THE EMS FULL HYBRID

a Landscape Design for a Troubled Estuary

Jonas Papenborg
Remco van der Togt

Master Thesis Landscape Architecture 2012
Wageningen University

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For quality of life

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Preface

After a productive cooperation in our minor thesis 'Landschapsplan Nederland', where we searched for the famous Dutch landscape architecture tradition, we decided to continue this successful collaboration during our major thesis Landscape Architecture.

Becoming even more fascinated with the Dutch landscape, we choose another fine Dutch tradition as starting point for the thesis: The constant struggle against nature and especially against our biggest nemesis: water. During the second half of the 20th century, the glory days of modernism, we Dutch constructed with the Delta works an ingenious response to the constant threat of the rising water and for many decades, the natural seemed controlled.
Recent studies have however shown the many downsides of this fixation of dynamics, for it needs constant maintenance with extra sand or dredging, and leads to ecological disasters, with extinction and massive algae growth.

Our study focuses on one of the last remainders of the dynamic delta landscape: the Ems estuary, connected to the vast Wadden Sea. Attempts to regulate the Ems estuary, in order to increase safety and economic activity, have led to a turbid system, and the solution in a clash between nature and economy. These presented solution seem to move into two directions: full control via the modernist tradition or a complete return to a historical and fully natural situation.
This thesis searches for a new Dutch tradition, which is not based on the separation between nature and economy maintained by technical control, but searches for a full synergy between nature and economy wherein nature can be productive and economy can produce nature. The end result of this quest lies in your hands, and we hope it will provide inspiration, as the process of making it has done for us.

Finally we want to thank the researchers, local experts and designers who gave us their time and helped us along the way. Thanks go to our supervisors, Paul Roncken and Harro de Jong for their comments and inspiration during the guidance moments. Special thanks go to friends, colleagues and family who were there to give us a boost during tough moments, criticized our work when needed, and distracted us from work to keep the moral high.

Summary

Key Words: *Ems estuary; Hybrid landscape; Hydrologic processes; Landscape architecture; Economic ecologic interaction*

The uncertainty of a natural system is often replaced by the certainty of human control to ensure safety and economical activities. This conflicts with the balance seeking natural system and can result into friction and eventually a clash with the controlled system. The Ems, an open estuary on the border of Germany and the Netherlands, is a system where such a clash has occurred and has escalated. The natural estuary has been shaped into a controlled state with a decreased hinterland and a severally deepened riverbed. This has resulted in an enlarged tidal effect, bringing in high amounts of sediment and increasing turbidity. But to accommodate economic activities, this depth has to be maintained by constant dredging, which in return leads to more sediment, thus making the problem worse. The result is a highly turbid system, which cannot support higher life during six months of the year and costing millions of euro's each year to maintain this troubled state. Solutions for the problem are numerous, but actions remain because of an impasse between economical progress and natural conservation. A fitting solution thus not only lies in solving the turbidity problem, but also breaking through the dichotomy of culture versus nature. This is achieved by introducing the idea of a hybrid landscape; this states that, instead of choosing between economic gain and nature conservation, processes of different dynamics are mixed and benefit from each other. The needed technical solutions, coastal breakwaters and new saline polders, are then designed in such a way that the new system solves the turbidity problem, but also creates new habitats, raises water safety and produces food.
Thus the Ems becomes a hybrid-system with a restored ecosystem, new economic possibilities and remaining accessibility for birds, seals and large ocean cruisers.

Samenvatting

Kernwoorden: *Eems estuarium; Hybride landschappen; Hydrologische processen; Landschapsarchitectuur; Ecologie-economie interacties.*

De onzekerheid van een natuurlijk systeem wordt vaak aan banden gelegd door technische ingrepen omwille van veiligheid of economisch gewin van de mens. Dergelijke tegennatuurlijke, technische aanpassingen zorgen geregeld voor frictie met het natuurlijk systeem, dat constant probeert zijn evenwicht te herstellen. Zo ook in de Eems, een open estuarium op grens van Nederland en Duitsland. Het natuurlijke estuarium is veranderd in een beteugeld systeem met een drastisch verkleind getijdengebied en een onevenredig diep estuarium. Dit heeft geleid tot een gigantisch getijdeverschil, waardoor grote concentraties sediment het estuarium in worden gebracht. Om de economische activiteiten te handhaven, wordt het estuarium 24 uur per dag uitgebaggerd. Dit zorgt ervoor dat de sedimentconcentraties al maar toenemen. Het gevolg is een uiterst troebel systeem, waar zes maanden in het jaar nauwelijks leven te vinden is en waarvan de baggerkosten de pan uit rijzen. In de loop van de jaren zijn er vele oplossingen voor dit probleem bedacht desondanks blijft de uitvoering achterwege omdat economische vooruitgang en ecologisch herstel elkaar constant in de weg lijken te staan. De oplossing voor dit vraagstuk ligt echter niet alleen in het oplossen van het slibprobleem. De uitdaging ligt juist in het doorbreken van de impasse tussen economie en natuur. Met het concept van hybride landschappen kan deze impasse worden doorbroken. Dit concept gaat ervan uit dat economie en ecologie elkaar niet in de weg hoeven te staan, maar dat functies met een verschillende dynamiek elkaar juist kunnen versterken en zelfs van elkaar kunnen profiteren. De voorgestelde technische oplossingen, als strekdammen en getijdenpolders, zijn zo ontworpen, dat deze niet alleen het slibprobleem oplossen, maar tegelijkertijd zorgen voor nieuw habitat, vloedpreventie en voedselproductie.
Het Eems estuarium wordt een hybride landschap met een hersteld ecosysteem en nieuwe economische functies, dat bovendien plaats blijft bieden voor zowel vogels en zeehonden als voor grote oceaanstomers.

Zusamenfassung

Schlüsselwörter: Emsmündungsgebiet, Hybridlandschaft, hydrologische Prozesse, Landschaftsarchitektur, ökologische – ökologische Wechselwirkung

