DredgDikes

South Baltic Guideline for the

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

ANNEX I

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

Universität Rostock

Traditio et Innovatio

GDAŃSK UNIVERSITY OF TECHNOLOGY

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CIP-Short Title:

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

Purchasing options:

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

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

Published by Universität Rostock
www.uni-rostock.de.

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CONTENTS

ANNEX I: ADDITIONAL INFORMATION

In this annex, additional information is provided regarding the DredgDikes guideline chapters. This may be information that complements that given in the guideline or text parts that did not find their way into the main document.

1. GENERAL INFORMATION

1.1. Dredged materials

Figure A1.1 exemplarily shows the disposition and application of dredged material in Rostock in the years of 1990 to 2014.

1.1.1. Definition and classification

The investigation of different fine-grained sediments in containment facilities (e.g. within the polders) in Mecklenburg-Vorpommern shows a large range of values.

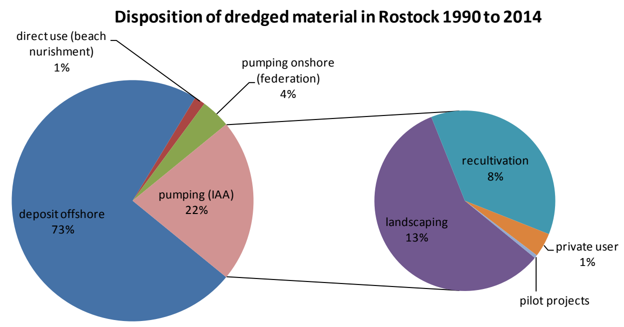

Figure A1.1. Disposition of dredged material in Rostock (WSA and IAA)

Table A1.1. Processing principles for DM [1]

Processing Principle	
Relocation	Open water disposal
	Injection dredging
Mechanical separation	Classification
	Sorting
Dewatering	Evaporation
	Mechanical dewatering
Contaminant separation	Chemical extraction
	Thermal desorption
Contaminant destruction	Biological reduction
	Chemical oxidation
	Thermal oxidation
Contaminant immobilisation	Chemical immobilisation
	Thermal immobilisation
Disposal	Sub-aquatic confined disposal
	Upland disposal

Table A1.2. Decision frame for the processing of DM [1]

	Type of Sediment			Level of contam.		Type of contam.	
Processing principle	silty	silty/ sandy	sandy	low	high	organic	in-organic
Classification	x	x	x	x	x	x	x
Sorting	x	x	x	x	x	x	x
Evaporation	x	x	x	x	x	x	x
Mechanical dewatering	x	x	x	x	x	-	x
Chemical extraction	x	x	x	-	x	-	x
Thermal desorption	x	x	x	-	x	x	-
Biological reduction	-	x	x	x	x	x	-
Chemical oxidation	x	x	x	-	x	x	-
Thermal oxidation	x	x	x	x	x	x	-
Chemical immobilisation	x	x	x	x	x	x	x
Thermal immobilisation	x	x	x	x	x	x	x

x process complies with environmental standards
- process does not comply with environmental standards

The organic matter content differs from 1 to 35 % (average 16 %) and the lime content in differs from 0,5 to 35 % (average 7 %). The grain size distributions vary in a large range: Clay 5 – 50 % (average 30 %), silt 20 to 70 % (average 50 %) and sand 1 – 75 % (average 22 %) [1].

1.1.1. Dredged material processing and treatment

A selection of processing and treatment options for DM from the SedNet project (work package WP 4) [1] is composed in Table A1.1 and Table A1.2. More information about treatment methodologies can be found in [2], with focus on river basins. The SMOCS project on the other hand composed information about treatment and processing options of marine sediments [3].

1.1.2. Environmental issues - Leaching

Normally, the fine-grained dredged material rich in organic matter are able to store a considerable part of the natural precipitation which is useful for the plants [4], [5]. If the dredged material is saturated with water (e.g. because of increasing precipitation or an increase in hydraulic conductivity) and the vegetation is not able to remove enough water by evapotranspiration, the excess water is discharged and may wash out substances such as salts and nutrients.

Lysimeter experiments with dredged material for soil improvement at the University of Rostock provide over 10 years of corresponding results [4]. The exemplary calculation of the discharge of chloride, sulphate and sodium showed that within four months 3 to 5 % of the initial contents were washed out. Experiences from the lysimeter experiments (dredged material mixed with topsoil) showed comparable results. After 10 years all of the original chloride and about 60 % of the original sodium amount were gone, while the sulphates will be washed out constantly for at least another ten years. On the other hand this experiment also proved that phosphorus and nitrogen will not discharge in considerable amounts from dredged material, particularly compared with the topsoil variations. These findings indicate that the discharge of salt has to be monitored when dredged material is used.

1.2. Coal combustion products

1.2.1. Definition and classification

To classify CCPs, the geotechnical classification system for coal ashes proposed by Prakash & Sridharan [6] was utilized in the project DredgDikes (Figure A1.2). The terms used in Figure A1.2 are compiled in Table A1.3.

Figure A1.2 also exemplarly shows the classification of the bottom ash (BA) that was used in the DredgDikes project. Most bottom ash is produced in dry-bottom boilers, where the ash cools in a dry state. BA, collected both from dry-bottom or wet-bottom boilers, is usually mixed with water and transported through pipes to a dewatering bin (or to an on-site impoundment).

Table A1.3. Abbreviations used in the classification for ashes after [6]

Abbr.	Explanation
GW	Well-graded gravel-size fractions (gravel-size fraction to sand-size fraction) mixtures, few or no fines
GP	Poorly graded gravel-size fractions (gravel-size fraction to sand-size fraction) mixtures, few or no fines
GMN	Non-plastic silty gravel-size fractions, poorly graded mixtures of (gravel-sand-silt) size fractions
SW	Well-graded sand-size fractions, gravelly sand-size fractions, few or no fines
SP	Poorly graded sand-size fractions, gravelly sand-size fractions, few or no fines
SMN	Non-plastic silt-size fractions, poorly graded mixtures or (sand-silt) size fractions
MLN	Non-plastic inorganic coarse silt-size fractions
MIN	Non-plastic inorganic medium silt-size fractions
MHN	Non-plastic inorganic (fine silt & clay) size fractions

