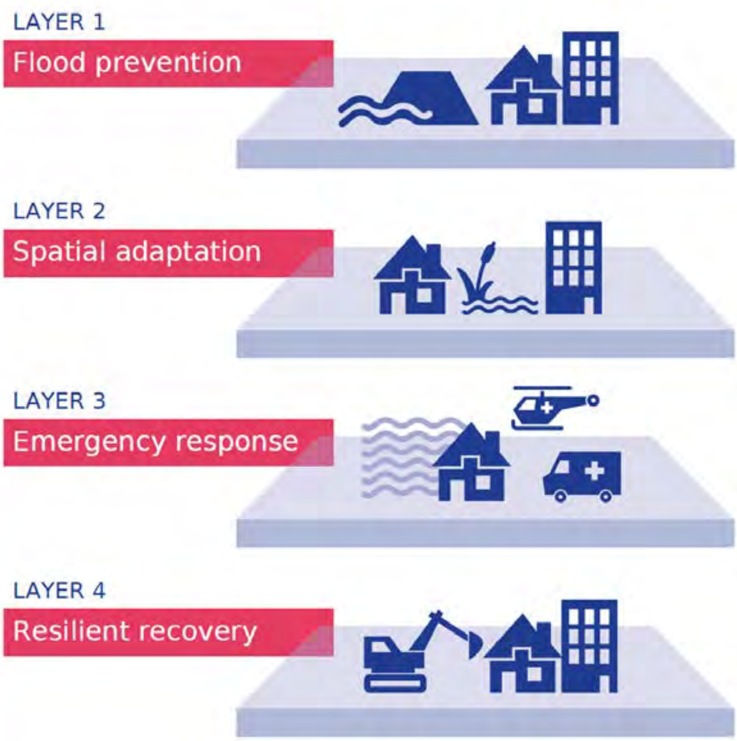
Interreg
North Sea Region
FRAMES
European Regional Development Fund
EUROPEAN UNION

Integrated Drainage Management Concept for Rural and Urban Areas



within the County of Wesermarsch

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Table of Contents

List of Figures

1. Introduction

Within the FRAMES project the City of Brake was selected as pilot area for problems in drainage management issues.

This is due to the fact that currently two different regional water management challenges affect the city of Brake at the same time: drainage requirements in times of rain water surplus, and watering needs in times of a water deficit in the northern parts of the Wesermarsch region.

At present, different planning processes are in progress which aims at the contribution to the solutions of both challenges.

The objective of this study is the integration of the different activities in order to maximise the synergies of the different planning processes for the implementation phase.

2. Focus Region – County of Wesermarsch

The region for the pilot area within the FRAMES project is the northern part of the county Wesermarsch (Figure 1), i.e. the City of Brake (~38 km²). Within the county of Wesermarsch more than 91,000 citizens live in 9 local communities (3 small cities and 6 rural municipalities, see LSKN, 2011). The region comprises two types of land-marine transition zones (i) the Weser estuary and (ii) the Wadden Sea with the unique Jade Bay. Surrounded by the North Sea and the river Weser, especially in the northern part, and with a coastline of 160 km, the Wesermarsch is characterised by water.

Two-thirds of the whole county area (approx. 822 km^2) are located below mean high tide water level, which requires coastal protection by dikes and a comprehensive drainage system consisting of ditches, canals and pumping stations to enable living and working in the county.

Nearly 80% of the Wesermarsch is characterised by agricultural use, besides tourism and harbour industry it is one of the most important economic sectors in this region. Due to the soil conditions, marsh and peat soils occur predominantly, 90% of the agricultural land is under grassland farming (meat and milk production, see LSKN, 2010).

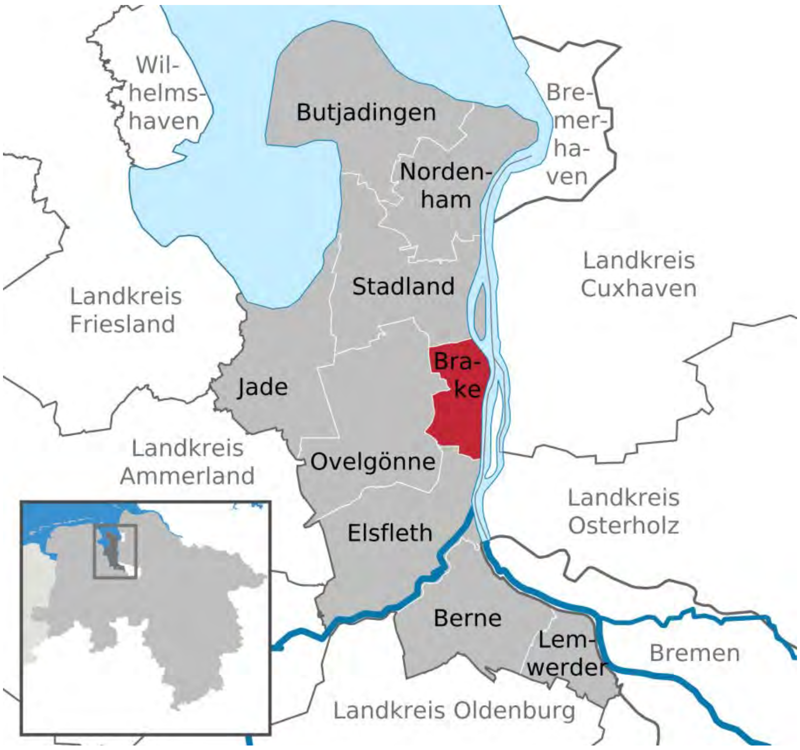

Figure 1: Location of the Wesermarsch county and the pilot area City of Brake. Source: Wikimedia Commons (2018)

An introducing description of the hydrological and geomorphological situation of the Weser estuary can be found e.g. in Lange et al. (2008). Furthermore, in the framework of the Water Framework Directive an Integrated Management Plan has been developed for the Weser, see FGG Weser (2009). In Figure 2 the estuarine zone are shown for the Weser estuary up-stream from Bremen.

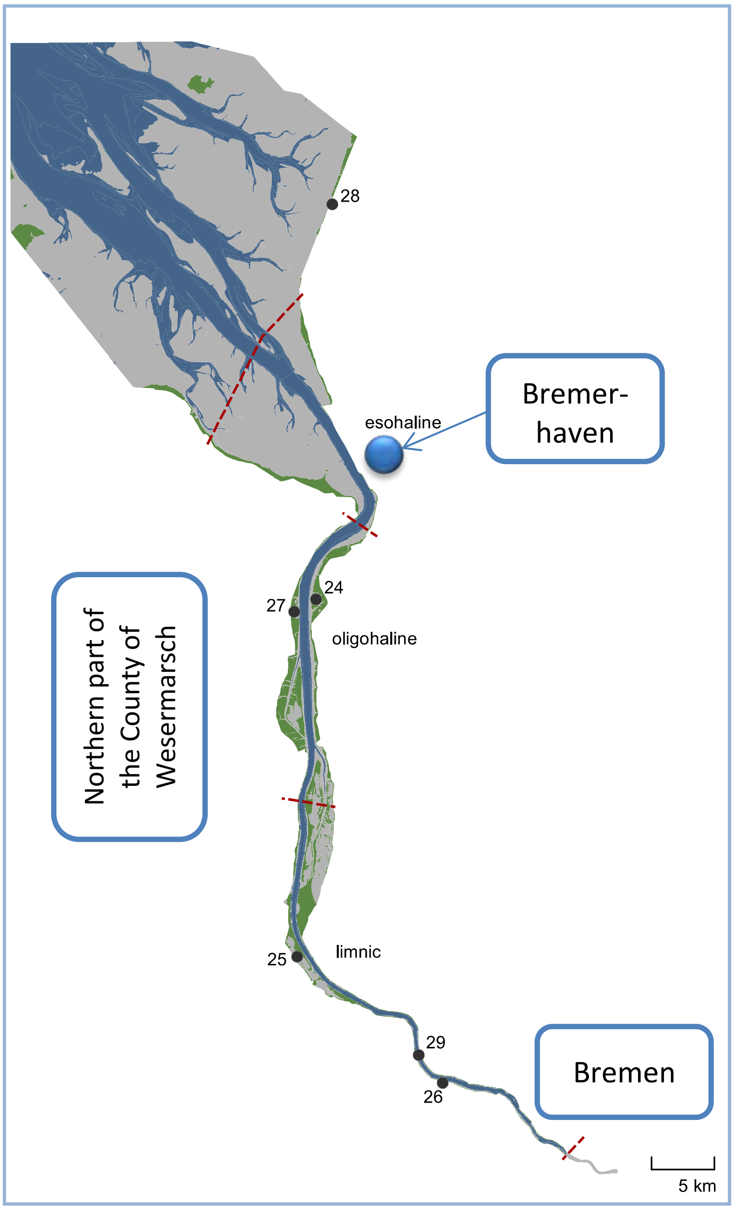

Figure 2: The Weser estuary from Bremen to Bremerhaven. The map is showing the different estuarine zones: limnic, oligo-haline, meso-haline and polyhaline (classification according to the EU Interreg IVB project TIDE, source: HPA et al. (2013)