In die Unsicherheit eines natürlichen Systems wird oftmals technisch eingegriffen, um die Sicherheit und wirtschaftlichen Gewinn für den Menschen zu gewährleisten. Solche unnatürlichen, technischen Umstellungen führen regelmäßig zu Komplikationen in den natürlichen Systemen, welche weiterhin probiert ihr Gleichgewicht aufrecht zu erhalten. So auch die Ems, ein offenes Mündungsgebiet an der Grenze zwischen den Niederlanden und Deutschland. Das ursprüngliche Mündungsgebiet wurde durch den Bau eines Dammes und Vertiefung der Fahrrinne verändert. Eine Folge sind gigantisch veränderte Gezeiten, wodurch große Mengen Sediment in den Mündungsbereich gelangen. Um wirtschaftlich Transfer weiterhin zu gewährleisten, wird das Mündungsgebiet 24 Stunden pro Tag ausgebaggert. Dies hat zur Folge, dass die Menge an Sediment täglich wächst. Hierdurch entsteht ein äußerst trübes Wasser, wo sechs Monate im Jahr kaum noch Leben zu finden ist. Gleichzeitig schnellen die Kosten zur Erhaltung der Fahrrinne in unberechenbare Höhen. Im Laufe der letzten Jahre wurden einige verschiedene Lösungen für dieses Problem bedacht, jedoch keine umgesetzt, weil sich Ökologie und Ökonomie dieser in einem steten Interessenkonflikt befinden. Die Herausforderung liegt daher nicht nur bei der Behebung des Schlickproblems, sondern gleichzeigt auch bei der Überwindung der Barrieren zwischen Wirtschaft und Natur. Mit dem Konzept zu Hybridlandschaften kann diese Barrikade überwunden werden. Dieses Konzept geht davon aus, dass sich Natur und Wirtschaft nicht im Wege stehen müssen, stattdessen Anforderungsprofile mit verschiedenen Dynamiken einander ergänzen und gleichzeitig selber davon profitieren. Die hier vorgestellten technischen Lösungen, wie Wellenbrecher und Gezeitenpolder sind daher so entworfen worden, dass sie nicht allein das Schlickproblem, sondern auch Lebensräume, Flutpräventionen und Nahrungsanbau beinhalten.

Das Ems-Mündungsgebiet wird somit zu einer hybriden Landschaft mit einem wiederhergestellten Ökosystems und neuen Wirtschaftlichen Angeboten. Gleichzeitig bietet es genügend Platz für Vögel und Robben sowie großen Kreuzfahrschiffe.

Content

1

INTRODUCTION

1.1 Fascination

1.1.1 The modernist tradition

Around the world, the Dutch are probably best known for their constant battle against water; draining polders, dredging canals and building dikes, ever busy to keep the water out. The reason for this approach was to ensure safety; low laying land may be dry one day, but with the incoming tide or overflowing river it can be flooded the next. To deal with these dynamics, the uncertainty of a natural system is

Control of dynamics

replaced by the certainty of human control. Rivers are canalised to prevent them from moving out of their bounds and the coast is diked to keep out the incoming tides. This is not a strategy belonging solely to the Dutch; all over the world coastlines are diked and (previous) high dynamic deltas like the Mississippi and the Mekong are tightly controlled (Winden et al., 2010, Mathur and da Cunha, 2001). It is a rewarding strategy, for it dramatically increases the land area that can continually be used for living, infrastructure and food production. This strategy has evolved over time and for the Dutch has resulted in grand engineering works such as the Afsluitdijk and

Downside of modernism

the Oosterscheldekering. These works are fascinating, but recent studies have given awareness to the downsides of this modernist approach and these engineering achievements (Sieweke, 2010, Groven and Officer, 2008, Sperling, 2009).

These studies show that men may obstruct certain natural effects, but the natural laws are still valid. A river may be straightened, but it still has the tendency to meander or to find space for excessive water. The coast may be diked and gullies may

be deepened, but the tide still takes in large amount of water and sediment every day (Veen, 1950). Countering these effects may prove simple, but a natural system is never constant. It is always moving in and out of balance, never fully stable and will thus lead to constant friction with the controlled state and may result in a drastically affected ecosystem. However to maintain control and ensure economic activities, further adaptations have to be made, moving further away from the natural balance. Which in return intensifies and accelerates the natural system. This moves in a viscous circle of constant adapting to the intensified extremes of nature, which can eventually lead to a point where the costs of maintenance exceed the benefits and where the natural system cannot restore itself on its own (Crutzen, 2002).

Figure 1.1 | [left]. Rhein II by Andreas Gursky, 1999. The modern Rhine. The natural curving river is reduced to a straight line. The Rhine is straightened to increase mobility and dikes are constructed to increase safety. It becomes controled to exclude uncertainty.

Figure 1.2 | [above]. Blauwe Kamer, 2011. The post-modern Rhine. New ideas about river management embrase naturalness as a way to deal with the uncertainty of changing water levels. Instead of a line, the river becomes a zone again. It drives out men, and human influence and nature reclaimes it.

1.1.2 The ecologic reversal

Rise of environmental protection

The unrestrained expansion and regulation drift of modernism has given rise to a new phenomenon: nature conservation. It began in 20th century in an attempt to save valuable natural areas from the cultural expansion, resulting in small conserved snippets of nature. Nature conservation took a flight in the sixties and seventies, as a reaction to the post-war boom and mainly because of the increasing intensification and expansion of agriculture at the expanse of nature (Windt, 1995, Papenborg and Togt, 2011). In these years, nature organizations achieved some important victories, stimulated by a growing crowd of proponents from the cities and a growing scientific support by environmentally conscious students (Westerman, 1999) [see intermezzo | the Dollard clash].

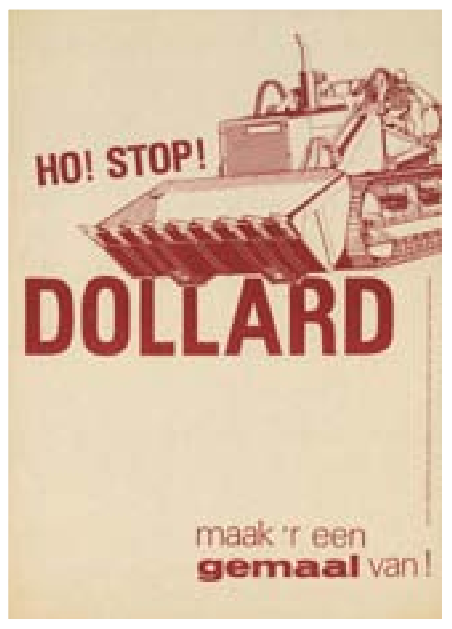

Figure 1.3 | Propanda poster for the pro-nature plan: ""Dollard; Hold! Wait! turn it into a pumping station!" (Nationaal Archief).

Figure 1.4 A,B | Two plans for the Dollard. (Abrahamse et al.):
[A] The pro-Economic, large Dollard plan, with the slogan: "Not a pumping station, but a channel"
[B] The pro-Nature, small Dolard plan, with the slogan: "Turn it into a pumping station!"

Intermezzo: The Dollard clash

Already before the great flood of 1953, a commission was set up to address to the hydrological state of the Dollard, restoring the low dikes and the poor drainage (Westerman, 1999). The plans remained on the bookshelf for ten years, but were reinstated in 1962/63. The commission 'Landaanwinning in de Dollard' (Land reclamation of the Dollard) developed two plans to improve the drainage of the peat colonies in the east of Groningen and Drenthe: The 'small Dollard plan' or 'pumping station plan' [figure x.x] and the 'large Dollard plan' or 'dike- and canal plan' [figure x.x] (Abrahamse et al., 1974).

