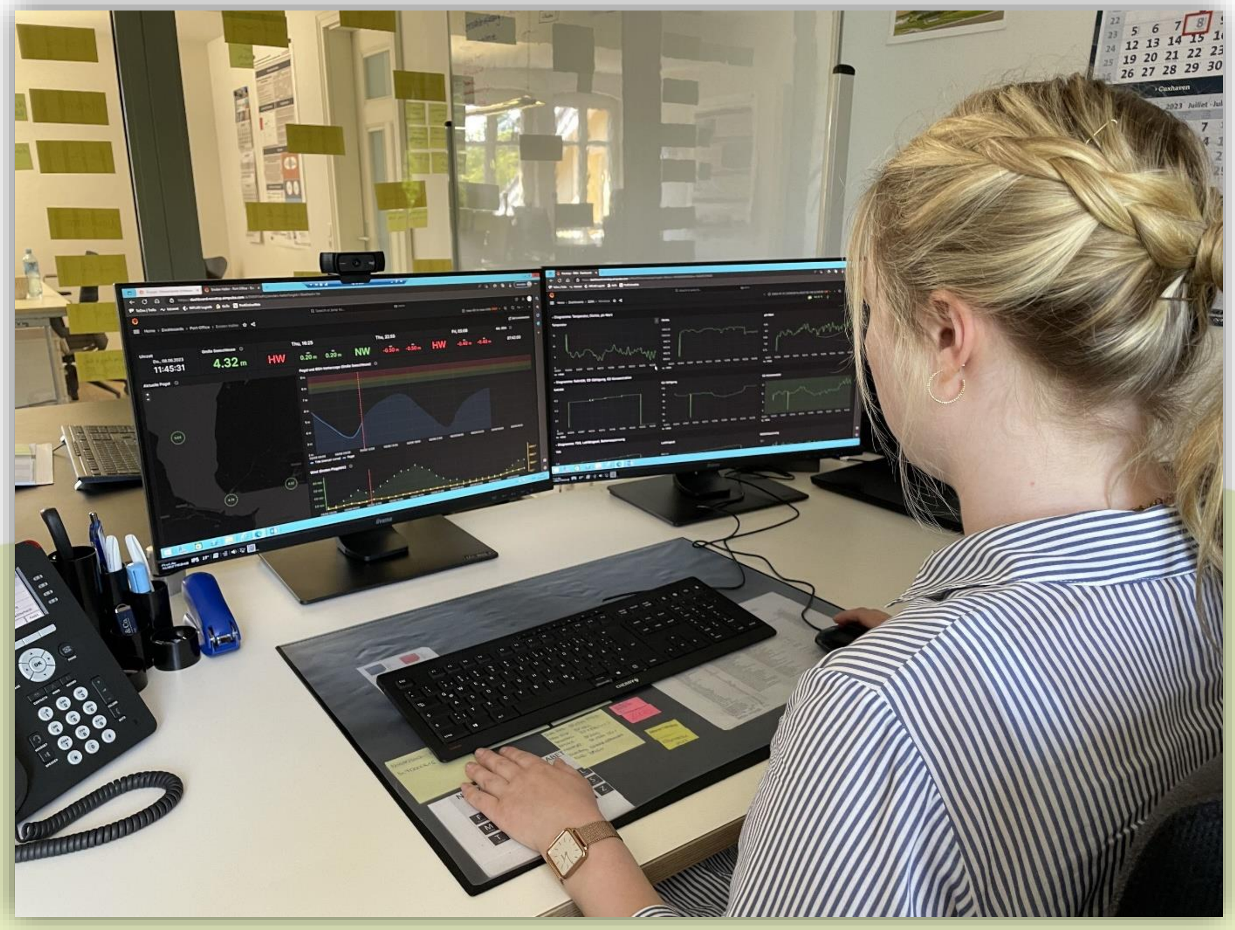
September 2023

Pilot 5
Integrated Water & Sediment Management Dashboard



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About NON-STOP

NON-STOP (New smart digital Operations Needed for a Sustainable Transition of Ports) is an Interreg North Sea Region (NSR) project that started in July 2019, with a duration of 3 years. Due to the COVID-19 pandemic, it extended until June 2023, with an increase in partners, pilots and budget. NON-STOP is based on the operational pilots in Small and Mediums sized Ports (SMP).

A series of pilot reports

NON-STOP consists of 8 pilot projects and partners from the port industry, tech business, as well as a law firm within sustainability and digitalization in port operations. In a series of publications, we are introducing each of the pilot projects highlighting the experiences, results and learnings from their work. Knowledge sharing is vital for the continuous development of sustainable energy and the publications of NON-STOP pilot projects will be a source for further work.

For more information about the Pilot 5: Integrated Water & Sediment Management Dashboard, please contact the NON-STOP partner:

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Summary of Pilot

As part of the EU INTERREG project NON-STOP, the pilot project in the Port of Emden aimed to develop and implement a concept for an intelligent sediment and water management system. The NON-STOP pilot project in the Port of Emden is committed to three synergetic goals:

Goal No. 1: Reducing influx of sediment material from the river Ems into the inner port
Goal No. 2: Supporting hinterland drainage system
Goal No. 3: Long-term support of recirculation dredging process for harbour maintenance

To fulfil those goals a knowledge of microbiology and sedimentology, the establishment of suitable water monitoring, and optimised interaction of infrastructural elements (e.g. locks and pumping station) are required. Additionally, long-term port management needs to account for the unpredictable impacts of climate change and to pursue strategies to counteract its negative effects. In pursuit of successful and effective measures, studies and trials were conducted, which were aimed to determine implementable strategies and solutions.

In view of these work objectives, Niedersachsen Ports pursued the following measures in scope of its NON-STOP pilot project the Port of Emden:

a) study on the feasibility of inland drainage from the city of Emden and surroundings via port structures
b) research contract for a study of the microbiology in the fluid mud of the Port of Emden after rd., 30 years' experience with the recirculation dredging method for port maintenance
c) analysis of sediment material influxes from the river Ems into the inland port
d) extension of the monitoring of water quality parameters in the port
e) development of a dashboard as an assistance system

Through a thorough understanding of the system and the utilization of digital technologies, natural phenomena, processes, and harbour operations were synergized for optimal integration. The culmination of these efforts materialized in the form of a dashboard system, a digital tool for the centralized access to relevant data and information, designed according to the users' requirements, informing and supporting decision-making.

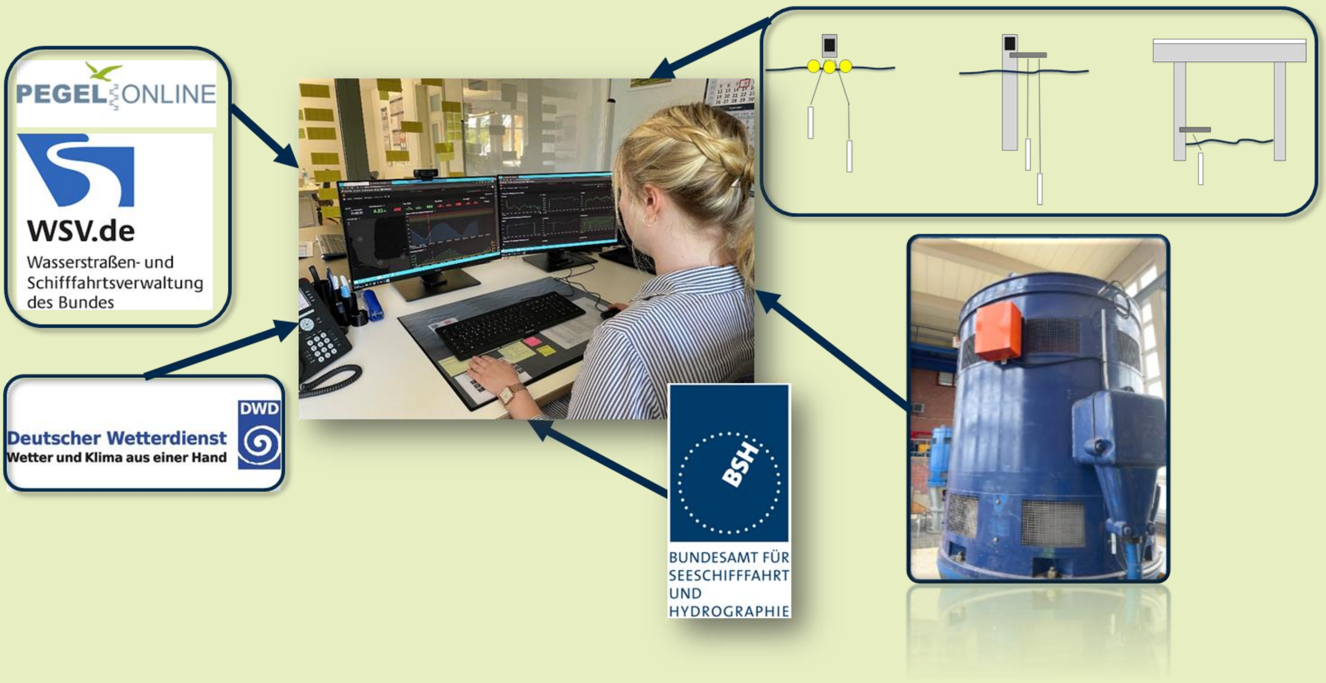


Figure 1. Port collaborator utilizing the developed Dashboard system and a schematic representation of the data sources that are integrated into the digital tool.

These measures were conceptualized to contribute to the NON-STOP ultimate goals of, though green investments:

- cutting down CO_2 emissions by 2%
- lowering the energy demand by 8% and
- reducing the time by 10%

of pre-defined logistical/maintenance port operations by building on collaborative expertise and joint practice.

For more information on the NON-STOP pilot project in the Port of Emden, visit:

https://northsearegion.eu/non-stop/about/

https://www.nports.de/nachhaltigkeit/projekte/non-stop/

Project Description

The Project's Objective

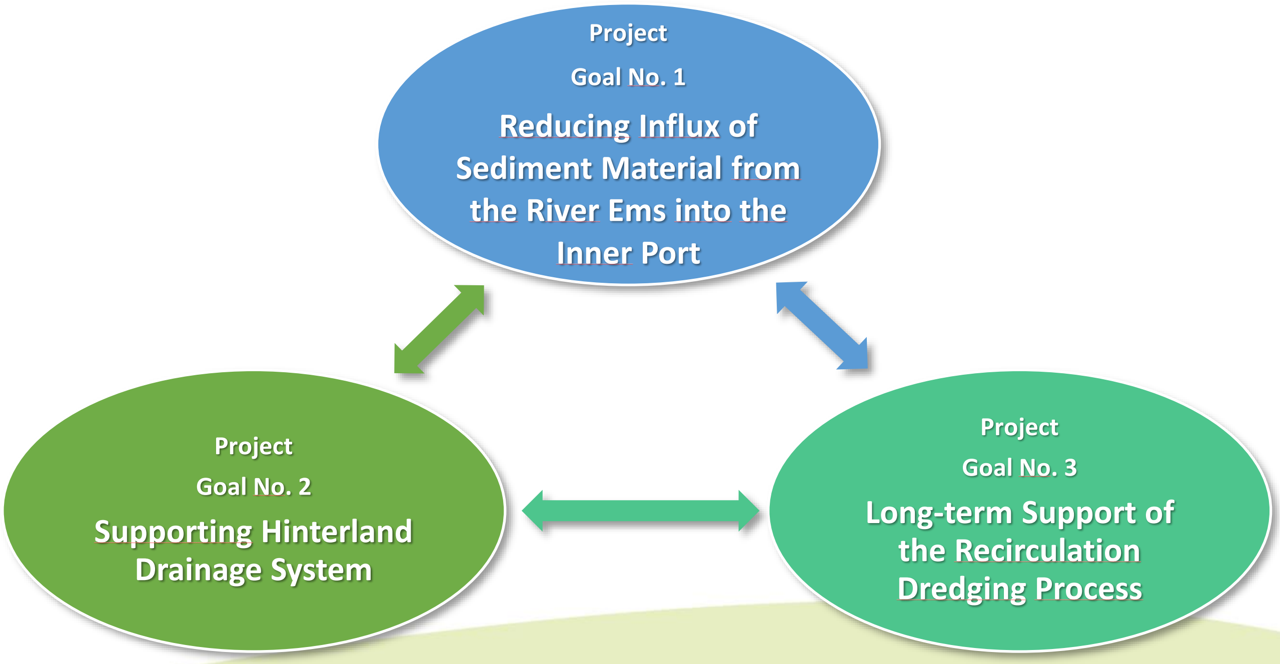


Figure 2. The three synergetc goals of the NON-STOP pilot project in the Port of Emden.

Goal No.1: Reducing Influx of Sediment Material from the River Ems into the Inner Port
In order to maintain the water depths in the harbour while minimizing dredging efforts, the project aims to investigate possible sources of solid material entry into the port, with the goal of mitigating this impact. This approach focuses on the prevention of the issue of sedimentation/siltation in the port and contributes to the overall optimization of the dredging strategy in place in Emden, the recirculation process.

Goal No. 2: Supporting Hinterland Drainage System
The port of Emden is situated downstream of the city of Emden and constitutes an important connection point between the hinterland and the river Ems. In the face of the effects of climate change, the Port of Emden could constitute an important contributor to the drainage of the surrounding settlements. In order to perform this task reliably and at the same time without comprising on the performance of the port activities, it is necessary to better understand the requirements and the potentials of the port in this role.

Goal No. 3: Long-term Support of the Recirculation Dredging Process
The practice of maintaining water depths and achieving a navigable fluid mud layer through the recirculation dredging has been developed and put into practice in the Port of Emden since 1992. Over the years, this complex system evolved and adapted to the local conditions. Through a better understanding of it, it becomes possible to infer tolerance ranges for various environmental conditions, which in turn allows for a more assured control and fine-tuning of the parameters involved in the process of sediment and water flow management.

Problem Definition

The Seaport of Emden is the third largest German North Sea port and is operated by Niedersachsen Ports. It is situated on the northern banks of the river Ems and consists of two parts: the outer port, exposed to the tides, and the tide-independent inner port (Figure 3), accessible via two sea locks. Niedersachsen Ports, as port infrastructure company, is also responsible for ensuring the required water depths in its ports so that they can be accessed by vessels safely, which entails complex sediment management and dredging operations.

Some key characteristics and facts about the Port of Emden include:

- 1.163 ha total area (of which 963 ha land and 201 ha water),
- the port can be divided into two distinct areas, the tidal outer Port and non-tidal inner Port,
- the port is located at the nodal point between hinterland and river Ems,
- the port disposes of 3 locks, 1 pumping station,
- presence of a navigable fluid mud layer between the water column and the consolidate sediment, and
- the nautical depth in the port are maintained through the process of recirculation dredging.

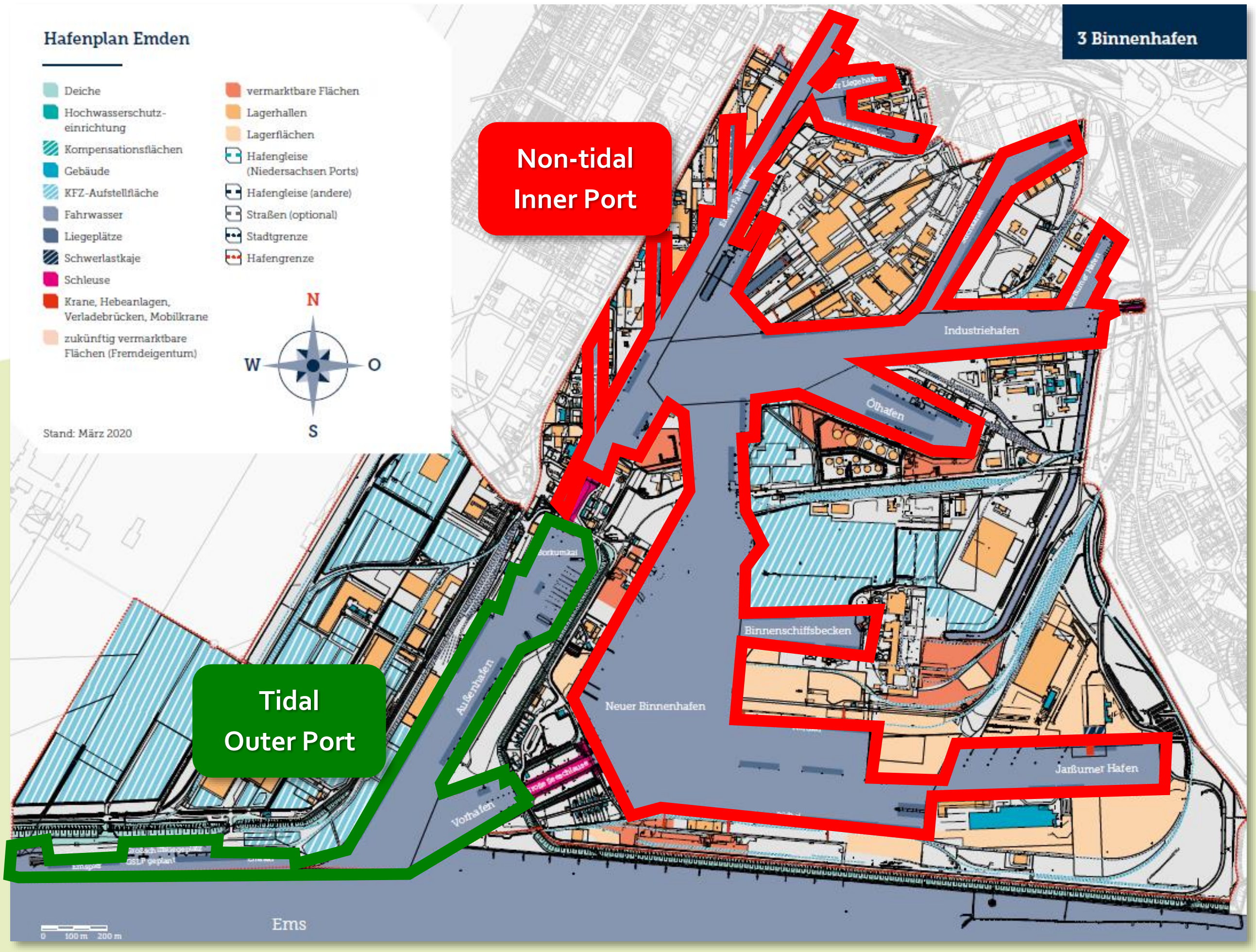


Figure 3. Overview of the Port of Emden with its tidal and non-tidal areas.