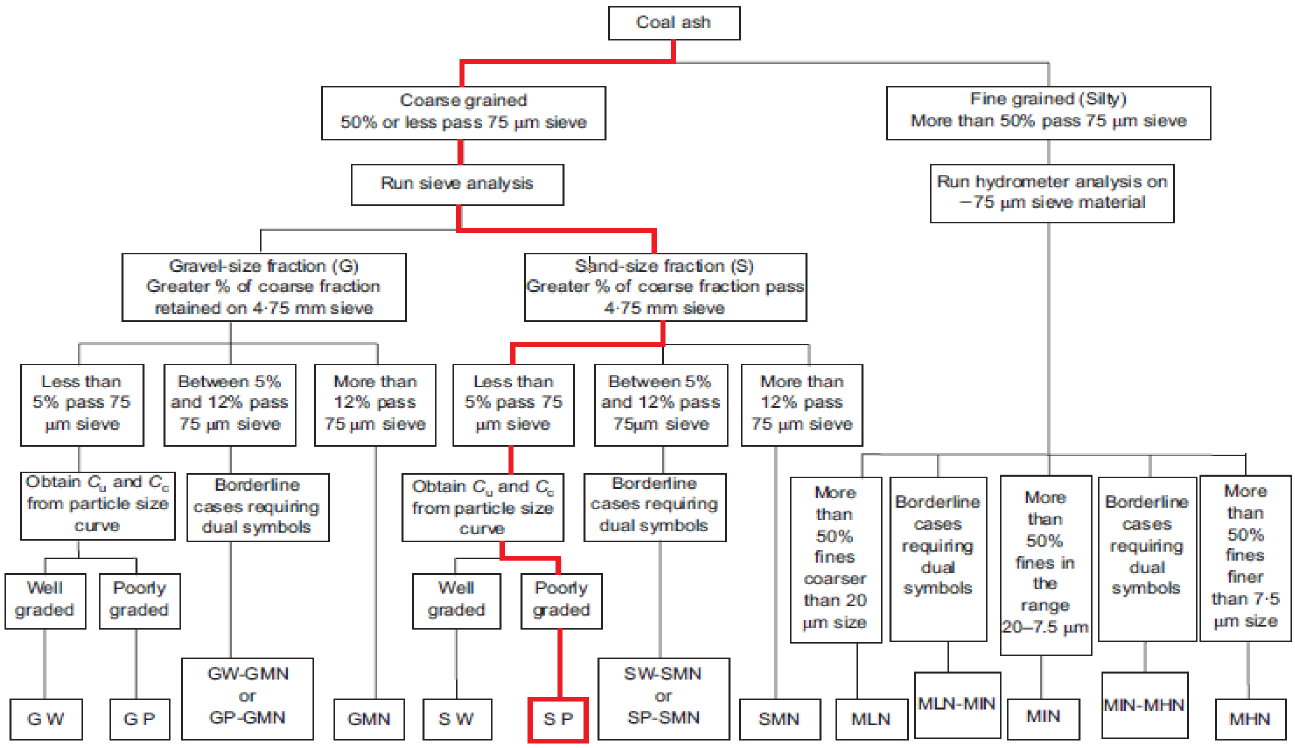

Figure A1.2. Flowchart for classifying coal ashes based on [6] and classification of the bottom ash used in the project

Power plants are equipped with particulate collection devices (electrostatic precipitators (ESPs) or baghouses), to remove the majority of the fly ash (FA) from the flue gas to prevent it from being emitted to the atmosphere. The collection of FA in an ESP is performed by electrically charged wires and plates, while baghouses use fabric filters. Dry FA collected in the ESP or baghouse can be either pneumatically transported to a hopper or storage silo (dry management), or mixed with water and transferred through pipes to an on-site impoundment (wet management).

1.1.1. Chemical composition and contaminations

The following tables and figures contain general information on the composition of ashes compared with soils collected from US American data bases [7], [8], [9], [10], [11]. The chemical composition of coal ash can change as power plants change fuels or add new air emission controls. Examples of air emission controls that can impact FA composition include the use of ammonia-based systems to

Table A1.4. Typical chemical composition of coal ashes and soils [7]

Compound	Fly Ash	Sand Ash	Bottom Ash	Soil
	[%]	[%]	[%]	[%]
SiO_2	38-65	37-75	23-73	43-61
Al_2O_2	16-44	11-54	13-27	12-39
TiO_2	0.4-1.8	0.2-1.4	0.2-1.8	0.2-2
Fe_2O_2	3-20	3-35	3-11	1-14
MnO	0-0.5	x-0.6	x-0.3	0-0.2
MgO	0.01-1.5	0.1-0.8	0.1-0.7	0.5-4
CaO	0.2-8	0.2-0.6	0.1-0.8	0-7
K_2O	0.04-0.9	0.1-0.7	x-0.6	0.3-2
Na_2	0.09-0.4	0.05-0.3	x-0.3	0.2-3
LOI	0.2-3.4	0.1-7.9	0.6-12.8	5-17

LOI: Loss on ignition at 950 °C; x: Trace

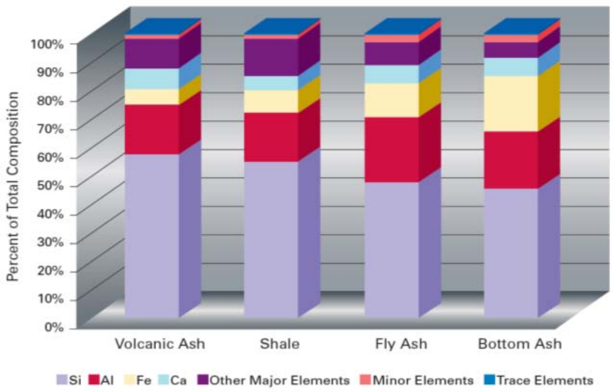

Figure A1.3. Composition of different ashes [7].