Initially there was no strong preference for one of the plans. But new developments in the province were decisive. After the discovery of a large gas field in the sixties, the north of the Netherlands was to become the 'Texas of Europe', with energy, chemistry and industry as the saviour of an underprivileged region. To ensure that also the deprived region of east-Groningen would benefit from these energy profits to choice fell on the Large Dollard plan. The Dollard was going to be diked in, reclaiming nearly 1000 ha of new agricultural land, and leaving a broad channel for large freighters, thereby boosting the industrialisation of Winschoten and surroundings (Westerman, 1999).

While the preparations for the construction of the large Dollard plan started, a counterparty of students and environmental experts arose who campaigned against the construction of this plan. According to them the Dollard was a valuable nature area of flats and salt marshes, highly important to many wetland bird species and for the avocet (Recurvirostra avosetta) in particular. The construction of the large Dollard plan would sharply reduce the area of salt marsh and would thereby be catastrophic for the birds. The environmentalist started a contra-propaganda and tried to reverse the plans in favour of a Small Dollard plan (Westerman, 1999). After years of protest, the nature demonstration prevailed: in 1972 the government voted for the smaller option, thereby sparing the Dollard. The choice was highly influenced by the European agricultural circumstances, which was dealing with 'butter mountains' and 'whine lakes', a surplus of agricultural products. To prevent further oversupply, farmers where paid subsidies to stop producing and leave their land bare. The high costing Large Dollard plan was thus doomed for failure if the valuable outer-dike nature were to be exchanged for fallow land (Westerman, 1999).

Unfortunately, construction of the large Dollard-plan had already started. Parts of the channel had been dug and the large sluice at the Punt van Rheide was already constructed. The sluice stood standing until they tore it down in 1993, putting an end to the memory of this debacle. This episode became an important milestone for nature protection and was one of the first times that the value of nature overcame economical gain (Westerman, 1999).

The continuing expansion of human activities and its consequences, and small conservation successes fed the idea that nature is better of without human intervention. Especially after the discovery of the Oostvaardersplassen in the 1970's came the realization that nature can even be steered and actually (re) created. It makes the basic recipe for the restoration of nature in damaged areas simple: remove human activities, restore the pre-men conditions and nature will come back on its own. This has not only made the nature lobby a strong actor within spatial planning, but has also given rise to a new ideal and feasible image of nature: Large untouched nature areas free of any human activity and intervention (Westerman, 1999).

Recipe for nature

It has led to the *"false dichotomy"* held by many ecologists, that landscape is either 'nature' or 'culture', and cannot be both (France, 2008). An attitude that is not very different from the idea of technical invincibility of the modernist engineers. Both nature conservationists and modernist engineers persevere in the idea that its objective is better without the influence of nature or culture. These rigid attitudes led to famous impasses like the case of the Hedwigepolder, where both nature and culture claim the land for its own (NOS, 2009). This attitude however neglects the fact that landscape is always a combination of natural and cultural elements, and cannot be without both functions, for landscape is: "an area as perceived by men, wherefrom its character is determined by the action and interaction of natural and human factors" (Papenborg and Togt, 2011). Nature, at least in Western Europe, is always influenced by men. If not made and maintained, it is visited, protected and perceived by men, determining the character of the place; to think men has nothing to with it, would be naïve.

False dichotomy between nature and culture

Figure 1.5 A-D | Protest actions against plans to turn agricultural land into new nature areas. It is typically called: 'ontpolderen', undoing the reclemation of the past and turning valuable land into 'worthless swamp'. (sources: A: prz.nl; B: nrc.nl; C: goednieuwskrant.com; D: volkskrant.nl

Figure 1.6 | The Ems-Dollard An apparant mix between culture and nature. They co-exist next to each other, without a (perceivable) negative influence on each other.

1.1.3 The apparent mix

In the past decades, spatial policy has been focussed on separation. It has resulted into concepts like the Ecological Main Structure (EHS) and the Delta Plan, devised to keep out either negative natural or cultural influences because of the feared negative influence on each other. But this idea of strong separation seems to perish in a lack of support nowadays (Sieweke, 2010). Excluding natural processes via a modernist approach has proven to be an unsustainable strategy. Not just because of negative effects on ecology but also because of economic and cultural reasons; endlessly heightening dikes or moving sediment is highly unpractical if the water and sand keeps coming back. Excluding cultural influence from nature is in a similar way undoable and unwanted. The concept of the EHS, based on a spatial division of robust nature and high-dynamic arable land, encounters considerable public resistance nowadays. The construction of a 'monotonous' network of nature in the landscape is seen by the public opinion as: an undemocratic and technocratic intervention, where man is excluded deliberately (Feddes et al., 2012). What is needed is a revision of the land-use concepts; a working mix based on collaboration between culture and nature instead of obstruction.

Excluding nature or culture in spatial policy

The photo above seems to show such a mix. The photo is taken at the border of the Germany and the Netherlands, showing the Ems estuary with all its aspects. The foreground of the picture shows a picturesque landscape; a dynamic river leaving traces in the sandy surface and widespread fields overgrown with waving reeds. The lookout cabin is used by hikers and birdwatchers to view the countless birds the place attracts. It is not surprising that this landscape is declared the most beautiful place in the Netherlands (Dijksterhuis, 2011). The background shows the opposite: an industrious area characterized by enormous factories and warehouses completed with colossal sky scraping windmills. A landscape intended for nothing else than production. But it seems a successful recipe, a landscape where men, animals, industry and natural processes interweave. But this harmony is only skin-deep. It is actually a deadly cocktail, which has resulted in a river (the Ems) so murky it cannot support higher life for six months in the year (Bos et al., 2012).

An apparent mix

One of the main causes is a cruise ship manufacturer located along this river, ironically a form of tourism that takes people to the most beautiful and spectacular landscapes and wildlife, such as the fjords in Norway and the Caribbean.

It is here where our thesis takes place. It is a perfect example of a wicked clash between nature and culture. With two extremes on the opposite sides of the field:

Wicked clash

- On one side the Wadden Sea, the largest natural intertidal area, famous for its dynamic natural processes and massive attraction to birds;
- And on the other economic progress; depictured by the cruise ship industry, as the ultimate symbol of wealth, consumerism and capitalism.

1.2 Problem introduction

1.2.1 Local problem

A dying river

Look at the photo on the right [figure 1.10]. Obviously there is something wrong here and the river has been described as "... being killed" and "dying" (Steenhuis, 2011). However it is not illegal chemical dumping that causes this peculiar colour, as one might expect, but simple sediment; small particles of sand and clay, which are being whirled around, turning the water brown and unclear.