The Port of Emden has since 1992 adopted a water depth conservation strategy, the so called recirculation process, internationally known as Active Nautical Depth (AND), also known as Keep the Sediment Moving (KSM), Keep Sediment Navigable (KSN) or Keep Sediment in the System (KSIS). In this method, the muddy sediment layer that is formed over time and grows above the maintained navigational depth is never removed from the bottom of the harbour basins. Instead, it is constantly resuspended and conditioned in order to remain navigable, providing more nautical depth for the ships (Figure 4 and Figure 5).

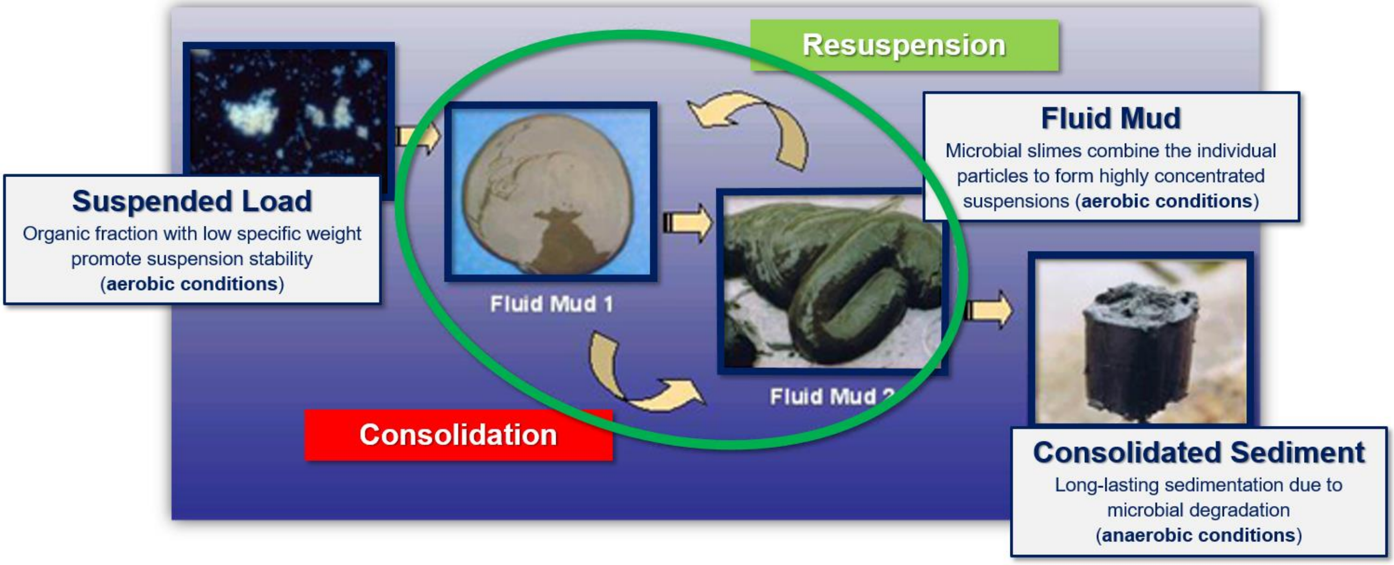


Figure 4. The difference stages of fluid mud. The dreging works in the Port of Emden conditionates the Fluid Mud 2 stage into the navigable Fluid Mud 1 stage, ensuring that the material doesn't consolidate.

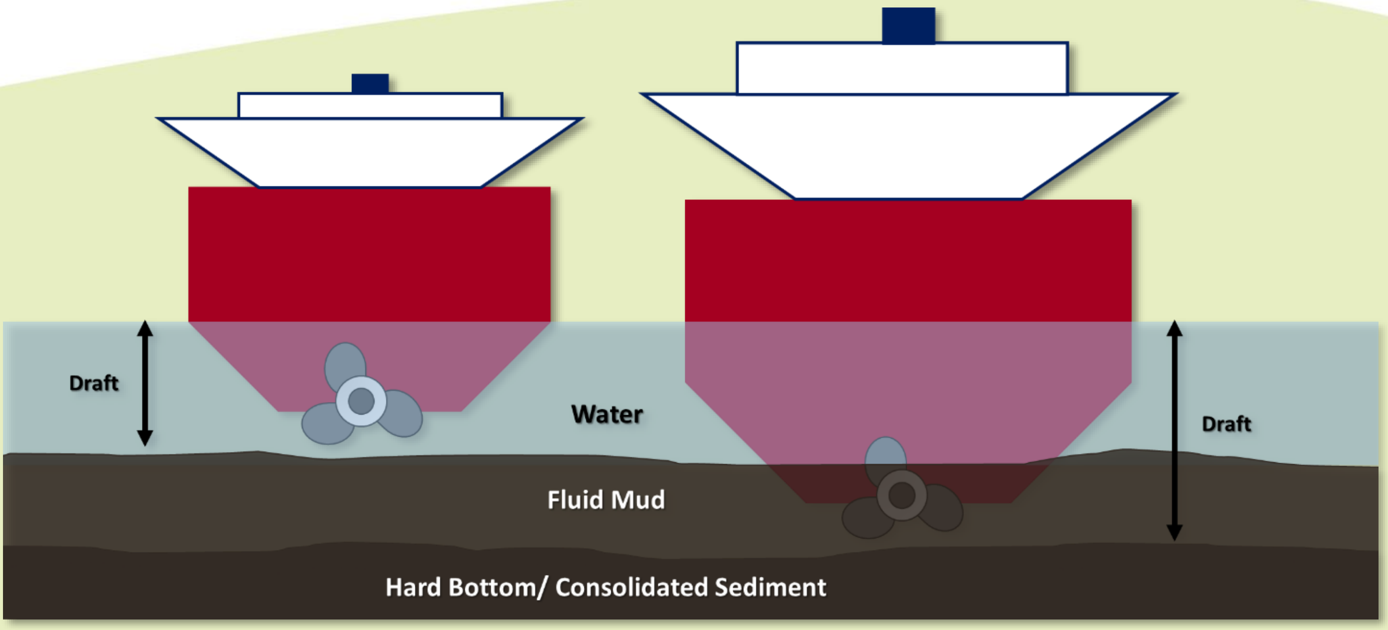


Figure 5. Ship on the right-hand side has a greater draft and navigates through the fluid mud layer.

To achieve that, a trailing suction hopper dredger (TSHD) is constantly in operation in the port, in order to periodically remove the uppermost layer of the very fine sediment particles, pump them into the dredger's cargo room where they come in contact with oxygen in the atmosphere and then finally release them back into the water column, as illustrated in Figure 6. The process creates a navigable fluid mud cloud that stays in suspension for days or even weeks, before the whole process has to be repeated.

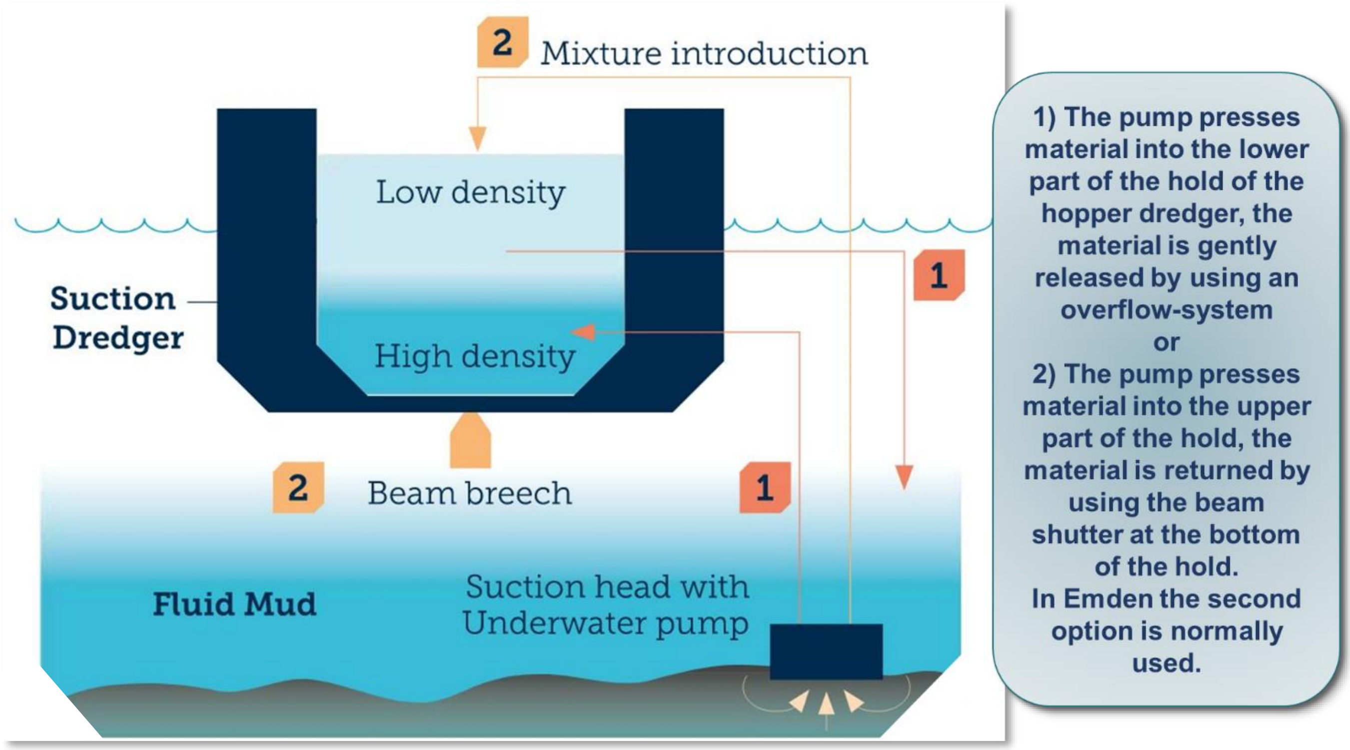


Figure 6. A cross-sectional view of the trailing suction hopper dredger (TSHD) deployed for maintenance dredging through the recirculation process in the Port of Emden.

The assumed pathways for entry of new, additional sediment material into the Inner Port of Emden have been a) sluicing events towards the inner port, especially through the *Große Seeschleuse* (Great Sea Lock), and b) pumping operations to restore the water level in the inner port via the port's pumping station.

With every sluicing action and use of the harbour pumping station, additional fluid mud can be introduced into Emden's Inner Port. The increased sediment inflow is a major challenge for the necessary water depth preservation in the ports. This can cause the fluid mud layer to become thicker and denser long-term, resulting in the need for more frequent dredging operations. Consequently, the recirculation dredging used exclusively since 2000 to maintain the water depths is gradually reaching its limits over time. As a result, removal dredging might have to be carried out again and sediment would have to be transported on land: the decreasing availability of land availability for disposal of dredged material and the frequently stringent environmental constraints pose obstacles.

During lock operation, sediments flow from the river Ems into the port, and, at the same time, lock activities lead to a loss of water from the port (in addition to natural evaporation). To compensate this loss, water is pumped through the pumping station to keep a constant water level for safe navigation in the port. This phenomenon could be amplified by the impact of climate change, especially if the warmer months become drier, leading to an imbalanced interplay among water, fluid mud, and sediment. Correspondingly, climate change models have indicated increased future discharge of fresh water from the hinterland into the saline water of the Port of Emden for the winter months (Figure 7), affecting the present seasonal patterns of water salinity and composition.

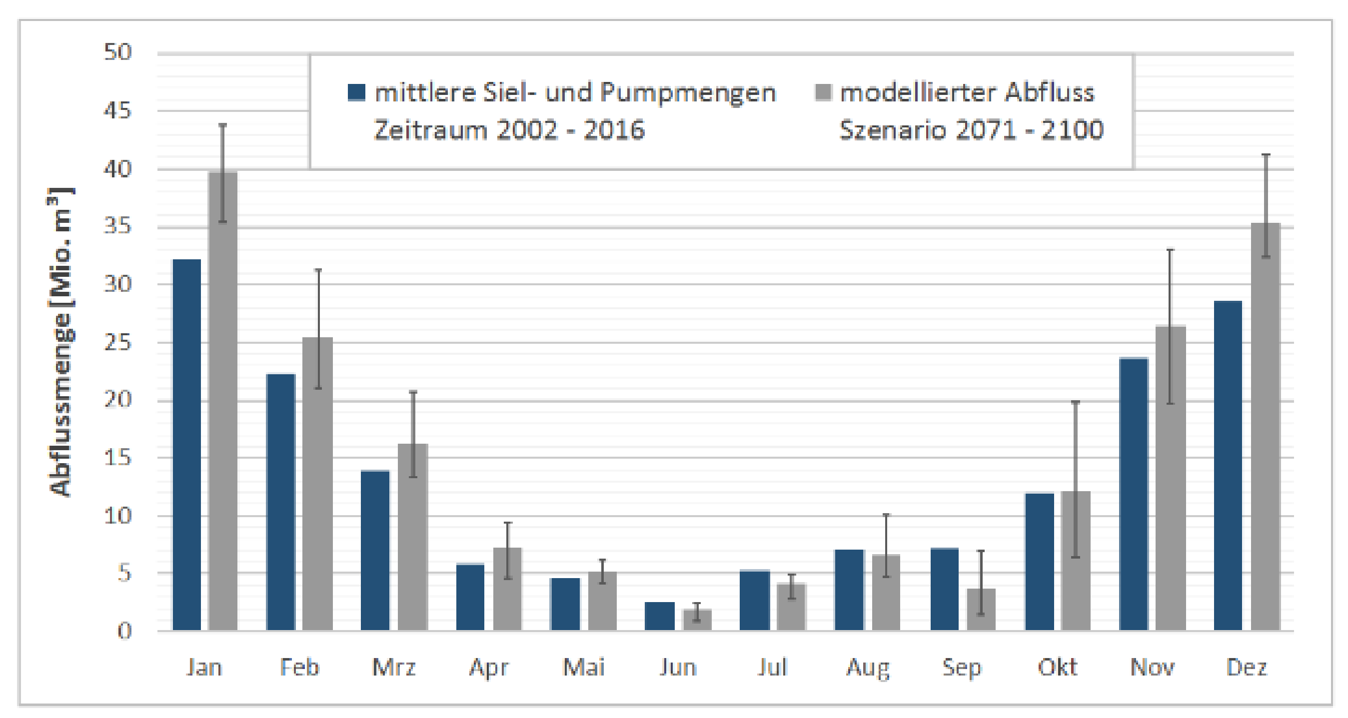


Figure 7. Model based estimation of the seasonal freshwater discharge in the area of the I.Entwässerungsverband due to climate change. Blue: Average of pumped discharge 2002-2016. Grey: average of modelled discharge for different climate scenarios 2071-2100. Source: Spiekermann et al. (2018).

While different parameters concerning fluid mud and recirculation dredging in the port of Emden are already regularly measured, there are yet no possibilities to draw direct inferences on the fluid mud microbiome. However, due to the bacteria's pivotal role in the Port of Emden and because external influences (e.g. more freshwater shares) could potentially change their habitat, their living conditions need to be monitored.

Moreover, the Port of Emden assumes a pivotal role as the primary recipient of inland drainage waters. In the case of heavy rainfall events, the excess water must be conducted away from the hinterland, and the Port of Emden is ideal for this purpose due to its large water receiving capacity and its direct connection to the river Ems. In addition, water from the hinterland can compensate for the loss of water in the port locks in the port, thus avoiding the energy- and cost-intensive use of the port pumping station. With the anticipated higher water levels in the outer port in the long-term due to climate change, however, the possibilities for tapping water from the hinterland and ensuring acceptable lock operation will pose challenges.

In order to operate a system that functions in the long term and to future challenges, sediment and water management must be considered in an integrated way. Only through this approach can the various needs be met, the limited resources effectively bundled and synergy effects can be achieved. The pursuit of a dashboard system emerges as the optimal alternative for seamlessly integrating all these multifaceted needs and conditions, providing a centralized platform that enables efficient monitoring, data analysis, and decision-making to ensure the long-term sustainability of sediment and water management in the face of evolving challenges, as summarized in the Figure 8.

Figure 8. Schematic representation for the concept of a dashboard system for the Port of Emden.

