are country specific (e.g. [41]).

5.4.3.1. Geotextiles

The quality control for geotextiles in hydraulic and geotechnical engineering is presented in the following documents: [20] to [22], [42], [43] (GER), [44] to [46] (PL).

5.4.3.2. Geosynthetic surface erosion control products

There is a variety of geosynthetic surface erosion control products; however, by now there is no standard or recommendation document for the application of surface erosion control products in Europe. In the meantime, the quality control recommendations and regulations for geotextiles should be applied.

5.4.3.3. Geosynthetic drainage composites

For the quality control of drainage composites the same documents apply as for geotextiles. Comprehensive information is provided in [25], [47], [48].

5.4.3.4. Geosynthetic clay liners

The installation and quality control of geosynthetic clay liners generally follows the EAG-GDT [24], which is also used outside of Germany.

5.5. Construction technology

This paragraph provides recommendations about the installation and compaction technologies for dikes made of fine-grained DMs rich in organic matter and CCP composite materials. Particularly when the DMs possess high natural water contents that are on the wet side of the optimum, the installation may differ from that of standard soils. The application of CCP-soil composites also requires special technology, particularly regarding the mixing of the composites. Finally, in the project some important issues regarding the installation of the used geosynthetics were found relevant to be included in this guideline.

5.5.1. Construction technology for DMs

The technology for the installation of dredged sand is sufficiently covered in [1]. Based on the tests performed and experience gained in the DredgDikes project together with information about projects in Bremen and Hamburg, recommendations can be given regarding the installation of DMs with a considerable amount of fines and a TOC of up to 9 % (Table 5.7). The recommendations focus on sea dikes and homogenous dikes rather than sealing material for river dikes. A detailed description of the installation tests and data analysis is included in Annex II.

The cover material is usually placed on the dike by dumpers or tractors with tipper trailers and then distributed and levelled with a bulldozer. Generally, a layer thickness of 30 cm (installed height) should not be exceeded during compaction of fine-grained DM.

Depending on the material quality and proven in the suitability test, the installation with a bulldozer alone may result in sufficient compaction for a sea dike cover. Then, a larger number of crossings together with a layer thickness of 10-20 cm will improve the compaction result regarding the homogeneity in both depth and across the surface.

Usually, additional compaction with a sheep's foot roller compactor will be chosen (Figure 5.5), even if the Degree of Compaction will not differ much from a standard roller compactor, because the knobs on the roller drum knead and remould the soil and in this way form a compound with higher strength and a more homogenous compaction result. Additionally, the interlocking of the different soil layers of max. 30 cm each is improved when the surface of each layer remains the marks of the sheep's foot drum.

The placement of DM by only using the excavator shovel cannot be recommended, since the compaction is always considerably lower than with a compactor. In the DredgDikes project the recommended quality parameters could not be met in this way (Annex II). For steeper slopes, where this technology is sometimes applied, alternative technologies have to be used or the slope has to be redesigned.

Figure 5.5. DM compaction with a sheep's foot roller compactor

Table 5.7. Recommended construction technology for DMs in dikes

	Recommendations
Material homogenisation (Paragraph 5.2.1)	Important for a dike cover material. Technology: windrow turners (usually in the treatment facility) or screener shovels fixed to an excavator (can also be used on the construction site).
Compaction technology for the cover layer of sea dikes	Installation with a bulldozer (max. 30 cm installed height per layer) Compaction with a roller compactor with sheep's foot drum, at least 4 crossings Installation and compaction of the cover layer across the whole dike section on top of the supporting body (preference). For steep slopes recommendations are provided in the text below. Test compaction technologies prior to the project in a testing field (5.4.1.1) Control values for compaction: 5.1.1.1.
Compaction technology for homogenous sections	Installation with a bulldozer (max. 30 cm installed height per layer) Compaction with a roller compactor with sheep's foot drum, at least 4 crossings (kneading important to reduce horizontal preferential flow paths) Installation and compaction of the cover in horizontal layers (preference). Test compaction technologies prior to the project in a testing field (5.4.1.1) Control values for compaction: 5.1.1.2.

Table 5.8. Benefits of a sheep's foot roller for DM compaction

Benefits of a sheep's foot roller for DM compaction
Kneading and remoulding effect to form a compound with higher strength and a more homogenous compaction
Nobs on the roller drum crush larger agglomerates which also adds to homogenisation and compaction
The uneven compacted surfaces allow interlocking of the different compacted layers. This increase
Increase in stability due to the interlocking of the different compacted layers as a result of the marks of the knobs on the roller drum that remain on the compacted surface
Reduction of layer-parallel preferential flow paths due to the interlocking of the layers (knob marks, layer interlocking)

The recommended installation quality for fine-grained DM as determined with the undrained shear strength and/ or the Degree of Compaction is given in Paragraph 5.4.1.

It is desirable to install the fine-grained DM with a water content as close to the optimal water content as possible, however, usually on the wet side of the optimal water content in spite of the possibility of a lower tendency to shrinkage when the water content drops below the optimum (Paragraph 5.1.1.1). On the dry side of the optimum the fine-grained organic materials are usually difficult to handle (e.g. extreme dust formation).

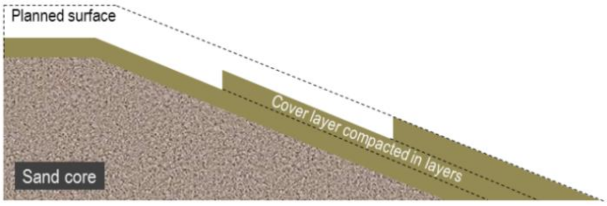


Figure 5.6. Standard installation of a cover layer on a sandy dike core

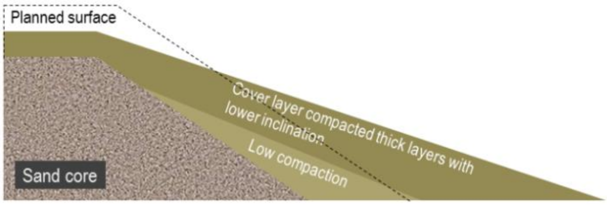


Figure 5.7. Possible problem when installing material in a flatter surface inclination to be profiled later

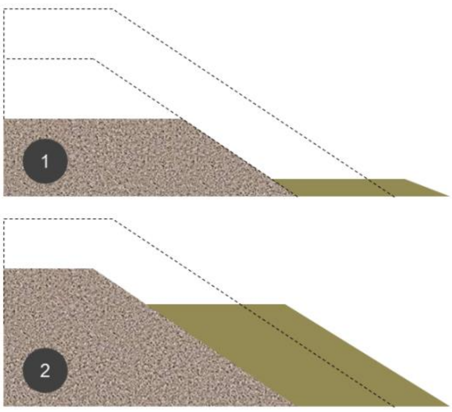


Figure 5.8. Horizontal placement and compaction of the cover layer at steep inclination embankments with sand core.

5.5.1.1. Dikes with sand core and cover layer

Standard bulldozers and compactors can be used up to a slope inclination of 1V:3H, which is usually the steepest inclination for a sea dike. Installation and compaction of the cover layer is then realised by moving across the dike surface in the desired inclination, which is usually the most practicable and efficient way (Figure 5.6).

For slopes steeper than 1V:2.5H the slope parallel installation is difficult with standard machinery. Therefore, alternative installation methods are recommended:

- Installation of the cover material with an inclination of 1V:3H and removal of the surplus material during profiling (depending on the height of the dike this may cause considerable additional mass movement). Particular care has to be taken to the maximum height of the layers (max. 30 cm), since installation in this way may easily result in layers that are too thick at the dike toe. Then the recommended compaction quality cannot be guaranteed there (Figure 5.7).
- Installation of the cover layer in horizontal layers until it reaches the top of the dike (Figure 5.8). Since large machines such as roller compactors and bulldozers usually need a base width of > 3 m to move safely, this would result in a cover layer of nearly 1.5 m on a 1V:2H slope, which is on the safe side (d ≥ 1 m; Chapter 4). If less cover material is demanded the surplus material needs to be removed during profiling.

One of the methods will be more efficient regarding mass movement, depending on the dike height, the desired cover layer thickness, the minimum working width during horizontal installation (usually > 3 m) and the inclination. A calculation example is included in Annex I.

For the compaction in horizontal layers of 30 cm installed thickness a roller compactor is necessary, since the caterpillar tracks of a bulldozer will not cover the whole width of the layers. Additionally, a sheep's foot drum is needed to reduce the effect of horizontal layers of increased permeability (precast flow-paths).

5.5.1.2. Homogenous dikes

If a homogenous dike is designed to be built from DM, the whole section is installed in layers of 30 cm (installed height) and compacted with a sheep's foot roller to reduce horizontal flow paths through the whole dike section. If using only a bulldozer for compaction, the layers need to be thinner and many crossings are needed to guarantee a good interlocking of the soil aggregates without producing preferential flow paths inside the dike body.

Often, the dike body is built in steps in a way that the lower parts of the embankment will be levelled and the surplus material will be used to be installed in upper layers to reduce mass movement. It is essential to guarantee good compaction up to the dike crest.

5.5.2. Construction technologies for CCP composites

For standard dike construction and renovation (raising), the composites from CCPs and (dredged) sand could be treated as common dike construction material. The composites are usually produced in in-situ mixing plants based on to the recipe determined in the laboratory tests. The recommendations for CCP composites as dike core or cover material follow those for DM in 5.5.1. In Table 5.9 the respective recommendations are summarised.

Table 5.9. Recommendations for construction technology for CCP composites in dike construction

	Recommendations
Material homogenisation	Important for a dike core material. Homogenisation with in-situ mixing plant.
Compaction technology for the supporting body (core) of dikes	Installation with a bulldozer (max. 30 cm installed height per layer) Compaction with a roller compactor with sheep's foot drum, at least 4 crossings (kneading important to reduce horizontal preferential flow paths) Installation and compaction in horizontal layers (preference). All compaction technologies need to be tested prior to the project in an installation testing field as for DMs (5.4.1.1) Control values for compaction: 5.1.2
Compaction technology for dike cover layers	Installation with a bulldozer (max. 30 cm installed height) Compaction with a roller compactor with sheep's foot drum, at least 4 crossings Installation and across the whole dike cross-section on top of the supporting body (preference). For steep slopes recommendations are provided in the text above (cf. DM). All compaction technologies need to be tested prior to the project in an installation testing field as for DMs (5.4.1.1) Control values for compaction: 5.1.2

Figure 5.9. Vertical barrier construction (courtesy Moebius Polska)

In addition, CCP composites can be used to produce materials suitable for vertical dike core or toe barriers using the diaphragm wall technology. Therefore, deep soil mixing, trench mixing, vibratory mixing barriers or jet-grouting are used. The mixtures including cement, bentonite or fly ash are produced in mixing plants installed near the construction site (Paragraph 5.2.2). Usually, a vibrator is used to compact the mixture inside the trench.

5.5.3. Installation techniques for geosynthetics

Generally, the installation of geosynthetics is either standardised or information is provided by the manufacturer. This guideline gives additional recommendations based on the DredgDikes project experience.