Estuaries are actually always naturally murky (Bos et al., 2012). Marine and riverine flows collide, mixing sediment and nutrients from both sides, causing a turbid zone. However, instead of a relative small and cloudy section, this zone is almost stretched out over the entire length of the Ems with a far larger sediment level (Bos et al., 2012). It has earned the Ems the title 'yellow river' (NOS, 2011). However unlike the Yellow River in China, which earned its name by its turbulent but natural sediment transport, the situation of the Ems is largely caused by the increasing intensity of human interventions. This has changed the estuary in such a way that, simply said, more sediment flows into the system than it can naturally handle. The accusation of the river being dead is a consequence of this. Because of the high turbidity sunlight cannot infiltrate deep into the water, reducing visibility for animals, but more importantly reducing oxygen production to almost an absolute zero, thus making it almost impossible for fish to live in the estuary (Firet, 2012) [figure 1.8, 1.9]. And as mentioned before, the situation is not improving. To maintain shipping draft, there has to be constant dredging to prevent the sediment from settling down [figure 1.7]. The particles are kept in suspension, allowing shipping but also maintaining and worsening the turbidity. It has even reached the point in where the natural system could not restore itself on its own, even if all human interventions would cease (Jager, 2011). This means that the need for action is now, before the system is ruined completely and the way back to a healthy estuary is irreversible (Bos et al., 2012, Firet, 2012, Jager, 2011, Schuchardt et al., 2009, Jonge, 2010).

The turbid problem of the Ems estuary is far more complex than outlined above and will be the main focus point of this thesis. A large part of the research is thus committed to understanding the issue, what the causes are, the consequences and possible future actions. This report will handle these topics step by step, working towards a healthy estuary.

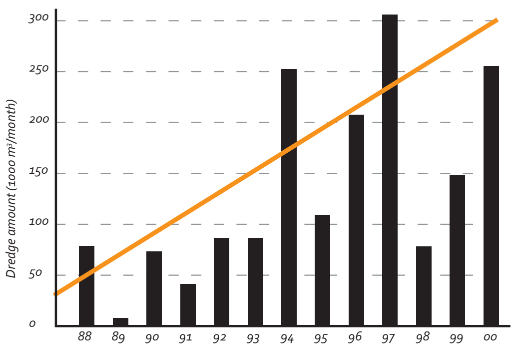

Figure 1.7 | Monthly dredging
The amount of montly dredging in the Ems estuary since 2000. The total is steadily rising and is already costing € 26 milion a year. Excluding deepening activities (source: Talke & de Swart, 2006).

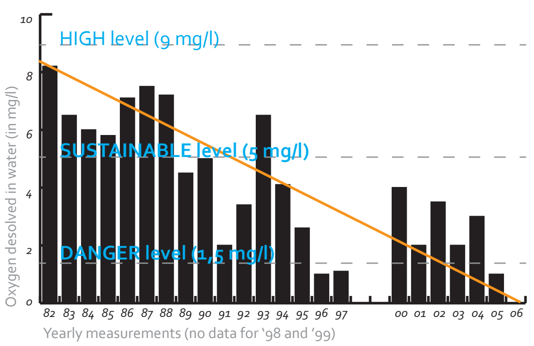

Figure 1.8 | Oxygen level
The oxygen production has fallen below the critical level for fish to survive (1,5 mg/l) (source: Lenntech; Talke & de Swart, 2006; Bos et al, 2012).

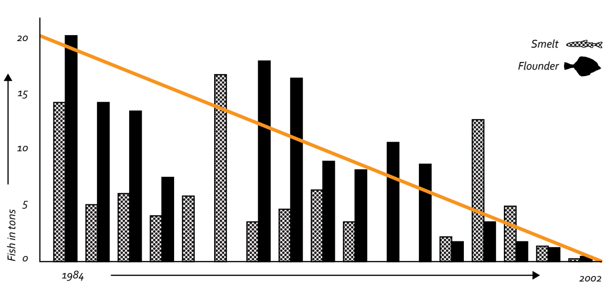

Figure 1.9 | Caught fish within the Ems-estuary. Both smelt and flounder is reaching an zero point (based on: Cofad, 2004).

Figure 1.10|The 'Yellow River' Photo taken from a boat saling on the river Ems.

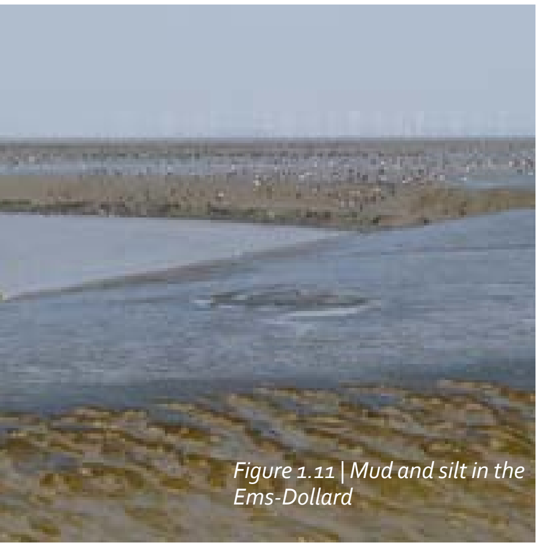

Figure 1.11 | Mud and silt in the Ems-Dollard

Figure 1.12 | Constant dredging in the Ems

Figure 1.13 | The spectacle of the cruise ships, one of the main causes of the turbid situation.

1.2.2 Problem context

From the previous paragraph, it has become clear that the Ems estuary is dealing with a problem. The reason why this problem is still apparent and has received so little media-attention, despite the seriousness of the case, is largely due to its location at the outskirts of two countries. The Ems lies on the border between the Netherlands and Germany, seen from both countries as an agricultural and periphery area (Hasse, 1993). It probably also explains the low speed at which the problem is being addressed, even though experts say the situation is critical (Bos et al., 2012, Firet, 2012). Nevertheless, the attention for the problem seems to be growing. The reason it receives any attention nowadays, although limited, is because of its open connection to the Wadden Sea, which was recently appointed as UNESCO world heritage site [figure 1.15].

Periphery area

The Wadden Sea

The Wadden Sea is the largest intertidal wetland in the world, attracting 12 million birds every year (UNESCO, 2009) [figure 1.14]. Because of its ecological uniqueness and importance, it is highly regulated and protected under laws and guidelines like: PKB-Waddenzee (Planologische KernBeslissing), UNESCO world heritage site, RAMSAR Convention-area, Nature 2000-area, European union's habitat- and birds-directive and water-framework-directive area (Rijksoverheid, 2011, Ecomare, 2012). These directives not only protect the ecological state, but they also have the power to reduce or stop (harmful) economic activities like shipping routes (NOS, 2011) and oil drillings (Telegraaf, 2012).

Impasse between economic progress and natural conservation

This is a new development and changes the roles as they have been in the last 50 years: whenever a new factory would arise, nature organisations would protest, but most of the time without success because economic progress was always the main goal. However, now with new power for nature organisations, economic lobbies like energy companies or port organisations are now protesting against new nature legislation that could potentially harm their economic position [see intermezzo | The Wadden in the UNESCO-race].