The Process – From Concept to Completion

Goal No. 1: Reducing Influx of Sediment Material from the River Ems into the Inner Port

Sub-Goal No. 1.1: Measurements at the Port's Pumping Station
To assess the potential material influx into the Inner Port of Emden via the port's pumping station, several measures were pursued. On one hand, multiple sample collections were conducted in the immediate vicinity of the port's pumping station at various time points, with the goal to demonstrate how much solid material is present in the samples taken at different depths and at different points around the pumping station, both in the inner port area and in the outer port area (Figure 9, **Table 1**). On the other hand, a field experiment with the instalment of existing barrier panels at the port's pumping station was carried out, aiming to demonstrate the effects of a "material barrier" on the material influx caused by pumping operations into the inner port (Figure 10).

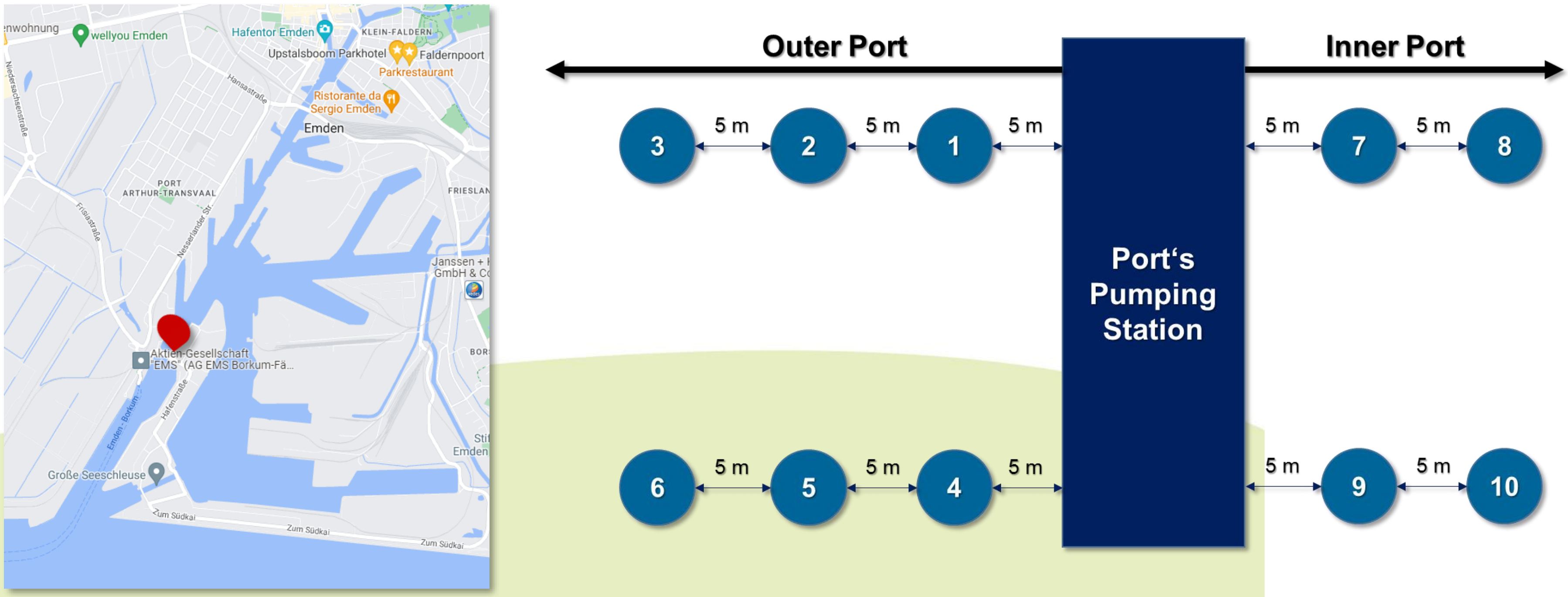


Figure 9. Location of the port's pump station in the Port of Emden (left-hand side) and schematic overview of sampling points for experiments concerning inflow of sediment material into the inner port via the port's pumping station (right-hand side). Source: Google Maps.

Table 1: Set-up of the three settling experiments that were conducted to investigate the potencial entry of sediment material into the inner port via the port's pumping station.

	Period	Framework Conditions
1st Experiment	Jan 2021	no previous use of the pumping system (control)
2nd Experiment	June 2021	right after a pumping event
3rd Experiment	Sep 2021	during the use of the dam plates as a "material barrier"

Figure 10. Panel board used as a sediment barrier in the inlet area of Pump 1 at the port's pumping station for the field test.

The material samples were analyzed by Niedersachsen Ports collaborators through a sedimentation test. For this purpose, the samples were homogenized, placed in graduated cylinders, and subsequently examined for the sedimentation processes that occurred. After the material had settled, it was possible to read out how much solid content was present in each sample. High solid contents in the samples taken in the inner port area could indicate an influx from material into the inner port. The following figure illustrate the experimental procedure.

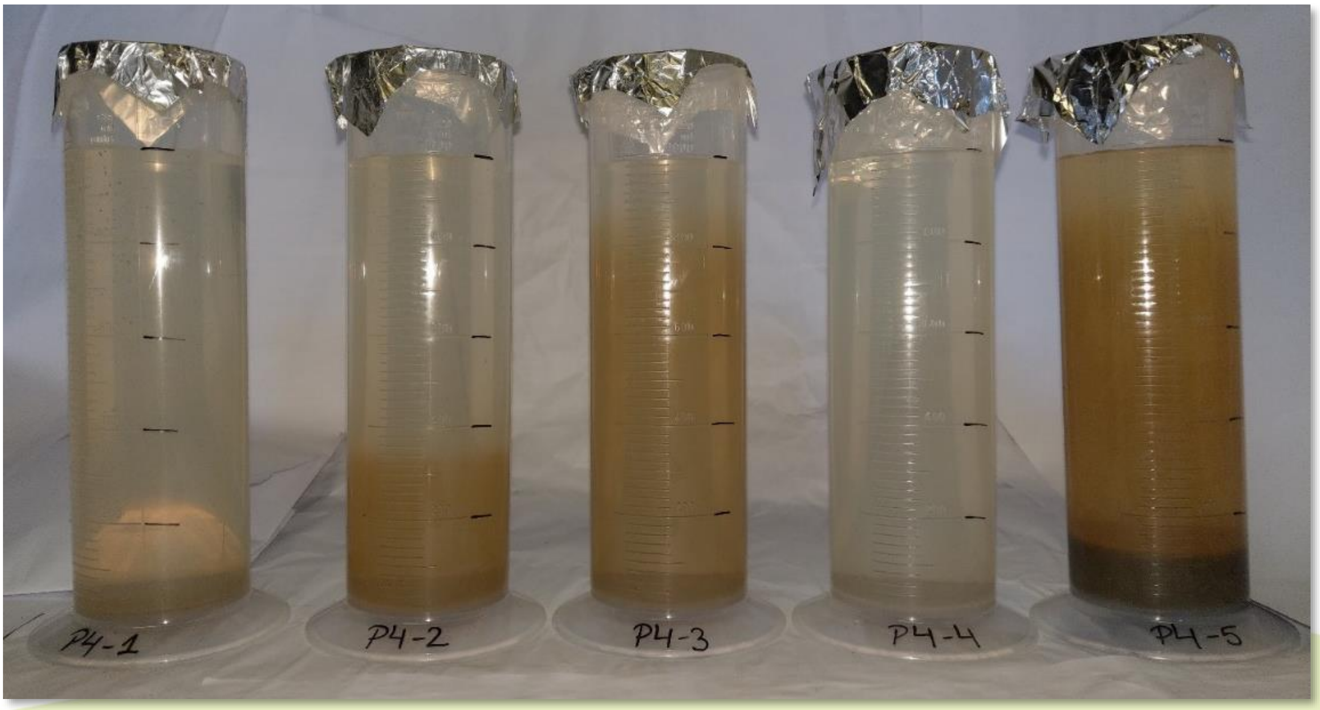


Figure 11. Experimental procedure with stand cylinders for sedimentation testing. Samples taken at the sampling point P4 in the outer port area at the depths of -1, -2, -3, -4, and -5 m (left to right) are shown. Sample P4, -5 m demonstrates a higher solid content.

Sub-Goal No. 1.2: Measurements Concerning Lock Operation

Due to its dimensions and type of usage, the *Große Seeschleuse* (Great Sea Lock) is assumed to play a significant role as a pathway for material from the Ems River into the Inner Port of Emden. Figure 12 clearly illustrates the sediment dynamics underlying these assumptions, depicted as differences in turbidity and resuspension in the areas surrounding the Great Sea Lock.

Even though the turbidity cloud initially suggests material inflow through sluicing events, such an effect had not yet been definitively proven. This matter was addressed under the NON-STOP project, among other aspects, through targeted soundings and density measurements in the area of the Great Sea Lock (entrance to the outer port, lock chamber, and entrance to the inner port).

Figure 12. Turbidity difference between the outer and inner port areas and a turbidity plume observed in the inner port.

Figure 13. Density measurement being conducted by a crew member on the surveying vessel "MS Delphin" from the Port of Emden. Credits: Synergetik GmbH.

Goal No. 2: Supporting Hinterland Drainage System

Although the Port of Emden is primarily entrusted with the handling of ship traffic, it also has another important function due to its geographical location. In the context of the so-called *Emder Wasserzirkus* (Emden water circus, an expression used as a descriptive term for the intricate water dynamics in Emden and it's vicinity), the port plays a regular role in hinterland drainage, especially during heavy rainfall. This is possible because the port is connected to the *Ems-Jade-Kanal* via the *Kesselschleuse*, a lock primarily designed to manage excess water from the neighbouring town of Aurich. From that, the water is then finally discharged into the river Ems through a natural gradient (inner port water level ≥ outer port water level) via the circulation channels of the *Große Seeschleuse* (Great Sea Lock). Figure 14 provides an overview of the so called "Emden water circus", showcasing different (target) water levels depending on the water body.

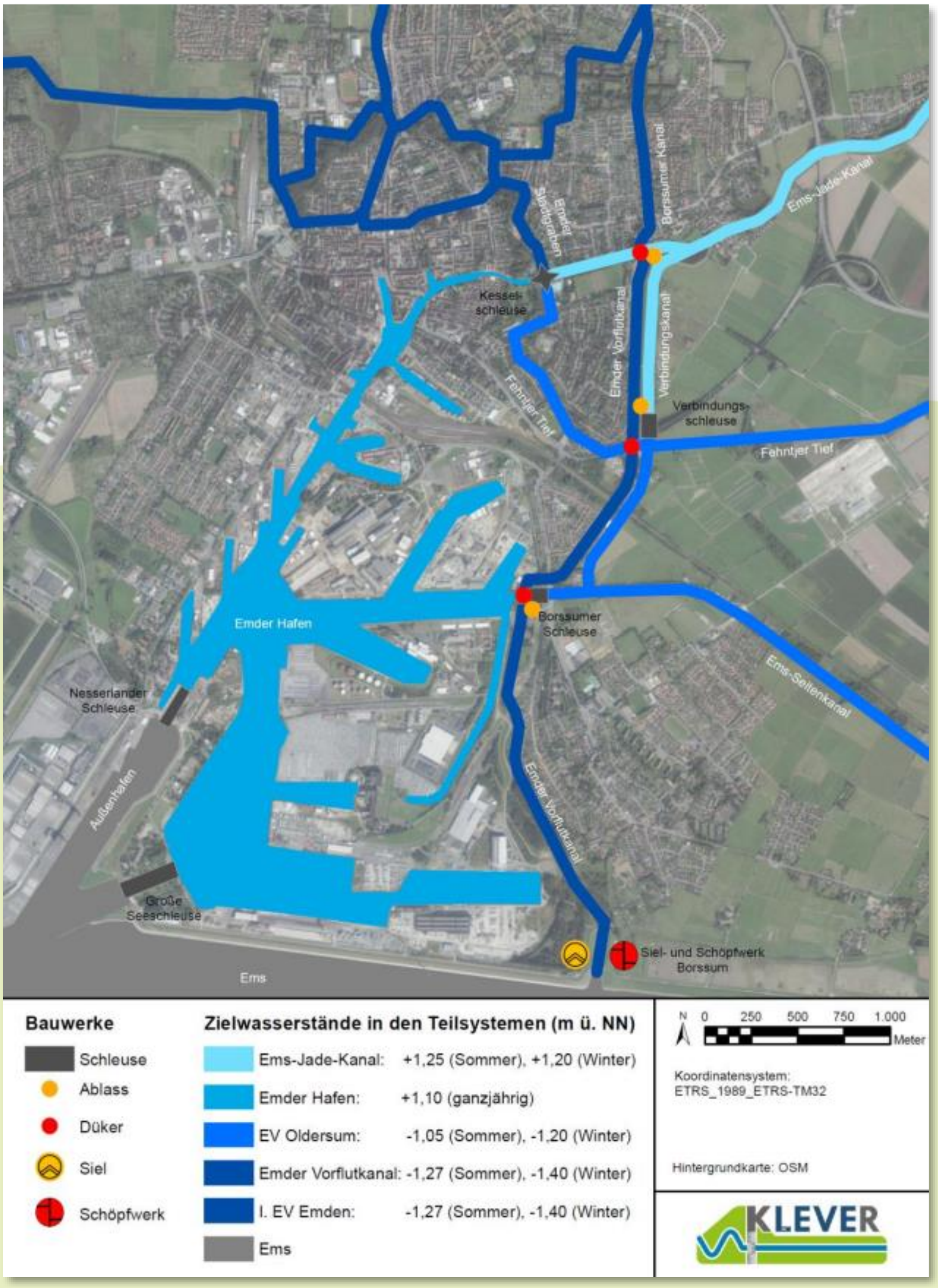


Figure 14. Overview of the *Emder Wasserzirkus*. Source: Spiekermann et al. (2018).

Up to the beginning of the NON-STOP project, the management of proportional hinterland drainage through the port of Emden had been exclusively conducted via telephone communication between the relevant stakeholders. On one hand, this involves the employees on duty at the *Kesselschleuse*, operated by the NLWKN Aurich (Department for Water, Coastal and Nature Conservation of the state of Lower Saxony). On the other hand, the respective Nautical Duty Officer at the Port Office Department of the Port of Emden is responsible for this coordination. Years of experience serve as the foundation for successful process management, which demands particular sensitivity and foresight due to the complexity of interrelations. Direct assistance through a drainage-specific support system was not yet available prior to the NON-STOP activities in the Port of Emden.

Furthermore, there is currently no comprehensive data foundation for water intake into the Port of Emden from the hinterland. Recognizing the significance of data regarding inflow and outflow into the Port of Emden, a permanent ultrasonic measuring point was to be pursued in close coordination with the NLWKN Aurich for the continuous measurement and record of the water level in the water body upstream of the Port of Emden, the *Ems-Jade-Kanal*.

Goal No. 3: Long-term Support of Recirculation Dredging Process

Sub-Goal No 3.1: Research Contract: Microbiology in Fluid Mud in the Port of Emden

A central measure within the scope of the Niedersachsen Ports' project work is the extensive investigation about composition of the microbiological communities found in the fluid of the Port of Emden. This is due to the microorganisms assumed vital functions as the basis for the type of procedure in maintenance dredging that has been developed and adopted for many years in the Port of Emden, the so called recirculation process.

As previously mentioned, the expansion of the capacities of drainage systems for the drainage of the hinterland is increasingly coming into focus in the context of advancing climate change. This also applies to the region of East Frisia, including the Port of Emden. Should the Port of Emden play an even greater role than before in regional inland flood management in the future due to increased freshwater intake, the microbiology in the fluid mud of the Port of Emden must be examined in detail beforehand. As described above, it is assumed that the recirculation process and thus the maintenance dredging in the harbour is based on microbiological metabolic processes. Any disturbances in these relationships, such as through a shift in the ratio between fresh and salt water in the inner port, could compromise the efficacy of the ongoing maintenance dredging efforts.

As a result of a public tendering and contract award procedure (in this case: award of contract following a partial tendering competition in accordance with German Regulation on Sub-Threshold Procurement UVgO), the research consortium TU Delft (NL) / Deltares (NL) / GEOMAR Kiel (DE) / Hamburg Innovation (DE) was commissioned with the research contract for microbiology in the Port of Emden in March/April 2021, with a run time from March 2021 to December 2022.