3. Participation Process

3.1 Stakeholder Analysis

OOWV – Oldenburgisch-Ostfriesischer Wasserverband (Regional Drinking Water and Sewage Company)

The predecessor organisation of the OOWV was established in 1948 as reaction on the poor drinking water support in the county of Wesermarsch. The county is surrounded by salt water, either from the North Sea or the river Weser. Due to the historical development of the low lying area and also caused by medieval storm surges a saline aquifer can be found below three quarter of the Wesermarsch. In former times the support of fresh water for drinking purposes had been done by collecting precipitation in small depressions in the landscape or surface wells. Finally, the predecessor organisation was re-named into OOWV in 1957, and the first water work in Marienhafe was launched (Diesing, 2008).

The area for drinking water supply and areas where the OOWV is responsible for the sewage discharge are shown in Figure 3. The red circle marks the pilot area of the FRAMES project in the county of Wesermarsch. Today, the OOWV is in total discharging the sewage water for approx. 500,000 people by maintaining approx. 4,200 km of pipes.

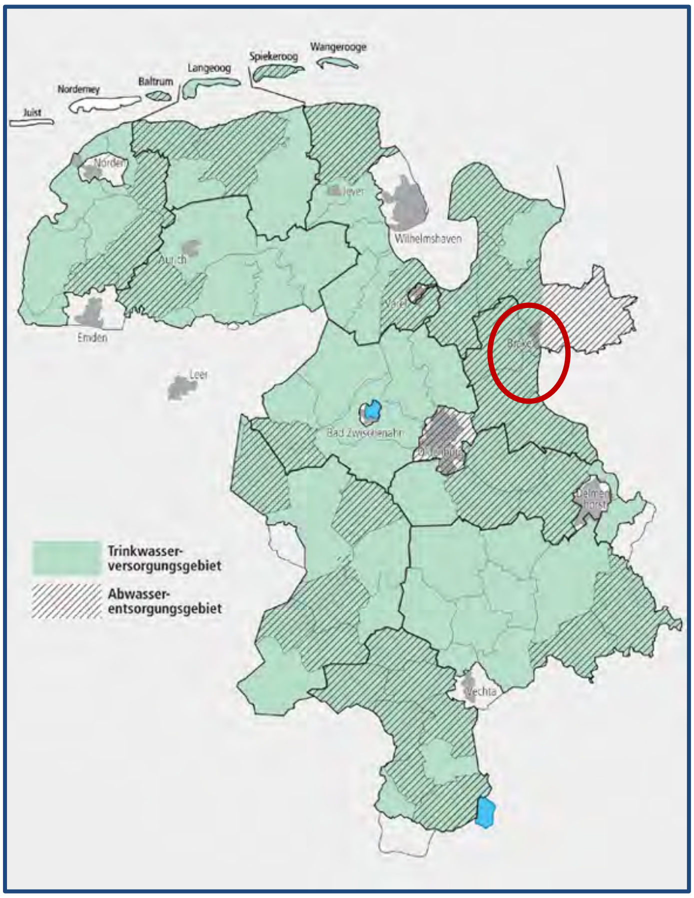

Figure 3: Area of the OOWV for drinking water supply and sewage water discharge. Red circle: Pilot area of the FRAMEs project. Source OOWV

Furthermore, the OOWV maintains in the city of Brake pipes of a total length of approx. 99 km for discharging surface water (KEC, 2016). The surface water discharge system in the City of Brake consists of a discharge system to convey directly into the Weser, a system of canals and pipes conveying surface into the bigger system and connecting ditches and small canals. The main discharge features are the Braker Sieltief, the Rönnel and the Golzwarder Sieltief (KEC, 2016), which serve multiple requirements: discharging the surface water of the rural areas surrounding the City of Brake, storing surface water in times of high water levels in the river Weser and, periodically, watering the rural areas with fresh water from out the Weser river.

Drainage Board Brake (Braker Sielacht)

The area of the Drainage Board Brake is about 14,400 ha including approx. 164 km of main discharge ditches and canals (Figure 4). Within the area there are 18 pumping station working in sub-drainage areas to keep the respective water level.

Figure 4: Area of the Braker Sielacht. Source: www.wabo-brake.de (2018)

Furthermore, two pumping station are discharging the surface into the river Weser. The Drainage Board Brake was founded in 1961 by merging four smaller drainage boards, i.e. the Unterhaltungsverband Brake, the Käseburger Sielacht, the Braker Sielacht and the Klippkanner Sielacht.

Regional Administration for Water Management, Coastal Defence and Nature Protection (Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz, NLWKN)

The NLWKN is the responsible regional administrative body for planning and building water management infrastructure in the area. As technical authority of the Ministry for the Environment of Lower Saxony it is serving the self-organised water management bodies, such as the drainage board Brake and the Planungsverband Wesermarsch for implementing the Master Plan Wesermarsch (NLWKN, 2018). Due to the regional water management challenges (see chapter 4) this Master Plan suggests a restructuring of the regional watering system. Its main focus is to guarantee the freshwater supply from the Weser River to the drainage and watering network of the Wesermarsch County in dry summer periods.

3.2 Process Design

The participation process is based on expert interviews which were conducted between autumn 2017 and spring 2018. Therein, the experts of the NLWKN and the OOWV were interviewed on the status-quo situation and on the envisaged solution options for the rural-urban drainage management, especially for the City of Brake. Due to the fact that water engineering issues of the drainage board Brake is mainly conducted and supported by the NLWKN it was decided to have a short interview with a representative of the managing board of the drainage board Brake. The results of these interviews are the basis for the following section on problem description and finding integrative solution options.

4. Problem Description

4.1 Drainage Management

Drainage of Rural Areas

Over centuries water management in the region Wesermarsch was affected by alternating flooding events and land reclamation, shaping the current coastline. Today's coastline has been established by building dikes over the last centuries while flood protection by dwelling mounds became less necessary simultaneously (e.g. Kramer 1992a). Dikes function as an artificial barrier between land and sea, which makes a natural water exchange impossible.

The importance of the protection of people against storm surges, however, requires an efficient drainage and watering systems consisting of ditches, canals and pumping stations (e.g. Kramer 1992b). Accordingly, the Wesermarsch region is drained during winter time to discharge the surplus of rainwater and watered in the late summer months to water the fields and cattle by ditches.

Water boards are responsible for the maintenance of this water management system in the Wesermarsch. The drainage board's Stadlander Sielacht, Braker Sielacht and Entwässerungs-verband Butjadingen are three of them (Figure 5).

They comprise 11,600 ha and 23,200 ha, respectively. The area of the drainage board Stadland is drained by ditches via the Strohauser canal and discharges the water directly into the river Weser. Pumping stations in the area of the water board are necessary to drain low lying areas. In Butjadingen six tidal gates are used to drain the area. The water is discharged into the North Sea, the Jade Bay, and the river Weser (Figure 6). Depending on the water level, the water has to be pumped or can be

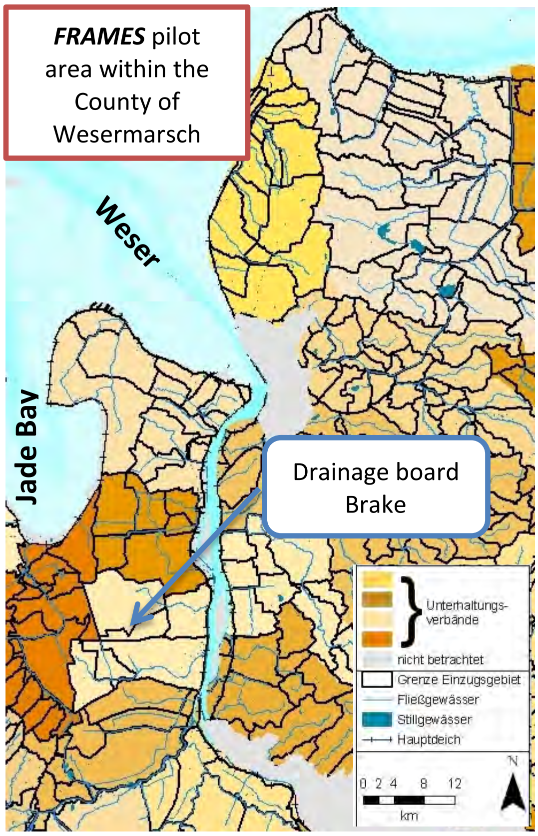

Figure 5: Pilot area of the German FRAMES project. Source: modified after Ahlhorn et al. (2010)

drained freely into in the coastal water bodies. The watering of the agricultural land in both regions is performed by extracting fresh water from the river Weser.