Table A1.5. Contaminations in fly and bottom ash compared to rock and soil [7], [8], [9], [10], [11]

Parameter	Fly ash*	Bottom ash*	Rock**	Soil***
	[g/kg]	[g/kg]	[g/kg]	[g/kg]
Aluminum	70–140	59–130	9.8–96	15–100
Calcium	7.4–150	5.7–150	6–83	1.5–62
Iron	34–130	40–160	8.8–95	7–50
Silicon	160–270	160–280	57–380	230–390
Magnesium	3.9–23	3.4–17	0.7–56	1–15
Potassium	6.2–21	4.6–18	4–45	4.5–25
Sodium	1.7–17	1.6–11	0.9–34	1–20
Sulphur	1.9–34	BDL–15	0.2–42	0.84–1.5
Titanium	4.3–9	4.1–7.2	0.2–5.4	1–5
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
Antimony	BDL–16	BDL	0.08–1.8	BDL–1.3
Arsenic	22–260	2.6–21	0.50–14	2.0–12
Barium	380-5,100	380-3,600	67–1,400	200-1,000
Beryllium	2.2-26	0.21–14	0.10–4.4	BDL–2.0
Boron	120-1,000	BDL–335	0.2–220	BDL–70
Cadmium	BDL–3.7	BDL	0.5–3.6	BDL–0.5
Chromium	27–300	51–1.100	1.9–310	15–100
Copper	62–220	39–120	10–120	5–50
Lead	21–230	8.1–53	3.8–44	BDL–30
Manganese	91–700	85–890	175-1,400	100-1,000
Mercury	0.01–0.51	BDL–0.07	0.1–2.0	0.02–0.19
Molybdenum	9.0–60	3.8–27	1.0–16	BDL
Nickel	47–230	39–440	2.0–220	5–30
Selenium	1.8–18	BDL–4.2	0.60–4.9	BDL–0.75
Strontium	270-3,100	270-2,000	61–890	20–500
Thallium	BDL–45	BDL	0.1–1.8	0.20–0.70
Uranium	BDL–19	BDL–16	0.84–43	1.2–3.9
Vanadium	BDL–360	BDL–250	19–330	20–150
Zinc	63–680	16–370	25–140	22–99

BDL – Below Detection Limit
* Most ash data from [7]. B, Be, Tl and Hg (BA only) from [8].
** Rock data from [9].
*** Most soil data from [10]; cadmium and thallium data from [11].

control NOX, powdered activated carbon injection to control mercury, and sodium-based sorbents to control SO_3. Examples of fuel changes include blending of different coal types, and co-firing of biomass with coal. EPRI [7].

1.2.2. Geotechnical classification of CCPs

As the FAs comprise predominantly silt-size particles, they are classified as fine-grained ashes. They can belong to one of five subgroups: MLN, MLN-MIN, MIN, MIN-MHN and MHN (Figure A1.2, Table A1.3). Both BA and pond ashes are coarse-grained and belong to one of eight subgroups: GW, GP, GW-GMN or GP-GMN, GMN, SW, SP, SW-SMN or SP-SMN and SMN (Figure A1.2, Table A1.3). In most cases, they are sand-size particles. Some BAs may contain small amounts of gravel-size fractions as well.

1.2.3. Recovery of CCPs

Governments (particularly the Polish government) are more and more favouring the use of CCPs as secondary raw materials. Legislation and rules to increase such use are constantly being improved. In several cases the minerals from coal combustion bring extra quality and higher performance compared to the primary raw materials which are being replaced. Applying CCPs can also add to energy savings and preservation of natural resources. In addition to improving the quality of concrete, the use of FA greatly reduces the energy use and CO_2 emissions associated with the production of concrete. In 2007, use of FA in concrete resulted in an estimated 55 trill. Btu in energy savings, and 10 mill. t in avoided CO_2 emissions [12]. These numbers are equivalent to the annual energy use for over 600,000 households and removal of 1.7 mill. cars from the road, respectively. Other benefits of using ash include conservation of virgin materials such as limestone used in cement production, and reduced need for disposal sites.

In addition to concrete, applications such as structural fills, cement production, waste stabilization, and mine reclamation use more than 1 mill. t of FA per year. The coarser BA and BS are primarily used as structural fills, road base materials, blasting grit or roofing granules, and snow and ice traction control.

US EPA actively promotes coal ash use under the Coal Combustion Partnership Program (C2P2), and has set a goal of 50 % utilization by 2011 [12]. The US Federal Highway Administration provides technical guidance on the use and benefits of FA for highway construction projects.

Table A1.6. General properties of German North Sea dikes

Relevant guidelines	EAK 2002	
Design flood level DFL	With foreland	No foreland
Inclination of dike toe (V:H)	1:10 - 1:15	1:3
Crest width	2.5 m to 3 m	
Incl. of sea side slope (V:H)	1:3 to 1:10	1:3
Incli. of land side slope (V:H)	1:3	
Thickness of cover layer	1 m to 2 m sea side slope 0.5 m to 1.3 m land side slope	

1.3. Dikes

To compare properties of North and Baltic Sea dikes (paragraph 2.4 in the original document), Table A1.6 shows general properties of German North Sea dikes. Comprehensive information is provided in [11].

2. LEGAL ASPECTS OF DM

While in the guideline the legal background with strong focus to the reuse of the DMs is compiled, here also information about the legislation regarding the mining and production of DMs is summarised.

2.1. European Legislation

2.1.1. European regulation framework

Since the 1970s the European Community follows an active environmental policy e.g. in the field of water protection, air pollution control and waste management. The environmental policy of the EU makes a contribution to preservation and protection of the environment as well as the improvement of their quality and the careful and efficient use of natural resources (Art. 191 TFEU [14]).

Under European law different framework directives rule the handling with subjects of protection e.g. the marine environment or water. Their task is to harmonize the legal frame for the policy within the EU and they are addressed to the national authorities. Their purpose is also to align the policy to a sustainable and ecological use of resources.

The disposal of DM in water bodies is widely regulated through the international and European conventions for the protection of the sea. Within the conventions DM guidelines [15], [16], [17] regulate the environmentally sustainable disposal/ relocation in the water bodies. The directives are harmonised and will develop consistently [18].

2.1.2. Water framework directive

The EC Water framework directive (WFD) [19] arranges aims of water quality and specifies methods how to achieve them. Until 2015 a good chemical and ecological status of surface water bodies shall be achieved. A good water quality cannot be regarded without a good sediment quality. Therefore the sediments have to be considered in the water management plans of the member states even if little attention is given to it in the WFD.

The commission recommends only the development of quality criteria for the concentration of the substances with priority in surface water, sediments and biota. An effective sediment management should also include an understanding for the system, an integrated management for soil, water and sediment as well as the direct correlations up and downstream, among others [20].

Under the umbrella of the WFD the groundwater directive [21] coordinates the protection of ground water against harmful contaminations. This aspect has to be kept in mind regarding onshore disposal or recovery and because of the potential discharge (particularly via leachate) to the groundwater.

2.1.3. Waste Framework Directive

The Waste Framework Directive [22] plays an important role when using DM. Through this directive harmful impacts of production and management of waste shall be avoided, the total impact of using resources reduced and the efficiency of using resources improved [22].