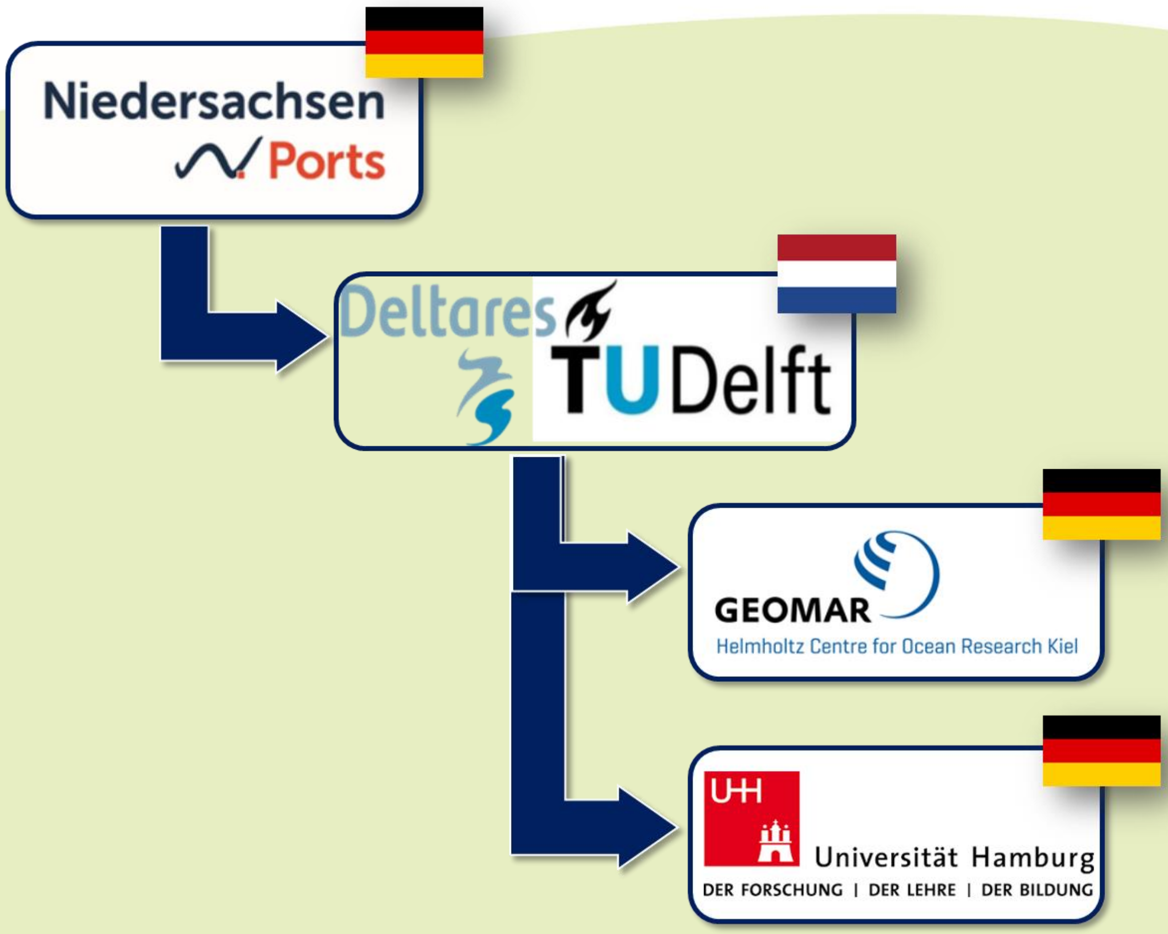


Figure 15. The research consortium comissioned with the investigation of the microbiology in the Port of Emden.

In this study, the fluid mud of the Port of Emden was to be investigated in terms of its rheological properties (Figure 16 and Figure 17) as well as the microbial community in the fluid mud in terms of its composition, metabolic processes and optimal life conditions.

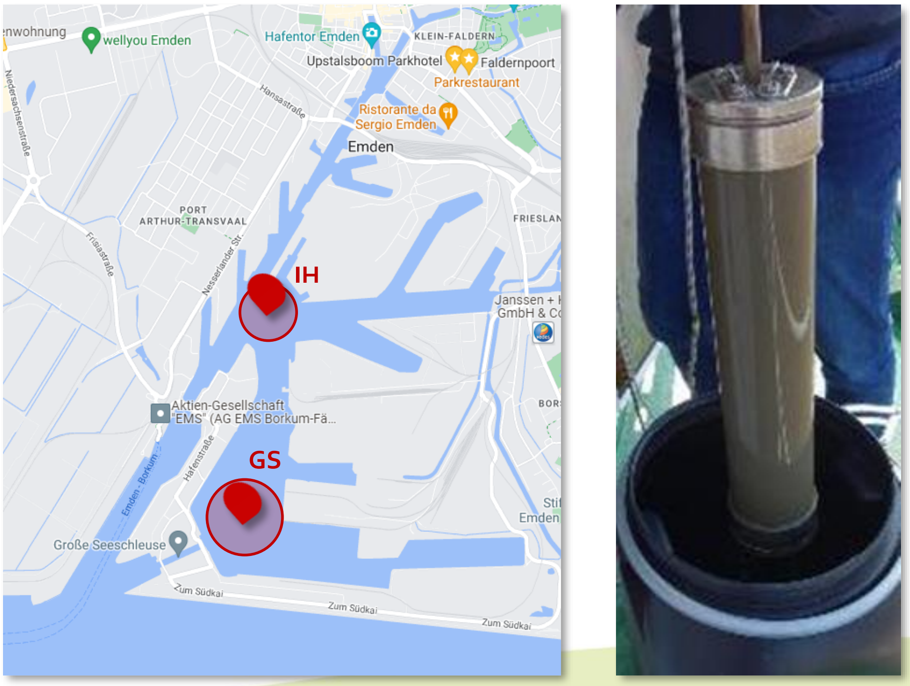


Figure 16. Sampling locations IH and GS in the Port of Emden (left). Source: Google Maps. Beeker sampler with fluid mud (right). Credits: TU Delft.

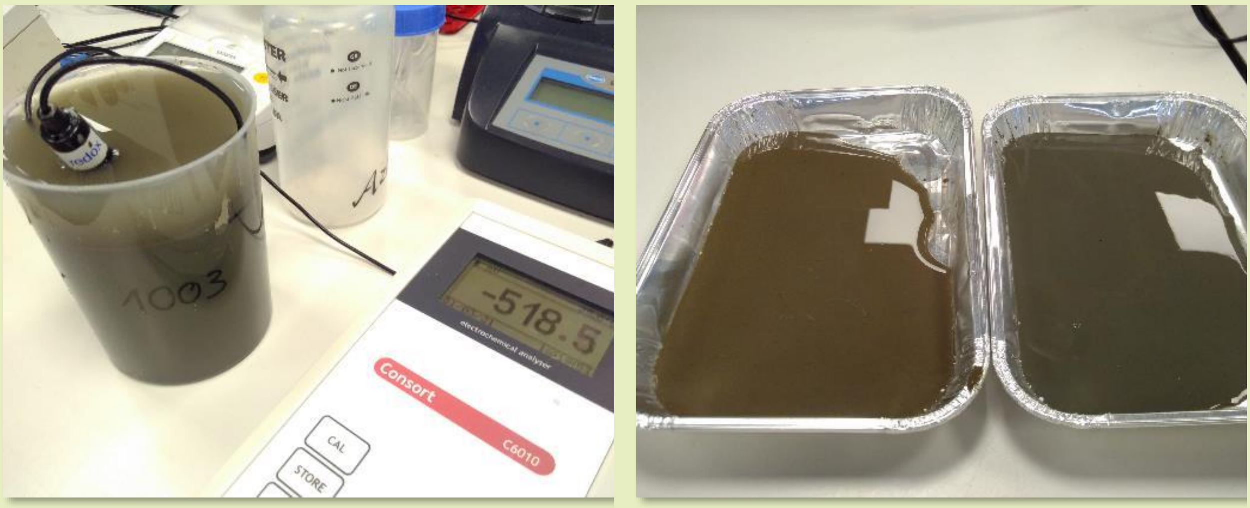


Figure 17. Examples of direct measurements of fluid mud properties. Left: Redox potential of sample from IH location. Right: Visual observation of fluid mud samples. Brownish discoloration is typical for more oxidized fluid mud from GS and grey colours indicate more reduced oxygen in fluid mud from IH. Credits: TU Delft.

In parallel, the microbiome found was to be deliberately exposed to larger quantities of freshwater from the Emden hinterland in the form of a dilution series under laboratory conditions (Figure 18 and Figure 19).

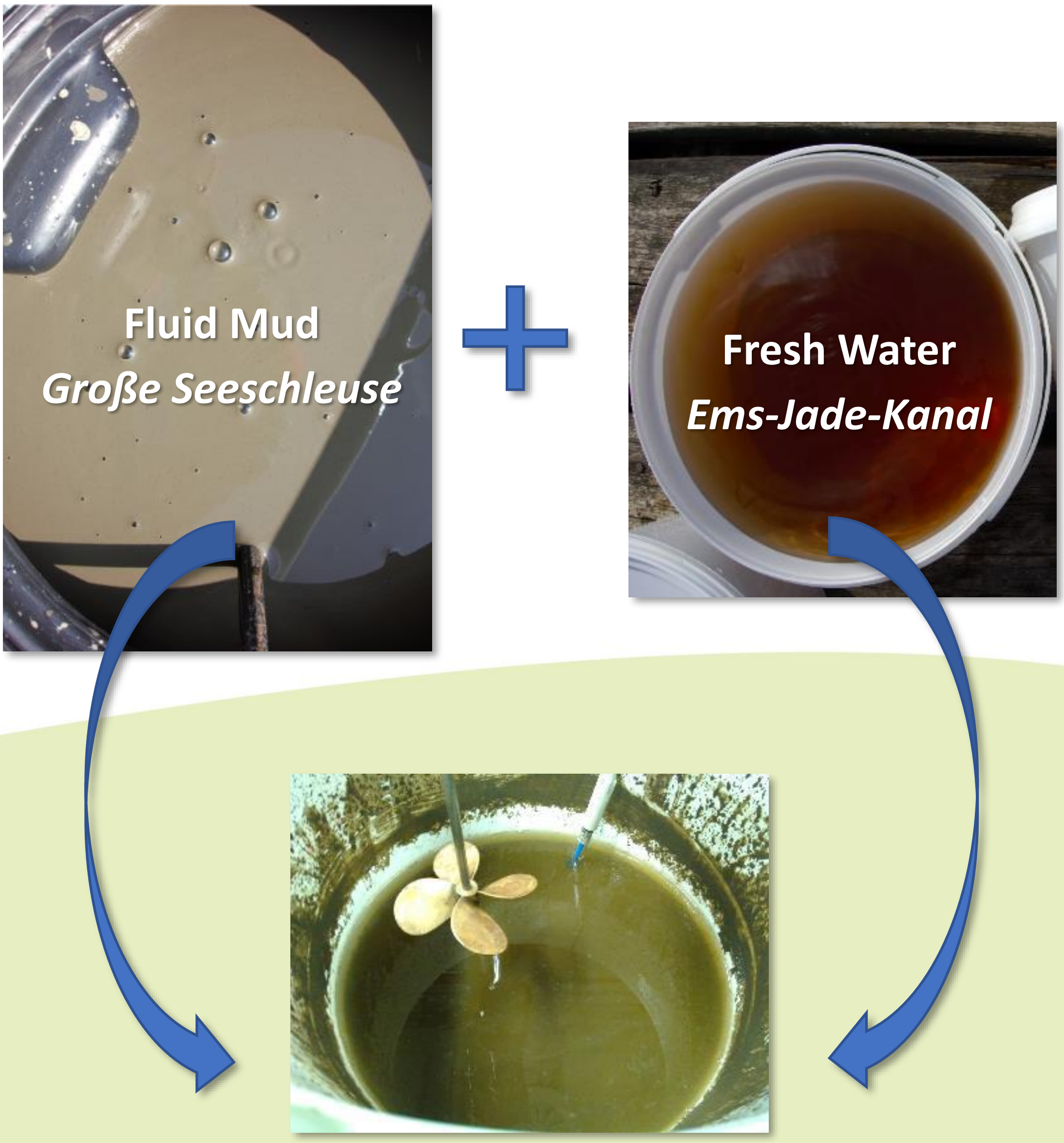


Figure 18. Preparation of fluid mud mixtures of different salinity, shear rates, sampling and analyses. Credits: TU Delft.

During this series of experiments, the recirculation process was also to be simulated so to replicate conditions as realistically as possible for the bacteria inhabiting the fluid mud medium. Upon the conclusion of this study, the accumulated insights have to enable a detailed comprehension of:

a) the microbiological processes associated with the maintenance of the fluid mud layer and the organisms responsible for them, as well as

b) the effects that can potentially be expected on these microbial metabolic processes as a result of the uptake of larger quantities of freshwater into the Inner Port of Emden.

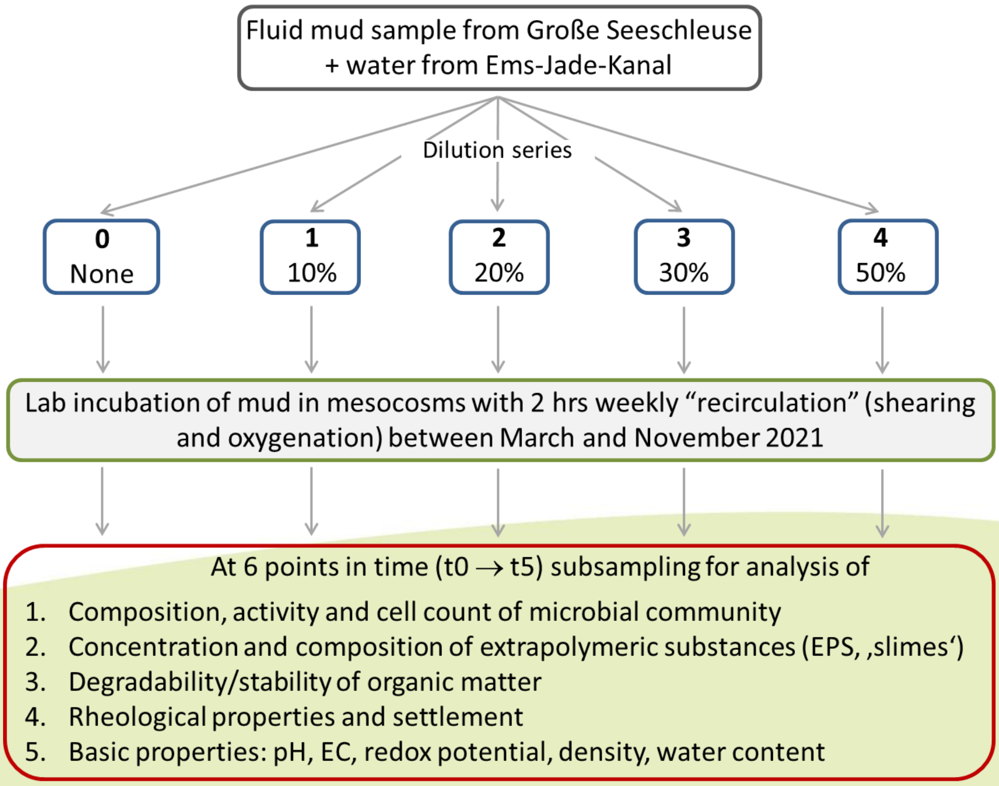


Figure 19. The experimental setup for the microbiological and rheological investigations. Credits: TU Delft.

Sub-Goal No 3.2: Sensor-based & Digital Water Monitoring

In addition to further data collection with already existing measuring devices, new possibilities for further permanent measurements were also to be realised within the framework of the NON-STOP project. The following diagram gives an overview of these new measuring stations to be implemented (Figure 20).

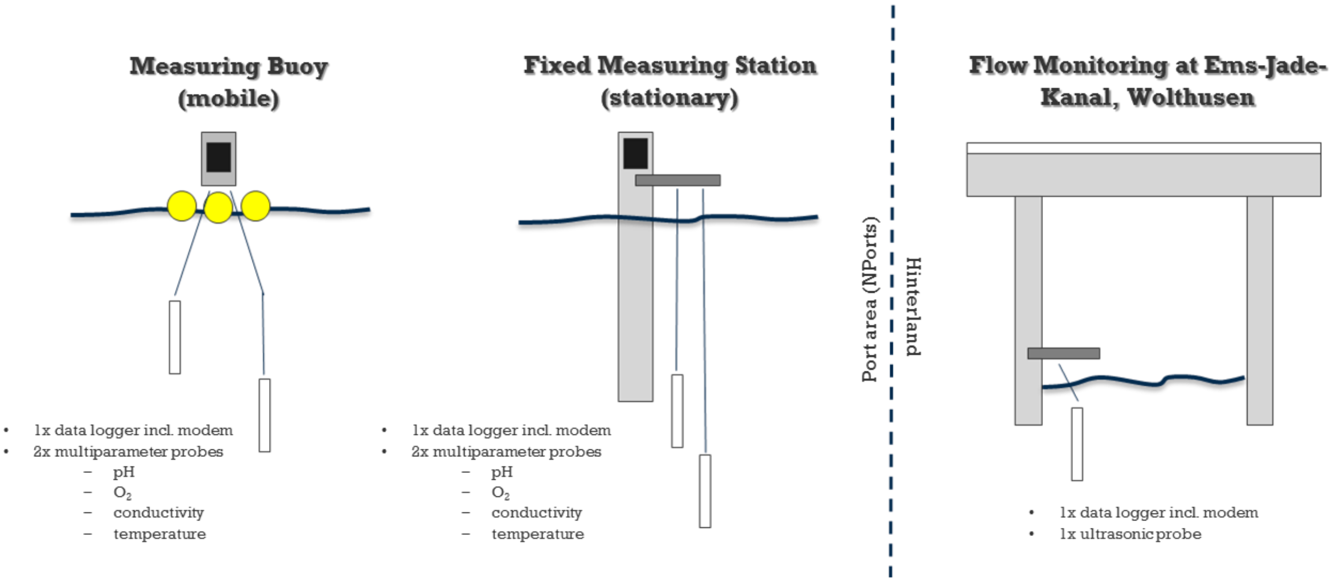


Figure 20. Diagram illustrating new measurement technology planned to be installed within the scope of the NON-STOP pilot project in the Port of Emden.

The **Mobile Measuring Buoy** can transmit measurement data from two selected depths at predefined intervals as a self-sufficient system powered by solar power and battery supply, utilising radio connectivity. It is equipped with one data collector and two multi-parameter probes. The versatility of this buoy lies in its ability to be deployed at various locations as needed, allowing for the monitoring of environmental conditions within both the water column and the fluid mud layer. In view of monitoring the microbiological living conditions in Emden's inner port waters, it was decided to build a measuring buoy based on the system originally designed by the *WSA Ems-Nordsee* (German Federal Agency for Waterways and Shipping Office), adapting it to fulfil the specific requirements of the Port of Emden.