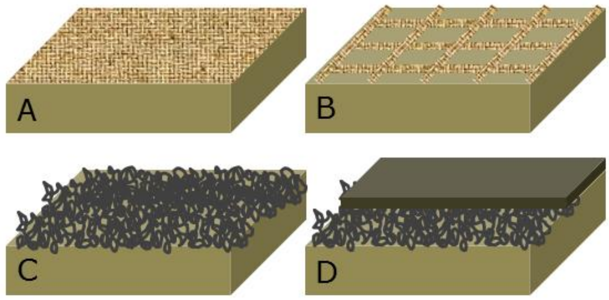


Figure 5.10. Basic types of surface erosion control products. A. erosion control mat GEC-M, up to 100 % coverage; B. grid/net type erosion control product, large spacing; C. Geomat (GMA) used for surface erosion control on top of the soil surface; D. GMA filled or covered with crumbly soil (root reinforcement) or to increase friction between the highly compacted dike cover and a less compacted top soil.

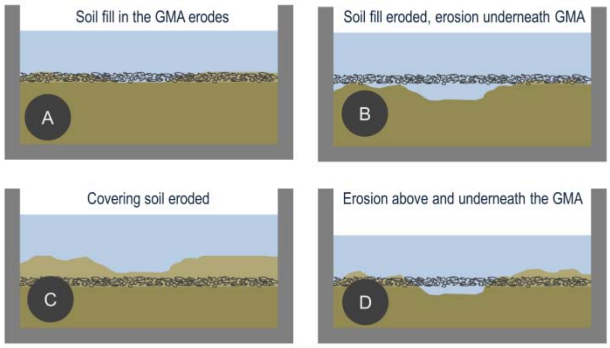


Figure 5.11. Erosion phenomena with GMAs. A. soil fill within the GMA erodes but the subsoil is protected; B. the soil fill has already been eroded or there was no earth fill (Figure 5.10 C), soil underneath the GMA erodes (failure); C. the covering soil erodes, but the GMA protects the subsoil; D. both the covering soil and the subsoil erode (failure).

5.5.3.1. Erosion control products for surface erosion protection and root reinforcement

There is a variety of geosynthetic erosion control products with different mechanisms of action, a selection of which is presented in Figure 5.10. The most important differences are the degree of coverage, the type of material (natural or synthetic), and the possibility to fill the materials with crumbly soil. In the project, a geomat (GMA) and a product combining the effects of a GMA and a geogrid were used. As long as the slope is unvegetated (before seeding or during the germination phase) water and wind induced erosion may occur. If only the soil above and inside the structure of the product is affected, this is relatively unproblematic (Figure 5.11 A,C). If the subsoil is eroded as well, the system starts to fail (Figure 5.11 B,D).

A geosynthetic erosion control product can strengthen a vegetated soil in different ways. When the product is placed directly on top of the soil surface (Figure 5.12 B), the plant itself is stabilised. Seeding may be performed prior to or after the placement of the product. On top of the product, drilling is not possible. Then, seeds should be spread by hand or with a hydraulic seeder. Restrictions regarding this technology on a DM embankment are given in Paragraph 5.6.1.3. When the seeds are placed below the product the opening size is very important. Standard GMAs are often lifted up by dicotyledonous plants, so that the connection of the product with the ground is lost and erosion may occur underneath or –if the product is fixed to the ground very tightly- only the grass species may grow.

When the product is filled with soil but there is no soil layer on top (Figure 5.12 C) the roots are held in place and the root network clings into the products from the beginning. This is the preferred method based on the knowledge gained in the project. In this case, the seeding may even be done before placing the GMA and filling the voids with maximum 1 cm of crumbly soil. With this method, the seedbed preparation as described in Paragraph 5.6.1.1 may be neglected. Further, a mixture of top soil and seeds may be sprayed into the voids with a hydraulic seeder.

If the product is covered with too much soil the root reinforcement layer may be too deep so that the very dense root network will not cling into the product, particularly not in the initial phase (Figure 5.12 D). Therefore, the materials should not be covered with more than 3 cm of soil but rather less. In this case, the seeding has to be performed after placing the product and filling it with soil unless a soil and seed mixture is used as explained above.

There is no standard or guideline about surface erosion control products in Europe so far. Thus, generally the manufacturers' product and installation documentations apply. The installation recommendations based on the project results are summarised in Table 5.10.

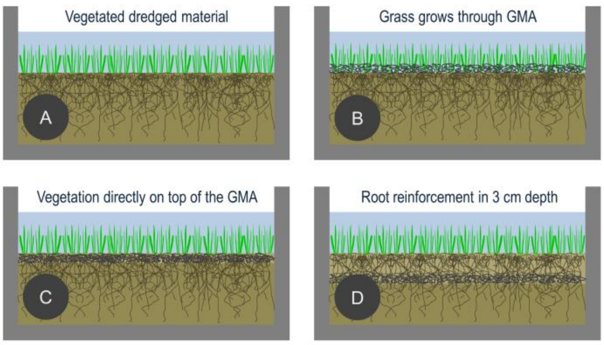


Figure 5.12. Combination of vegetation and GMA. A. vegetated DM without GMA; B. the grass grows through a GMA placed directly on top of the surface (Figure 5.10 C); C. vegetation directly on top of the soil-filled GMA; D. root reinforcement in a depth of ca. 3 cm (Figure 5.10 D)

Table 5.10. Installation recommendations for erosion control products

Recommendations for the installation of surface erosion control products and the associated seeding technology
Fix the product on one side and then stretch it tightly before fixing it to the slope, then walking on the product will not induce shifting and buckling. This guarantees a good contact to the ground.
Fix the product to the ground according to the manufacturer's installation documentation. If steel rods are used to fix the product, a good adaption of the product to the ground has to be guaranteed. Otherwise erosion may occur underneath the product. Therefore, a minimum grid of 1-2 fixations per m² is generally recommended, depending on the material flexibility.
Cover the product with maximum 1 cm of top soil before seeding. This means that the product is rather filled with soil than covered. Very flat products should not be covered to prevent the loose soil on top of an erosion control product from sliding on the product before the roots have clung into the subsoil (Annex II). It is preferred to fill only the voids of the GMA with crumbly soil.

5.5.3.2. Geosynthetic drainage composites

Geosynthetic drainage composites can be used as a replacement for other drainage elements. They are easily installed by rolling them out in longitudinal dike direction. Installation manuals are provided by the manufacturers. Additional information is provided in [25], [47].

In a dike, drainage is usually positioned at the land side toe to define the outflow of the seepage water and to protect the land side slope from wetting or uplift. The standard method is to replace the cover material and sometimes even part of the supporting body / sand core with a stone filter prism (filter load). Alternatively, drainage pipes can be placed at the land side of the dike core. These are led through the cover in defined spacing, depending on the design flow rate [1].

Geosynthetic drainage composites may be used in the following ways to add to or replace these standard methods. An important advantage is the increased filter stability of the products which can also be guaranteed in the long term as demonstrated in [25].

To increase the drainage capacity of a core drainage pipe, a drainage composite may be placed in parallel to the drainage pipe and connected to it. The geotextile filter of the composite needs to be wrapped around the pipe to enable a durable connection. In this way the seepage line will be lowered further inside the core and the pipe installations will still be positioned at the land side corner of the dike core.

To enhance the accessibility of the drainage system with respect to maintenance the drainage pipes may even be placed inside the cover layer with a geosynthetic drainage product attached reaching into the dike core.

Drainage composites may also be placed in a way that they collect the seepage water inside the core / supporting body and drain freely at the dike toe. Then, however, the seepage water drains along the whole dike toe (as with a granular filter load) and special care has to be taken to dissipate the drainage water, since otherwise the area in front of the dike toe may constantly soak and become unstable with respect to overflowing or even become an overall stability threat. Additionally, the drainage composite should always be placed at least 20-30 cm above the ground to prevent unintended coverage with soil or dirt (during or after the construction work) that would block the product and impede the outflow. The actual position should be subject to the design. In homogenous dikes, this system can be enhanced with a gravel rigole which is usually installed as soon as the construction reaches the height in which the rigole ends. Then a trench is dug, a geosynthetic filter is placed inside and the trench is filled with filter gravel before the actual dike is raised to its final height.

More information and drawings of general cross-sections of the different possibilities to use geosynthetic drainage composites for dike drainage are provided in Chapter 4.

5.5.3.3. Geosynthetic reinforcement

There are two standard applications for the use of reinforcement geosynthetics in dike construction: The reinforcement of the dike body itself, often realised by the wrap-around method [49], and the ground reinforcement by placing a geosynthetic reinforcement layer underneath the dike on top of the planum to level settlements and to insure trafficability during the construction (e.g. reinforced construction road). The German EBGEO guideline [45] is used instead of a national application document of CEN in many European countries. Dike reinforcement can be built in accordance with this guideline.

In the project, reinforcement was also used inside the dike cover layer made of DM to reduce the size of single desiccation cracks to the depth of the geosynthetic, based on the experience gained in research about the geogrid reinforcement in mineral sealing liners [50].

As a general recommendation for the installation of geosynthetic reinforcement products used as dike base reinforcement, the planum should be prepared particularly even to allow the pretensioning of the product (e.g. with a traverse fixed to an excavator or wheel loader) and guarantee a good contact between product and planum.

5.5.3.4. Geosynthetic clay liner

The installation of a geosynthetic clay liner generally follows the EAG-GDT [24] guideline as well as the installation manuals provided by the manufacturers.

5.6. Vegetation cover

Vegetation (grass cover) is the most common erosion protection measure on dikes. Even if some parts of a dike are particularly armoured by stone or asphalt revetments, a well-established grass cover is vital for the stability of most dikes. The turf provides protection against erosion and also reduces moisture penetration from precipitation. The vegetation needs to establish quickly after the completion of the dike construction and needs to be maintained in a good condition during the lifetime of the dike to keep a dense grass cover. A variety of investigations regarding the vegetation development on DMs and CCP-composites were performed in the DredgDikes project (Annex II). Based on the project findings recommendations are presented here.

5.6.1. Vegetation cover on dredged materials

In the German EAK 2002 [1], which is also applied in Denmark, the following seeding method is recommended to achieve a dense turf on dikes:

- Harrow the soil to a depth of 5 cm,
- Spread the seed with a spreader and press it to the surface with a roller,
- Initial fertilising is regarded advantageous,
- Perform seeding in adequate weather conditions (not too wet/ too dry, no wind, soil temperature > 8°C).

The recommendations for DMs based on the DredgDikes project and also a long-term experience of vegetated landfill covers made of DM [51] partly differ from those above as will be shown in the following. A summary of the most important recommendations is presented in Table 5.11.

If the dike cover layer is made of fine-grained DM rich in organic matter no additional top soil is needed for the vegetation. The DMs usually possess a favourable soil fertility and high water holding capacity which supports a fast and durable greening (information on the field capacity of fine-grained DMs is provided in Paragraph 4.7.4.1). Only DMs with extremely high clay contents may have to be additionally covered by a fertile top soil, as is usually the case for the standard marl and marsh clay.