At European and national level there is consensus that DM which will be used onshore directly or reused after treatment is a waste and it is subjected to the regulations of waste law by disposal, treatment and beneficial use. The directive contains the European waste catalogue [23] and mentions DM under the numbers 170505 (containing hazardous substances) and 170506 (DM not mentioned under 170505) in chapter 17 "construction waste and demolition waste". Until the end of 2020 defined recycling rates have to be achieved. For DM this means that 70 % of the material coming on shore will have to be recovered. If the sediments are contaminated or another reason is arguing against relocation in the water bodies (such as particular compositions or a violation of the "same to same principle" according to the HELCOM Guidelines [17], the DMs have to be taken on shore.

2.1.4. Soil framework directive draft

The soil framework directive only exists as draft as yet. The major aim of this draft directive is to implement the principle of sustainability in the field of soil protection. The basic aims follow general specifications of soil protection, such as avoidance of further aggravation of soil quality and conservation of soil functions and restoration (under functional aspects and consideration of costs). This means, among others, the protection against erosion, compaction, salinization, acidification, loss of organic matter and contamination [24]. Cohesive and highly organic DM may fulfil many of these requirements when recovered. DM may improve surface soils in their structure and supply nutrients. They may also increase the stability against erosion and reduce the discharge capacity of contaminants.

2.1.5. International guidelines for handling DM

There are different international recommendations for the handling of DM. PIANC gives recommendations for the use of less contaminated DM of harbours and rivers [25]. The Central Dredging Association CEDA and the International Association of Dredging Companies IADC provide general guidelines for DM management, e.g. [26]. More information on the handling of DM is provided by the Dutch-German-Exchange (DGE) [18] and the OSPAR EIHA [27].

2.2. German legislation

2.2.1. National Water law

The German water law changed with the introduction of the WFD [19] in 2000 and received new impulses. Until now the topic of DMs does not attract much attention in the continuous national process of implementation. The WFD names sediments in their meaning as habitat not in their role as a medium of contaminants. So far it was not apparent that sediment management plans were integrated in the river management plans [28].

In Mecklenburg–Vorpommern (MV) sediments are evaluated according to quality criteria of the WFD implementation decree (heavy metals: copper, zinc and arsenic) in its river management plans [29].

The priority placing of DM is achieved through relocation in water bodies which is ruled by the water management law [30] or the waterway law [31]. This concerns all slightly contaminated sediments at the North and Baltic Sea coasts, generally sand and marl in MV.

Due to the onshore disposal the protection of the groundwater during treatment and recovery of DMs obtains a special meaning because of possible influences through leachate. The groundwater protection is regulated by the [19], [21] and [30] as well as the ground water ordinance [32]. The criteria for land disposal can be found in regulations of waste and soil law [33].

2.2.2. National Waste law

In Germany, the recycling management act [34] forms the common legal basis. By this act the specifications of the EU Waste Framework Directive [22] were implemented into German law. A possible recovery of waste -if technically feasible and economically reasonable- has to be proper and harmless (no impairment of the public interest, particularly no accumulation of pollutants in the recycling process [34].

Apart from the regulations of BBodSchV [35] and LAGA [36] for the recovery of DMs (see main document), the beneficial use of waste materials like DMs can also be realised through the landfill ordinance DepV [37] as restoration material in the recultivation and water storage layers. As yet (2014), 14 projects of landfill recultivation with the application of DMs have been realized in MV. The conditions mostly complied with [37]. The guidance limits of [37] for el. conductivity, chloride and sulphate were exceeded due to the origin of DM (brackish water) and therefore the location specific application was subject to individual case permits. The heavy metal values of the DM from Rostock were significantly below the limit values of [37] for restoration layers. Also the organic contaminants were inconspicuous [38].

2.2.3. National Soil conservation law

Germany adopted suitable regulations by implementation of the soil conservation and contaminated site act (BBodSchG) [39] and ordinance (BBodSchV) [35]. In both the act and the ordinance as well as in the discretional implementation help to §12 BBodSchV [40] DM is named and an application on existing top soils and as top soil replacement is allowed if the conditions comply with the precautionary values of Table 2, Annex 2 BBodSchV [35].

2.3. Polish legislation

The exploitation of fragmental material deposits beyond surface waters, as well as in river valleys, is regulated by the Geological and Mining Law Act [41]. To exploit a deposit in a river valley, in accordance with [41], one should obtain a license, due to the fact that such a deposit constitutes a natural accumulation of minerals. However, pursuant to art. 23.1.2 [41], granting a license to exploit a deposit on areas of direct or potential flood hazard requires an agreement with the authority responsible for water management and an opinion of the authority competent for granting a permit required by the Water Law Act [42].

Moreover, the sand found in river beds, formed by river silt, is characterized by significant in-time state volatility, thus such aggregates may not be classified as mineral deposit. Such deposits are not subject to the mining license obtaining procedure under [41]. Carrying out dredging works under surface waters of rivers is governed by the principles of common and specific use of water, as provided in [42]. The provisions of [42] set out the principles of collecting aggregates from river and torrent beds, define the acceptable mining procedures, and implement the regulations restricting the possibility of such actions.

The collection of aggregates from river beds may take place under common and specific use of water. The principles of extraction of stone, gravel and sand under common use of water are regulated by the provisions of art. 34-35 of [42]. Common use does not cover the extraction of stone and gravel from mountain torrents. Pursuant to art. 34.2 [42], extraction of gravel, stone and sand may take place under common use when the purpose of collection of those materials is only to satisfy the needs of a person, a household or a farm, and when it is collected without the use of special technical instruments (e.g. excavators, dredgers). According to art. 37 item 7 [42], any other actions constitute specific use of water and pursuant to art. 122.1.1 they require the acquisition of a permit required by the Water Law Act issued by the competent authority.

The Water Law Act relieves the obligation to acquire a permit required by the Water Law Act in the case of excavation of stone, gravel, sand and other materials in relation with the maintenance of water, waterways and repairs of water devices.

Under art. 37, art. 122 sec. 1 item 1 and sec. 2 item 3 of [42], a permit is also required for the excavation or storage of DM in the areas of direct flood risk.

The permit required by [42] specifies the conditions of aggregate dredging, rights and obligations necessary due to environmental protection and interests of the population and economy, among others. It also specifies, if required, the works to be performed, the participation in water maintenance costs (according to the increase of the costs resulting from the implementation of the permit for aggregate collection) and the participation in water devices maintenance costs, according to the benefits achieved.

Holding a permit required by [42] shall not relieve one from the requirement of holding a license, and similarly holding a license shall not relieve one from the obligation to hold a permit required by [42], as both administrative acts consider separate aspects of using environmental resources.