The **Stationary Measuring System** functions analogously to the mobile measuring buoy in terms of its measurement technology. The primary distinction lies in the fact that this measuring apparatus is affixed permanently to a dolphin or quay wall. This setup allows for continuous, prolonged measurements in locations where using a measuring buoy would entail excessive risk (e.g., due to stronger waves and the increased likelihood of capsizing or water damage).

The **Permanently Mounted Water Flow Measuring Point** is also designed to be self-sufficient. The pursuit of this approach is driven by the need to fill the data gap concerning inland water inflow into the Port of Emden from the *Ems-Jade-Kanal*. By employing an appropriate measuring device to monitor the water flow, it becomes feasible to estimate the volume of freshwater from the *Ems-Jade-Kanal* entering the inner port at any given time, providing valuable insights into drainage-related matters.

These new measuring devices not only allow long-term self-sufficient monitoring of the water conditions in the Port of Emden, but they also facilitate enhanced control over the influx of freshwater from the hinterland into the port, promoting optimized management.

Sub-Goal No 3.3: Digital Coupling of Data by Means of Dashboard System

In the Port of Emden, a wide variety of data is regularly collected to illustrate the situation in the different port basins. Nevertheless, there is an increasing demand for additional data collection, coupled with its aggregation and visualization, in order to provide targeted support to the relevant actors involved in a variety of port operations and processes. For instance, the introduction of new measuring technology is, as already mentioned, necessary in order to monitor the microbiological living conditions and the ecological state of the water in the Port of Emden. As previously mentioned, new self-sufficient permanent measuring stations were to be set up in the harbour area to measure and record various environmental parameters (including pH, oxygen concentration, electric conductivity and temperature). In addition, an ultrasound measuring station was to be set up to record the flow in the *Ems-Jade-Kanal*, so that in future the volumes of water flowing into the Port of Emden from the inland in the context of the hinterland drainage can also be determined.

Finally, a digital assistance system in the form of a data-visualising dashboard was to be developed so that existing data on weather and tide, for example, as well as the additionally collected water parameters in and around the Port of Emden can be effectively combined and visualised.

In the summer of 2021, various exchanges took place between Niedersachsen Ports and bremenports regarding their respective research projects. As part of their funded project in the scope of the funding program for innovative port technology IHATEC from the German Federal Ministry for Digital and Transport *Tide2Use: Intelligente Schleusensteuerung*, where Niedersachsen Ports is an associate partner, *bremenports* has developed a system for digitally capturing pump events and a corresponding dashboard to gather and display the collected data. Building on the information exchange with *bremenports* and internal discussions, it was decided to entrust the task of developing a dashboard for the Port of Emden to the company *Aimpulse* from Bremen, the same organisation responsible for creating the dashboard for *bremenports*.

The development of the dashboard is based on an application utilizing the open-source software *Grafana*, which offers economic advantages.

Results

Goal No. 1: Reducing Influx of Sediment Material into Inner Port

Sub-Goal No. 1.1: Measurements at the Port's Pumping Station

The following tables showcase the results from the experiments aimed to quantify solid material at different depths in selected points in the inner and outer port, carried out under three different circumstances.

Table 2. Results of the three settling experiments after 4-5 days for the samples from the **inner port**.

Sampling Point	Sample ID	1st Experiment	2nd Experiment	3rd Experiment
P7	P7-1	< 20 ml	< 20 ml	< 20 ml
	P7-2	< 20 ml	< 20 ml	< 20 ml
	P7-3	< 20 ml	< 20 ml	< 20 ml
	P7-4	< 20 ml	< 20 ml	< 20 ml
	P7-5	< 20 ml	< 20 ml	< 20 ml
P8	P8-1	< 20 ml	< 20 ml	< 20 ml
	P8-2	< 20 ml	< 20 ml	< 20 ml
	P8-3	< 20 ml	< 20 ml	< 20 ml
	P8-4	< 20 ml	< 20 ml	< 20 ml
	P8-5	< 20 ml	< 20 ml	(no sample)
P9	P9-1	< 20 ml	< 20 ml	< 20 ml
	P9-2	< 20 ml	< 20 ml	< 20 ml
	P9-3	< 20 ml	< 20 ml	< 20 ml
	P9-4	< 20 ml	< 20 ml	< 20 ml
	P9-5	< 20 ml	< 20 ml	< 20 ml
P10	P10-1	< 20 ml	< 20 ml	< 20 ml
	P10-2	< 20 ml	< 20 ml	< 20 ml
	P10-3	< 20 ml	< 20 ml	< 20 ml
	P10-4	< 20 ml	< 20 ml	< 20 ml
	P10-5	< 20 ml	< 20 ml	< 20 ml

Table 3. Results of the three settling experiments after 4-5 days for the samples from the **outer port**.

Sampling Point	Sample ID	1st Experiment	2nd Experiment	3rd Experiment
P1	P1-1	< 20 ml	< 20 ml	< 20 ml
	P1-2	< 20 ml	< 20 ml	< 20 ml
	P1-3	< 20 ml	< 20 ml	**40 ml**
	P1-4	< 20 ml	< 20 ml	(no sample)
	P1-5	< 20 ml	**240 ml**	(no sample)
P2	P2-1	< 20 ml	< 20 ml	< 20 ml
	P2-2	< 20 ml	< 20 ml	< 20 ml
	P2-3	< 20 ml	< 20 ml	**300 ml**
	P2-4	< 20 ml	< 20 ml	(no sample)
	P2-5	< 20 ml	**140 ml**	(no sample)
P3	P3-1	< 20 ml	< 20 ml	< 20 ml
	P3-2	< 20 ml	< 20 ml	< 20 ml
	P3-3	< 20 ml	< 20 ml	**80 ml**
	P3-4	< 20 ml	< 20 ml	**60 ml**
	P3-5	**350 ml**	< 20 ml	(no sample)
P4	P4-1	< 20 ml	< 20 ml	< 20 ml
	P4-2	< 20 ml	< 20 ml	< 20 ml
	P4-3	< 20 ml	< 20 ml	**120 ml**
	P4-4	< 20 ml	< 20 ml	(no sample)
	P4-5	**200 ml**	**120 ml**	(no sample)
P5	P5-1	< 20 ml	< 20 ml	< 20 ml
	P5-2	< 20 ml	< 20 ml	< 20 ml
	P5-3	< 20 ml	< 20 ml	(no sample)
	P5-4	< 20 ml	< 20 ml	(no sample)
	P5-5	< 20 ml	**100 ml**	(no sample)
P6	P6-1	< 20 ml	< 20 ml	< 20 ml
	P6-2	< 20 ml	< 20 ml	< 20 ml
	P6-3	< 20 ml	< 20 ml	< 20 ml
	P6-4	< 20 ml	< 20 ml	< 20 ml
	P6-5	**160 ml**	< 20 ml	**480 ml**

The table clearly indicates that any solid particulates on the outer port side hardly or not at all find their way into the inner port as a result of the harbour pumping station's operation. In all 1-liter samples taken on the inner port side, the solid content identified through sedimentation consistently remained under 20 ml. This translates to a constant solid content of 2% with a liquid content of 98%. This situation also remained unchanged over an extended period under different sampling conditions (no pumping operation, pumping operation, and sediment barrier).

→ Based on these findings, it could be concluded that, for the time being, the operation of the port's pumping station has a negligible impact on the material or dredged sediments present in the Emden Inner Port.

These results provide valuable insight into the dynamics that govern solid material entry into the port and allow for a confident shift in the focus in the pursuit of solutions for avoiding additional sediment material entering the harbour, which after considering these findings, can only take place through the Great Sea Lock.

Sub-Goal No. 1.2: Measurements Concerning Lock Operation

Within the context of NON-STOP, this question was addressed through targeted soundings and density measurements in the area of the Great Sea Lock (entrance area of the outer port, lock chamber, and entrance area of the inner port). Figure 21 shows a sounding difference model from June 2021, illustrating the difference in elevation for the sounding frequencies 210 kHz and 15 kHz. While the higher frequency detects the upper edge of the fluid mud layer, the lower frequency captures its lower edge. These results highlight the difference in the thickness of the fluid mud layer in the surveyed area, which can reach a value of ≥ 3 m in the vicinity of the lock entrances. Inside the lock chamber itself, the thickness of the fluid mud is lower, ranging from 1 m to 2.5 m.

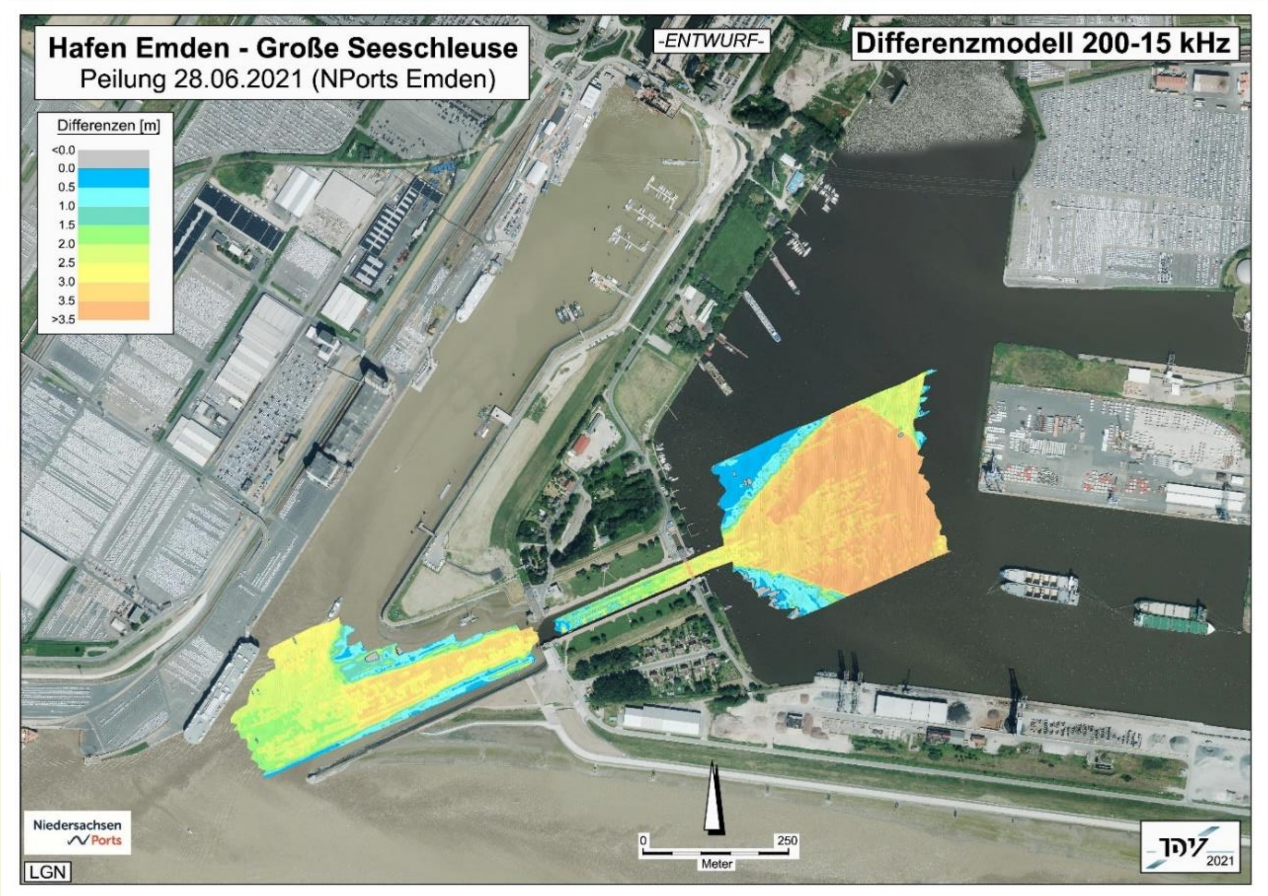


Figure 21. Sounding results from the Great Sea Lock area as difference model 200 - 15 kHz.

These measurements were conducted across diverse conditions, encompassing variations in seasons and tide patterns, among other factors. Establishing a solid database and a variety of results is crucial for developing a model that describes the sediment transport in the studied area that is able to facilitate the formulation of strategies aimed at avoiding the additional introduction of surplus solid materials, which ends up having to be incorporated and managed through the recirculation dredging strategy. Also, the potential to substantiate future initiatives, including the possibility of returning solid materials from the harbour back into the river Ems.

Additionally, various observations and analyses from recorded data suggest that the outer gate of the Great Sea Lock often remains opened for a significantly longer duration than required by navigation needs, allowing unrestricted inflow of materials into the lock chamber (possible influencing factors could include density differences, tidal conditions, and flow patterns). Thanks to this investigation, light has been shed on an issue that will be explored in more depth in upcoming projects. One such project is the upcoming renovation of the Great Sea Lock. This project will provide various opportunities for automating and digitalisation of sluicing processes, ultimately leading to significantly improved efficiency. These enhancements will yield numerous benefits, including improvements to the overall balance of the water-fluid-mud-sediment system by limiting the periods where the gates remain open to the absolute necessity, in order to avoid excess material entering the inner port.

Goal No. 2: Supporting Hinterland Drainage System

In view of the relevance of the data concerning the water inflow and outflow into the Port of Emden, it was agreed in close consultation with the NLWKN Aurich to set up a permanent ultrasound measuring station with equipment from the company *Quantum Hydromet*, which was installed in October 2021 at the bridge *Wolthuser Brücke* across the *Ems-Jade-Kanal* (Figure 22). The station records water levels, discharge, and flow velocity at intervals of 5 minutes.

Figure 22. The bridge *Wolthuser Brücke* over the *Ems-Jade-Kanal* in Emden. Credits: NLWKN.

Due to the interest of the Port of Emden in the measured data, Niedersachsen Ports decided to contribute financially to the acquisition of the equipment. The measured data was integrated as one further data source for the dashboard (more on the dashboard will follow) (Figure 23).

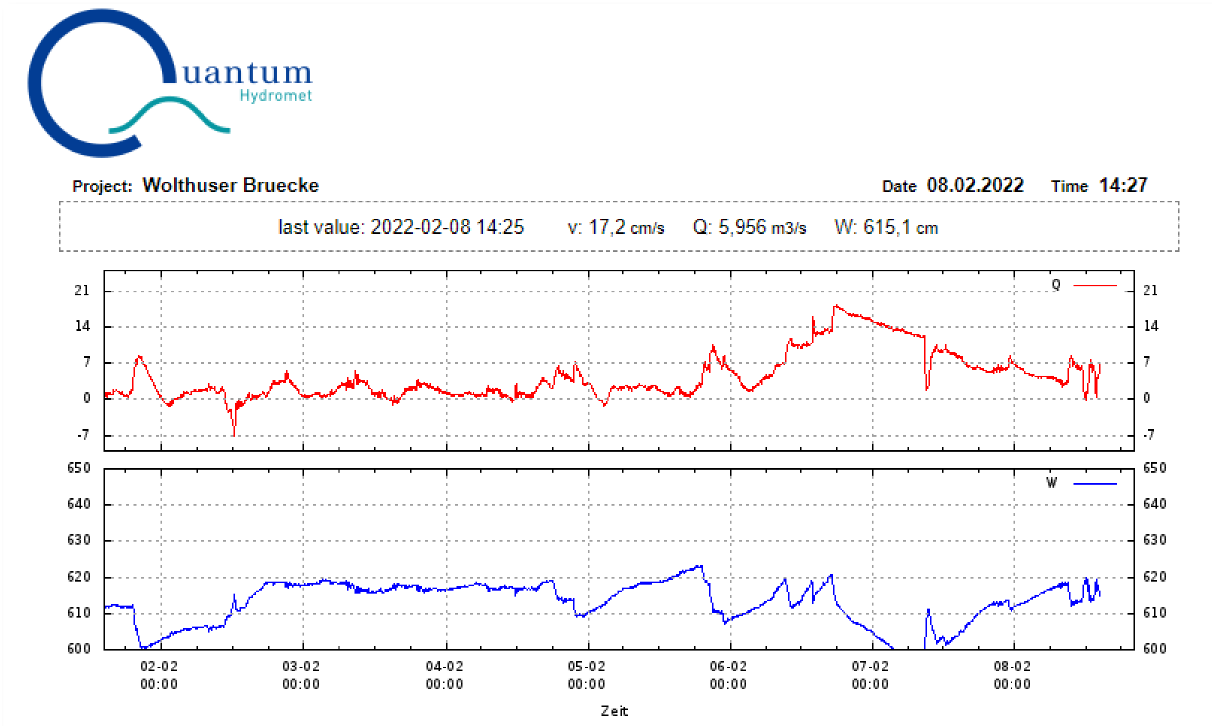


Figure 23. Data interface from the company Quantum Hydromet where the measured data on flow velocity, discharge, and water level can be accessed. Credits: NLWKN Aurich.

Finally, as a basis for future discussions on possible measures, the Port of Emden in the scope of the activities of NON-STOP also created a so-called drainage map (Figure 24). This map provides an overview of the interaction between the port of Emden and the NLWKN Aurich as well as the surrounding drainage associations in the course of hinterland drainage. The document contains information on central structures, their use and the responsibilities of the respective institutions and organisations.