Over the last decades problems regarding the drainage capacity in winter time and the quality of fresh water in late summer occurred (see e.g. Ahlhorn et al. 2010; Umlauf et al. 2011; Ahlhorn et al. 2011; Bormann et al. 2012). More often the drainage system has not been sufficient enough to store and discharge the amount of rainwater. In summer time the salt concentration in the Weser exceeds the threshold for watering due to an upstream movement of the salt and fresh water frontier, especially caused by deepening of the Weser and an increasing sea level (Kunz, 1995; Lange et al., 2008).

In future, it is assumed that the water management in the Wesermarsch has to cope with an intensification of the present problems (Bormann *et al.*, 2009, Bormann et al., 2012). Climate change simulations for the Wesermarsch region project an increase of water scarcity in summer, an increase of runoff formation in winter, and a rising sea level. Consequences may presumably be a longer watering period in summer and higher drainage demand in winter with concurrently less discharge ability due to sea level rise.

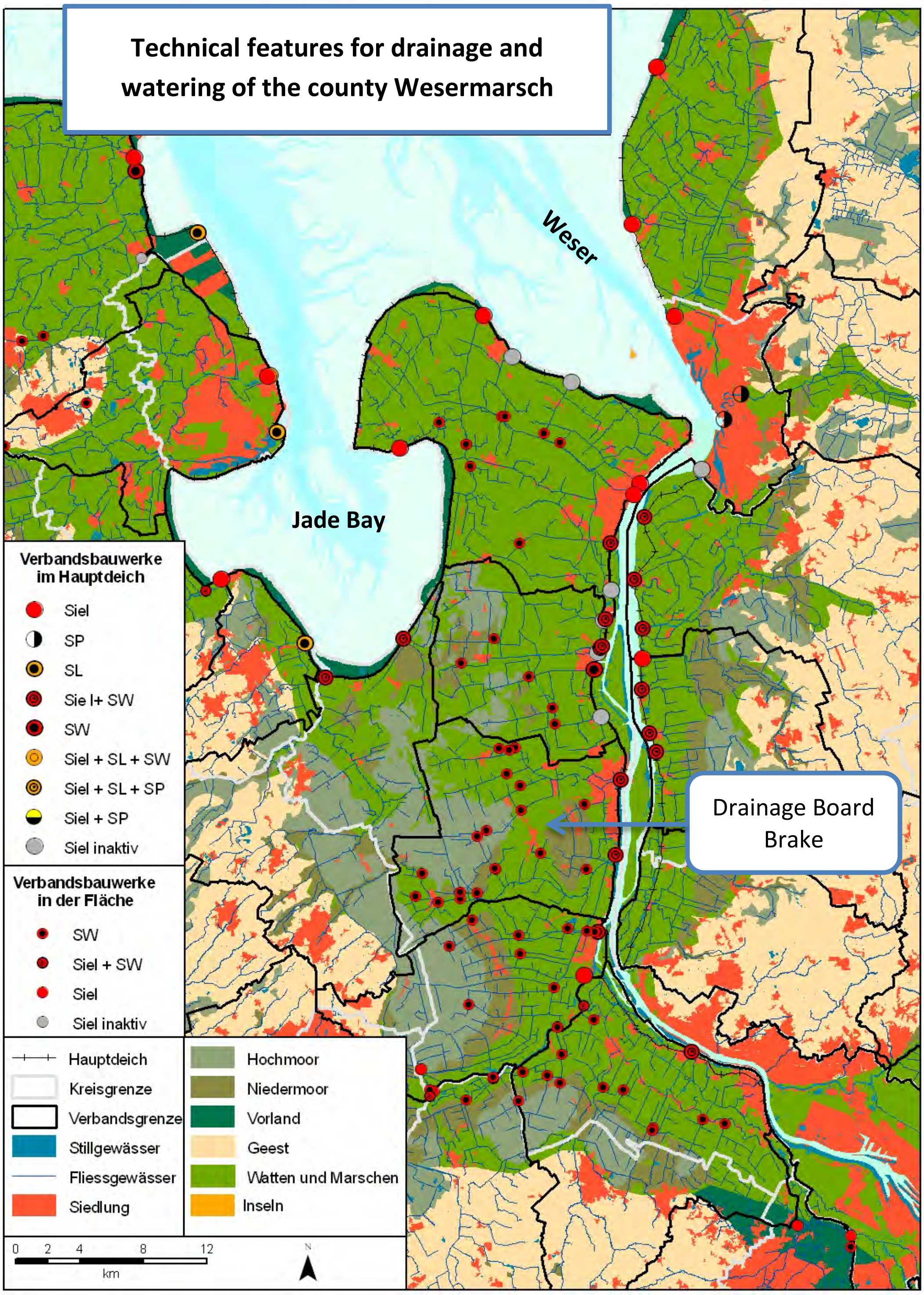

Figure 6: This map shows the water boards and the technical features to ensure the drainage and watering of the northern part of the county Wesermarsch. Source: modified after Ahlhorn et al. (2010)

Drainage of Urban Areas

Due to the topography (Figure 7), drainage of the City of Brake is organised by canals and ditches in the city. The surface water is conveyed into two main drainage channels: The Braker Sieltief and the Rönnel (Figure 7). The Braker Sieltief is also draining the rural area surrounding Brake. This canal is flowing through northern part of the city. The Rönnel is a small ditch/canal which is draining the surface of south of the city.

A comprehensive system consisting of ditches, canals and pipes is serving to convey the surface water out of the city of Brake (see KEC, 2016). The investigation conducted by KEC for the Master Plan Surface Water Drainage revealed that besides investments in order to rehabilitate in the existing drainage system it was recommended to construct a new spillway cut in the Rönnel.