The permit required by [42] shall not violate:

- the arrangements regarding the conditions of using the waters of the water region or the conditions of using the basin waters;
- the arrangements of the local spatial development plans, the decision on setting the location of a public purpose investment and the planning permission;
- the requirements for the protection of human health, environment and cultural assets entered into the monument registry, and
- the requirements under separate regulations.

In particular cases, the collection of aggregate from dredging works may require an environmental impact assessment (EIA). Enterprises which can significantly impact the environment are defined in the ordinance of the Council of Ministers of November 2010 on enterprises which can significantly impact the environment and the ordinance divides them into the following groups:

- enterprises which can always significantly impact the environment (so-called group I),
- enterprises which can potentially significantly impact the environment (so-called group II)

For group I enterprises, an EIA is obligatory while for group II enterprises an EIA is discretionary and the decision on imposing the obligation to carry out an assessment is made by an environmental protection authority.

Finally, the provisions of Natura 2000 apply if such an area may be impacted.

3. PLANNING AND DESIGN

3.1. Subsoil and construction site

3.1.1. 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. Thus it is important to perform a detailed soil investigation to get comprehensive information on:

- Soil layering including soft or organic deposits and coarse grain strata with high 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 on soil samples, including strength, deformability and hydraulic conductivity

With these data the designer should be able to properly design the section and to undertake the construction of the dike including the failure risk. The dike settlements both during the construction period and long term settlements including 50 years forecast should be estimated with this data. The subsoil layering is also crucial to admit the possible failure mechanisms during a flood event.

The soil density is an important parameter in the stability analysis, where it can be an active force or counteractive action. It determines an effective stress on the shear plane and the shear resistance. The soil density of the clayey layer on the inner side will influence the heave or uplift failure mechanism. It is also an indication of soil consistency and strength. Grain size distribution and grain shape is useful for hydraulic conductivity estimation with empirical formulas.

Mechanical soil properties can be defined using the following field tests:

- Static soundings CPTU tests. Pore pressure measurement is particularly useful as it facilities soil classification and indicates the deposit history and permits to distinguished the layers with drained and undrained conditions of penetration. The dissipation tests allow the hydraulic conductivity and consolidation coefficient to be evaluated.
- Dilatometer tests (DMT) permit to estimate the constrained modulus for settlement calculation and also undrained shear strength and stress history.
- Pressuremeter tests (PMT) are very useful for both deformability and strength parameters determined in one test.
- Dynamic penetration tests permit to deliminate the soft and resistant soil layers and roughly estimate the compaction of cohesionless deposits.
- Standard penetration tests (SPT) can be used for determination of soil layering including soft and competent layers.

- Vane test is very useful for undrained shear estimation in soft deposits including the soil sensitivity.

A typical dike subsoil in Northern Poland is composed from a cover layer of clayey soils and a sand-mud (or peat) Holocene sandwich over Pleistocene sands. The cover clay layer of variable thickness is sometimes discontinuous due to erosion. Its presence is very important for seepage and stability analysis. The proper estimation of soft soil layers and particularly organic layers is crucial to calculate the dike settlements and to limit nonuniform settlements. The typical cross-section of a dike and subsoil in the Żuławy area is shown in Figure A1.4. It is similar to low land areas in Holland (Figure A1.5) and Northern Germany. Holocene deposits consider clays, including organic clays, muds and peat and sandy soils enclosures. Pleistocene strata is generally built from compacted sandy deposits.

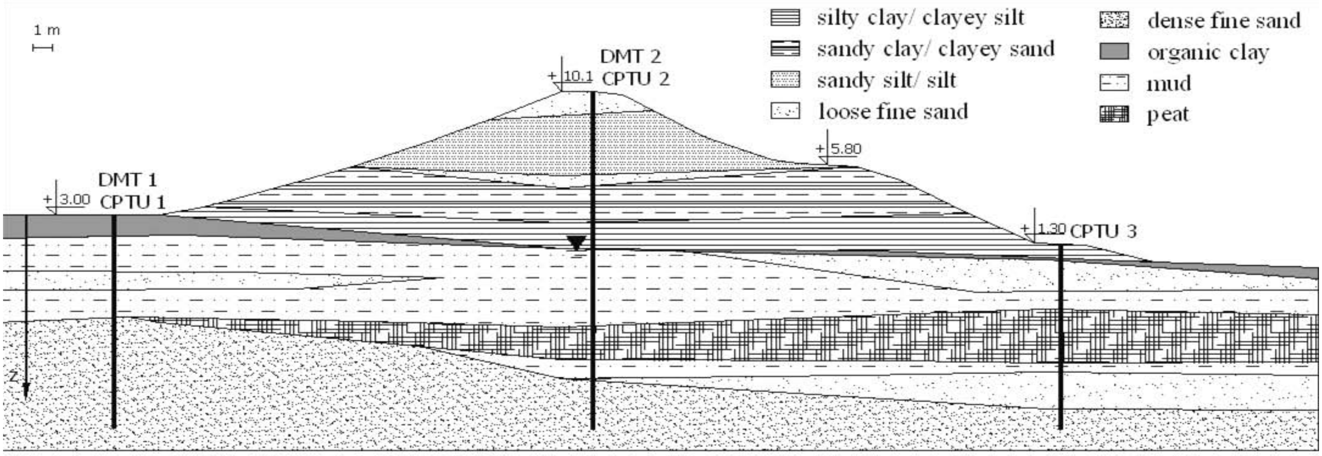

Figure A1.4. Typical dike cross-section with the subsoil in Żuławy area [43]