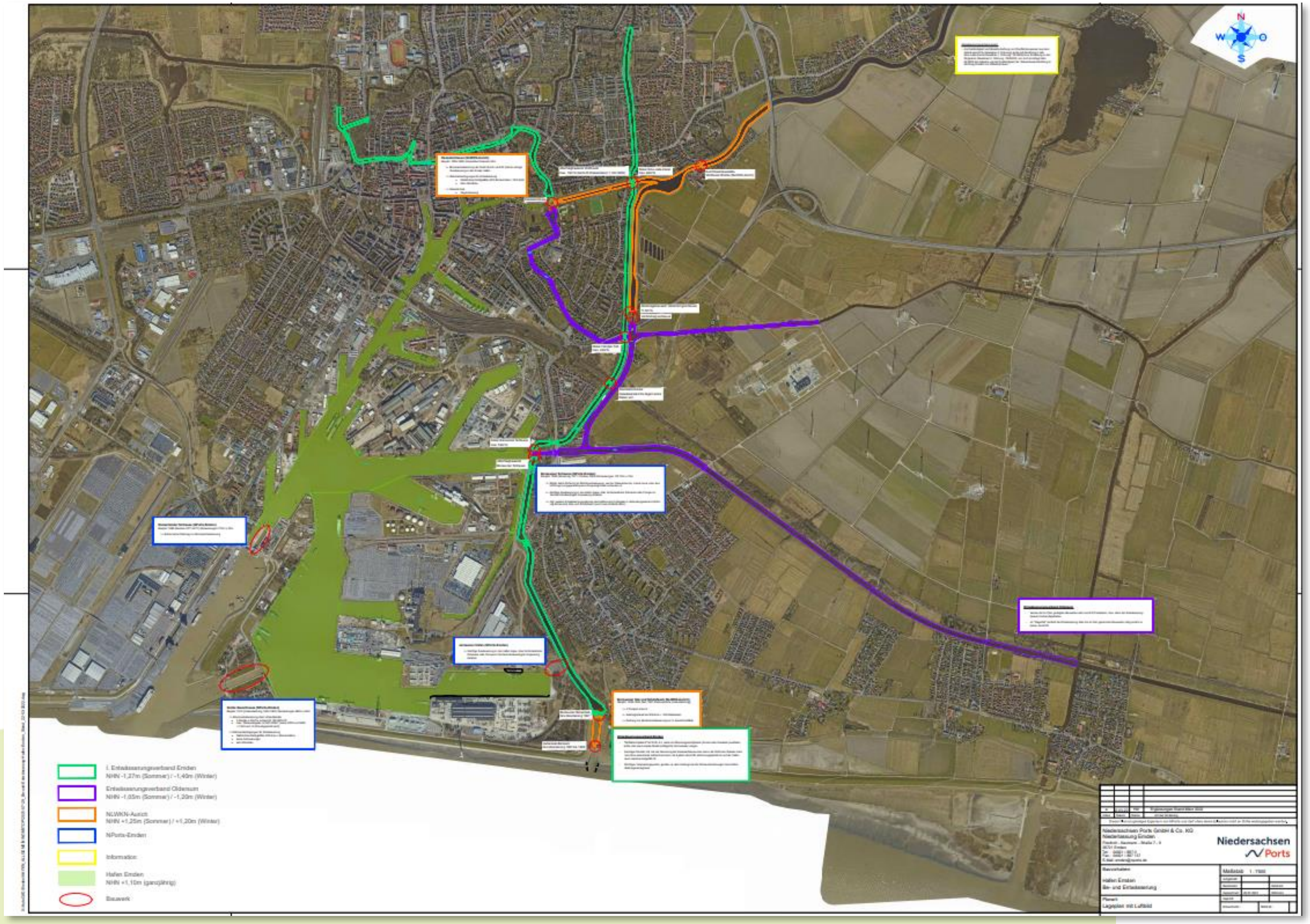


Figure 24. Drainage map containaing an overview of the interaction of the Port of Emden with the NLWKN Aurich as well as the surrounding drainage associations in the context of hinterland drainage.

Goal No. 3: Long-term Support of Recirculation Dredging Process

Sub-Goal No 3.1: Research Contract: Microbiology in Fluid Mud in the Port of Emden

Presented here is a summary of findings extracted from the comprehensive yearlong investigation conducted by the TU Delft at the Port of Emden. Regarding the relationship between fluid mud properties, microbial community composition, extracellular polymeric substances, changes in the share of fresh water and their relevance for the effect of maintenance dredging, the following conclusions can be drawn:

- In the Port of Emden, there is a significant seasonal change in the mix of freshwater and saltwater. From 2021 to 2022, the **salinity** of the water varied threefold (Figure 25), which is much larger than what is expected from climate change in the region. Given the current practice of recirculation dredging, no effect of the natural seasonal variation in fresh water share on yield stresses and settling rates as determined on monthly field samples could be detected.

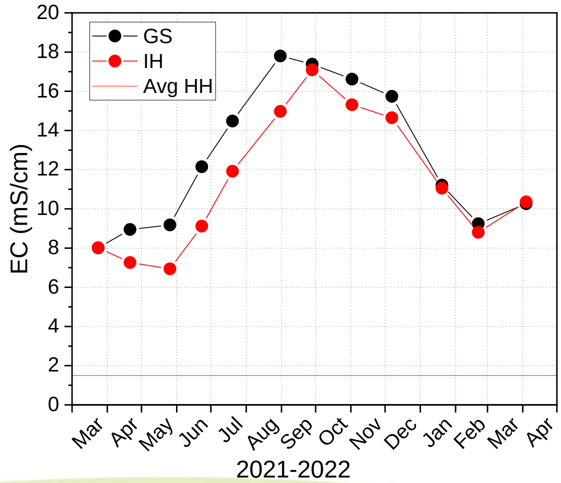


Figure 25. Electrical conductivity (EC) of fluid mud at sites GS and IH. Credits: TU Delft.

- The **yield stresses** and settling rates of fluid mud in the Port of Emden are consistently low and heavily influenced by density. Under the current recirculation dredging method, yield stresses well below 50 Pascals were consistently observed (Figure 26). By examining how yield stresses and settling rates respond to changes in density, we can define an ideal density range, a so called 'window of optimum density.' In this case, densities between 1.10 and 1.15 grams per cubic centimetre appear to be optimal because they result in low settling rates of less than 5-10 millimeters per day while maintaining low shear stresses below 50 Pascals, which aligns with the desired conditions.

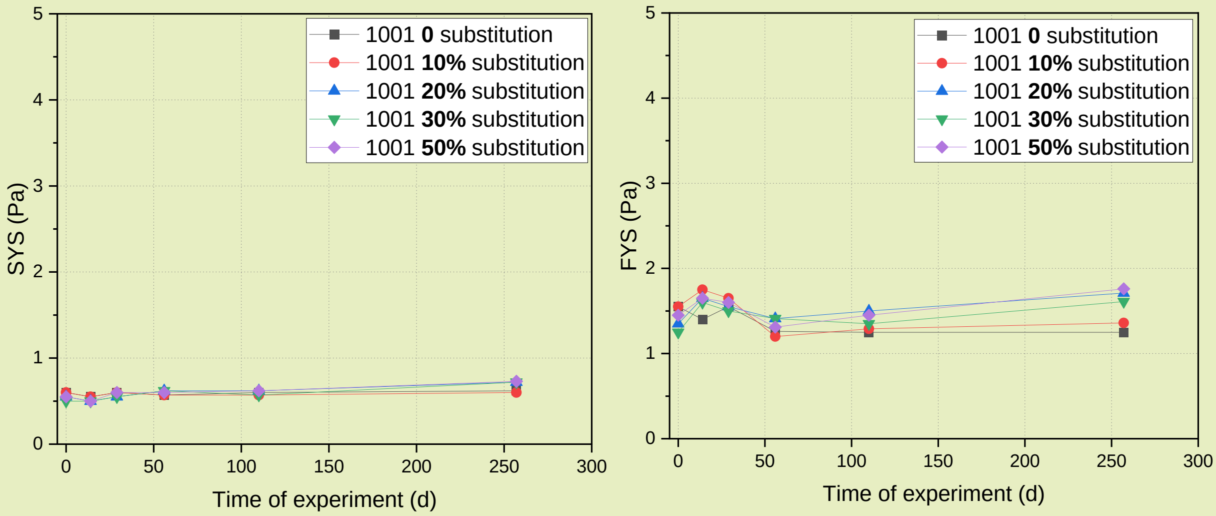


Figure 26. Static (left) and fluidic (right) yield stress over time of experiment. Credits: TU Delft.

- With respect to its chemical properties, in the Port of Emden, the fluid mud has high concentrations of **iron (Fe)** in both the solids and the water phase (Figure 27). This likely leads to the formation of larger, open flocs that settle slowly. The source of this iron could be iron-rich freshwater or industrial activities within the port. Further research is needed to determine the source and how the pore water composition affects flocculation behaviour.

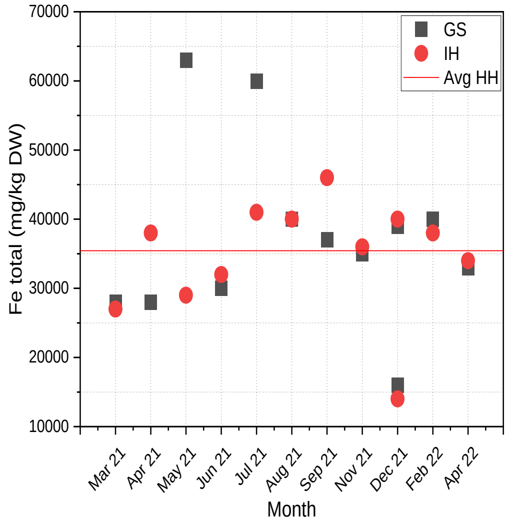
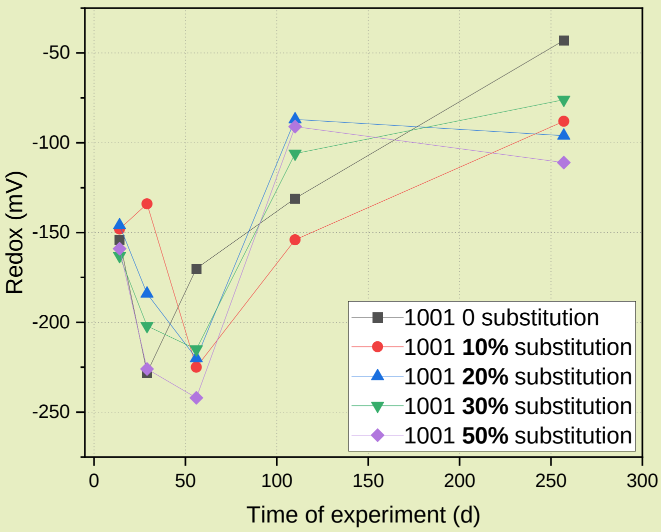


Figure 27. Concentration of total iron (Fe) in fluid mud at sites GS and IH. Credits: TU Delft.

- The fluid mud has very low **redox potentials** and oxygen levels (Figure 28). Even intense mixing did not significantly increase oxygen levels, suggesting that recirculation dredging is unlikely to introduce enough atmospheric or water phase oxygen to affect the microbial community.



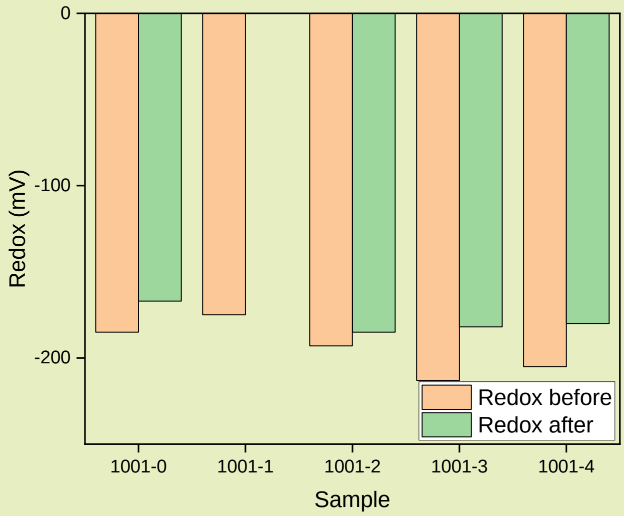


Figure 28. Redox potential over time of experiment (left) and effect of sample mixing (vane, 2 hours) on the redox potential (right). Credits: TU Delft.

- Freshwater admixture did not affect the **rheological response** of fluid mud, provided that the same density was maintained (Figure 29). This implies that future possible increases in shares of hinterland freshwater will likely not impede the effect of the current practice of maintenance dredging. Consolidated sediment instantly acquired rheological properties of fluid mud upon suspension in water (lowering the density). Dilution of fluid mud further decreased yield stress but increased the settling rates.

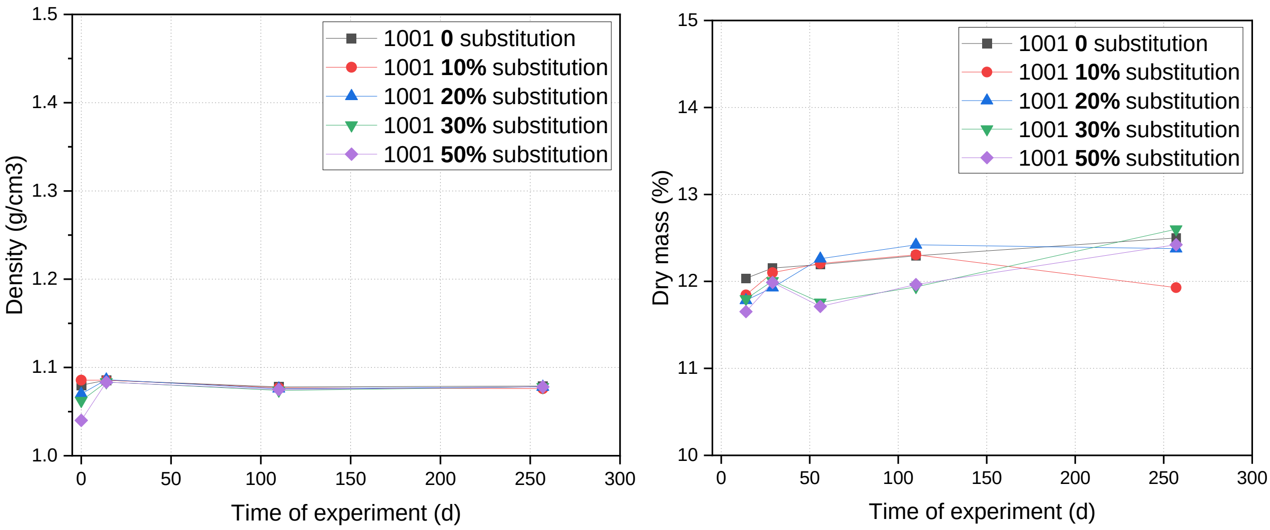


Figure 29. Density (left) and dry mass measured (right) over time over time of experiment. Credits: TU Delft.

- Replacing the original water with freshwater from the *Ems-Jade-Kanal* did not change the concentration or composition of **extracellular polymeric substances (EPS)**. Instead, EPS dynamics seemed to be influenced by limited supplies of easily degradable organic matter and restricted metabolite release, similar to *in situ* conditions. This was supported by consistent changes in organic matter degradability, which was not affected by the level of freshwater mixing. In the field, EPS concentrations followed a seasonal pattern, peaking in spring and dropping in winter, showing the microbial population's dependence on net primary production (Figure 30).

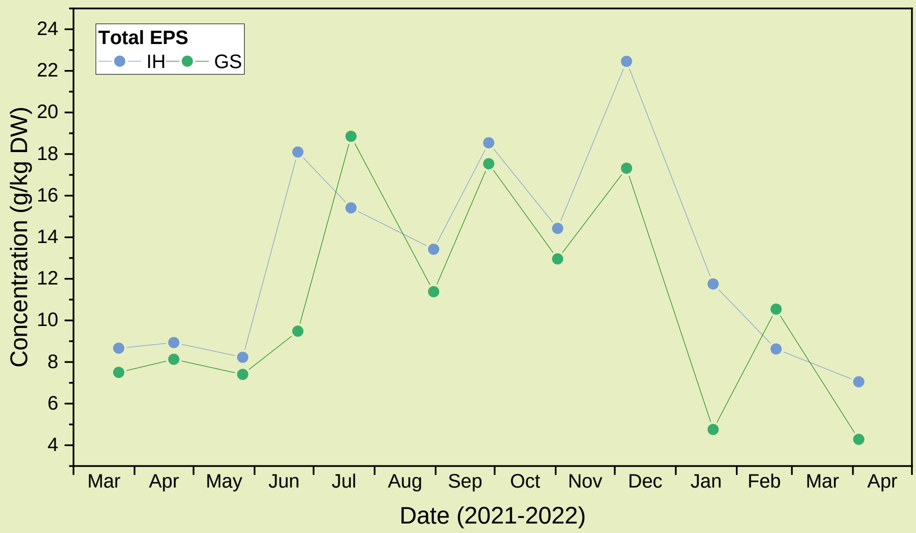


Figure 30. Concentration of total EPS over time in in-situ samples from sites GS and IH. Credits: TU Delft.

- The **microbial community** in field fluid mud is abundant and highly diverse. Bacteria dominate strongly over Archaea and microalgae. Abundances show a temporal variation (Figure 31, 32, and 33). Community composition differs distinctly between sites GS and IH and the laboratory study, suggesting swift adaptation to changes in environmental boundary conditions in a material that otherwise shows very similar properties throughout the harbour area. Differences in community composition do not explain differences in organic matter degradation rates between sites GS and IH, which indicates that similar rates of substance cycling and fluxes are facilitated by different members of the community.

Figure 31. Total cell counts at sites IH (left) and GS (right) in the period March 2021 - April 2022. Credits: GEOMAR.