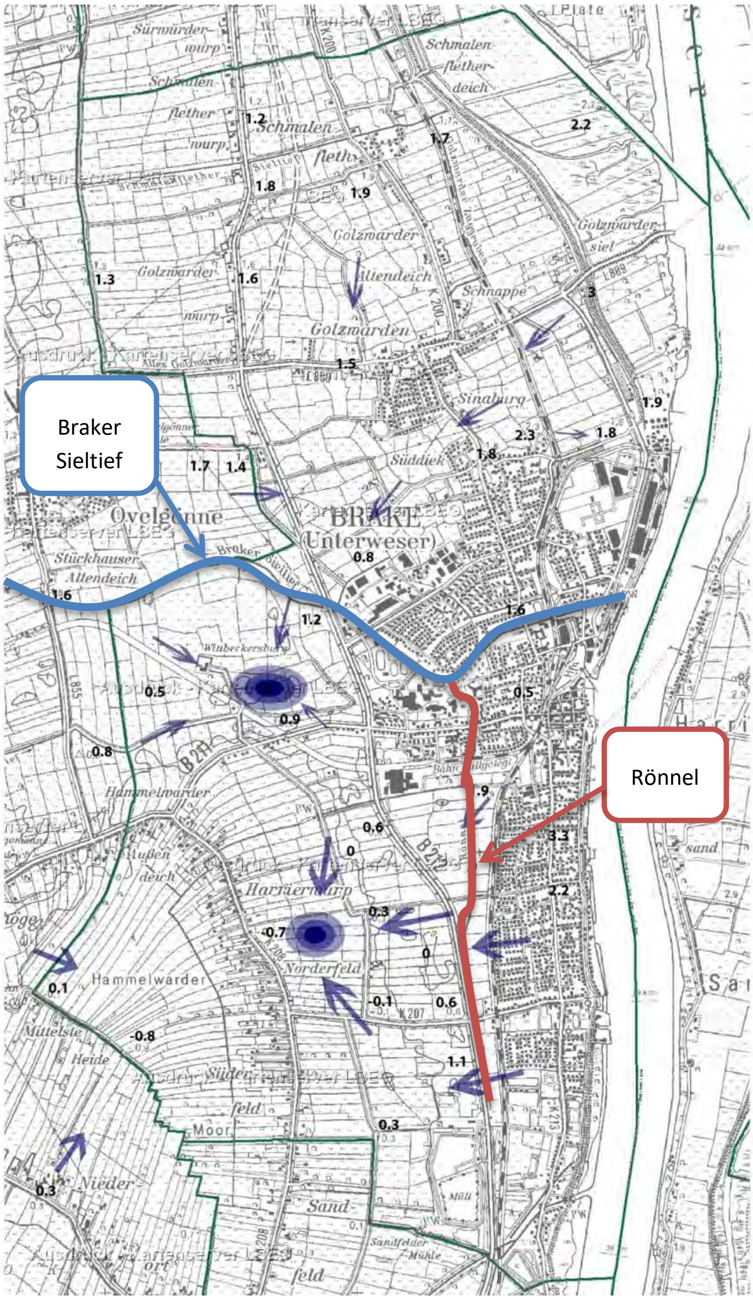

Figure 7: Topography of the City of Brake; arrows showing the normal flow direction of the surface water.

4.2 Hydrological Conditions

Status quo

Due to current climate conditions and climate variability, the county of Wesermarsch already faces water management problems in terms of a water surplus in winter time, requiring an intense drainage, and partly serious water deficits in summer time, requiring a transfer of fresh water from Weser River into the marsh water bodies over the entire summer period. These challenges are due to the natural variability of runoff generation, as described by Bormann and Neumann (2015; Figure 8):

While extremely wet conditions would reduce the productivity of the soils, extremely dry conditions in summer would reduce the possibility to water the cattle from ditches and to use the ditches as natural barrier instead of fencing. In summer time, additionally, high salt concentrations of surface and groundwater bodies would occur, causing water quality problems.

Current water management options of the regional water boards are

- To pump out exceeding water in winter time,
- To water the county in summer time using water from Weser river,
- And to interrupt watering in case of salt concentration exceeding 2.5 mg/l.

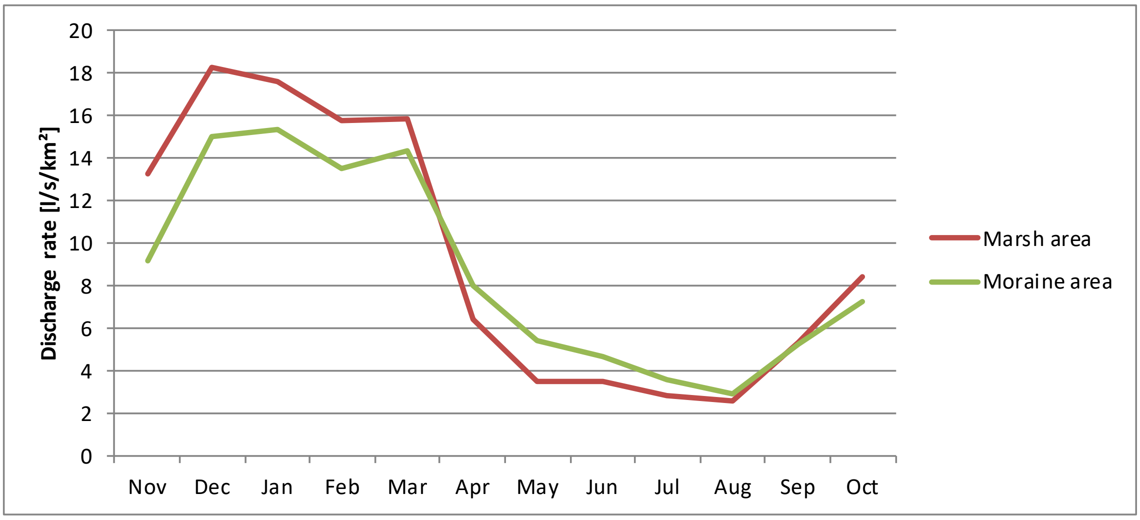

Figure 8: Discharge rates of Wesermarsch rivers, characterized by marsh and moraine catchment.Source: changed after Bormann and Neumann (2015).

Due to dredging activities and correction of the Weser River in the past decades, the salt water from the North Sea intrudes further upstream into the Weser estuary, resulting in an upstream movement of the brackish water zone, as well. In case of high tide in the North Sea and low discharge of the Weser River, this brackish water zone limits the usability of the river water for watering the Wesermarsch region.

Future Development

Further dredging activities in the Weser River expected for the future will intensify the problem of rising salt concentrations in the water of the Weser River. As a consequence, alternative solutions are required to solve the challenge to guarantee sufficient quality river water for regional watering.

Beyond water engineering, climate change will affect the water management of the Wesermarsch. A model based climate change impact assessment as part of the Climate Proof Areas project (Bormann et al., 2009) indicated that the current seasonality of runoff generation is expected to get further intensified. Driving a physically based model with regional climate change projections resulted in increasing runoff rates in winter and an increasing water deficit during summer months (Bormann et al., 2012; Figure 9).

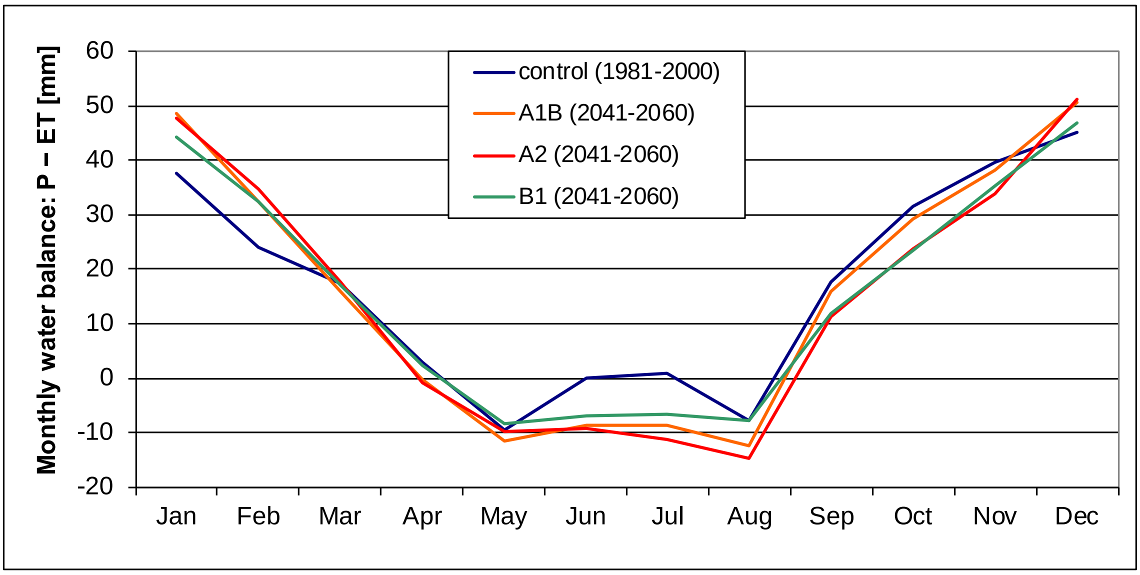

Figure 9: Water balance projections (precipitation–evapotranspiration) of a physically based hydrological model based on WETTREG climate projections for the Wesermarsch (IPCC scenarios A1B, A2, B1). Source: Bormann et al. (2012).

Changes in the simulated water balance can be interpreted as changes in water volumes to be additionally drained (winter) or watered (summer), respectively. While in winter runoff generation increases by 10 mm per month until year 2050 (scenario A1B), water deficit during summer months increases by approximately 10 mm per month (scenario A1B), as well. Similar to the climate projections, for a mid-term time horizon (year 2050), the differences among the three investigated climate scenarios are smaller than the differences between baseline and scenarios. In the second half of the 21st century, the hydrological projections based on the SIMULAT model significantly diverge for the different scenarios as the climate projections do in terms of seasonal precipitation. Analysing the simulation results reveals an expected increase in maximum water deficits during summer time as well as in maximum duration of periods with negative water balance.