Table 5.11. Recommendations for vegetation establishment on DMs

	Recommendations
Seedbed preparation	Remove stones, weed and other foreign objects. Till the surface twice to a depth of 5 cm. Alternatively: Roughen the surface to a depth of 2 cm. Hydraulic seeding directly on the compacted surface only in optimal weather conditions.
Seed mixture	Choose seeds typical for the region. Choose seeds that germinate quickly and generate a thick, dense grass cover. For sea dikes: choose salt resistant species (both regarding the salt water and possible salt contents of the DM). Output quantity usually 20 – 30 g/m².
Seeding technology	Work the seed into the prepared seedbed (rake the seed in by hand or use a drilling machine). Hydraulic seeding is only recommended in optimal weather conditions (see text). No fertilizer donation necessary for fine-grained DMs rich in organic matter. Keep the surface rough (do not use a roller).
Seeding period	Recommended seeding periods: September-October (standard). March-early April (exception).
Maintenance	Early cut to reduce / eliminate species naturally contained in the DM (weeds). Additional early cut when the seeded vegetation is 10-15 cm high. Strong grass growth (due to the fertility of the DMs) may lead to increased maintenance effort compared to other top soils, however also increased stability of the surface. The maintenance issues should be clearly described in the contract.

5.6.1.1. Seedbed preparation

Before seeding, the surface needs to be prepared, e.g. by tilling to a depth of 5 cm twice. Weed, stones and other foreign objects have to be removed. The surface has to be kept free from weed until the seeding is finished [1].

Seeding directly on the compacted cover material / dike surface should generally be avoided. The upper few millimetres of fine-grained DM quickly dry out, especially on a dike which is particularly affected by wind, reducing the germination to zero in a dryer period. In addition, the seed will easily be replaced by the wind if not fixed to the surface.

However, underneath this very thin dry crust the DMs usually hold enough water for the seed to grow. Therefore, at least the roughening of the surface to a depth of 2 cm is necessary to keep the seed on the surface and guarantee enough moisture in good weather conditions.

The seeding on the compacted surface without seedbed preparation may only be an option in combination with a hydraulic seeding technology and in optimal weather conditions (moist and not too cold for several weeks) while the technology may not work in very dry weather due to the quick drying of the surface (as experienced in the DredgDikes project). In addition, hydraulic mulch seeding or other technologies which cover the surface and keep the moisture around the seeds may be used; however, these technologies may not be cost efficient since the DMs are very fertile and show very good germination with the standard methods.

The harrowed seedbed may bring the following benefit: Since the crumbly surface will not crack the compacted DM underneath is protected from the direct solar radiation and thus also partly from evaporation. This may even prevent an extreme initial cracking in the dike cover (while it will not prevent cracks from long-term desiccation processes).

On the other hand the seeding directly on the compacted surface (or the roughening of the surface to only 2 cm depth) may bring the benefit of increased erosion stability, both unvegetated and vegetated.

5.6.1.2. Seed

A dike seed mixture typical for the region is recommended. Information about German standard seed mixtures and special dike seed mixtures with salt tolerance is available in [52]. An output quantity of the seeding mixture of 20 to 30 g/m² is recommended if not otherwise specified by the supplier of the seed mixture.

A standard seed mixture for dike greening supports the stability against erosion of the dike cover because the vegetation will develop fast and permanent. An example for a standard seed mixture for sea dikes is given in Table 5.12. The red fescue (*Festuca rubra trichophylla* LIPROSA/ LIBANO and *Festuca rubra rubra* NFG/TAGERA) is considered salt resistant and forms a dense turf.

5.6.1.3. Seeding technology

The seed has to be raked by hand (Figure 5.13) or drilled with a machine into the prepared seedbed of crumbly DM to support the contact of seed and soil and to enable a good water supply [53].

In the South Baltic Region, it is recommended to perform the seeding in early autumn (Sept - Oct). The seeding in spring (March - early April) is also possible; however, dry and/or cold periods are more likely then. The period from late April to mid-August is not recommended for seeding. Generally, an initial fertilizer donation will not be necessary when fine-grained DMs rich in organic matter are seeded. However, it is recommended to build a test field of 1 m² with the chosen DM prior to the dike construction to evaluate the germination capacity of the seeds.

The project could demonstrate that there is no advantage of pressing the seed to the surface if the seed is worked into a prepared seedbed. The flattened surface dried out even faster and showed desiccation fissures. The rough surface had a higher water infiltration capacity (together with a higher potential to hold precipitation and dew on the slope), was less vulnerable to fissuring and still showed sufficient erosion stability regarding medium rainfall events.

The germination on dikes made of very fine grained DM may be delayed (particularly when compacted or if the seedbed is flattened with a roller) that desiccates fast in exposed positions. Additionally, salt stress may play a role in very warm and dry weather conditions. Salt can cause a repression of germination. For the germination a period of 7 to 10 days is decisive for the further development of the plants. In this period a

Table 5.12. Example for a common German sea dike seed mixture

Cultivar	Seed portion [%]	Seed amount [g/m²]
Festuca rubens	60	18
Lolium perenne	30	9
Poa pratensis	10	3
Total amount	100	30

Figure 5.13. Seeding and raking in by hand on the DredgDikes pilot dike

Figure 5.14. Vegetation cover 1 y after seeding (Rostock test dike)

Figure 5.15. Strong root network system (Rostock test dike)

permanent humidity for germination in the top 1 cm is required. An adequate water supply is also necessary if there is an increased salt concentration in the material. In the Baltic Sea Region, this condition may be expected most likely from September to October, also in March, however seldom from April to August and during the cold period.

In the DredgDikes project the seeding could not be realised in conformity with these recommendations. On the experimental dike, both the geometry and the time factor indicated to choose an alternative technology and timeframe. Hydraulic seeding on the blank compacted surfaces of the exposed slopes with inclinations of up to 1V:2H was carried out in June, just before a dry season of nearly three months started. The germination of the seed failed initially (although germination commenced best on the areas on which no additional actions were taken during the summer once the moisture returned in autumn), however, within one year a good turf (about 80 % cover ratio with the vegetation in a good condition) established on the dike. Since a quick greening is recommended, this may still be rated as a non-optimal combination of method and time.

Recommendations about the seeding in combination with erosion control products are provided in 0.

5.6.1.4. Turf development

As soon as the seed germinates on the DM and when it withstands the first stress there will be an intensive growth (Figure 5.14). The growth of grass on a fine-grained or mixed soil type DM is generally stronger than on some sandy top soils on existing dikes inspected in M-V and the vegetation is able to better endure dry weather conditions. The turf and root development is very good. In the materials used in the DredgDikes project a very thick rooting layer developed during the first year.

The root density gives information about the resistance of the turf against flowing water and wave attacks. The root density in a dike cover should exceed 10^{-5} g/cm³ [56]. This corresponds to a thick and strong rooting network. With DMs from Rostock an average root density in the upper soil layer (15 cm) of $7 \cdot 10^{-3}$ g/cm³ was reached (Figure 5.15).

The investigations on turf development on the research dike started in September 2012. They showed only marginal initial differences between different seeding options (Annex II). In the following years no differences between the variations could be detected. Additional information on the vegetation tests can be found in the project reports [54], [55].

5.6.1.5. Maintenance work – re-seeding and mowing

Good information for the maintenance of the vegetation on sea dikes can be found in [1]. There should be a first initial cut once the grass is 10 to 15 cm high. A second cut should be carried out before acceptance of the seeding through the client. The mowing residues have to be removed, weeds have to be eliminated and bare areas have to be re-seeded. In case of rainfall induced erosion possible rills have to be filled and seeded. The watering of problematic areas may be claimed during the time of contracted maintenance.

The condition for acceptance by the client is reached if the vegetation is uniform in growth and distribution and has a projective cover ratio of 75 % (freshly cut) regarding the plants from the seeding mixture. This should be achieved within 6 months with DMs.

Dredged materials often naturally contain very high portions of seeds and plant remains which are able to germinate, such as reed (*Phragmites australis*), saltbush (*Atriplex*), sea aster (*Aster tripolium*) and quitch (*Agropyron repens*). These weeds may even germinate faster and thus oust the seeded species. An early cut helps to get rid of some species (e.g. *Atriplex*) and to give the seed the light it needs to grow (Figure 5.17). For the seeded species this early cut is also advantageous because it entails tilling of the grass, resulting in a close and green vegetation cover.

During the first year, mowing may be necessary more often than usual (compared to dikes in Mecklenburg-Vorpommern: standard twice a year) because of the DM specifications with its outstanding soil conditions (TOC content, nutrients, water storage capacity).

Figure 5.16. Abundant vegetation before mowing (Rostock test dike)

Figure 5.17. An initial cut on the DredgDikes pilot dike brings unwanted vegetation down and enables the grass development

These aspects should be included in the contract. Useful maintenance strategies and contract specifications can be found in [1], [5].

5.6.2. Vegetation on dike covers made of CCP composites

To establish a healthy, dense grass cover on dikes built with a cover layer of CCPs, an additional cover and / or top soil layer has to be installed. For this additional layer the common requirements and recommendations from the above paragraph apply.

The Polish recommendations and regulations for vegetation on dike covers are identical to those for road embankments as described in [57].

The recommended top soil layer thickness in case of CCP-based dikes is 20-40cm. For this, the benching technique is recommended to stabilise the top layer and avoid sliding on the core or cover blanket made with CCPs. On slopes with low inclination a geosynthetic erosion control mat can be applied to reinforce the top soil on the embankment without the need for benching.

The top soil humus must be prepared as vegetation layer and properly compacted (Degree of Compaction DoC s≥ 90 % at optimum water content).

The composition of ground particles in the top soil (humus) is recommended as follows: 12-18 % clay, 20-30 % silt, 45-70 % sand, > 20 mg/m^2 phosphorus (P_2O_5), >20 mg/m^2 potassium (K_2O), pH > 5.5.

The seeding technique recommendations are the same as in paragraph 5.6.1. Based on the experiments with prefabricated grass sods on the Polish test dike, this technology is not recommended. A seed spreading or hydraulic seeding should be used instead. In case of a hydraulic seeding, the seed mixture should contain fermented sludge, a composition of grass seeds and legume seeds, mulch, fly ash as long-term mineral fertilizer and an acid neutralizer.

The following general seed mixture is recommended for dikes in Poland: *Festuca ovina* 50%, *Festuca rubra* 30%, *Lolium perenne* (10%), *Bromus erectus* (5%), *Brachypodium pinnatum* (5%). It can be customised to specific climate conditions accordingly.

The substantial difference to DM dikes is the lack of nutrients in the actual dike construction material, so attention should be paid to control the nutrition supply during the growing season.

References

[1] EAK 2002. Empfehlungen für Küstenschutzwerke, korrigierte Ausgabe 2007, *Die Küste* **65**, KFKi (Kuratorium für Forschung im Küsteningenieurwesen), 589 pp.