These developments are taking place on the Wadden scale but also, and more fiercely, on the smaller scale of the Ems [figure 1.16]. The estuary is protected and accredited as ecological important by eleven different regulations spread over nine different governmental institutions and NGO's (CWSS, 2010), but at the same time has five industrial harbours looking for growth. This has led to a provisional standstill; both parties are unable to progress because opposing lobbies keep each other in check.
Meanwhile the problem remains and even worsens.

Figure 1.14 | The Estuary landscape within the context of East Atlantic Flyway

Figure 1.15 | The Ems within the context of the UNESCO heritage landscape the Wadden Sea

Figure 1.16 | The Ems estuary

Intermezzo:
The Wadden in the UNESCO-race

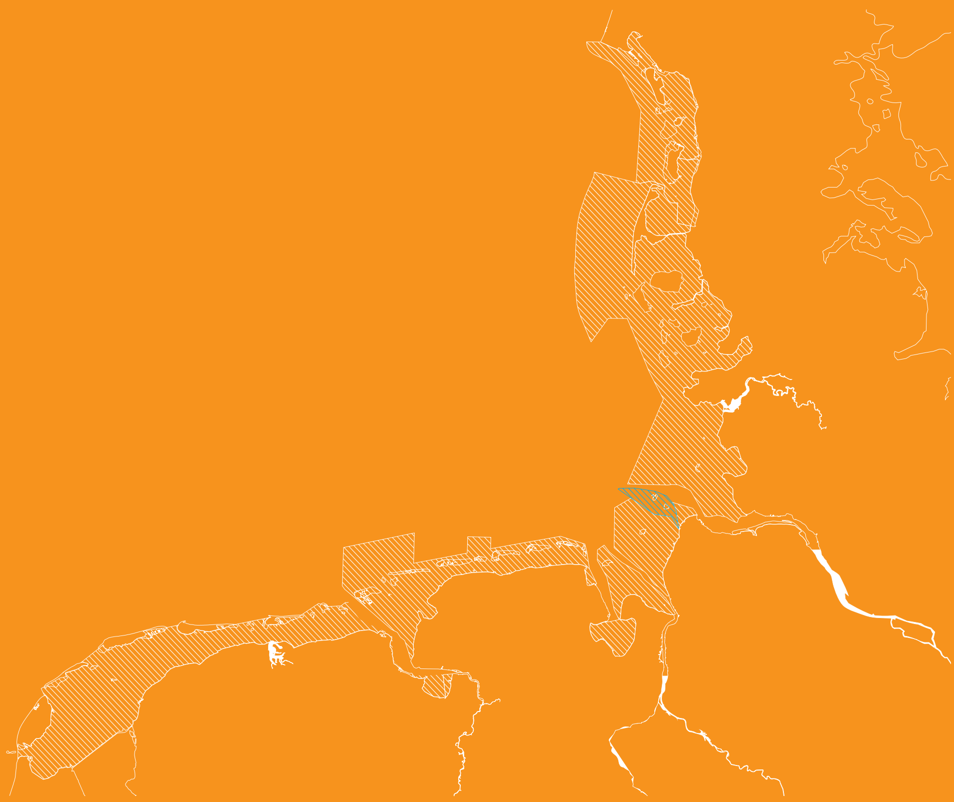

Figure 1.17 The Wadden Sea as a protected UNESCO World Heritage Site (based on UNESCO, 2009). In blue is the section along the estuary of the Elbe. Added to the UNESCO area in 2011 after objections by the Hamburg state had passed

The Wadden Sea is the largest intertidal wetland in the world, stretching 500 km from the southwest of Denmark till the northwest of the Netherlands. Because of its sheer size and three main qualities it was appointed as an UNESCO world heritage site in 2009 (UNESCO, 2008):

- On-going natural processes. The Wadden Sea is unique in its current state, but the effects that formed it are still apparent and ever in motion. With this it achieves a constant rejuvenation of the ecosystem and the maintenance of its habitats (Marencic, 2009).
- The diversity of habitat. The Wadden Sea has a multitude of transitional zones between the extremes of wet-dry and fresh-salt. This creates countless habitats, leading to one of the highest biomass production in the world.
- Biodiversity and biomass. The previous qualities attract an enormous number of wildlife, the total number of species in the Wadden Sea ecosystem is estimated to be around 10.000 different species of flora and fauna, four times as many as the Everglades (Marencic, 2009, Junk et al., 2006).

Despite of the general revelry after the world heritage nomination not everybody was happy with the nomination of the Wadden Sea as world heritage. While in the Netherlands the nomination was only put up for discussion by a few parliamentary questions out of fear of the oil- and gas revenues (Financieel Dagblad, 2008), the resistance in Germany was much fiercer. The government of Hamburg (second largest port of Europe) was afraid of the consequences for the economy of the state and were therefore reluctant to participate in the nomination (NRC Handelsblad, 2008). To ensure the economic position of its harbour, the government of Hamburg was planning to deepen the main shipping canal of the river Elbe. The government was afraid, that an intensification of the protected status of the Wadden Sea would lead to the obstruction of the economic development of the harbour and thereby of the state (NRC Handelsblad, 2008). Although the Hamburg part of the Wadden Sea was added later on in 2011 (Wadden Sea world heritage, 2011), the statement of the economic actors in the Wadden Sea is clear: The protection and restoration of the ecological values in the Wadden Sea has limits and must not constrain the economic functioning of the area.

1.3 Purpose of the Thesis

The turbid state of the Ems estuary is the main problem of this thesis, searching for clever actions, which could potentially solve the problem, the main purpose. But we are not ecologists or hydrologists; we have only a basic knowledge about dynamic natural processes, so why do we think landscape architects are needed? Being a generalist discipline, landscape architecture has "the capacity to design adaptive strategies aimed towards stability in the context of an environment that continues to change in a dynamic way." (Sieweke, 2010). Rivers, coastal zones and estuaries are great examples of landscapes that are under the constant pressure of different dynamics, both natural and cultural. And precisely the discrepancy between these two dynamics is a main reason why the Ems problem still remains. Industries are reluctant to change because they want to conserve their economic position, while nature lobbies want to change everything, making it impossible for industrial activities to continue. It results in a trench war and neither sidseis moving towards each other. Meanwhile the ecologic lobby, represented by NGO's and scientists, produce a vast collection of scientific studies and reports about the situation of the Ems (131 and counting). The studies however mainly concern ecologic data, largely incomprehensible for laymen and non-scientists.

Main problem

We believe landscape architecture is needed to break through this impasse. We have the ability to:

- Make complex problems understandable
- Look from both a cultural and natural view
- Deal with the aspect of time, dynamics and uncertainty
- Look for solutions that physically work
- Use design as a way to explore, inspire and break through impasses

Purpose

The purpose of the thesis is thus to confront the Ems as a landscape architect. We call this a landscape architectural approach. Ultimately finding a working mix, which does not hold to the "false dichotomy between nature and culture" (France, 2008), but are 'full hybrid' combinations. They transcend the standard 'natural area with park,bench' and are a mix of different sectors, which are not just situated next to each other, but actually benefit from each other. We believe such a mix is needed for the Ems and that we as landscape architects, as holistic discipline, can act as a mediator, and provide an alternative and positive perspective for this troubled and forgotten region.