Results from the KLEVER project in East-Frisia indicate that the sea-level rise calculated by the IPCC (2013; Figure 10) will lead to a significant reduction of the potential of gravitational drainage of surplus water to the Weser river and the North Sea in the second half of the 21th century. Such decrease in potential of gravitational drainage would require an increase in pumping capacity to keep the current drainage standards of the region (for details see Bormann et al., 2018).

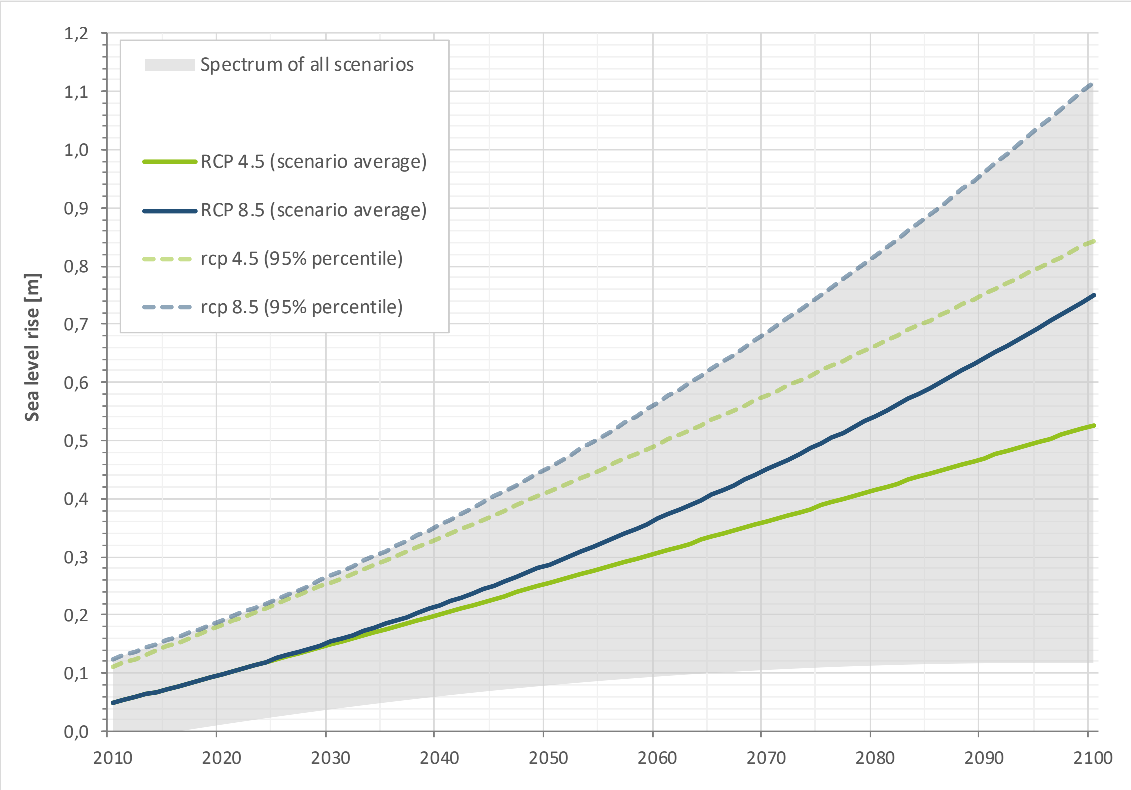

Figure 10: Scenario based prediction of future sea level rise in the German Bight according to the IPCC (2013).

5. Description of Solution Options

This section of the report summarizes the available solution options for the regional water management challenges, describing separate solution options …

a) … for the rural areas drainage problems, i.e. watering and drainage: Master Plan Wesermarsch (NLWKN, 2018) and

b) … the approach to tackle the urban drainage problems focussed at the situation of the City of Brake: Master Plan Drainage Brake (KEC, 2016)

5.1 Solution Options for Rural Areas

Solutions based on European projects

Based on the results of the EU Interreg IVB project "Climate Proof Areas (CPA)" in Figure 11 solution ideas jointly developed by the regional forum Wesermarsch are shown. The map shows a collection of different ideas which are aiming at solving the identified problems and challenges in the Wesermarsch. These solution ideas do not reflect a joint consensus between participants of the regional forum. Some of the ideas have to be discussed in more detail between participants because the analyses of risks and benefits of each idea are needed.

Based on these results of the former EU Interreg IVB project EMOVE an investigation was started to enhance the list of possible solution ideas for the watering problem in the county of Wesermarsch. In the context of the EMOVE project this investigation had been conducted by applying the DPSIR (drivers, pressure, state, impact, response) approach. According to the DPSIR approach the identified solution ideas were named responses. The outcome of the investigation of Work Package 3 within the EMOVE project and the entire list of responses can be found in EMOVE Consortium (2015).

The main focus to improve and ensure watering and drainage is on technical solutions. One solution could be the extension of the Butjadinger canal using existing watercourses (blue line). The water could be stored, distributed, and transported over a longer distance and could be available for a wider area for watering purposes.

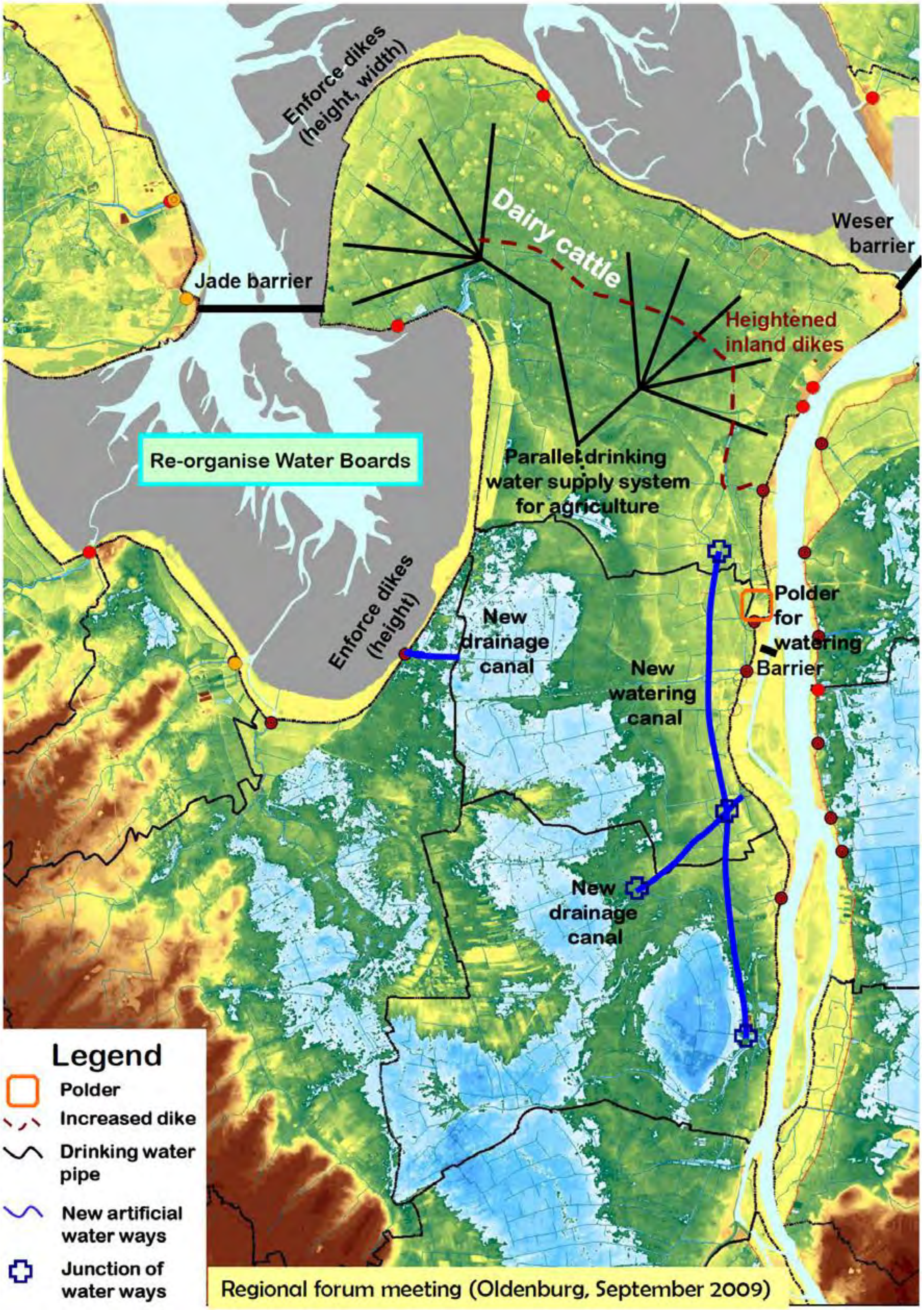

Figure 11: Sketch of solution ideas collected by the regional forum Wesermarsch during the participation process within the framework of the EU Interreg IVB project Climate Proof Areas. Source: modified after Ahlhorn et al. (2011)

It can be drawn from the map of the CPA project that these measures would affect different drainage boards (e.g. the drainage board Brake), which supports the idea to re-organise the watering and drainage system across the northern drainage boards and to have transboundary cooperation between these boards. In the meantime, a joint venture has been established between the three drainage boards of Butjadingen, Stadland and Brake (Figure 5) called "Planungsverband Wesermarsch" (Planning Association Wesermarsch).