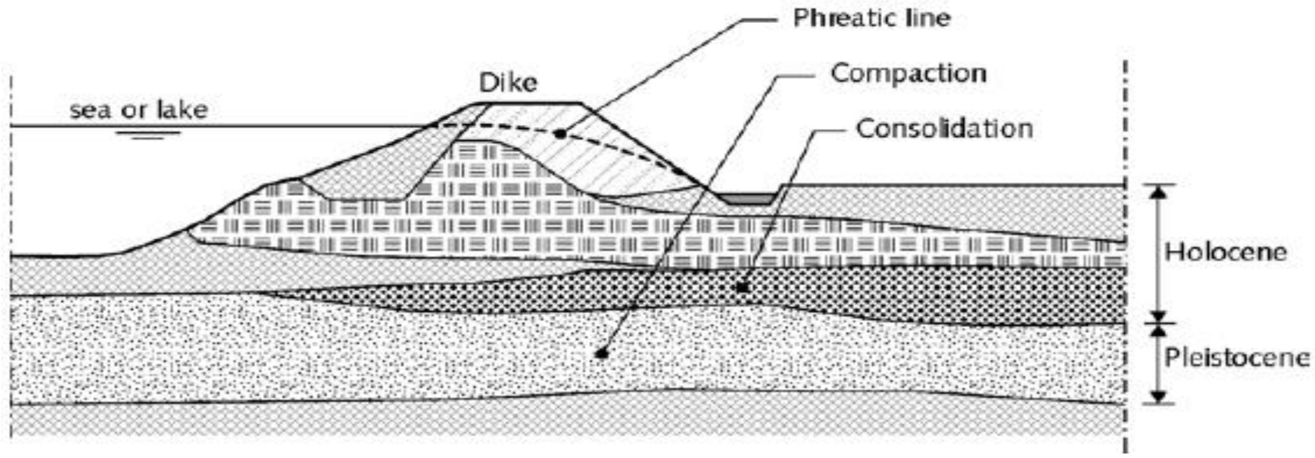

Figure A1.5. Typical dike cross-section in Holland with typical layered subsoil [44]

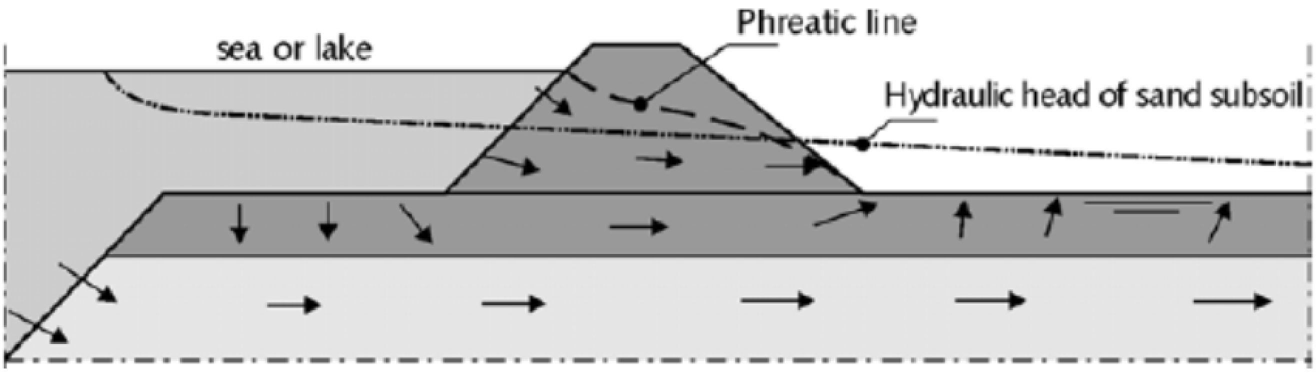

Figure A1.6. Groundwater flows in dike profile and substratum [44]

Table A1.7. Example of soil investigation efforts in the project phases [44]

Phase	Data	Source of information	Scope	Comments
Definition	Archive	Maps, old measurements	Entire stretch of the dike	Interim layer Structure
	Geological background knowledge, experience, local knowledge	Advisor	Entire stretch of the dike	
Preliminary design	Preliminary investigation	Geophysical	3 survey lines	Layer structure, presumption of parameters on the basis of classification
		Continuous drilling	1 per 200 to 1,000 m	
		Penetration tests	1 per 50 to 150 m	
		Hand drilling	1 per 50 m	
		Classification	8 per drill	
	Detailed investigation	Additional (special) drilling and sampling	Depending on the situation	Any layer structure adjusted per location, Parameters based on field and laboratory tests
		Triaxial tests of the drilling samples	3 per drilling sample / at least 4 per layer	
		Compression tests of the drilling samples	2 per drilling sample / at least 3 per layer	

Figure A1.6 shows the possible groundwater flow paths in a dike cross-section including the layered ground. This shows that the whole system of soils and earth materials needs to be considered when designing a dike.

The soil investigation is usually organized in three phases: The definition phase, the preliminary design phase and the design phase. An example for a soil investigation plan for (river) dikes is given in Table A1.7.

For sea dikes to be built from scratch the following investigation grid is recommended as a minimum measure [45]. The extent of necessary investigations is given in Table A1.8. For reconstruction and upgrading works at sea dikes with little additional loading the extent of analysis may be reduced.

Table A1.8. Investigation raster for the construction of new sea dikes

Analysis	Description
Boreholes	1 borehole every 100 m of dike length, alternating between water and land side. The necessary borehole depth is given in DIN 4022
CPT	CPT with local measurement of cone tip resistance and sleeve friction (DIN 4094-1). 1 CPT every 50 m dike length, alternating between water and land side. From cone tip resistance and sleeve friction the so-called friction ratio is computed, that allows a reliable determination of the soil type together with the results of the drillings. Depth of CPT in accordance to the borehole depth.
Laboratory analyses	The extent of laboratory analyses results from the subsoil conditions detected/found. Clay and organic soils require more analyses than sand. Recommendations about the laboratory testing programme are given in [11].

In case of very soft soil deposits in the ground, soil improvement can be performed to accelerate the subsoil consolidation in form of vertical drains (prefabricated, granular or made with the microblasting technique) and to speed up the construction process. Berms and an appropriate slope inclination should also be considered.

3.1.2. Environmental issues regarding the construction site

Through the high sorption capacity and the neutral or slightly alkaline pH values of the DM, the mobility of heavy metals and organic contaminants in the materials are limited [46]. The concentrations in the eluate are usually in the range of the detection limit.

The determined values of heavy metals in leachate from natural precipitation do not constitute a potential risk of the different protective subjects soil, plants or animals. They are below the limit values of different regulations as also are the values in the solid. Heavy metals and organic contaminants are chemically stable and hardly available. The issue of changing redox conditions is discussed in the main document and so is the problem of salts in the leachate.

It could be shown that the common inorganic contaminants contained in the DMs will not violate the requirements of the respective ordinances, but it is the discharge of salt ions that could be problematic for the environment [4], [47].

3.2. Dike design

3.2.1. Additional design recommendations for sea dikes made of DMs

In Germany, the legal background leads to the following peculiarity: All materials installed in the rooting layer in landscaping and agriculture (upper 15-30 cm) should comply with the soil protection ordinance (BBodSchV) [35]. For the recovery of waste materials in a technical construction, such as a dike, materials with classification limits Z0 and Z1 on the basis of LAGA M20 can be used without further measures, once the individual case permit has been received, taking into account a separate agreement about acceptable levels of salts and TOC in case of brackish and/or organic DMs. Since the organic matter is extremely stable exceeding TOC values are not generally a problematic issue and should not be a reason to deny a permit.