[2] DIN EN ISO 14688-2 Geotechnical investigation and testing - Identification and classification of soil - Part 2: Principles for a classification 2004 (Table 5).

[3] NLWKN 2011. Qualitätssicherung für den Kleieinbau. NLWKN Recommendation (regional coastal authority of Lower Saxony).

[4] ZTV-W-205 1992. Zusätzliche Technische Vertragsbedingungen – Wasserbau für Erdarbeiten.

[5] DIN 19712. Hochwasserschutzanlagen an Fließgewässern, January 2013.

[6] DWA-M 507. DWA Regelwerk, Merkblatt DWA-M 507-1, Deiche an Fließgewässern Teil 1: Planung, Bau und Betrieb, Dec 2011.

[7] BAW EAO 2002. Empfehlungen zur Anwendung von Oberflächendichtungen an […] Wasserstraßen, *Mitteilungsblatt der Bundesanstalt für Wasserbau* **85**, 30 pp.

[8] ZTV-W-210 2006. Zusätzliche Technische Vertragsbedingungen – Wasserbau für Böschungs- und Sohlensicherung, 14 pp.

[9] Directive of the Ministry of Environment - Technical conditions to be met by flood structures, defined in: Regulation of the Minister of Environment of 20 April 2007 on the technical conditions […] hydraulic structures […] (Journal of Laws 2007.86.579).

[10] PN-EN 1538: 2010: Performance of special geotechnical works, diaphragm walls.

[11] Aprobata techniczna ITP.AT/18-2012-0052-01.

[12] Cantré, S: & Schulz, H. 2011. Innovative Baggergutentwässerung mit geotextilen Schläuchen – ein mobiles System im Feldversuch, *Wasser und Abfall* **13** (3): 24 - 29.

[13] SMOCS 2011. Sustainable Management of Contaminated Sediments – Guideline. 32 pp. Available online: www.smocs.eu.

[14] Lime treated soil as an erosion-resistant material for hydraulic earthen structures: state of the art and presentation of the French DIGUE.ELITE project, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 75-84. Available online: www.dredgdikes.eu.

[15] Midwest 2014. Website of Midwest Bio-Systems Inc. www.midwestbiosystems.com/system.html [cited 15 Jan 2015].

[16] Kuś, R. & Słowikowski, D. 2012. Zastosowanie Wybranych Technologii Uszczelniania Podłoza Gruntowego W Budownictwie Hydrotechnicznym – Wieloletnie Doświadczenia PRGW, *European Symposium Anti-Flood Defences*, Paris/ Orléans, 8 pp. Available online: www.donnees.centre.developpement-durable.gouv.fr/symposium/expose/ST2-2_pol.pdf [cited 10 Jan 2015].

[17] DIN 19731. Bodenbeschaffenheit, Verwertung von Bodenmaterial,

[18] DIN 18915. Vegetationstechnik im Landschaftsbau, Bodenarbeiten

[19] Ecotech 2008. Ogólna Specyfikacja Techniczna: Ulepszanie Gruntów Spoiwem Tefra 15.

[20] FGSV 2005b. Technische Lieferbedingungen für Geokunststoffe im Erdbau des Straßenbaues (TL Geok E-StB 05) – 549.

[21] FGSV 2005a. Merkblatt über die Anwendung von Geokunststoffen im Erdbau des Straßenbaues (M Geok E-StB) – 535.

[22] FGSV 2005c. Checklisten für die Anwendung von Geotextilien und Geogittern im Erdbau des Straßenbaues (C Geok E-StB) – 535/1.

[23] Ogólna Specyfikacja Techniczna. Dział 03 Roboty ziemne (General Technical Specifications Chapter 3 Earthworks)

[24] EAG-GTD: Empfehlungen für die Anwendung von geosynthetischen Tondichtungsbahnen (Bentonitmatten). Empfehlungen des Arbeitskreises 5.1 „Kunststoffe in der Geotechnik und für den Wasserbau“ der Deutschen Gesellschaft für Geotechnik DGGT. Ernst & Sohn, 2002.

[25] BAM 2014. Richtlinie für die Zulassung von Kunststoff-Dränelementen für Deponieoberflächenabdichtungen, BAM FB 4.3, 5. Auflage, 31 pp. Available online: www.bam.de.

[26] EN 1997-1. Eurocode 7- Geotechnical design - Part 1: General rules, 1997.

[27] LAGA 2003. Länderarbeitsgemeinschaft Abfall, Anforderungen an die stoffliche Verwertung von mineralischen Abfällen – Technische Regeln. As of 6 Nov 2003 as note 20. Erich Schmidt, Berlin 2004; 128 pp. Available online: www.laga-online.de [Cited 16 Dec 2014].

[28] ZTVE-StB 09. Floss, R. (Ed.) 2009. Zusätzliche Technische Vertragsbedingungen und Richtlinien für Erdarbeiten im Straßenbau, Kommentar und Leitlinien mit Kompendium Erd- und Felsbau, 4. Auflage, 660 pp.

[29] BBodSchV 1999. Bundes-Bodenschutz- und Altlastenverordnung as version from 12th of July 1999 (BGBl. I S. 1554). Last change through article 5 paragraph 31 of the act of 24 February 2012 (BGBl. I S. 212), 34 pp. Available online: www.gesetze-im-internet.de [Cited 16 Dec 2014].

[30] RGMinStB93Bek 1996. Regulations for quality monitoring of materials in road construction, German administrative regulation.

[31] Koda E., Osiński P. & Głażewski M. 2010. Agrogeotechnical improvement of earth structure slopes, Scientific Review – Engineering and Environmental Sciences **50**(4): 36–47. Available online: http://iks_pn.sggw.pl/z50/art4.pdf.

[32] Koda E. & Osiński P. 2011. Slope erosion control with the use of fly-ash and sewage sludge, Annals of Warsaw University of Life Sciences – SGGW, Land Reclamation **43**(2): 101–111. Available online: http://ann_landreclam.sggw.pl/z432/art1.pdf.

[33] PN-B-06050. Geotechnika, roboty ziemne, wymagania ogólne.

[34] PN-B-02479. rządzenia wodno-melioracyjne. Nasypy. Wymagania i badania przy odbiorze, 1997.

[35] Modernizacja wałów przeciwpowodziowych, Poradnik projektanta, *CETCO, Zielona Góra. Available online: www.cetco.pl.*

[36] Borys M., Mosiej K. & Topolnicki M. 2006. Projektowanie i wykonawstwo pionowych przegród przeciwfiltracyjnych z zawiesin twardniejących w korpusach i podłożu wałów przeciwpowodziowych, Wydawnictwo IMUZ, Falenty, 64 pp.

[37] Polish project of Law: Ordinance of the Minister of Environment of 15 February 2015 on soil & ground quality standards.

[38] Saathoff, F. 2003. Geosynthetics in geotechnical and hydraulic engineering, *Geotechnical Engineering Handbook*, Vol. 2: 507 - 597. Berlin : Ernst & Sohn.

[39] ISO EN 9001. Quality management systems – Requirements.

[40] CEN/TR 15019. Geotextiles and geotextile-related products. On-site quality control, 2006.

[41] DIN 18200. Assessment of conformity for construction products - Certification of construction products by certification body, 2000.

[42] Saathoff, F. 2005. E 5-5: Qualitätsüberwachung für Geotextilien (Entwurf), *Die Bautechnik*, **82**(9): 590-592.

[43] Wilmers, W. 2009. Qualitätssicherung bei der Anwendung von Geokunststoffen im Erdbau, *BauPortal* 9/2009: 530-537.

[44] PN-EN 1997-1:2008. Projektowanie geotechniczne. Część 1: Zasady ogólne.

[45] EBGEO – Empfehlungen für Bewehrungen aus Geokunststoffen, Deutsche Gesellschaft für Geotechnik, 2010.

[46] Specyfikacje Techniczne Wykonania i Odbioru Robót Budowlanych

[47] DIN EN 13252. Geotextilien und geotextilverwandte Produkte - Geforderte Eigenschaften für die Anwendung in Dränanlagen; [EN 13252 Geotextiles and geotextile related products. Characteristics required for use in drainage systems].

[48] BAM 2013. Richtlinie für die Anforderungen an die Qualifikation und die Aufgaben einer fremdprüfenden Stelle für Kunststoff-komponenten im Deponiebau, BAM FB 4.3, 7. Auflage, 16 pp. Zudem: Anlagen 3, 4.3, 5. Available online: www.bam.de.

[49] Saathoff, F. 2006. Beispiele zur Sanierung und Ertüchtigung von Deichen mit Geokunststoffen, *2nd Symposium Sicherung von Dämmen, Deichen und Stauanlagen*, Universität Siegen.

[50] Thomas, H. & Cantré, S. 2009. Applications of low-budget photogrammetry in the geotechnical laboratory, *The Photogrammetric Record* **128**(24): 332 - 350.

[51] Morscheck, G. & Henneberg, M. 2012. Einsatz von gereiftem Nassbaggergut als Rekultivierungssubstrat in Oberflächen-abdichtungssytemen, report for the Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern, 78 pp.

[52] FLL 2014. Website of the Forschungsgesellschaft Landschafts-entwicklung und Landschaftsbau e.V., www.fll.de, [cited: 16 Dec 2014].

[53] DIN 19657. Sicherung von Gewässern, Deichen und Küsten-dünen; Richtlinie. Ausgabe 1973-09.

[54] Henneberg, M. 2014a. Begrünungsversuche im Rahmen des EU Projektes DredgDikes. Prüfung des Auflauf- und Anwuchsverhaltens […] in einem Gefäßversuch. Final report, 41 pp. Available online: www.dredgdikes.eu.

[55] Henneberg, M. 2014b. Begrünungsversuche im Rahmen des EU Projektes DredgDikes. Parzellenversuch auf dem Pilotdeich Körkwitzer Bach […]. Final report, 27 pp. Available online: www.dredgdikes.eu.

[56] Vavrina, L. 2012. Bewertung der Schutzfunktion bewachsener Deichbinnenböschungen gegen Erosion. Ph.D thesis, Essen: VGE-Verlag.

[57] Specyfikacja Techniczna GDDP nr D - 06.01.01 „Umocnienie powierzchniowe skarp, rowów i ścieków".

6. MAINTENANCE AND MONITORING

The operation and maintenance of dikes in general is well documented in [1], [2], [3], [4], [5]. The maintenance concerns encroachments, vegetation management, burrowing animals, erosion and bank caving, settlements, seepage, general and local instability, cracking, and transitions. Many of these aspects are independent of the particular earth materials used for the construction and thus are valid for dikes made of DMs and CCPs likewise, such as the assurance of long-term stability and functionality and the control of long-term deformations. However, there are specific issues with DMs and CCPs when it comes to monitoring and maintenance, such as the vegetation cover and the preservation of the overall average hydraulic conductivity (fissuring, soil formation). Dike inspections are intensively covered in the standard dike literature, including investigations, instrumentation and monitoring, e.g. for seepage water control.