To guarantee the livestock drinking water supply in summer time the existing drinking water system could be adjusted to the increasing demand (black ramified lines). This means, using high quality water to feed the cattle and increasing rates of drinking water supplied by the supply rate of the water works adjacent to the south western parts of the Wesermarsch. A combination with water storage in winter time in reservoirs, for example constructed close to the Beckumer Siel (orange box in the east), might be a possible solution for having enough water in summer.

Associated with the currently planned fairway deepening of the Weser is an avoidance solution for the northern drainage boards in the Wesermarsch. This avoidance solution comprises an improved steering of the watering features and the heightening of the dikes around the Butjadingen canal which is feeding the fresh water into the drainage board areas.

The adaptation of the water management system in the Wesermarsch region to climate-induced changes should aim in an effective and efficient watering and drainage system. To preserve the characteristics of the landscape as formulated in the development targets for the Wesermarsch region (see Ahlhorn et al. 2011), the development of these possibilities have to be intimately connected with the future use of the rural landscape and should not have a negative influence on the environment.

Regional Solutions based on Administrative Planning

The first ideas of the re-organisation of the drainage and watering features in the county of Wesermarsch consisted of constructing new canals. Nowadays, the idea is rejected and the re-organisation is going to be implemented by using existing canals and ditches as much as possible. Figure 12 shows the currently discussed ideas of the re-organisation, suggested by the Master Plan Wesermarsch (NLWKN, 2018). The fresh water for watering the northern part of the Wesermarsch will be extracted south of the city of Brake, at the Käseburger

Siel. The fresh water will then be conveyed through a system of existing canals and ditches up to the north. Based on these plans some new canals would have been constructed one from the south of the city of Brake (red line) and one in the north-west of the city (light green line).

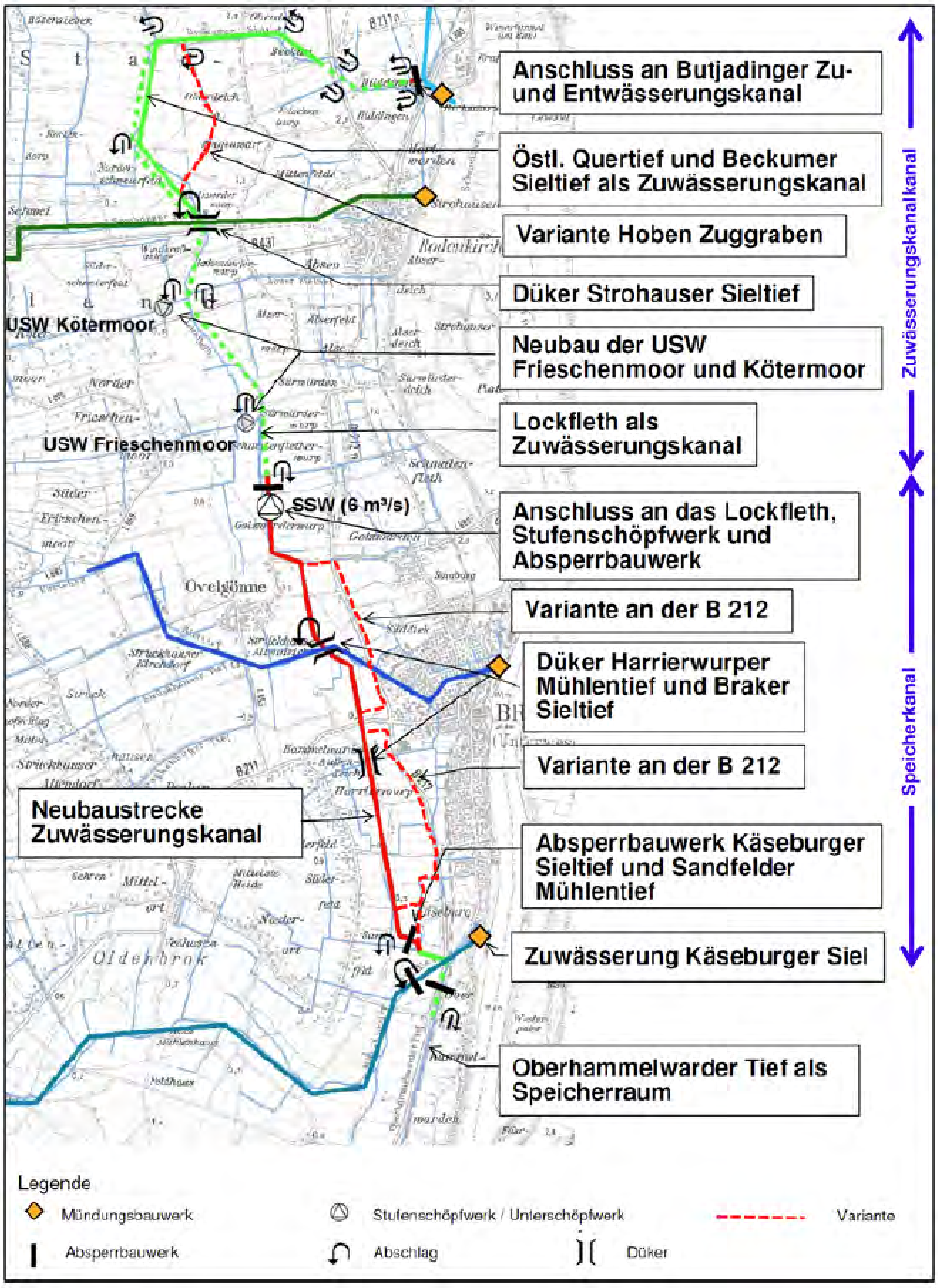

Figure 12: Current plan of the Master Wesermarsch as solution for the salinization problem (only German). Source: NLWKN (2018).

Such re-organization potentially affects the urban drainage of the City of Brake since the channels are used for different purposes: Watering and drainage. Thus, in dry summer periods with storm events the drainage network could be needed for watering and drainage functions at the same time: while agricultural areas in the northern part of the county need freshwater from the Weser River, urban drainage could require drainage functionality to drain storm water. For such events additional storage capacity would be required.

5.2 Solution Options for Urban Areas

Solutions based on European projects

Within the EU Interreg IVB project "Climate proof Areas" (CPA) several ideas have been studied to improve the urban drainage situation of the City of Brake. In the following paragraphs the solutions options will be described in more detail.

City as "Sponge"

The idea of increasing the storing capacity of a city is simple but difficult to implement. Within the EU Interreg IVB project "Climate Proof Areas" first ideas for creating more storing capacity in the city have been collected and described as the concept of the "City as a Sponge". The advantages of creating more storing capacity in the city is that the precipitation will not immediately flow into the drainage system, but will be conveyed with a time delay.

Some examples have been collected within the CPA project. Furthermore, these examples have been applied to the situation within the city of Brake.

Figure 13: Example for roof greening in the city.

In Figure 13 public buildings such as schools, gyms and administration are potential for roof greening. As can be seen in the figure these buildings are near one of the main drainage canals (Rönnel) which can, during heavy rain fall events, take the pressure of this feature.

Figure 14: Roof greening in industrial or trade areas.