1.4 Problem statement and research questions

This fourth paragraph holds the problem statement and research question that form the guidelines during this study and will be answered throughout the thesis.

Problem statement
The Ems estuary has reached a level of turbidity where oxygen production no longer takes place and where the biodiversity and biomass has dropped significantly and has led to a dying river. This has been caused by continuing technical adaptations, which have to be continued and even increased to maintain the current economic level. This in return worsens the ecological state and leads to higher maintenance costs.

Research goal
The main goal of this research is to confront the problematic state of the Ems estuary as landscape architects. This implies that we want to confront the problem statement not just from a natural or morphological view, but from a social and economic view as well. The achieve this, the goals of this research are:

- Understand how the estuarine system works and how the mix of different economic and ecologic dynamics has led to the Ems' turbidity problem.
- Create a design that uses the economic and ecologic dynamics to solve the turbidity problem and provides more opportunities in the process.

Research question
To achieve these goals the following research question must be answered throughout the thesis:
How can the Ems' sludge problem be solved and how can this lead to an economic and ecologic healthier landscape, using a landscape architectural approach?

The following sub-questions help to answer this question:

1. *How should dynamic systems like the Ems estuary be handled argued from a landscape perspective? [CH 2]*
2. *How does the dynamic estuarine system work and in what has caused the current troubled state in the Ems system? [CH 3]*
3. *How can the estuarine system be changed or steered to avert the current and future turbid challenge? [CH 4]*
4. *How can the interventions be designed in such a way that they deal with the uncertainty of the system and fit within the Ems landscape? [CH 5,6,7]*

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2

THEORETICAL FRAMEWORK

2.1 Introduction

Summarising the first chapter it can be concluded that the case of the Ems revolves around two statements:

- The Ems is a dynamic estuarine system and is continually exposed to natural effects causing water and sediments to move and change constantly and unpredictably.
- Economic progress and ecologic conservation do not mix in the Ems. Both sides cause negative effects for the other, causing an impasse and a standstill for problem solving.

These two different statements lie at the foundation of the troubled state the Ems is currently in. In the modernistic attempt to control the dynamics of the Ems, they actually have accelerated and have become harder to control. Where as the current impasse between economy and ecology causes a standstill in solving the problem. Understanding how these cultural and natural dynamics function and interact with each other is a vital part of this thesis, and will be handled in chapter 3. This chapter discusses how we as landscape architects can deal with the above statements. It sets up a theoretical framework that will assist in dealing with these dilemmas. This framework is divided in two sections:

- How to deal with uncertainty and dynamic systems [2.2].
- How can a landscape architectural solution help to break through the current impasse between culture and nature [2.3].

Figure 2.1 | The Great Canute
The Great Canute proves to his servants he is not all- powerfull, for even he cannot stop the tides.

2.2 The uncertainty of a dynamic system

As already stated in chapter 1, a modernist approach to landscape and its natural processes has proven to be an unsustainable strategy for the future. Benefits may be gained on the short term, but ultimatly problems increase and expences grow. It can result in mild problems or an enormous clash such as has taken place in the Ems. To overcome this, instead of locking dynamics out, we need to embrace it; dealing not only with matters of space, but also with time and the accompanying change.

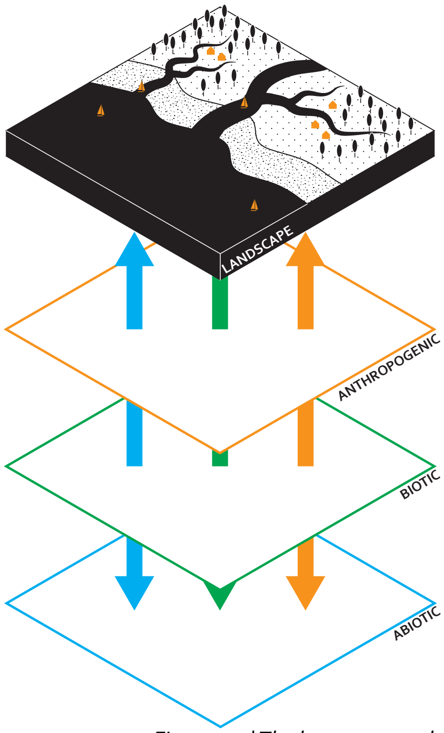

Figure 2.2 | The layer approach, different processes interacting. (after: Kerkstra et al., 1976 in: Hidding, 2006

2.2.1 Dynamics and uncertainty

Time is an important feature when dealing with the aspects of landscape. And unlike from the modernistic point of view, landscapes are not static or closed entities that move towards a climax-state, but are dissipative systems that are constantly changing. They are individualistic, non-equilibrium systems, a unique combination of physical, biological, and cultural elements that are constantly changing over the course of time under the influence of powerful dynamics of the landscape and the changing intentions of men (McHarg, 1969, Johnson, 2002). These are landscape forming processes that can be seen as a set of layers, affecting and interacting with each other over time (Kerkstra et al., 1976 in: Hidding, 2006) [figure 2.2].
This interaction has been significantly reduced by the actions of men, who, over the course of time, have increased its own influence at the cost of the natural layers, thereby reducing the dynamics of nature [figure 2.3].

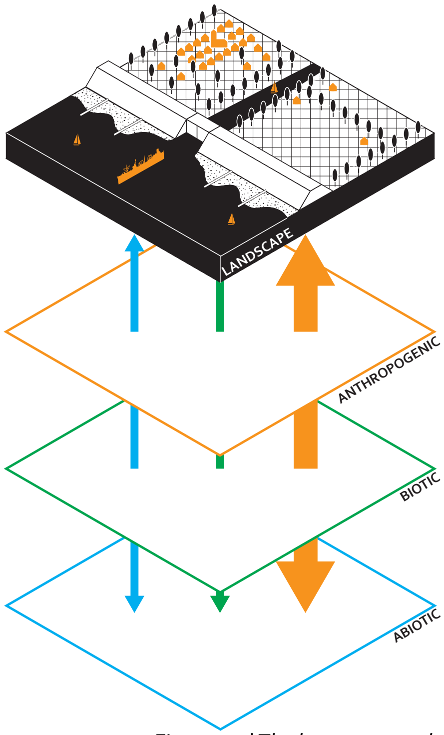

Figure 2.3 | The layer approach, the influence of men increases.