In Poland, all procedures concerning the maintenance and monitoring for (river) dike constructions must be aligned with the law [5]. Periodic monitoring must be scheduled at least once a year to control the technical state and once every five years to check the functionality state. The yearly inspection is a rough visual control without testing. Generally the monitoring is made in spring, but it is also suggested to make an additional inspection in autumn. The five years inspection is more detailed and includes some testing and geodetic surveys. The principal aim of periodic control is to establish the list of all necessary repairs, their extent and schedule. Additionally, extraordinary inspections must be carried out after some events, i.e. when the flood water level exceeds warning or alarm levels or when the dike or hydraulic structures were damaged.

During the periodic or extraordinary inspections four elements should be evaluated: the construction of embankment, the subsoil incl. ground water flow, the hydraulic structures and the area around the dike (50 m).

In Mecklenburg-Vorpommern, an official yearly dike inspection is performed at river dikes only. The legal basis is provided in the Water Act of the federal state of Mecklenburg-Vorpommern [8]. The inspection should be performed by the dike associations (not in M-V, therefore performed by an authority) or the water & soil associations (lower order dikes).

Only a selection of interesting and critical issues of sea dikes is inspected during the yearly coastal inspection tour (Küstenbereisung) of the StALU. Dikes made of DM and CCPs should always be included in the yearly inspection tour or separate yearly inspections should be organised. During the first year, the inspections should be more frequently to gain sufficient data on all important aspects. This may be contracted in the frame of the construction monitoring according to the environmental requirements defined in the planning approval.

In the following, recommendations are given for the maintenance and monitoring when constructing dikes with DMs or CCPs.

6.1. Maintenance and monitoring of dikes made of fine-grained DM

When dikes are built with fine-grained DM and particularly if it is rich in organic matter, there are several issues that need particular attention, such as the susceptibility to fissuring including possible countermeasures, the vegetation development and maintenance, animal activity and the monitoring of seepage discharge.

6.1.1. Maintenance of dike covers and crack repair

The problem of desiccation cracking is discussed in Chapters 4 and 5. If cracks occur in a cohesive cover layer made of DM during the construction time, different actions are possible:

- Large cracks can be backfilled with the same DM and compacted, e.g. using a rammer.
- In case of a large number of cracks, the surface can be broken up (e.g. using a soil tilling machine) and then recompacted. The initial cracking may be completed by then and further cracking will be minimised.

Still, it cannot be assured, that cracks will not develop in a certain depth underneath the embankment surface (inside the cover layer or a homogenous dike). This may happen if the DMs possess a very high capillary suction potential so that the pore water can be transported to the surface from several decimetres in depth. If the upper 50 cm are intact (e.g. reconstructed) and there are no particularly wide cracks going through the whole cover layer reaching the sand core, the cracks are not assessed as critical under this guideline. Thus, surface maintenance (influence of 50 cm) should be effective.

Once the vegetation has been developed, the tilling of the surface will destroy the grass cover which will have to be rebuilt. Therefore, the filling of single and particularly large cracks may be sufficient as long as the quality of the grass cover is good. In case of a large number of cracks, however, this may be inefficient.

The frequency of dike inspections in which, apart from other issues, also cracks should be detected, are defined in the national guidelines and standards on river and sea dike construction (cf. above).

6.1.2. Maintenance of a good vegetation cover

The vegetation usually develops well on fine-grained DMs rich in organic matter. Due to the good water holding capacity the availability of water for the vegetation during dry periods is also advantageous compared to sandy top soils often used to establish vegetation on standard clay dike covers (marsh clay, marl, standard clay).

In general, a uniform turf will develop within one year. In the beginning, intrinsic seeds (e.g. saltbush and reed) often grow intensively (pioneer vegetation) and tend to supress the new grass seeding. Particularly the saltbush and reed can be supressed by an early cut, only sometimes a second cut is needed. As soon as the grass germinates and starts to build a dense turf, the pioneer vegetation will be supressed permanently.

Due to the favourable soil fertility of DMs rich in organic matter together with the high water storage capacity, the grass may grow faster and denser once established than on standard top soils. Therefore, additional cutting may be necessary, particularly during the first two years.

The responsible bodies need to decide during their inspections when the grass should be cut and what kind of mowing technique should be applied. If the undesired weeds exceed an area coverage of 20 %, the vegetation should be cut immediately. In the maintenance plans, a late summer date may be chosen at least for some parts of the dikes to keep the habitat for insects as long as possible and to foster the seed production of the vegetation for a better long-term turf development.

The quality of the turf should be controlled every spring before the new grass starts to grow or alternatively directly after the cut (usually in summer). Then a degree of coverage may be determined and single spots of low vegetation quality (this may even be caused by animal activity) should be immediately reseeded (therefore the spring inspection is preferable). The determination of vegetation coverage and surface damages may be performed using air based observation techniques (e.g. using unmanned aerial systems [6]).

A pasturing with sheep as on the North Sea dikes may be an alternative. The tread of the sheep reduce the cracking and the activity of burrowing animals.

6.1.3. Repair and prevention of damages caused by animals

DM rich in organic matter used to build a homogenous dike or a sea dike cover in only one material layer is in danger of voles and other burrowing animals. The comparably soft and light characteristics of the materials (in spite of a good compaction), in combination with the formation of cracks (which are also used and extended by voles), the high internal erosion stability of the DM (stable burrows) and an increased food supply (roots, seeds and other organic particles) support the activity of voles and other animals, such as rabbits, foxes, raccoon dogs, minks and wild pigs. This problem should be addressed with standard methods like filling the burrows or using sheep on the dike (which also trample on the burrows, cf. above). In the DredgDikes project an intensive vole activity could be observed in the Rostock experimental dike, however, there was no loss of stability. Initial seepage leakages from vole burrows could only be detected in the first year of investigations. Without additional measures the leakage stopped in the second year. Therefore, the inspection and assessment about the dimension of the vole activity is of great importance.

In some regions, the beaver may be a problem. However, the European beaver only digs burrows in earth constructions bordering directly on water, so that the burrow entry is located underneath the water surface and thus they are no threat to dikes distant to the usual water current. A detailed description of methods of preventing damages caused by beavers is included [7]. In some Polish dikes the regional water management authorities (RZGW) impose the placement of a special metal grid in the surface layer to prevent burrowing in renovated dikes.

Damages from these larger animals usually impose the frequent repair of the sections, preferably with a DM of similar quality than the one originally used for the construction. Also, the issue of possible damages caused by larger animals should be considered during the construction, e.g. by the use of wire meshes that are bite resistant or additional gravel layers [2], in which, for instance, the animals cannot build burrows.

6.1.4. Discharge monitoring

As experienced in the DredgDikes project and in other applications of brackish DMs in Germany (M-V), salts and nutrients can be washed out by rainfall and seepage. Furthermore, changing redox conditions may cause the precipitation of ferrous oxides often contained in the DMs.

Therefore, a discharge monitoring should be included in any dike construction project with the use of DMs, even if they are not contaminated. The monitoring should include standpipes for seepage sampling at different points along the dike. Together with the permitting authority (e.g. nature protection agency) the boundary conditions including the number of standpipes and the frequency of sampling and analysis should be agreed.

The recommendation of this guideline is the installation of a system of standpipes for both water sampling and an automated electronic measurement of the ground water table / phreatic line. Usually more than one reference cross-section should be defined with at least three standpipes each. Their exact position and the choice of the actual number of reference sections and instrumentation are subject to a functionality based expert decision in the frame of the permit planning (in Germany: Landscape Conservation Plan and Environmental Impact Study in the course of the Planning Approval Process).

If different batches of DM are installed in a larger dike construction, the decision regarding reference sections should include their characteristics (e.g. different classifications in the respective national DM classification systems). Exposed locations and places where the high water will first act on the dike may be considered, together with the features of the area, the foreland, and the ground.

The most important issue regarding the discharge of soluble substances from the DM is the path to the ground water. Therefore, the setup of the standpipe system should take into account ground water flow directions and (sub-) soil characteristics.

The sampling is recommended to be performed at least once per year or better, during different high water incidents. The actual outcome of the analysis of the first years may be used as a basis for further decisions on the extent and frequency of the long-term discharge monitoring.

6.2. Maintenance and monitoring of dikes made of CCP composites

There are no particular recommendations in Poland or Germany concerning the monitoring and maintenance of dikes made of CCP composites. Generally, the recommendation of this guideline is to follow typical procedures for river dikes stated above. With regard to discharge monitoring, the recommendations for DMs apply accordingly. An automatic measurement of the water level in the piezometers is also recommended to provide guidance when samples should be taken.

According to the project results from the Gdansk experimental dike, cracks are not an issue in dikes made with CCPs due to the low shrinkage rate of the produced composites. Also, there is no animal activity inside the CCP composites, mainly due to the high pH value and the high degree of compaction that can be realised together with the cementation effects that further strengthen the composites.

Vegetation, on the other hand, is an issue for possible maintenance and monitoring measures, particularly when only a thin top soil layer is built on a dike sealing blanket made with CCPs. A regular visual control of the vegetation cover is recommended during the first two years after construction, followed by the standard periodic visual control from the responsible bodies (Table 6.2 and Paragraph 6.3). However, more investigation is needed on this aspect.

6.3. Responsibilities

The Water Act of the federal state of Mecklenburg-Vorpommern [8] is the official legal basis for coastal and flood protection in Mecklenburg-Vorpommern. The act also defines the responsibilities. The State Agencies for Agriculture and Environment are responsible for the technical supervision in the field of environmental and landscape preservation, water, soil, and coastal protection and particularly for the federal dike system. The authorities are further concerned with the examination of material applicability for dike constructions in general, the planning and approval of coastal and other flood protection structures. In addition, they are responsible for the general supervision of first order dikes (as representatives for the non-existing dike associations) while the water and soil associations (WBV) are responsible for the lower order dikes. Legally, however not actively, the superior authority concerned with dikes is the State Office for Environment, Nature Conservation and Geology (LUNG). In case of a new dike construction or a dike restoration, nature conservation aspects play an important role. The responsible bodies are then the various nature protection authorities.

In Poland the regional water management authorities (RZGW) and the regional water equipment authorities (ZMiUW) are responsible for dike construction, maintenance and monitoring. In-situ inspections are performed by the commission from the local ZMiUW. Maintenance and monitoring must be organized by the RZGW.