Another possibility is the roof greening of buildings within industrial or trade areas. For example, if these ideas are considered from the outset in legally binding land-use plans than these roofs could be constructed to hold the necessary carrying capacity. Examples for this idea could be found in, e.g., in Hamburg where a hardware store provided this feature. The trade area in Figure 14 is in the proximity of the Braker Sieltief which drains the surface from the rural area of the drainage board Brake and, while it flows through the city, it is also draining parts of the surface water of the city itself. During extreme events the surface water of the rural areas has to cross the city and is discharged through a tidal gate in the main dike. This tidal gate approaches its conveying capacity more often in recent years, so the Brake Sieltief could in future be a bottle-neck for the drainage board.

Multifunctional and dynamic land use concepts are another idea of creating the city as a sponge. Different features are feasible to be implemented to retain surface water in respective areas. These areas have to be prepared for these functions, but timely consideration can help avoiding flooding's.

In Figure 15 an area is shown which is planned to be transferred into a residential area for elderly people. Implementing a combination of ditches, small ponds and depressions to collect the water during extreme rain fall events will serve as retaining basin. For example, this area is crossed by the Braker Sieltief, so retaining water in this area will temporarily help reducing the pressure on this drainage canal. Furthermore, these features also can be used as scope for designing a (water) friendly area for the inhabitants.

Figure 15: Multifunctional development of building areas.

Another example for using existing areas as retention ponds or retaining areas is shown in Figure 16. Normally, the area is used as a sports field for the adjacent school. But, during extreme events this areas could be used as retention pond, because of the proximity to the main drainage canal (Rönnel). If the area is adapted to this functions (e.g., by small dams around the sports field) water could be actively discharged into this area. After a certain time the retained water could flow back into the Rönnel and could be discharged into the river Weser.

Figure 16: Sports field as flood control area in the proximity of the drainage canal.

Rural Areas as Retention Pond

If the capacity of the area within the city is limited and more storing capacity is needed the integration of the rural is indispensable. The flow direction of the water shown in Figure 7 indicates that normally the surface water is flowing into the rural hinterland of the city. The installation of canals, tidal gates and pumping stations enables draining the area the other way around. In case of extreme rain fall events the city of Brake is at high risk of flooding and therefore damages of (sensible) infrastructure. In these cases it might be worthwhile to think of flood escape ways for the surface water into the rural hinterland which are adequately prepared. In the proximity of the Rönnel there are small ponds existing which could be used as storing basins for the surface water of the city of Brake. Ideas of a flood escape ways are shown in Figure 17. To implement these ideas different and comprehensive investigation have to be conducted and several stakeholders such as the drainage board, farmers and inhabitants of the city have to be involved.

In Figure 17 an overall view all ideas are put into the map of the city of Brake. The main drainage canals are shown as thick blue line.

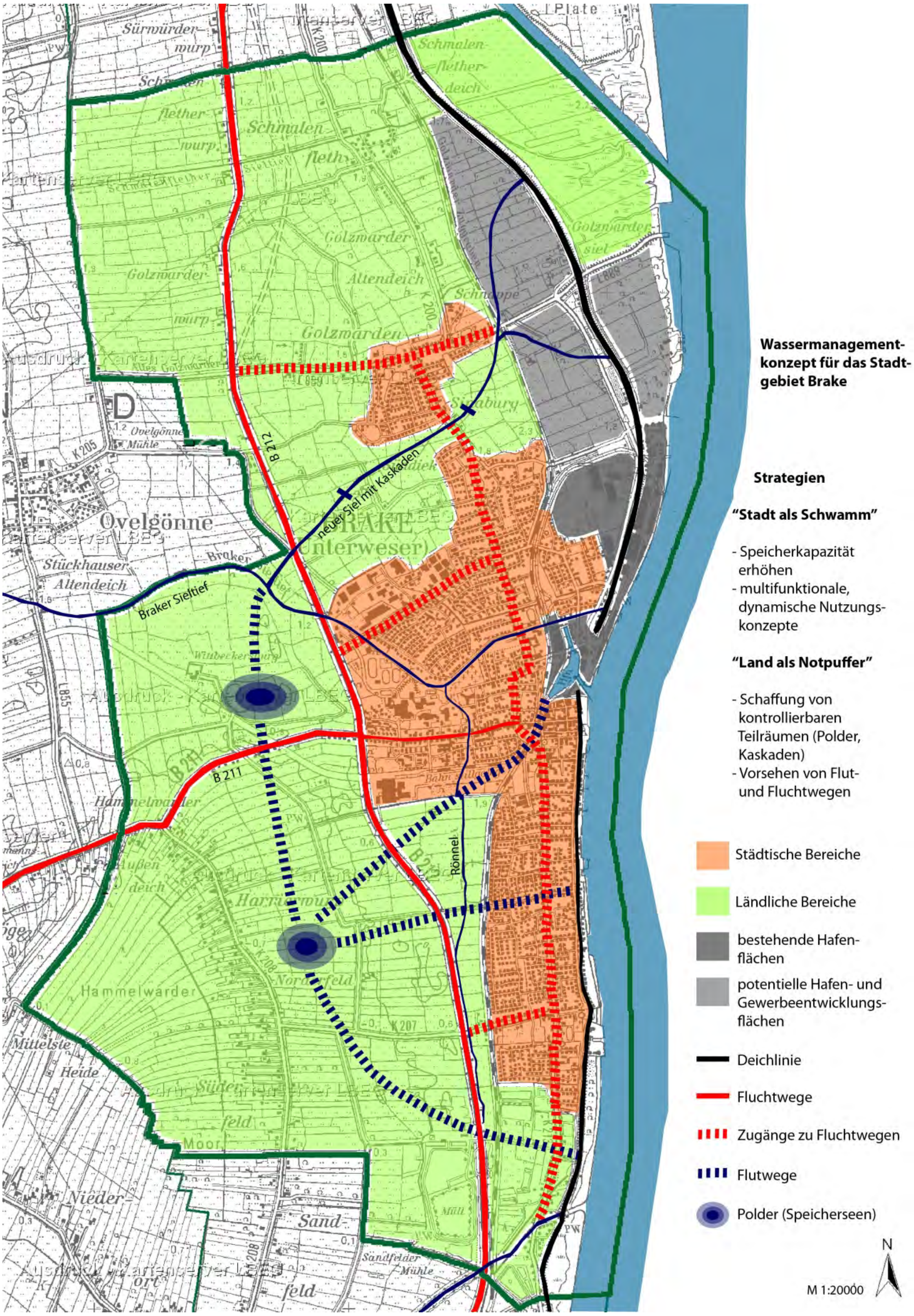

Figure 17: Draft of the urban drainage solution options within the EU Interreg IVB project CPA (in German).

Solutions based on the OOWV

The OOWV as drinking water supplier of the area is also responsible water the drainage of the surface of the city of Brake. As the boundary conditions changed due to climate change (e.g. probably more often extreme rain fall events) and city developments (e.g. sealing of areas which lead to increased and faster run-off) it is necessary to adapt the city drainage system to circumstances (KEC, 2016). As already described above the main drainage canals of the city are the Braker Sieltief in the north and the Rönnel in the south. Due to changes in the drainage and water management of the rural areas the situation for the city might also be influenced. At present, the discharge direction of the Rönnel is to the south into the Käseburger Sieltief which conveys the water into the river Weser. Whilst the plans of using the Käseburger Sieltief as watering canal for the northern part of the county Wesermarsch the flow direction might reversed. The consequence could be that during high surface water run-off the watering of the rural in the northern takes place and the canals are not able to keep more water. The drainage system around the city of Brake is mainly installed for watering and discharging the precipitation of the rural hinterland, so, today, the drainage of the city plays a minor role.

To cope with the existing situation in the Rönnel and with the rural drainage management the investigation of the adaptation of the city drainage system reveals that a spillway cut will be installed in the city to regulate the water levels. This spillway cut could be combined with a pumping station so that in case of higher water levels flooding's could be avoided by pumping the water into the Rönnel. This solution requires comprehensive and thorough investigations and stakeholder involvement process, because it affects the inhabitants (in case of mutual heavy rain fall event and watering of the rural area) of the city as well as the drainage of the rural hinterland (probably more water in the system than needed for watering).

In the last years OOWV has installed precipitation data management system based on rain gauges and radar system. The purpose of this system is the optimisation of the water level management in the pilot area.