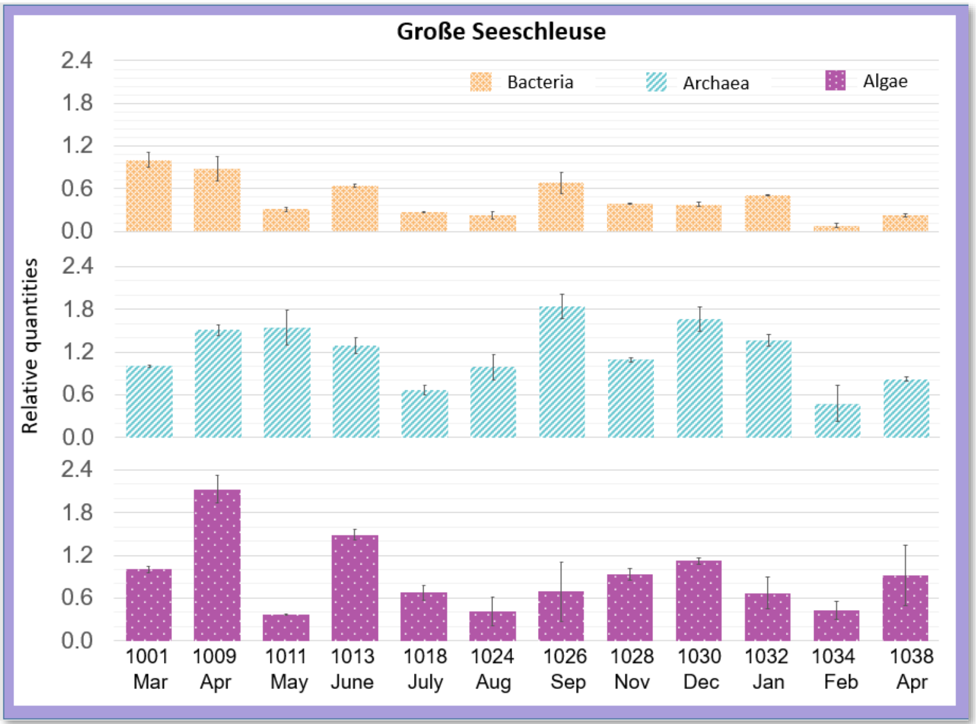


Figure 32. Relative abundance of bacteria, archaea and algae at the site GS. All data normalised to field sample 1001. Credits: GEOMAR.

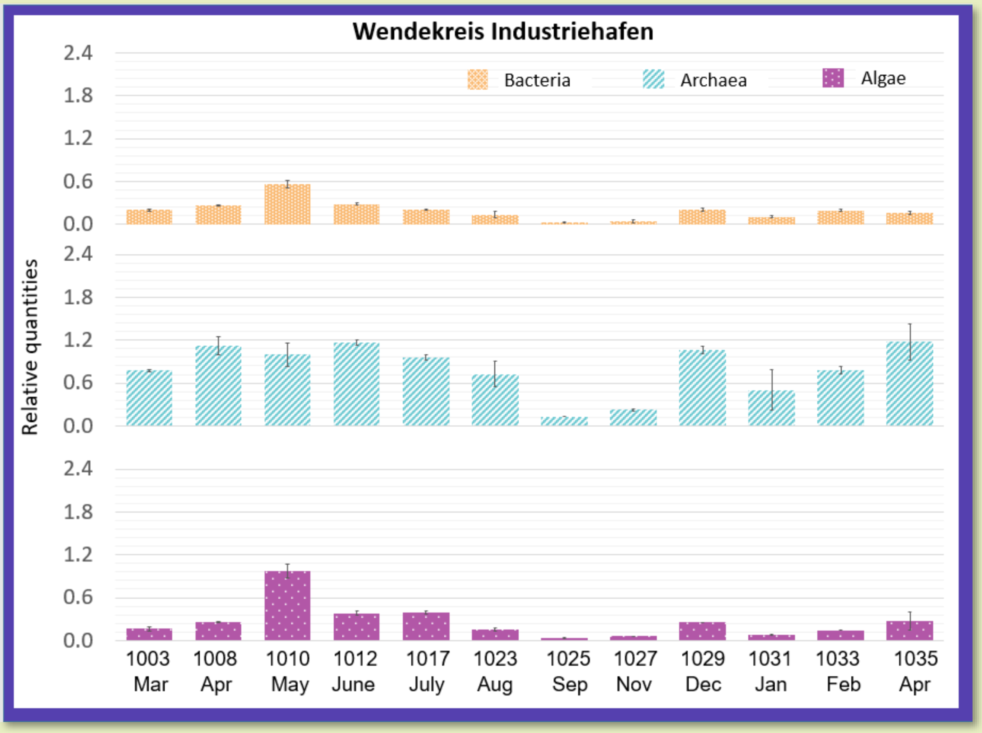


Figure 33. Relative abundance of bacteria, archaea and algae at the site IH. All data normalised to field sample 1001. Credits: GEOMAR.

- Changeover to *ex situ* (laboratory) and substitution of saline water with freshwater both reduced relative **abundance of bacteria, archaea and algae** found in the original field sample (Figure 34). Effects initially increased with increasing level of substitution, thereafter there was no systematic pattern anymore. Also, community composition changed. Effects reflect both the capped inflow of fresh organic matter (reduced long-term cell counts) and other changes in the biogeochemical boundary conditions occurring with the change from in situ to *ex situ* conditions. This also corroborated by reduced concentrations in EPS and organic matter degradation rates. Long-term incubation levelled out the effects of different shares of fresh-water admixture, as the community in all samples adapted to the *ex situ* growth conditions.

Figure 34. Relative abundance of bacteria, archaea and algae, for each freshwater substitution level and over time of experiment. All data normalised to original field sample 1001. Credits: GEOMAR.

Overall, the findings suggests that the low yield stresses of fluid mud in the Port of Emden are not the result of particularly high concentrations of EPS, but can be solely attributed to a reduction in density as achieved by re-circulation dredging. The diversity of the microbial community is high, its functionality redundant and it adapts swiftly to changing boundary conditions over the season, such as the strong changes in salinity or temperature. Seasonal increases in the share of hinterland water and hence the changes in environmental boundary conditions that occur already now are much larger than the changes predicted from climate change scenarios for the region.

→ It therefore appears unlikely that increases in freshwater discharge, either due to climate change or due to changes in hinterland water management, affect the efficiency of maintenance dredging in the Port of Emden.

Sub-goal No. 3.2: Sensor-based & Digital Water Monitoring

In light of the interest in monitoring microbiological living conditions as well as water quality parameters in the waters of the Inner Port of Emden, it was decided as previously mentioned to create a replica of a measurement buoy from WSA Ems-Nordsee for internal purposes.

The components and the sources from which the materials were obtained are listed as follows (Figure 35):

- Solar compact unit **equipped with lead-gel battery and three solar panels** (supplier: *SABIK Offshore*)
- **Data logger** incl. modem for storage and transmission of measured values equipped with a SIM card (supplier: *SEBA Hydrometrie*)
- **Aluminium frame** as support for buoy construction (crafted by the Technical Service of Niedersachsen Ports Emden)
- Three **fender buoys** as buoyancy bodies
- Two **special measuring cables** of 10 metres each (supplier: *SEBA Hydrometrie*)
- Two **multiparameter probes** with up to eight sensor slots; so far equipped with electric conductivity, temperature, pH, and O_2 sensors (supplier: *SEBA Hydrometrie*)
- 2.20 metre **iron rod** with wings as protection against tipping over in waves

Figure 35. Pilot measuring buoy and its features.

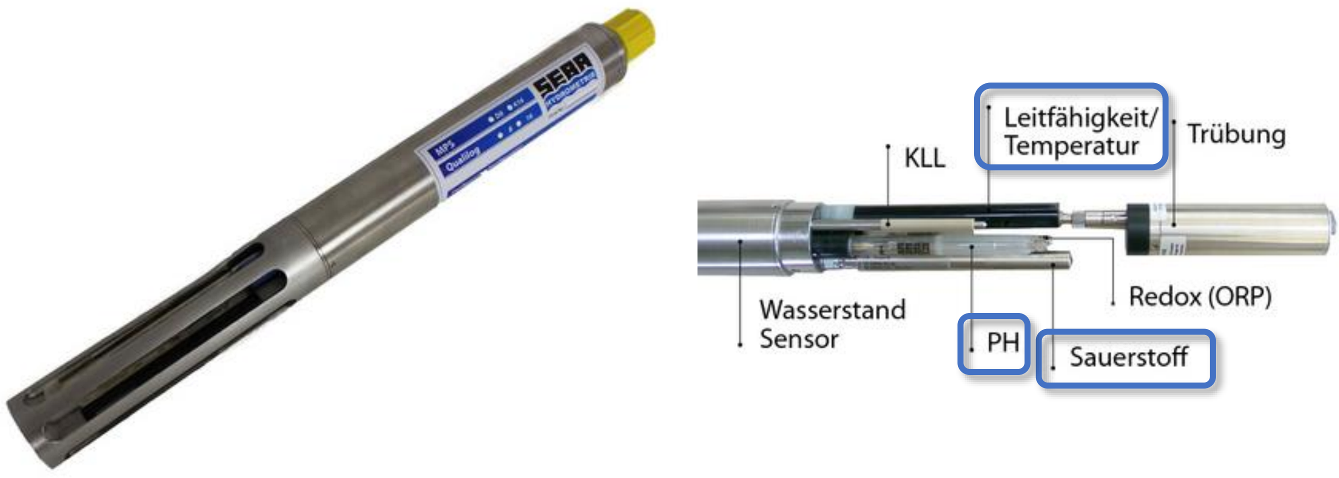


Figure 36. The multiparameter probe model used in the construction of the measuring buoy (left). Highlighted sensors were chosen to encompass the measuring spectrum of the buoy (right). Credits: SEBA Hydrometrie.

The measuring buoy makes it possible to measure various parameters in two depths in parallel (for instance, one probe can be placed at the depth of 3 m to measure values from the water column and the other one at the depth of 10 m, which would be located within the fluid mud layer), and to transmit the collected data by radio at a selected transmission interval to an online database. The collected measured values are transferred to the *SEBA Hydrocenter* software via the measured data collector according to the selected measuring and transmission intervals, currently every hour (Figure 37).

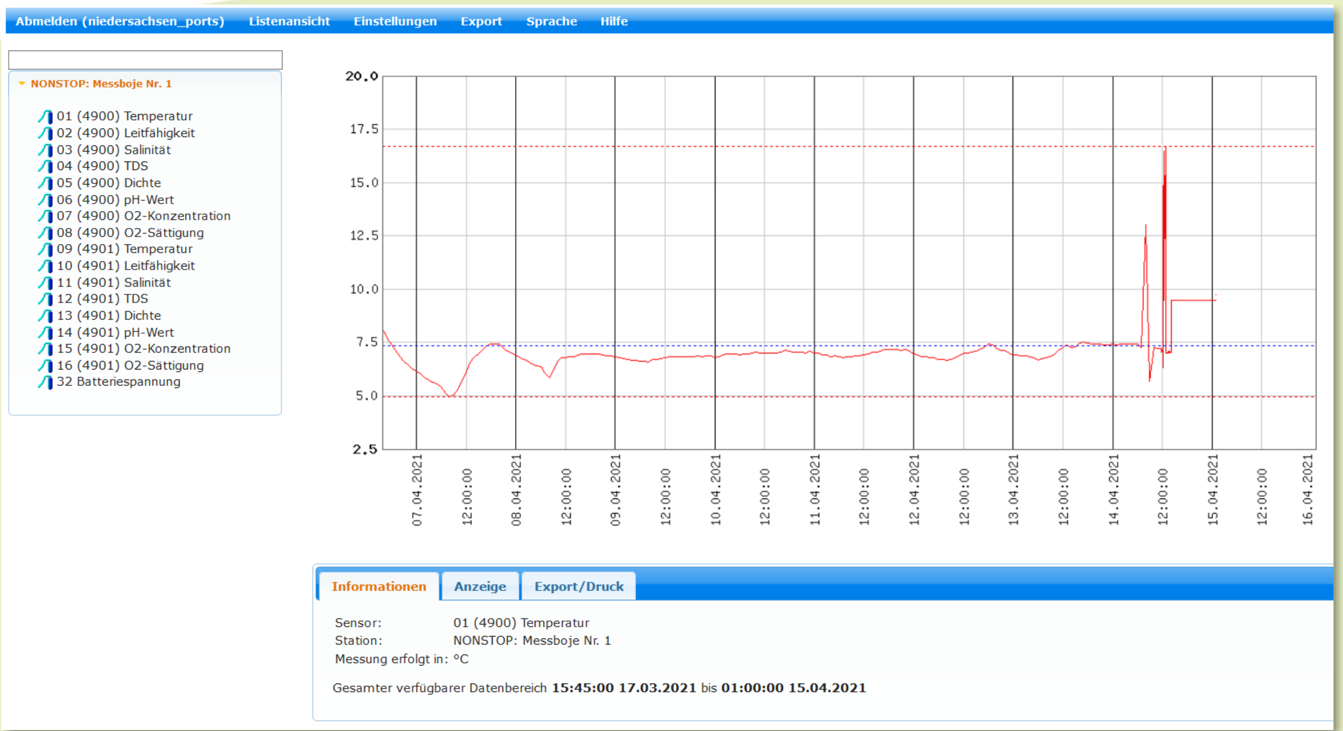


Figure 37. Representation of temperature measurement from the measuring buoy in the *SEBA Hydrocenter* software.

The measuring buoy is energy self-sufficient as long as the energy consumption for the measurements and data transmission does not exceed the energy generation via the three solar panels of the solar compact attachment. Up to the present moment, however, there have been no problems with the energy supply.

This mobile system is employed within the framework of measuring campaigns, which are planned measuring events carried out with the support of the Niedersachsen Ports' surveyor ship *MS Delphin*, since the system needs to be fixated and monitored during its use, and eventually quickly removed from the water surface depending on the ship traffic requirements during the mission.

The existing measuring buoy has demonstrated its effectiveness in monitoring the microbiological conditions of the harbour water. To ensure a continuous and real-time representation of the water's status in the harbour area over the long term, the installation of additional measuring stations is required. For this reason, the installation of a fixed measuring station was pursued, employing identical measuring technology (Figure 38).

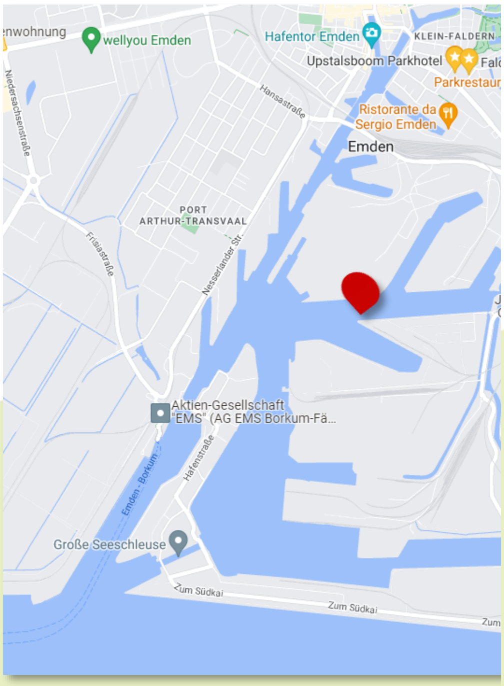


Figure 38. Selected location for the installation of a fixed measuring station (left). Wood pilling where the measuring devices are mounted (right).

Sub-goal No. 3.3: Digital Coupling of Data by Means of Dashboard System

As previously mentioned, the Dashboard developed for the Port of Emden consolidates both self-collected measurement data and weather information from the German Weather Service (DWD), water level data from the Ems-Nordsee Waterways and Shipping Office (WSV), and tidal predictions from the Federal Maritime and Hydrographic Agency (BSH) via their respective interfaces. This integration not only facilitates centralized access to these data but also enables retrieval over an extended period. This is particularly pertinent given that the websites of the aforementioned institutions only provide data for the last 3 months.

Throughout the project's duration, the dashboard has been continually expanded and tailored to specific needs. To accomplish this, regular interactions occurred with colleagues from different departments (Technical Department, Electrical Engineering, Port Office), who serve as potential end-users of this platform. Their feedback was crucial in designing user-centric dashboards. An illustrative instance is the dashboard dedicated to water monitoring, showcasing the data collected by the measuring buoy (Figure 39). Additionally, another dashboard was crafted for the Port Office division, functioning as part of a control centre (Figure 40).