Table 6.1. Summary of the recommended maintenance and monitoring for dikes made of dredged materials

Topic	Maintenance measures	Relevant documents	Responsibility
General	General inspections for maintenance and monitoring are a basic rule during the operation of flood protection construction such as dikes.	DIN 19712 (chapter 15) [2] DIN 18310 (security works at waters, dikes and coastal dunes) [9] Din 19657 [10] IMUZ recommendations [3] The International Levee Handbook [4]	**Germany:** Federal dike associations, in M-V the lower water agencies (StÄLU) for 1st order dikes. Dike / water & soil associations for all other dikes. **Denmark**: Municipalities and land owners **Poland**: Responsible authority (RZGW, ZMiUW)
Cracking	*Only in case of sea dikes:* Filling of cracks during and after construction Tilling and recompaction of cracked embankment surfaces during / after construction	EAK 2002 [1] The International Levee Handbook [4]	
Vegetation	Early cut to supress weed growth (intrinsic seeds) Regular cuts, due to the high fertility of the DMs 1 additional cut (decided by responsible body)	EAK 2002 [1] IMUZ recommendations [3] Internal maintenance documents of authorities	
Animals	Close vole burrows (if large or many), Repair larger damages from animal, activity (e.g. beaver or fox burrows), Install wire mesh to prevent burrows, Use sheep to keep the surface compacted which helps against voles.	EAK 2002 [1] International Levee Handbook [4]	
Discharge monitoring	Monitor salts and nutrients in the seepage. Standpipes for sampling / measurements	Report on long-term lysimeter experiments in Rostock [11]	**Germany**: Lower nature agencies Water and soil associations **Poland**: RZGW, ZMiUW

Table 6.2. Summary of the maintenance and monitoring for dikes made of CCPs

Topic	Maintenance measures	Relevant documents	Responsibility
General	General inspections for maintenance and monitoring are a basic rule during the operation of flood protection construction such as dikes.	DIN 19712 (chapter 15) [2] DIN 18310 (security works at waters, dikes and coastal dunes) [9] Din 19657 [10] Building Law Act, instructions for maintenance of dike constructions [5] The International Levee Handbook [4]	**Germany:** Federal dike associations, in M-V the lower water agencies (StÄLU) for 1st order dikes. Dike / water & soil associations for all other dikes. **Poland**: Responsible authority (RZGW, ZMiUW)
Vegetation	Use thick layer of top soil Initial maintenance may include watering	EAK 2002 Building Law Act, instructions for maintenance of dike constructions [5] Internal maintenance documents of authorities	
Discharge monitoring	Monitor heavy metals and other possible contaminations in the seepage. Standpipes for sampling / measurements	Building Law Act, instructions for maintenance of dike constructions [5]	**Germany**: Lower nature agencies Water and soil associations **Poland**: RZGW, ZMiUW

References

[1] EAK 2002. Empfehlungen für Küstenschutzwerke, korrigierte Ausgabe 2007, *Die Küste* 65, KFKi (Kuratorium für Forschung im Küsteningenieurwesen), 589 pp.

[2] DIN 19712-2013. Hochwasserschutzanlagen an Fließgewässern (Flood protection works on rivers). Beuth: Berlin, 68 pp.

[3] Borys M. 2006. Metody modernizacji obwałowań przeciwpowodziowych z zastosowaniem nowych technik i technologii, Wydawnictwo IMUZ, Falenty 2006.

[4] CIRIA 2013. The International Levee Handbook, 1350 pp. Available online: www.ciria.org.

[5] Polish Building Law Act of 7 July 1994 (Journal of Laws 2000.106.1126 with subsequent amendments).

[6] Naumann, M., Bill, R., Niemeyer, F. & Nitschke, E. 2014. Deformation analysis of dikes using unmanned aerial systems, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock, 119-126.

[7] Czech A. 2005. Analiza dotychczasowych rodzajÛw i rozmiaru szkód wyrządzanych przez bobry oraz stosowanie metod rozwiązywania sytuacji konfliktowych, *Environmetal Protection Institute*, Kraków.

[8] LWaG M-V 1992. Water Act of the federal state of Mecklenburg-Vorpommern (Wassergesetz des Landes M-V). Available online: Available online: www.landesrecht-mv.de.

[9] DIN 18310. Security Works at waters, dikes and coastal dunes.

[10] DIN 19657. Protection of beds, banks of waters, dikes and coast dunes.

[11] Henneberg, M. & Neumann, R. 2011. 10 Jahre Lysimeterversuche zum Einsatz von gereiftem Baggergut zur Bodenverbesserung in der Landwirtschaft, report, 37 pp. Available online: www.htg-baggergut.de.

GLOSSARY

There are several substantial glossaries on dredged materials, waste recovery, hydraulic constructions and geosynthetics (e.g. [1], Annex I of [2], [7]). Only a selection of terms important for the guideline is summarised here, ordered by the topics Dikes, Dredged Materials, Coal Combustion Products and General Terms of Waste Management.

Dikes

Air side slope

Cf. downstream slope.

Containment dike

A containment dike is a dike that is used to enclose a basin for temporary or permanent containment of water or sludges. Permanent containment dikes are often used on dredged material containment facilities, temporal containment dikes are used e.g. while dredging the sand for the construction of a dike sand core or for temporary deposits of dredged sludges.

Dike

A dike is a dam to protect the hinterland against flooding, which mainly consists of earth materials (soils) and which is only temporarily loaded by water (e.g. in extreme flood events). Synonymous terms are "dyke" and "levee". The main distinction is made between river and sea dikes because of their fundamentally different operation [3].

Downstream slope

The downstream slope of a flood protection structure is the slope with direction to the hinterland. It is only attacked in case of overtopping/ overflowing water. This term is used for river dikes.

Inner slope

Cf. downstream slope, also used for sea dikes.

Landside slope

Cf. downstream slope, however also used for sea dikes.

Levee

See dike. In American English usually a river dike.

Outer slope

Cf. upstream slope, also used for sea dikes.

Overflowing

Overflowing in the frame of this guideline is the term for water flowing over the crest of a flood protection structure due to a static water level that exceeds the crest height.

Overtopping

Overtopping in the frame of this guideline is the generic term for water coming across the crest of a flood protection structure while exceeding the crest height. This can be wave overtopping or overflowing.

Polder

A polder is a low-lying area in the vicinity of water bodies which is enclosed and thus protected by dams or dikes. In the containment facility of the Rostock municipality the areas where the dredged material is initially dredged to and which are enclosed by containment dikes are also called polders (dredging polders). Therefore, the basins of the Rostock research dike facility, which are enclosed by the test dikes, are named polders as well.

River dike

A river dike is a dike protecting the land adjacent to a river from high water levels and flooding.

Sea dike

A sea dike is a dike protecting the coastal lowlands from storm surges and high sea water levels. Also: coastal dike.

Upstream slope

The upstream slope of a flood protection structure is the slope with direction to the water body. It is usually directly attacked during flood events. This term is used for river dikes.

Waterside slope

The water side slope of a flood protection structure is the slope with direction to the water body (cf. upstream slope). This term is also used for sea dikes.

Wave overtopping

Wave overtopping in the frame of this guideline is the term for water coming across the crest of a flood protection structure due to the wave run-up leaking over the crest.

Dredged materials

Biodegradation

This means natural decomposition of plant fibres/ organic matter through microorganisms. These processes can be stepped up through technical appliance and support the decomposition of contaminants, e.g. load of mineral oil.

Brackish DM

Brackish sediments/ DMs consist of sand and silt as well as natural soils like marl/till and mud. The organic matter content often exceeds 10 %. In containment facility polders in Mecklenburg-Vorpommern (particularly near the water outlet at the end of the polder) clay particle contents of more than 40 % and lime contents of up to 10 % have been found.

Chemical bonding

The chemical bonding should immobilize the inorganic contaminants through addition of substances which decreases the elution of contaminants from the treated sediments/DMs [4].

Classification

Classification in the context of sediment management and treatment is the separation of different grain fractions, by sieves, hydrocyclones or sedimentation basins. This also refers to the separation of less contaminated coarser fractions and more contaminated fine fractions from the original DM (grain classification).

In the context of material characterisation, the dredged materials may be classified according to regulations and recommendations with regard to their contaminations.

Dewatering

Dewatering enables the separation of water from the solid content. Sand and gravel can be dewatered easily in dewatering fields or with dewatering screens. Silty materials can be dewatered either naturally in dewatering fields or technically, e.g. using belt filter or chamber filter presses. Dewatering is the most common treatment to affect the soil mechanical properties of DM. Dewatering may include several steps, from initial dewatering via the dewatering in fields to the final (long-term) dewatering on stockpiles / ripening fields.

Dredged material (DM)

Dredged materials are excavated materials with different parts of mineral and organic properties, which accumulate in or on the water bodies in the course of waterway maintenance and other hydraulic construction work. In this guideline the terms “dredged sand”, “fine-grained DM”, “mixed soil”, “DM rich in organic matter” and “ripened DM” describe the term in more detail.

Dredged material rich in organic matter and lime

Dredged material rich in organic matter and lime in the frame of this guideline is defined as material that has an organic matter content of more than 5 % (or TOC > 3 %) and a lime content of more than 5 %.

Dredged sand

Dredged sand is sand (> 0,063 mm) with a maximum amount of fines < 10 % and a TOC < 5 % that has been dredged from water bodies.

Fine-grained dredged material

Fine-grained dredged material in the frame of this guideline is DM with > 15 % of the finest fraction (< 0.002 mm, clay particles). These materials often contain 15 – 35 % clay; 25 – 55 % silt and 20 – 55 % sand particles.

Fines/ fine particles

The term “fines” with respect to the mineral grain size distribution relates to the silt and clay particle fraction (d < 0.063 mm).

Finest/ finest particles

The term “finest” with respect to the mineral grain size distribution relates to the clay particle fraction only (d < 0.002 mm).

Heap

Cf. windrow.

Limnic DM

Limnic DM usually contains less silt than brackish DM, however, the organic matter and the lime content can exceed 30 %. A variety of investigations showed the great range of variations in the its composition. In M-V clay contents differ from 2 to 30 %, the TOC from less than 5% up to 30% and the lime content from 0 to 70%. Despite of the biogenic sulphur compounds, limnic DM contains only small portions of sodium and chloride.

Mixed soil / mixed dredged material

Mixed soil in the frame of this guideline is DM having a high degree of uniformity incl. a considerable amount of fines. These materials often contain 5-15 % clay, 5-25 % silt and 65-90 % (fine to mid) sand particles.

Recovery of dredged material

Recovery of DM means "any operation the principal result of which is waste serving, a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy" [5].

Reuse of dredged material

In [5], "reuse" "means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived", however, such a type of reuse is not possible for dredged materials, which is why it is often used synonymously for recovery.

Ripening / ripened dredged material

The ripening process is generally the drying of the DM, associated with mineralisation and soil genesis effects. Ripened DM is thus material with considerably reduced water content and with aerobic soil genesis effects at least started. This term mainly describes fine-grained dredged material or mixed soils such as sandy loams and loamy sands. Physical, chemical and biological effects affect the ripening process.

Separation

In the scope of this guideline this term is used for the separation of batches by grain size, for instance by sieves or hydro-cyclones. Separation is mainly used in the grain size range of 20 <d < 63 µm (cf. classification).

Thermic processes

Desorption, oxidation and bonding are thermic processes that are used to destroy, removed or bind contaminants in the matrix of a product (made of DM), e.g. bricks or sinter products.

Thermal desorption

The thermal desorption depends on the difference of the relative volatility of the contaminants and mineral sediment particles. It is normally operated in the temperature range of about 450 °C.