The advantage of precipitation radar data is the characteristic high spatial resolution. The vision of the utilization of precipitation radar data for drainage planning and operation in the Wesermarsch is depicted in Figure 18.

The radar data needs to be accurate and georeferenced in order to be useful for local drainage management. Therefore, the first step may be to employ a precipitation data management system for data processing, visualization and output. Next, chosen outputted historical precipitation radar data could be used for drainage planning. The historical data could be imported to hydrological models for calibration and simulation of floods, storage capacities and risk areas. In addition, the influence of uneven rainfall distribution on the drainage system could be simulated.

Real-time and forecasted precipitation radar data may be helpful for drainage operation. On the one hand, the ditches need to be watered to support agriculture during summer. On the other hand, the watering during summer leads to reduced discharge capacities in case of heavy rain events. In addition, the watering leads to reduced performance of the rain drainage system due to the back pressure of the ditches during heavy rain events. To solve this problem, the management of the watering and drainage of the Wesermarsch needs to be supported digitally. The visualization of future rainfall amounts could inform the water board about an upcoming heavy rain event. Consequently, the water board could lower the water level and ponds prior to the event. Automated services based on precipitation radar forecasts could result in more efficient drainage management in the Wesermarsch. Chosen recipients could be informed (e.g. via e-mail) about the intensity and location of an upcoming heavy rain event. Further, real-time and forecasted precipitation data may be connected to hydrological models in order to generate warning messages for current and upcoming deficits in storage capacities.

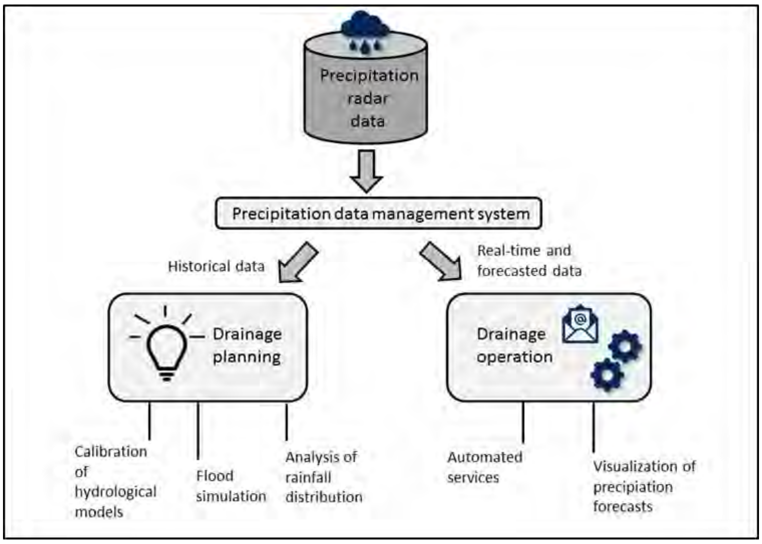

Figure 18: *Vision of future drainage management in the Wesermarsch using precipitation radar data.*

6. Proposition to improve the Solution Options – Integration

The integration of the different solution options for rural and urban water challenges requires

1) Considering the demands for watering and drainage at the same time,
2) Harmonizing of the different technical options, including a check for counterproductive effects,
3) Identifying possible bottlenecks in the existing systems,
4) Deriving solution options for such bottlenecks in terms of technical adjustment and management.

Watering and drainage demand as well as solution approaches were described and analysed in chapters 5.1. and 5.2. Similarly, counterproductive effects were identified: While relocating the water abstraction southwards guarantees an adequate water quality of the abstracted water, the storm water problem increases in the city of Brake. This could be regulated by the installation of a spillway cut at the Rönnel, which would enable using the Rönnel for watering and for drainage of the city of Brake without increasing local flood risk.

However, one challenge remains: even if the water level of the channels can be regulated efficiently, water storage capacity is required for such an efficient regulation. Such additional water storage capacity could be gained from

- Storing water in city areas (city as a sponge, see chapter 5.2); such solution requires a re-structuring of urban areas, introducing multifunctional areas and promoting green-blue urban structures;
- Storing water in depressions close to the city (see chapter 5.2); such solution requires the availability of area and the installation of pumping stations for regulations;
- Deepening and widening the channel system; such engineering action requires space for widening, a huge effort for stabilizing and maintenance;

All solutions require the smart involvement of stakeholders and citizens since private property is affected.

Creating additional storage capacity could be supported by an efficient management of the available storage capacity. For instance, lowering the water level of the channels and ponds prior to a storm event could provide additional storage capacity. Efficient management then would require an exact prediction of rainfall amount and moment in time. Accurate predictions are particularly required to minimize negative effects on the aquatic system and aquatic organisms. Radar systems could be used for this purpose, or even coupled Weather model – Radar systems in order to extend the forecast. Such systems could be used for future and innovative solutions in water management (digitalised management of drainage systems).

7. References

Ahlhorn, F.et al. (2011) *Klimasichere Region Wesermarsch. Die Zukunft der Wasserwirtschaft*. Oldenburg.

Ahlhorn, F., Meyerdirks, J. und Umlauf, I. (2010) *Speichern statt pumpen. Abschlussbericht*. Wilhelmshaven.

Bormann, H. et al. (2009) „Climate Proof Areas - Konzeption von an den Klimawandel angepassten Wassermanagementstrategien im Norddeutschen Küstenraum“, *Korrespondenz Wasserwirtschaft*, 2(7), S. 363–369. doi: 10.3243/kwe.2009.07.002.

Bormann, H., Ahlhorn, F. und Klenke, T. (2012) „Adaptation of water management to regional climate change in a coastal region – Hydrological change vs . community perception and strategies“, *Journal of Hydrology*, 454–455, p. 64–75. doi: 10.1016/j.jhydrol.2012.05.063.

Bormann, H., Kebschull, J., Ahlhorn, F., Spiekermann, J., Schaal, P. (2018): Modellbasierte Szenarioanalyse zur Anpassung des Entwässerungsmanagements im nordwestdeutschen Küstenraum. Wasser und Abfall 20(7/8), 60-66.

Bormann, H., Neumann, P. (2015) "Hydrologie – Oberflächengewässer". OLV, BSH (Eds.): Die Jade - Flusslandschaft am Jadebusen. Landes- und naturkundliche Beiträge zu einem Fluss zwischen Moor, Marsch und Meer. Isensee, Oldenburg. p. 71-77

Diesing, G. (2008) *Oldenburgisch-Ostfriesischer Wasserverband 1948-2008. Eine Chronik*. Brake: OOWV.

EMOVE Consortium (2015) „Estuaries on the move. Work package 3 - European Joint Fact Finding. Part 2“.

FGG Weser (2009) *EG-Wasserrahmenrichtlinie für die Flussgebietseinheit Weser. Bewirtschaftungsplan 2009 für die Flussgebietseinheit Weser. Maßnahmenprogramm 2009 für die Flussgebietseinheit Weser*. Hannover.

HPA et al. (2013) *Management of Estuaries. The need to understand nature & society. TIDE summary report*. Hamburg.

IPCC (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley (Ed.)]. Cambridge University Press, Cambridge, UK, und New York, NY, USA, 1535 pp.

KEC (2016) *Generalentwässerungsplanung 2016. Regenwasser*. Brake.

Kramer, J. (1992a) „Entwicklung der Deichbautechnik an der Nordseeküste“, in Kramer, J. und Rohde, H. (Hrsg.) *Historischer Küstenschutz*. Stuttgart: Verlag Konrad Wittwer, S. 63–110.

Kramer, J. (1992b) „Küstenschutz und Binnenentwässerung zwischen Ems und Weser“, in Kramer, J. und Rohde, H. (Hrsg.) *Historischer Küstenschutz*. Stuttgart: Verlag Konrad Wittwer, S. 207–254.

Kunz, H. (1995) „Salinity and water levels in the weser estuary during the last hundred years- anthropogenic influences on the coastal environment“, *Coastal Engineering*, (1901), S. 3533–3547.

Lange, D. *et al.* (2008) „The Weser Estuary“, *Die Küste*, 74, S. 275–287.

NLWKN (2018) Master Plan Wesermarsch.

Umlauf, I., Meyerdirks, J. und Ahlhorn, F. (2011) „Identifikation zukünftiger Konfliktpotenziale im niedersächsischen Küstenbereich im Projekt “Speichern statt Pumpen”“, *Coastline Reports*, 17, S. 191–202.