These legal boundary conditions basically lead to the cross-sections presented in Figure A1.7 and Figure A1.8 when recovering DMs in dikes. All DM would have to be covered by ca. 15-30 cm of material that complies with BBodSchV which may also be a DM. The classification limis of BBodSchV are basically equal to those of LAGA Z0 for loamy soils. If the fine-grained or mixed DM used for the construction is classified as Z0 after LAGA, it can be installed in one stratum of h > 1.0 m (cover layer) or one homogenous cross-section; however, the final layer to be compacted (30 cm) would have to be classified according to BBodSchV. If LAGA Z1 material is used, another DM or top soil will have to be installed in the final layer (15-30 cm). Then it depends on the geotechnical quality of the final layer material whether the total thickness of the cover layer (consisting of two (dredged) materials) or the Z1 material alone need to meet the threshold of h > 1.0 m.

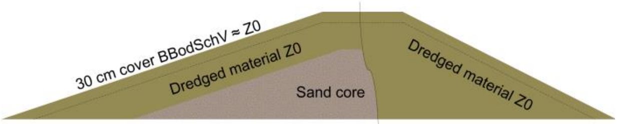

Figure A1.7. General dike section for Germany using clean DMs (LAGA class Z0), considering BBodSchV

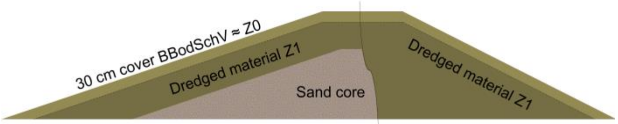

Figure A1.8. General dike section for Germany using DMs with low contamination levels (LAGA class Z1), considering BBodSchV

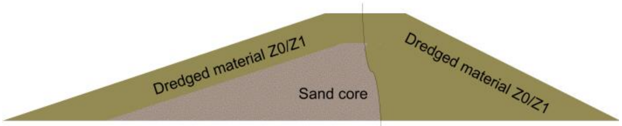

Figure A1.9. Suggested general dike section for Germany using DMs (LAGA class Z0 and Z1)

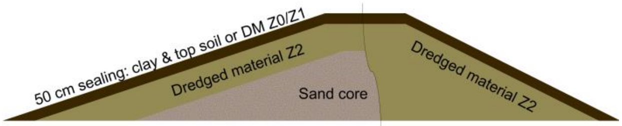

Figure A1.10. Suggested standard dike cross-sections for DM with some contamination (LAGA M20 class Z2)

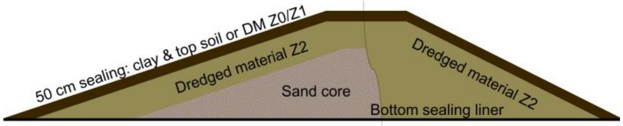

Figure A1.11. Suggested standard dike cross-sections for LAGA Z2-DM for environmentally sensitive areas (no natural bottom sealing)

This, however, seems to be a comparably complicated way of treating this problem. In the project, this issue was discussed with the responsible ministry and permission authorities in MV and the following recommendation can be given: 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 only (again, 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 also Z1 should be installed at the surface (Figure A1.9), disregarding the classification according to BBodSchV. Only if legitimate objections are raised by a permitting authority, the above (more complicated) procedure should be used.

If the available DM contains some contamination (LAGA class Z2), it usually has to be covered by a suitable uncontaminated sealing layer (Figure A1.10). This may be a standard clay, or even a cohesive Z0/Z1 dredged material with a low hydraulic conductivity and low shrinkage ratio. This cover sealing prevents the dike body from infiltrating water and thus from water movement inside, preventing contaminants to be washed out by the leachate. However, the serious contaminations like heavy metals or organic contaminants are usually fixed in the dry matter and are not easily soluble, so that this protection is only an additional safety measure. A similar project was performed in Bremen (see case study in the main document).

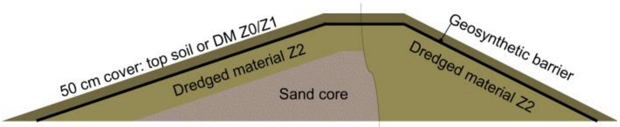

Figure A1.12. Suggested standard cross-sections for DM with some contamination (LAGA M20 class Z2) using a geosynthetic barrier system

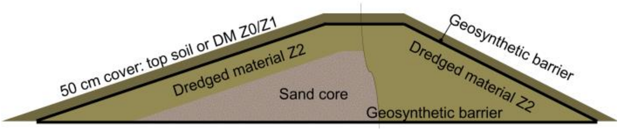

Figure A1.13. Suggested standard dike cross-sections for LAGA Z2-DM for environmentally sensitive areas (no natural bottom sealing), using a geosynthetic barrier system

In environmentally sensitive areas and on a subsoil which is not a natural barrier with low hydraulic conductivity, a bottom sealing liner (e.g. mineral sealing liner) should be installed to prevent eluates to migrate into the subsoil, again an additional safety measure, which should allow the approval of such a project (Figure A1.11).

Finally, the encapsulation may be realised using geosynthetic barriers, such as geosynthetic clay liners (Figure A1.12, Figure A1.13).

4. CONSTRUCTION

4.1. Construction technology

4.1.1. Compaction technology for DMs

One of the methods described in Paragraph 5.5.1.1 of the main document 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.

Compared to the construction with a 1V:3H inclination, the mass movement can be evaluated with Equation 4.1.

$$y\ (A1 \geq A2) \geq \frac{2hc}{\sin(arctan\frac{1}{m})(3-m)} \qquad (4.1)$$

with y = crest height
h = thickness of cover layer
c = minimum width for horizontal machine installation/ compaction (usually c = 3 m)
m = inclination variable (1V:mH)
A1 = area (resp. unit volume / meter) of the material to be removed after a 1V:3H installation
A2 = area (resp. unit volume / meter) of the material to be removed after horizontal installation

4.1.2. Installation technologies for geosynthetics

In the project DredgDikes, five different types of geosynthetics were applied: At the research dike in Rostock, a geosynthetic clay liner (GCL) was used as lower hydraulic boundary condition beneath the dike, a geosynthetic erosion control product was installed on top of selected slopes, a grid-type erosion control product was used as reinforcement layer inside selected cover layers and drainage composites were positioned at the western dike toe, in the homogenous dike and attached to the drainage pipes inside the eastern dike core. At the pilot dike, a woven reinforcement geotextile was used to allow the construction road to be built on the saturated peat ground.