Thermal oxidation

The thermal oxidation depends on combustion of organic material at high temperatures. All types of organic material can be burned.

Treatment of dredged material

Treatment refers to the recovery or disposal operations, including preparation prior to recovery or disposal [5].

Use of dredged material

In the scope of this guideline this term is used for the direct utilisation of DM without prior treatment [5] because the materials were dredged/ mined for a particular application. If DM is directly used, it may not fall under the waste law. The need for maintenance dredging and the need of construction material are often not concurrent, thus, in most cases an interim storage is necessary, which makes the DM legally a waste. The same applies if the materials cannot directly be used because of a high water content, but need to be processed and treated before application.

Windrow

In this context windrows are long piles of soil-type materials on dewatering and storage fields, usually having a triangular or trapezoidal cross-section.

Windrow turner

Windrow turners are machines developed for compost production in waste treatment plants. With these machines the compost can be piled up to windrows of heaps. During this process the materials are also mixed and homogenised. These machines can also be used to pile windrows or heaps from soil materials and DM.

Coal combustion products

Boiler slag

Boiler slag (BS) is a type of bottom ash collected in wet-bottom boilers (slag-tap or cyclone furnaces) which operate at very high temperatures (1500 to 1700°C). The particles are cooled in a water basin. Due to the high temperatures in the furnace some of the minerals in the boiler melt and flow down into the water basin where they are cooled down rapidly and form a coarse granular material (max. particle diameter ca. 8 mm). Boiler slag is a black, angular, smooth, glassy and environmentally sound material of which about 55 wt.-% are used in road construction, e.g. in drainage layers.

Bottom ash

Bottom Ash (BA) is a granular material made of heavier particles that fall to the bottom of the furnace. It is composed primarily of amorphous or glassy aluminosilicate materials, similar to fly ash. Most bottom ash is produced in dry-bottom boilers, where the ash cools in a dry state. BA is usually mixed with water and transported through a sluice pipe to a dewatering bin or an on-site impoundment. BA is coarser than fly ash, with a sandy texture (particle diameter ca. 0.1 mm to 50 mm) and a higher carbon content. BA from dry-bottom boilers is generally dull black and porous in appearance.

Coal combustion product (CCP)

Coal combustion products (CCPs, also coal combustion wastes) are by-products of coal-fired power plants which burn either hard or brown coal. According to the European Waste Catalogue [6], coal combustion products are wastes (ECC/100101 and 100102), which can be recovered according to European and national regulations. They may also be classified as construction material (secondary material) according to EU Regulation 305/2011 (REACH). CCPs are subdivided in fly ash, bottom ash, boiler slag and others.

Flue gas desulphurisation gypsum

Flue gas desulphurisation (FGD) gypsum is a natural gypsum-like product which is obtained by wet desulphurisation of flue gas and a refining process in the FGD plant including an oxidation process followed by gypsum separation, washing and dewatering.

Fluidised bed combustion ash (FBC)

Fluidised bed combustion (FBC) ash is produced in fluidised bed combustion boilers. The technique combines coal combustion and flue gas desulphurisation in the boiler at temperatures of 800 to 900°C. FBC ash is rich in lime and sulphur.

Fly ash

Fly ash is a fine powder, which is mainly composed of amorphous or glassy aluminosilicates. The ash particles also contain some crystalline compounds that either pass through the combustion zone unchanged or are formed at high temperatures. Depending upon the type of boiler and the type of coal, siliceous and calcereous fly ashes with pozzolanic and/or latent hydraulic properties are produced. Typical fly ash particles are spherical in shape, either solid or with some vesicles. There are also thin-walled hollow particles called cenospheres. Fly ash particles are fine-grained (1 to 100 µm diameter, median diameter of 20 to 25 µm).

Semi dry absorption product (SDA)

A semi dry absorption (SDA) product is a fine-grained material resulting from dry flue gas desulphurisation with lime acting as the sorbent.

Geosynthetics

Geocomposite

A geocomposite is a manufactured, assembled material using at least one geosynthetic product among the components [7].

Geogrid

A geogrid is a planar, polymeric structure consisting of a regular open network of integrally connected tensile elements […] linked by extrusion, bonding or interlacing, whose openings are larger than constituents [7].

Geosynthetic

Geosynthetic is the generic term describing a product, at least one of whose components is made from a synthetic or natural polymer, in the form of a sheet, a strip or a three dimensional structure, used in contact with soil and/or other materials in geotechnical and civil engineering applications [7].

Geosynthetic barrier

A geosynthetic barrier is a low-permeability geosynthetic material, used in geotechnical and civil engineering applications with the purpose of reducing or preventing the flow of fluid through the construction [7].

Geosynthetic clay liner GCL

A geosynthetic clay liner is a factory-assembled structure of geosynthetic materials in the form of a sheet which acts as a barrier (the barrier function is essentially fulfilled by clay entrapped between or inside the geosynthetics) [7].

Geotextile

A geotextile is a planar, permeable, polymeric (synthetic or natural) textile material, which may be nonwoven, knitted or woven, used in contact with soil and/or other materials in geotechnical and civil engineering applications [7].

General terms of waste management

Prevention

Prevention means measures taken before a substance, material or product has become waste, that reduce:

(a) the quantity of waste, also by the re-use or the extension of the life span of products,

(b) the adverse impacts of the generated waste on the environment and human health, or

(c) the content of harmful substances in materials and products [5].

Use

Direct use is the immediate utilisation of waste material without prior treatment [8].

Reuse

Reuse means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived [5].

Recovery

Recovery is the application of waste after treatment, for instance as a substitute to natural resources [8].

Disposal

Disposal means any operation which is not recovery even where the operation has the reclamation of substances or energy as a secondary consequence. A non-exhaustive list of disposal operations is provided in Annex I of the Waste Framework Directive [5].

European waste catalogue

The European Waste Catalogue (EWC) [6] is used for the classification of all wastes and is designed to form a consistent waste classification system across the EU. It forms the basis for all national and international waste reporting obligations, such as those associated with waste licences and permits, the National Waste Database and the transport of waste. The EWC is a hierarchical list of waste descriptions established by Commission Decision 2000/532/EC. It is divided into twenty main chapters each of which has a two-digit code between 01 and 20. Most of the chapters relate to industry but some are based on materials and processes. Individual wastes within each chapter are assigned a six figure code. The descriptions and codes within the EWC are a suitable part of the description of your waste so as to comply with your duty of care.

References

[1] CEDA 2015. Online dictionary on hydraulic construction, dredging and management of DM http://www.waterdictionary.info/ [cited 15 January 2015].

[2] Köthe, H. 2002. Baggergut im Kontext nationaler und europäischer Regelungen, *presentation on the 2. Rostocker Baggergutseminar.* Online: www.sednet.org/download/DGE-Part-I-Legislation.pdf.

[3] DIN 19712-2013. Hochwasserschutzanlagen an Fließgewässern (Flood protection works on rivers). Beuth: Berlin, 68 pp.

[4] HTG 2006. Verwertung von feinkörnigem Baggergut im Bereich der deutschen Küste, Fachbericht der Hafentechnischen Gesellschaft Fachausschuss Baggergut, 37 pp. Available online: www.htg-baggergut.de /Downloads/HTG%20Verwertungsbericht%200906.pdf [cited 16 Dec 2014].

[5] EC 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Waste Framework Directive).

[6] EC 2000. The European Waste Catalogue (2000/532/EC).

[7] EN ISO 10318: Geosynthetics – Terms and definitions

[8] HTG 2002. Positionspapier Umgang mit Baggergut, Definitionen, Erläuterungen, Empfehlungen, 23 pp. Available online: www.htg-baggergut.de/ [cited 15 January 2015].

ABBREVIATIONS

AT_4	Breathability test to determine the decomposition rate of OM for wastes for disposal
BA	Bottom ash
BAM	Bundesanstalt für Materialforschung und -prüfung
BAW	Bundesanstalt für Wasserbau (German Federal Waterways Engineering and Research Institute)
BBodSchV	Bundesbodenschutzverordnung (German Soil Conservation Ordinance)
BImSchV	Bundesimmissionsschutzverordnung (German federal immission protection ordinance)
BNatSchG	Bundesnaturschutzgesetz (German federal soil conservation act)
BS	Boiler slag
CCP	Coal combustion product
cf.	compare, see also (Latin: confer)
DM	Dredged material
DredgDikes	Dredged Materials in Dike Construction – Implementation in the South Baltic Region using Geosynthetics and Soil Improvement
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall
EAK	Empfehlungen für Küstenschutzwerke (German recommendations for coastal protection structures)
EBGEO	Empfehlungen für den Entwurf und die Berechnung von Erdkörpern mit Bewehrungen aus Geokunststoffen
EC7	Eurocode 7 for geotechnical design
EEC	European Economic Community
EPA	US Environmental Protection Agency
EP-Act	Environmental Protection Act (Danish)
EPRI	Electric Power Research Institute
ERDF	European Regional Development Fund
EWC	European Waste Catalogue
FA	Fly ash
FBC	Fluidised bed combustion
FFH	Flora fauna habitat directive 92/43/EEC
FGD	Flue gas desulphurisation
GBR	Geosynthetic barrier
GCL	Geosynthetic clay liner
GCO	Geocomposite
GER	Germany
GMA	Geomat
GSY	Geosynthetic
GTO	Geotextile related product
GTX	Geotextile
HELCOM	Helsinki Commission
IAA	Industrielle Absetz- und Aufbereitungsanlage Rostock (municipal DM treatment plant)
IMO	International Maritime Organisation
ITB	Building Research Institute
KrWG	Waste management and recycling act
LAGA M20	Recommendations for the recovery of mineral wastes by the LAGA working group
LAGA	Länderarbeitsgemeinschaft Abfall (German Interstate Working Group on Waste)
LBauO	Landesbauordnung
LUNG	Landesamt für Umwelt, Naturschutz und Geologie Mecklenburg-Vorpommern
LWaG	Landeswassergesetz
METHA	Mechanische Trennung von Hafensediment (mechanical separation of harbour sediments), treatment plant in Hamburg
M-V	Mecklenburg-Vorpommern
NLWKN	Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PIANC	The World Association for Waterborne Transport Infrastructure
PL	Poland
REACH	Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals
RZGW	Polish regional water management authorities
SDA	Semi dry absorption
StALU	Staatliches Amt für Landwirtschaft und Umwelt (State Agency for Agriculture and the Environment M-V), pl. StÄLU
TCLP	Toxicity Characteristic Leaching Procedure
UV	Ultraviolet radiation
UVPG	Gesetz zur die Umweltverträglichkeitsprüfung (German act on environmental impact assessment)

WBV	Wasser- und Bodenverband (water and soil association)
WHG	Wasserhaushaltsgesetz (German water management law)
WL	Water law (Poland)
WSA	Wasser- und Schifffahrtsamt (German Water and Navigation Board)
Z0, Z1, Z2	Classification limits for soils for recovery according to LAGA M20
ZMiUW	Polish regional regional water equipment authorities
ZTV-W	Zusätzliche Technische Vertragsbedingungen, Wasserbau (additional technical contracting conditions)

NOMENCLATURE

C	Cohesion
c_u	Undrained shear strength
$c_{u,r}$	Undrained shear strength determined with remoulded samples
d	Grain diameter
DoC	Degree of compaction, compares to the compaction index Is
F	Area
FC	Field capacity
H	Horizontal (in 1V:3H)
Hs	Significant wave height
Ic	Consistency index
k_s	Saturated hydraulic conductivity
LI	Liquidity index
LL	Liquid limit
LOI	Loss on ignition
OD	Optimal dry density / Proctor dry density
OM	Organic matter
PI	Plasticity index
PL	Plastic limit
Q_m, Q_k	Probabilities for polish dike classification
q_s	Specific discharge or permittivity
TOC	Total organic carbon
U	Coefficient of soil uniformity
V	Vertical (in 1V:3H)
V_e	Sample volume at the end
V_i	Initial sample volume
Vs	Volumetric shrinkage rate
w, w_{nat}, w_{opt}	Water content (natural, optimal)
γ	Specific weight, bulk weight
φ	Angle of internal friction
ρ_{Pr}	Optimal Proctor dry density, cf. OD

DREDGDIKES PROJECT DOCUMENTS

The following documents were prepared within the DredgDikes project. They may provide additional information beyond the contents of this guideline. They are available on the project website www.dredgdikes.eu.