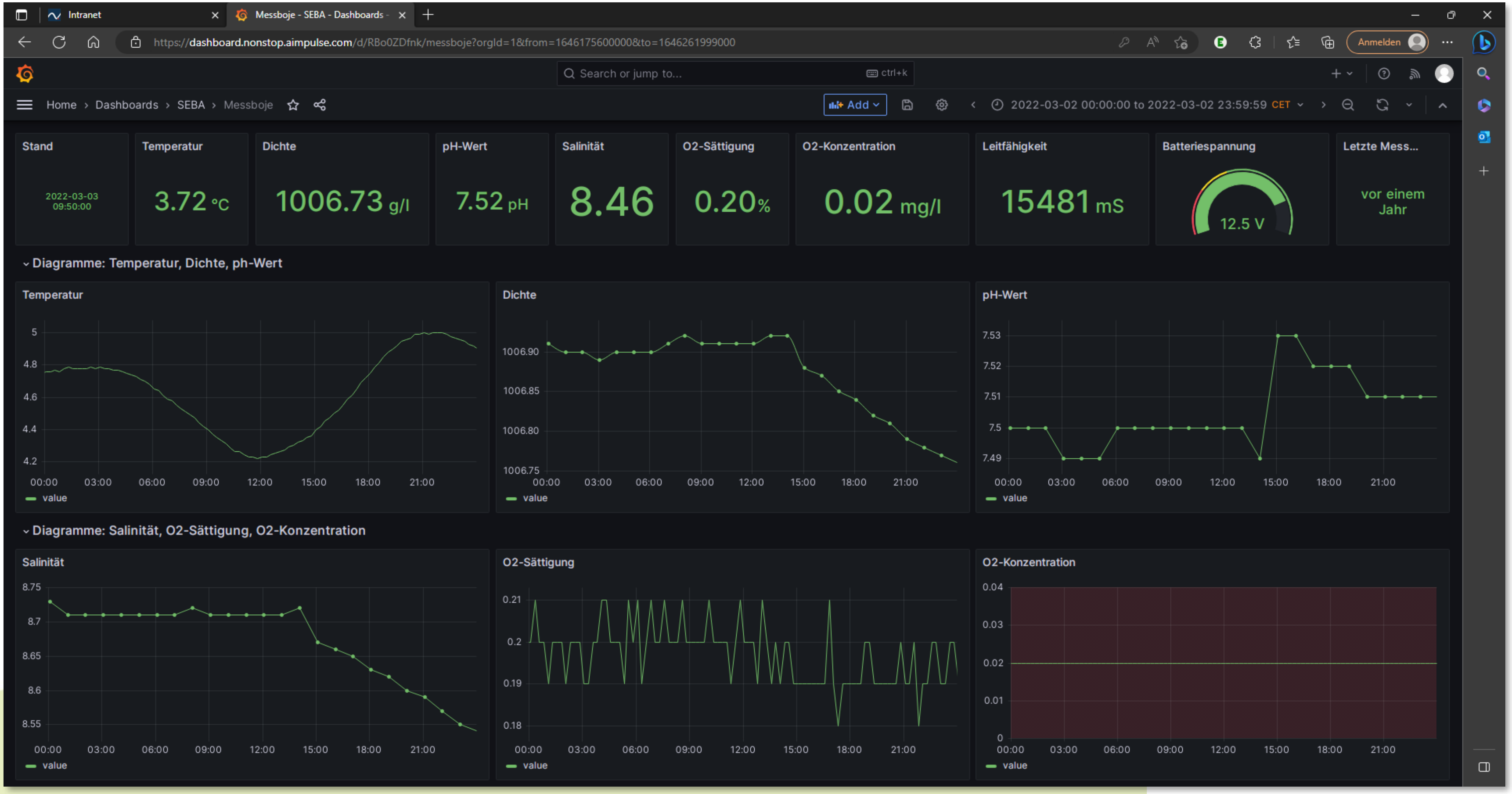


Figure 39. Measured data from the measuring buoy displayed on the developed dashboard develooped for the Port of Emden.

Figure 40. Dashboard created for the Port Office Department, featuring wind conditions, water level measured and predicted values, and costumized reference points indicating need for action following a traffic light system.

To detect and record pump activity in the Emden port's pumping station, a smartphone, equipped with the specific required applications and making use of the phone's built-in motion sensor, developed for *bremenports* in the scope of their project *Tide2Use* was installed in the pumping station in a test run and the recorded measurement data was transmitted to the dashboard through an interface developed by *Aimpulse* (Figure 41). The test run successfully demonstrated that pump activity can be reliably detected in this way. Therefore, the Port of Emden will now permanently install a corresponding smartphone in the pumping station for this task and this additional data source was integrated into the dashboard (Figure 42).

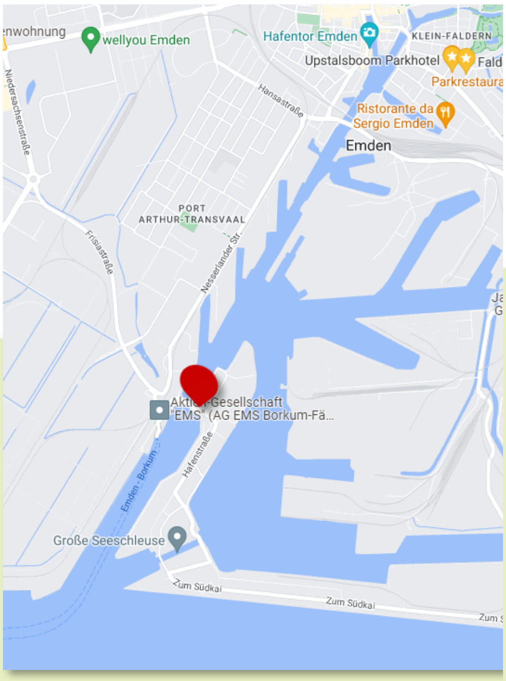


Figure 41. Location of the port's pumping station (left) and the box containing the so called *Sensorphone*, that detectes and records pump activities (right).

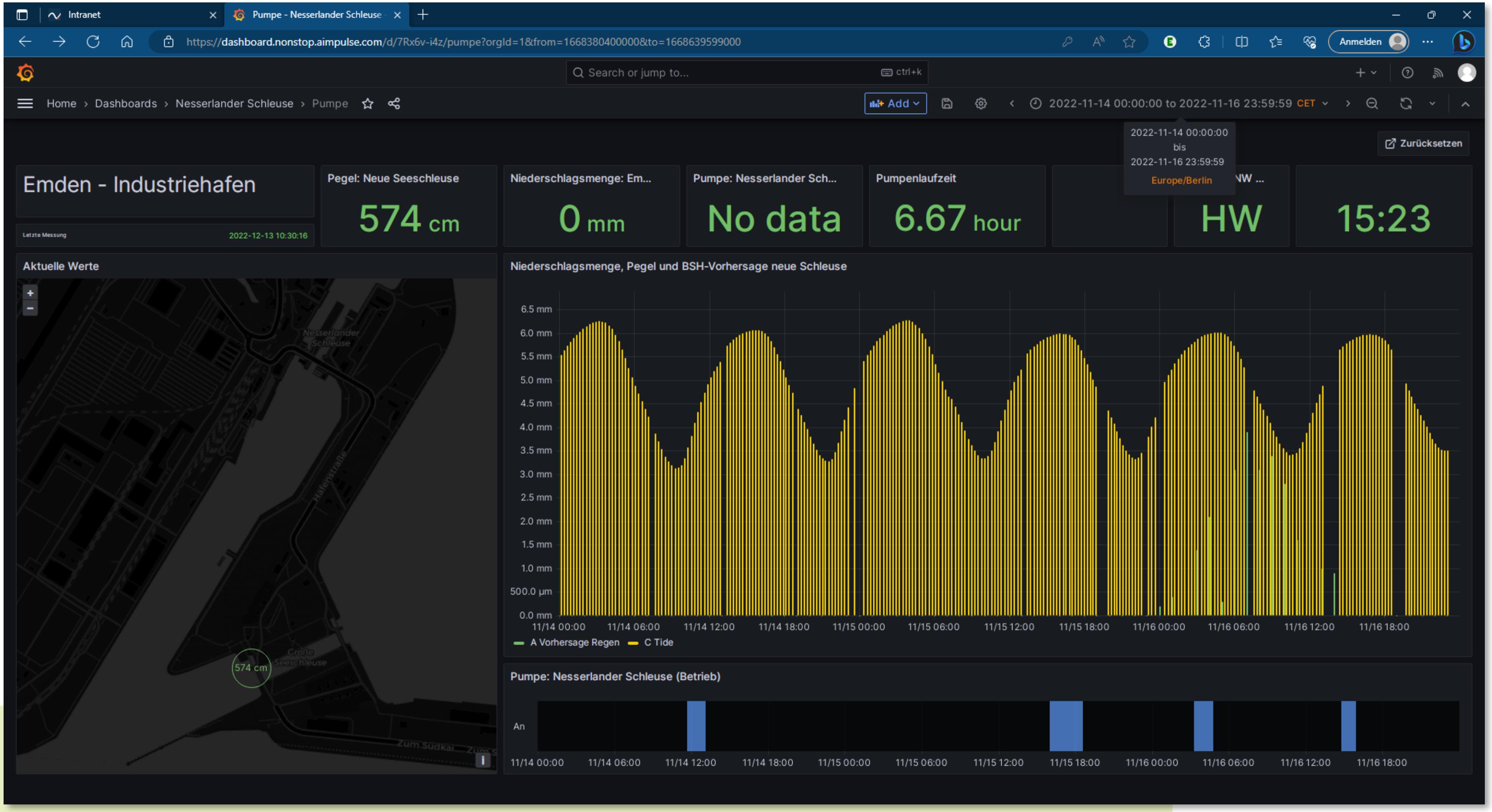


Figure 42. Dashboard featuring the water level in the outer port, precipitation forecast, and pumping events (the four blue bars on the bottom right).

Deliverables and Milestones

The pilot project in the Port of Emden aimed to develop and implement a concept for an intelligent sediment and water management system and was committed to three synergetic goals: 1) Reducing influx of sediment material from the river Ems into inner port, 2) Supporting hinterland drainage system, and 3) Long-term support of recirculation dredging process for harbour maintenance.

By achieving these goals, we were able to optimize various processes, making better use of key components such as the port's pump station, sea lock, as well as accomplishing a more efficient sediment management and ultimately a reduction in the need for dredging activities. This overall effort not only improves operational effectiveness at the port but also aligns with our broader goals of the NON-STOP project of reducing time, emissions, and energy consumption.

2% CO_2 Reduction

8% Energy Reduction

10% Time Reduction

Incorporating **automatic measurement systems,** which collect and store water quality data in predefined time intervals and finally transfer them to digital monitoring systems, eliminating the need for frequent ship deployments in the framework of labor intensive, manual measurement campaigns, reducing energy consumption and emissions from ship diesel, ultimately leading to a significant reduction in CO_2 emissions, as well as time and personnel effort.

Implementing of **energetically self-sufficient measurement systems** that rely on solar power and batteries for continuous operation, replacing conventional energy sources with an alternative, renewable energy source. This eliminates the need for transporting other measuring devices to buildings for regular recharging using conventional electricity.

Introducing a smart water management system that merges measured data with supplementary sources into an accessible **dashboard** stands to significantly trim energy consumption and CO_2 emissions. By offering clear insights, it helps pump operators make smarter choices, using pumps only when truly needed. The dashboard system additionally reduces the time required for the process of inland drainage data via the Port of Emden thanks to the aid of sensor data on water level conditions as well as data aggregation and visualization (previously only experience-based telephone exchange between operating personnel without digital support).

What makes this project sustainable?

In addition to the already mentioned contributions to the overarching NON-STOP goals of **time, energy, and CO_2 reductions**, the pilot project in the Port of Emden encompasses various sustainability aspects, such as:

What?	How?
Contribution to Flood Prevention By actively participating in urban runoff and stormwater management, ports can reduce water pollution and minimize the risk of flooding. This commitment not only enhances the port's environmental stewardship but also fosters positive community relations. Furthermore, it strengthens the port's resilience to changing weather patterns.	✓ Synergies and exchange with the project *KLEVER-Risk*. ✓ Creation of a comprehensive drainage map for the port and the region. ✓ Contribution to the acquisition of a water level ultrasound measuring station in the neighbouring water body upstream of port (*Ems-Jade-Kanal*) under administration of NLWKN Aurich (Department for Water, Coastal and Nature Conservation of the state of Lower Saxony).
Continuous Monitoring of Water Quality in the Port This proactive approach helps to monitor and maintain the health of the aquatic ecosystem within and around the port. This commitment to ongoing monitoring enhances the port's sustainability profile, fostering trust with stakeholders and attracting eco-conscious partners. It ultimately ensures a cleaner and more secure port environment, benefiting both the ecosystem and the long-term viability of the port itself.	✓ Construction and installation of one mobile and one fixed water quality measurement stations.
Cooperation with Universities and Research Institutions By making valuable information accessible and actively participating in knowledge exchange, the port enriches research institutions' data banks, fostering collaborative open-source science. This collaboration not only advances our understanding of port environments, but also promotes innovative solutions for sustainable port operations. It is a win-win scenario, benefiting the port through cutting-edge insights while also contributing to global efforts for a more sustainable and environmentally responsible maritime industry.	✓ Delivering presentations and lectures in university courses and conferences ✓ Supervising one bachelor's and one master's theses, ✓ Tendering and issuing an international research contract, which resulted in open access scientific publications.
Exchange and Partnership with Local Institutions Engaging in collaborative projects with local authorities and organizations, facilitating expertise exchange, and maintaining transparent stakeholder communication offers numerous sustainability benefits for a port. These partnerships foster a shared commitment to responsible practices, leading to improved environmental and operational efficiencies. Moreover, by actively involving local stakeholders, ports can better align their strategies with community interests and concerns. This collaborative approach ensures that the port not only thrives economically but also contributes positively to the social and environmental well-being of its surroundings.	✓ Creation of the advisory board with the participation of government representatives, academic stakeholders, and experts from the relevant fields.

Contribution to Digitalization

The technologies tested and implemented in the scope of the NON-STOP pilot project in the Port of Emden provide real-time data insights, allowing for more informed decision-making and efficient operations. As digitalization progresses in various other areas, such investments can seamlessly integrate new functionalities and stay up-to-date with emerging trends. This flexibility not only ensures efficient resource management but also paves the way for continuous improvements in environmental performance. Ultimately, these smart systems contribute to a future-proof, greener, more sustainable port that can readily adapt to evolving industry standards and technological advancements.

✓ Synergies and exchange with the project *Tide2Use*.
✓ Construction and installation of one mobile and one fixed water quality measurement stations, which can be upgraded with additional sensors to increase their measurement spectra.
✓ Creating and developing a dashboard that can be continually expanded with additional functions as more port structures are automated and digitized, providing the required interfaces for integration with this centralized information tool.

Data, Facts and Figures

2
- university final dissertations in the scope of the pilot project in the Port of Emden

4
- research institutions participating in cross-border, trans-national or interregional research projects

5
- green products, services and processes piloted and adopted by the Port of Emden

100
- organi-zations and enterprises informed about new solutions from the pilot project in the Port of Emden

Conclusions & Lessons Learned

Being a part of the EU INTERREG project NON-STOP, significant progress was achieved in the development of an intelligent sediment and water management system for the Port of Emden. The pilot project pursued three main objectives: reducing the influx of materials from the Ems River into the inner port, improving the hinterland drainage of Emden, and providing long-term support for the port maintenance dredging strategy, the recirculation dredging process.

To achieve these goals, extensive knowledge in microbiology and sedimentology was required, along with the establishment of a suitable water monitoring system and the optimization of infrastructure elements, such as the port's pumping station. By pursuing a better understanding of systems and process (natural ones as well as the ones linked to port operations) and by utilizing digital technologies, natural processes were better integrated and interconnected to ensure the sustainability of the Port of Emden and its immediate surroundings.

The NON-STOP pilot project in the Port of Emden has demonstrated that an intelligent sediment and water management system can effectively contribute to reducing material influx. The long-term commitment to an optimized maintenance dredging strategy ensures that the port can continue to operate optimally.

The results obtained from the NON-STOP project are of great importance for the sustainability of the Port of Emden and could serve as a model for similar projects for other organisations. The insights gained into microbiology and sediment-fluid-mud-water systems, as well as the developed monitoring and infrastructure solutions, are valuable resources for future initiatives in sediment and water management.

The findings from the NON-STOP pilot project in the Port of Emden are also highly relevant for other projects developed by Niedersachsen Ports, such as the *AMISIA* funded project, which runs from October 2021 to September 2024, and aims to create a concept for an optimized, automated dredging vessel for the Port of Emden.

In conclusion, the EU INTERREG project NON-STOP has made a significant contribution to the development and implementation of an intelligent sediment and water management system in the Port of Emden. The project has demonstrated that sustainable solutions to the port's challenges can be created by using digital technologies. The insights and solutions obtained contribute to the port's future sustainability and can serve as a foundation for further research and development projects.

Some of the lessons learned during the NON-STOP endeavour include:

Step by Step: Digitalization efforts should prioritize opportunities that can be expanded and refined over time. By taking a slow and steady approach, organizations can thoroughly assess their needs, invest in scalable solutions, and ensure that each digital initiative aligns with their long-term goals. This deliberate approach allows for continuous improvement and adaptation, ultimately leading to more sustainable and effective digitalization efforts in the ever-evolving landscape of technology.

Together we go far: Networking and collaborating with similar projects undertaken by other organizations opens up a world of opportunities for knowledge exchange, shared resources, and mutual growth. Through these connections, organizations can tap into a diverse range of perspectives and expertise, enabling them to solve complex challenges more effectively. Moreover, collaborative efforts often lead to innovation, the discovery of best practices, and the ability to collectively address larger-scale issues.

NON-STOP learning: The pursuit of studies and investigations to assess the current state of processes and systems serves as the cornerstone of informed decision-making and continuous improvement. By allocating efforts into understanding how processes have evolved over time, organizations can adapt and stay relevant in a rapidly changing world. Equally significant is the validation of old assumptions, as it ensures that decisions are not based on outdated or inaccurate information. This commitment to thorough examination and scrutiny promotes innovation, efficiency, and a deeper understanding of the dynamic forces at play within any given context.

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- *Entwässerungsverband Emden*
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- *Bundesamt für Seeschifffahrt und Hydrographie (BSH)*
- *Deutscher Wetterdienst (DWD)*
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