4.1.2.1. Erosion control products for surface erosion protection and root reinforcement

The geosynthetic erosion control product used in the project was placed over the finished dike surface and then covered with a few centimetres of crumbly dredged material of the same kind as in the cover layer underneath (Fig. 14). The product was fixed to the ground with 0.4 m long steel rods, approximately 2 per m². During installation it seems to be of importance to fix the material on one side of the dike first and then pull it tight so that the product will not stretch and deform when it is necessary to walk over it, e.g. while installing the fixation rods. Walking on the material may also be necessary when covering the materials with soil, seeding and mowing the freshly developed turf. Also then the product should be kept in place with as much contact to the soil as possible.

4.1.2.2. Geosynthetic drainage composites

The geosynthetic drainage composites used to control the seepage line in cross-section H and at the toe of the western dike covers could be easily placed (Fig. 12). They were rolled out in dike longitudinal direction, using the full production width of 5.0 m, which will also be the most practical way in a real project. Thus, the cross-machine transmissivity is relevant for the design.

4.1.2.3. Geosynthetic reinforcement

In the DredgDikes project two geosynthetic reinforcement solutions were applied. (1) The pilot dike at the Körkwitzer Bach was constructed on very weak ground and thus a reinforced construction road was built prior to the actual dike construction. (2) The cover layer of two sections of the German research dike in Markgrafenheide was reinforced in-plane to investigate the effect on crack reduction.

The reinforcement of construction roads on weak ground can be realised with woven reinforcement material as well as a combination of geogrids and non-woven geotextiles. This is a standard geosynthetic technology which is described in [48] and which was used but not investigated in the DredgDikes project. In the project, the construction road, which now serves as the gravelly dike core, was wrapped with a woven reinforcement product to combine reinforcement and separation in one product and thus to facilitate the installation.

It should be noted, that for later installations in the dike core (such as piezometers), the wrapping by a woven geotextile is problematic. Since the construction road made of well compacted gravel material was too hard to get installations (standpipes) rammed in, the installation holes would better be bored into the ground. However, the woven geotextile would not allow any of the available earth augers to cut through.

Geosynthetic reinforcement inside the cover layer parallel to the surface (in-plane) may have a positive effect on shrinkage cracking. Also, it serves as an additional erosion protection in the unlikely event of a surface failure. Since during the project the positive effect of the reinforcement could not finally be proven, this method did not find its way into the guideline. Still, it is worth mentioning in this annex.

There are different ways on how to install such a reinforcement product, depending on whether it is installed across the whole dike cover or only on the outer slope.

The geogrids for reinforcement were planned to be installed in slopes of V1:H2 and V1:H3 inclinations. However, since an installation of 30 cm layers of cover material was not possible on the 1V:2H slopes, the proposed system of geosynthetic reinforcement could not be applied. The reinforcement was therefore only installed in the cover layers with a 1:3 inclination. The first layer of 30 cm of DM was installed and compacted on top of the sand core; then the geogrid was placed on top of it, pulled tight and fixed at the ends before more DM was quickly placed on top of the grid and a layer of 0.4 m was installed and compacted. Finally the second layer of geogrid was wrapped over the whole surface before the final layer of 30 cm of DM was installed on top of the geogrid.

Figure A1.14. GCL installation at the Rostock research dike

4.1.2.4. Geosynthetic clay liner

At the research dike, the geosynthetic clay liner (GCL) was used as the lower hydraulic boundary condition (for the seepage measurements and for the subsequent numerical modelling) and thus rolled out from the top of the separation dams across the prepared formation using a traverse fixed to an excavator arm. Before placing the GCL the planum needs to be cleared of large sharp stones, roots and other sharp or pointed elements to prevent the GCL from being perforated when load is applied.

The overlappings were sealed using a bentonite paste prepared from bentonite powder on site and protected by non-woven geosynthetic strips. This interferes the construction process since the sealing takes more time than the placing of the GCL. It may be easier to seal the GCL overlappings with readily mixed special glue, because the GCL needs to be covered as soon as possible after placement in case of unsteady weather to prevent the GCL from swelling during rain events. Swelling should only start once a load is applied to the GCL surface, thus when covered with earth material of at least 50 cm.

4.2. Vegetation cover on DMs

4.2.1. Preparation of the seed bed

For a better contact of the seed with the bed a crumbly, 4-5 cm thick layer of dredged material should be created (Figure A1.15).

4.2.2. Seed and seeding

The seeding process is intensively discussed in the main document. Here, some additional remarks are given. The availability of water is essential for the germination of the seeds. It leads to the enlargement of the cells and the

Figure A1.15. Seed bed preparation in the DredgDikes project: fine crumbly dredged material on the top layer.

Figure A1.16. Hydro-seeding on a compacted surface of the DredgDikes research dike in Rostock

activation of ingredients. A good contact to the soil relieves the absorption of water. The seed soaks, the husk opens up and the root tip appears. In this stage consistent and adequate soil moisture is elementary. Aridity leads to the loss of the germinating seed. Besides the water, an adequate oxygen supply plays an important role during germination. Soils affected by slurry seal coating and compaction may not generate good conditions for the germination of grass [49].

These issues need to be considered if applying a hydro-seeding technology, particularly directly on the readily compacted surface. Figure A1.16 shows the surface of the Rostock test dike directly after the hydro-seeding. The seed is lying at the very top and because of the very dry period that followed the seeding, the drying out of the upper few millimeters together with a wind movement of seed may lead to a poor performance of germination in the beginning, in spite of the prediction of the hydroseeding company.

4.2.3. Turf development

At the pilot dike at Körkwitzer Bach near Rostock the germination and turf development was initially a bit laid back (seeding in April 2014), particularly in the area of the dike crest. After the seeding, the dominant weather conditions were sunny, dry and windy with high evaporation rates. Soil born weeds, like reed and saltbush, developed quickly and kept light and residual humidity from the seed. The first cut to remove the weeds was performed too late. This led to a good turf development at the end of Sept. / early Oct. only. In spite of the sub-optimal initial phase, a good turf was developed until the end of 2014.

4.2.4. Maintenance work – re-seeding and mowing

In the project a repeated mowing was chosen and realized as tending strategy. On the one hand the mowing made sure that a thick and closed vegetation cover was established. On the other hand it is responsible for an increased growth of roots in the top layer of the soil. Also, the strong growth of the salt bush was supressed after the first cut.

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