DredgDikes 2011-2015. DredgDikes Newsletters no. 1 (2011) – no. 9 (2015).

Henneberg, M. 2014a. Begrünungsversuche im Rahmen des EU Projektes DredgDikes. Prüfung des Auflauf- und Anwuchsverhaltens der Deichsaatmischung für Küstenschutzdeiche in einem Gefäßversuch. Final report, 41 pp.

Henneberg, M. 2014b. Begrünungsversuche im Rahmen des EU Projektes DredgDikes. Parzellenversuch auf dem Pilotdeich Körkwitzer Bach zur Prüfung des Auflauf- und Anwuchsverhaltens der Deichbegrünung unter verschiedenen Düngergaben und Saatbettbedingungen. Final report, 27 pp.

Nejrup, L.B. 2014. Legislation and the potential for utilisation of dredged material in Denmark. Report, Orbicon A/S, Roskilde, Denmark, 57 pp.

Saathoff, F. & Cantré, S. (ed.) 2014. Proceedings of the Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction (ISBN 978-3-86009-409-9), 202 pp. Also available as print version in limited quantity.

Sikora, Z. & Duszynski, R. (ed.) 2014. Proceedings of the South Baltic Conference on New Technologies and Recent Developments in Flood Protection.

LIST OF ARTICLES PUBLISHED WITHIN THE DREDGDIKES PROJECT

Balachowski, L. & Sikora, Z. 2013. Mechanical Properties of Bottom Ash – Dredged Material Mixtures in Laboratory Tests, *Studia Geotechnica et Mechanica*, XXXV(3): 3-11.

Balachowski, L. 2012: Mechanic Parameters of fly ash-sand mixtures from laboratory test, *7. Rostocker Baggergutseminar*, Rostock: 59.

Balachowski, L. 2014. Stability of the Inner Slope of the Polish DredgDikes Research Dike at Stationary Flow, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 105 - 110.

Cantré, S. & Saathoff, F. 2013. Installation of fine-grained organic dredged materials in combination with geosynthetics in the German DredgDikes research dike facility, *Engineering Structures and Technologies* **5**(3): 93 - 102.

Cantré, S. & Saathoff, F. 2013. Investigation of dredged materials in combination with geosynthetics used in dike construction, *Procedia Engineering, Proceedings of the 11th International Conference on Modern Building Materials, Structures and Techniques* **57**: 213 - 221.

Cantré, S. & Saathoff, F. 2014. Untersuchungen zum Einsatz von Baggergut im Deichbau am Rostocker DredgDikes-Versuchsdeich, *Wasser und Abfall* **16**(3): 14 - 20.

Cantré, S., Große, A.-K., Neumann, R., Nitschke, E., Henneberg, M. & Saathoff, F. 2013. Fine-grained organic dredged materials for dike cover layers – material characterisation and experimental results, *WODCON XX: The Art of Dredging*, Brussels, Belgium – conference proceedings, 14 pp.

Cantré, S., Nitschke, E. & Saathoff, F. 2012. Dredged Materials in Dike Construction - DredgDikes Project Overview, *WASCON 2012 Conference Proceedings*, Gothenburg: 4 pp.

Cantré, S., Nitschke, E. & Saathoff, F. 2012. Verwendung von Baggergut aus dem Ostseeraum im Deichbau – erste Erkenntnisse aus dem Projekt DredgDikes, *7. Rostocker Baggergutseminar*, Rostock: 45 - 57.

Cantré, S., Nitschke, E. & Saathoff, F. 2013. Investigation of Fine-Grained Organic Dredged Materials from the Baltic Sea for Application in Dike Construction, *Proceedings of the GeSed International Conference*, Caen: 25 - 36.

Cantré, S., Saathoff, F. & Duszynski, R. 2012. DredgDikes – Ein Kooperationsprojekt zum Einsatz von Baggergut im Deichbau, *Wasser & Abfall* **14**(10): 10 - 14.

Cantré, S., Saathoff, F., Große, A.-K. & Just, H. 2014. Two Research Dikes Made of Fine-Grained Organic Dredged Materials, *Proceedings of the South Baltic Conference on New Technologies and Recent Technologies in Flood Protection*: 8 pp.

Cantré, S., Saathoff, F., Große, A.-K. & Nitschke, E. 2012. Dredged Materials in Dike Construction : First Results of the DredgDikes Large-Scale Field Tests in Rostock, *Proceedings of the 12th Baltic Sea Geotechnical Conference*: 281 - 285.

Cantré, S., Saathoff, F., Nitschke, E., Große, A.-K. & Olschewski, J. 2014. Verwendung von Baggergut im Deichbau – Erkenntnisse aus dem Projekt DredgDikes, *Tagungsband zum 8. Rostocker Baggergutseminar,* Rostock: 51 - 66.

Große, A.-K. & Saathoff, F. 2014. Geotechnical Characterization of Different Fine-Grained, Organic Dredged Material Batches from the Baltic Sea Area - Peculiarities and Adaptions, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction,* Rostock: 19 - 30.

Große, A.-K., Cantré, S. & Saathoff, F. 2014. The Geotechnical Characterisation of Fine-Grained Organic Dredged Material From the Baltic Sea Area for Application in Dike Construction, *Proceedings of the 7th International Conference on Environmental Geotechnics*, Melbourne: 8 pp.

Henneberg, M., Morscheck, G. & Neumann, R. 2014. Projekt DredgDikes: Umweltmonitoring beim Einsatz von aufbereitetem Baggergut im Deichbau, *Tagungsband zum 8. Rostocker Baggergutseminar,* Rostock.

Naumann, M., Bill, R., Niemeyer, F. & Nitschke, E. 2014: Deformation Analysis of Dikes Using Unmanned Aerial Systems (UAS), *Proceedings of the South Baltic Conference on dredged materials in dike construction*, Rostock: 119 - 126.

Neumann, R. & Henneberg, M. 2014. Legal Aspects for the Reuse of Dredged Material and the Application in Dike Constructions, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 189 - 194.

Neumann, R. & Henneberg, M. 2014. The Project DredgDikes: Characterization of Chemical Properties of the Dredged Material and First Results on Vegetation Monitoring, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 31 - 44.

Neumann, R. 2014. Environmental issues of dredged materials used in the DredgDikes Project in context with national legal aspects, *Proceedings of the South Baltic Conference on New Technologies and Recent Developments in Flood Protection*, Gdansk: 12 pp.

Nitschke, E. 2014. Comparison of two Methods to Evaluate the Data from Seepage Tests at the German DredgDikes Research Dike, *Proceedings of the South Baltic Conference on New Technologies and Recent Developments in Flood Protection*, Gdansk: 8 pp.

Nitschke, E., Cantré, S. & Saathoff, F. 2014. Full-Scale Seepage Experiments at the German DredgDikes Research Dike, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 53 - 59.

Olschewski, J., Cantré, S. & Saathoff, F. 2014. Flume Experiments to Determine the Erosion Stability of the German DredgDikes Research Dike, *Proceedings of the South Baltic Conference on New Technologies and Recent Developments in Flood Protection,* Gdansk*:* 11 pp.

Olschewski, J., Cantré, S. & Saathoff, F. 2014. Overflowing Tests on the Rostock DredgDikes Research Dike, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 67 - 74.

Ossowski, R. & Sikora, Z. 2012. Perspektywy Zastosowania Materialow Antropogenicznych W Konteksie Zielonej Geotechniki, *Zeszyty Naukowe Politechniki Rzeszowskiej* **59**: 65-71.

Ossowski, R. & Wyroslak, M. 2012. Hybrydowa Technologia Wzmacniania Gruntu W Renowacji Walow Przeciwopowodziowych, [Hybrid Technology of Ground Improvement in Dike Renovation], *Inżynieria Morska i Geotechnika*, 2012(4): 483-486.

Ossowski, R. 2014. Selected Results and Conclusions from Large-Scale Dike Experiment at Polish Test Site, *Proceedings of the South Baltic Conference on New Technologies and Recent Developments in Flood Protection*, Gdansk: 6 pp.

Ossowski, R., Sikora, Z., Duszynski, R. & Sawicki, J. 2014. Investigation on Water Infiltration and Water Content Changes in a Large-scale Experimental Test Dike, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 47 - 42.

Saathoff, F. & Cantré, S. 2014. Geosynthetics and Dredged Materials in Dike Construction, *Proceedings of the 10th International Conference on Geosynthetics*, Berlin: 10 pp.

Saathoff, F. & Cantré, S. 2014. The Project DredgDikes, *Proceedings of the South Baltic Conference on Dredged Materials in Dike Construction*, Rostock: 7 - 10.

Saathoff, F., Cantré, S., Große, A.-K. & Nitschke, E. 2014. Deichdeckschichten aus feinkörnigem Baggergut aus dem Ostseeraum, P*roceedings HTG-Kongress 2014 zum 100jährigen Jubiläum der HTG*.

Sikora, Z., Duszynski, R. & Cantré, S. 2013. Projekt DredgDikes – wykorzystanie urobku z robót czerpalnych do budowy walów przeciwpowodziowych, *Inzynieria Morska i Geotechnika* **34**(1): 64 - 68.

Sikora, Z., Szczygielski, T. & Ossowski, R. 2012. Green geotechnics in practice and theory, Proceedings of the 40th Annual Conference on Foundations, Brno: 184-191

Sikora, Z. & Ossowski, R. 2013. Geotechnical Aspects of Dike Construction Using Soil-Ash Composites, *Procedia Engineering, Proceedings of the 11th International Conference on Modern Building Materials, Structures and Techniques* **57**: 1029 - 1035.

ISBN: 978-3-86009-423-5