Although limited, some areas have escaped this total control by men and are still under the influence of natural processes, which we call dynamic landscapes. They are marshes, coastal zones or estuaries, and are still under the influence of tides and floods and change constantly. These landscapes and processes are studied extensively and although the processes underlying these nonlinear dynamics are mostly understood, they are hard to predict. These systems are so complex that: "Surprise is inevitable and uncertainty is high because we are relatively ignorant of the many parts of living systems..."(Karr, 2002). A direct result of this high uncertainty is that men try to replace this with the certainty of human control to ensure safety and economical activities. This can drastically reduce the space in which dynamics can occur, but ultimately natural phenomena, like storms and daily tides cannot be stopped [figure 2.1].
It should therefore be taken into account that under the influence of natural processes, dynamic landscapes constantly change and are never fully stable. Although hard to predict, this change has the tendency to move in and out of an equilibrium state. This state can be seen as a reiterative process, moving in and out of balance, returning back to its

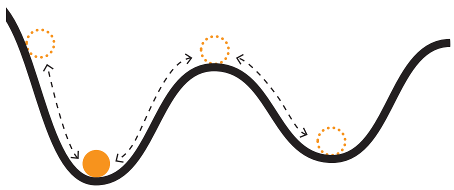

figure 2.4 | A dynamic balance
A dynamic system can be seen as a marble set on a serie of hills, always changing under the influence of natural effect, but staying around one equilibrium state. Under a large disturbance, either natural or humane, the system is thrown out of balance and finds a new equilibrium state (After Steijn, 2002).

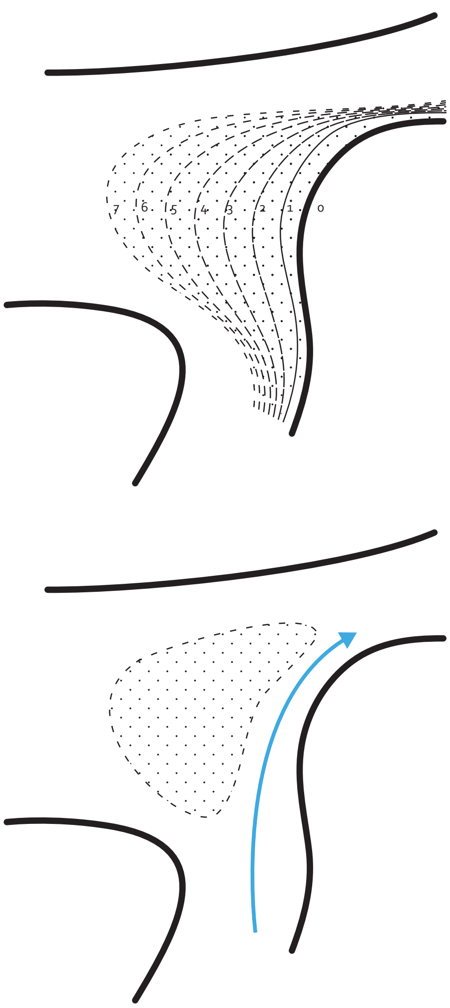

Figure 2.5 A,B | A dynamic balance
An inner bend of a meander slowly moves west under the effects of meandering and sedimentation. After a while the floodgully will break through and the process repeats itself, although the settings will not be identical (After Veen, 1950).

starting position, without the guaranty that it will return to a previous state [figure 2.4 & 2.5] (Steijn, 2002).
And as men interfere within this system, it affects all layers, thus also disturbing this dynamic balance. Finding its old or a new balance can in return lead to friction or a clash between the fixed cultural state and the unpredictable ever-changing natural state [figure 2.6].

As stated above, the prediction of the movement of natural processes is extremely complicated and therefore not fully understood, not even by experts. As such the study of estuaries (and the Ems) deals with a high level of uncertainty (Foster, 2008, Bos et al., 2012). Interfering within these dynamic systems thus also has a large risk, as: "We simply cannot foresee all the ways complex natural systems will react to human-initiated changes, at their present scale, scope and velocity" (Orr 2002 in: Foster, 2008). Interfering within a natural system thus has a high risk for unforeseen consequences. But when a natural system is already altered or damaged, are there no ways to restore it? According to Foster, we do not have a choice, we must either undo our historic mistakes or forfeit restoration goals: "Not only must we abandon the isolated technologies of traditional engineering; we must actually dismantle the tradition's legacy whenever that legacy impedes natural systems". (RAE-ERF in: Foster, 2008). If we follow this strategy, then there is nothing left to do but retreat and let natural systems like the Ems restore on its own. However, even in theory this is unlikely to work (Jager, 2011), let alone in practice. The Ems is not a theoretical estuary from which we can walk away and let nature 'reset' the landscape. Besides the much discussed ecologic qualities, there still exists the economic and cultural value, which cannot be easily replaced. Men need dikes and a shipping channel for safety, food and jobs [Chapter 3 System analysis]. Environmental restoration is thus not just a nature concern, but also a design process. For it does not only concern ecological values, but economic and social values as well (France, 2008).

2.2.2 Wicked problems

As France (2008) states, designers (including landscape architect) are needed within these high dynamic cases, not only for their ability to combine natural and cultural processes, but also because of their experience with uncertainty and complex problems.
In contrast to natural scientists, designers often deal with design problems which are not well-formulated, are ill-structured and open ended, also described as 'wicked problems' (Lawson, 2004, Stremke, 2010). For these types of problems there could exist an infinite number of possible solutions that might offer a slight improvement over the current state, but without any clear preference. And any of these solutions can be developed further without ever reaching the final state of improvement (Lawson, 2004, Stremke, 2010). There is thus no absolute answer for a design problem and the only sure way of deciding if a design improves

or worsens the situation, is to test it out in practise (Lawson, 2005). It is a form of heuristic research: experienced-based techniques of problem solving where the main progress is made by doing. To move forward, the designer or researcher must take educated guesses, based on empirical research but with a high level of uncertainty.
Such a strategy is needed for the case of the Ems, for its complex problem can be described as a 'wicked problem'; because even though a vast amount of information and models is available, there still exist a high level of uncertainty on how the system might evolve and it might respond opposite to what is expected (Steijn, 2012).

Figure 2.6 | 1927 Mississippi Flood Levee Breach (source: commons.wikimedia.org).

2.2.3 Dealing with uncertainty as a designer

According to this chapter, the reintroduction of dynamic processes is necessary. That this is needed is certain, the manner on how this can be done is doubtful, for "surprise is inevitable and uncertainty is high" when dealing with natural systems (Karr, 2002). Dealing with this uncertainty is a binary process:

Surprise is inevitable and uncertainty is high

- You must first understand how the uncertain and dynamic system works (McHarg, 1969, Steiner, 1991, Alcamo, 2003, Delbene, 2009).
- And if this system is uncertain, suggested actions must be able to deal with this uncertainty.

The first step is taken in Chapter 3, where the processes, functions and changes of the Ems estuary are fully explored. The second step is elaborated in the design chapters [Chapter 5,6,7], and is founded on the following theoretical basis:
"Surprise is inevitable and uncertainty is high because we are relatively ignorant of the many parts of living systems..."(Karr, 2002). Predicting the changes within a system is thus difficult, and interfering within such a system can generate unanticipated effects, for: "...engineering solutions to natural resources problems can generate irreversible impacts and may cause many new problems not amenable to engineering solutions."

(Feldman 1991 in: Foster, 2008). The difficulty is thus, that human involvement may also generate new problems. And avoiding this risks by only implementing small-scale interventions will not work efficiently, because: "The scale of the solution should be of the same scale as the problem." (Steijn, 2012). What is needed is a rhizome strategy, starting small and experimental and increasing in size, scale and amount to have "a significant effect on overall estuarine functioning and health" (RAE-ERF in: Foster, 2008).

scale of the problem = scale of the solution

This is interpreted as follows:

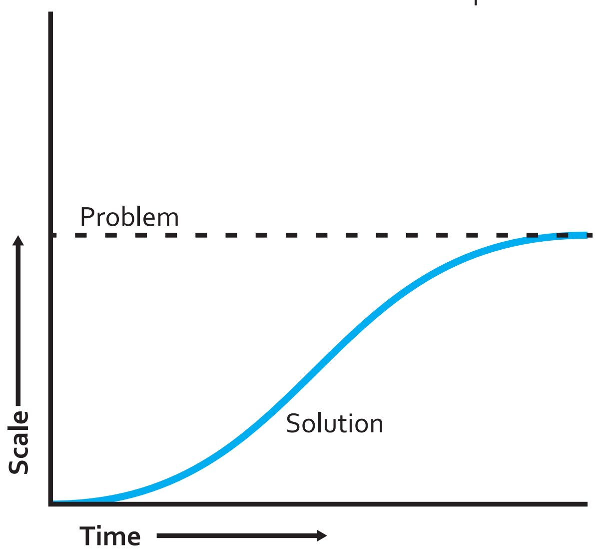

Figure 2.7 | A growing strategy
A growing solution to the scale of the problem

- Small interventions, being of negligible scale compared to the entire estuary, do not have a lasting effect on the long run.
- Because of high uncertainty in dynamic systems, large-scale engineering solutions fitted to the scale of an estuary, have a high risk of having an irreversible negative effect on an ecosystem.
- Large-scale problems must be counter measured by solutions of the same scale.
- As a consequence any intervention in a high dynamic estuary must be a growing solution. Starting from small-scale low-impact solutions, measuring the outcome, and slowly growing into larger solutions, to have a lasting effect on the estuary.

What is needed for the Ems is a growing strategy, a strategy for change [figure 2.7]:

Design for change

In order for a landscape architect to work within the changing landscape, his ideas and intentions should be adaptive to time and his designs needs to deal with the high uncertainty of on-going processes; he must make a design for change (Steiner, 2007).

2.3 Breakthrough the impasse

2.3.1 Landscape: an idea

As the previous paragraph stated, landscape is the result of the different physical layer processes interacting with each other. But because of its cultural layer, it is not only determined by its physical space but also by the idea of landscape and is "inseparable from particular ways of seeing and acting" (Corner, 1999 p. x-xi). Landscape thus not only changes at cause of natural effects, but also evolves under the influence of "the imaginative and material practices" of changing societies (Corner, 1999 p. x-xi). The Wadden Sea for example, has been a shallow tidal area ever since men settled there, but over the course of time it has been seen as: a dangerous crossing for cargo ships [figure 2.8], a valued source for new agricultural land [figure 2.9] and a valuable nature area [figure 2.10]. The idea of what a landscape is, is thus also inherent to change and affects men's actions within this landscape.

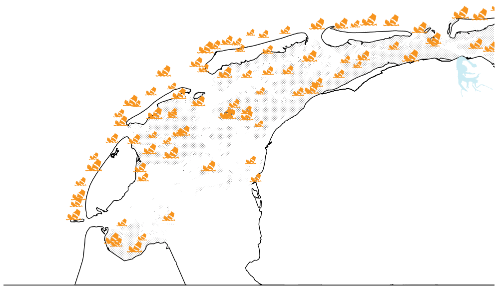

Figure 2.8 | The Wadden as dangerous shallow sea (source: www.waddenkiosk.nl)

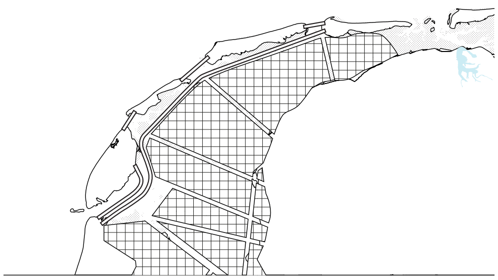

Figure 2.9 | The Wadden as a new polder (source: plan Buma, 1882)

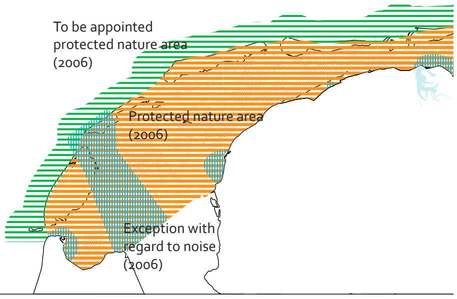

Figure 2.10 | The Wadden protected area (source: PKB Waddenzee)

This is important to realise for the Ems case, for it influences the ways the problem is seen and being handled. For the Ems' situation may be severe and worsening, the turbidity problem has been around since 1985. The reason why environmentalists are currently drawing attention to the problem is thus not only for the severity of the problem, but also because the influence of pro-nature parties has expanded. Resulting in the fact that it is now acknowledged (by most) as an environmental problem, where before this extra sediment was only perceived as extra maintenance. The solution for the problem is however in debate, for environmentalists want to reduce industrial activities and restore the natural situation, while the industrialists do not want to loose their economic position. But in the previous paragraph it was concluded that in order to move towards a healthier landscape, natural dynamics have to be reintegrated. While at the same time maintaining a place for cultural dynamics, for we cannot simply go back in time and erase cultural influence, replicating an imagined previous state of nature (France, 2008).
For men has claimed his place in the landscape, and is dependent on the current forms of land use, whatever impact it may have nowadays. Consequently this can result in an impasse where the health and the wealth of a system conflict with one another, represented by nature organisations and industrialists. This can result in a standstill for problem solving, as has been the case for the Ems estuary [1.2]. This paragraph focuses on averting this problem by finding a mix between the apparent contradictory elements culture and nature, building on three concepts:

Three concepts

- Ecosystem services
- Hybrid landscapes
- Landscape machines

Figure 2.11 | Ecosystem services
The ecosystem provide different services, ranging from provisioning services, regulating services, supporting services and cultural services (Alcamo, 2003).

2.3.1 Landscape: servicing

Ecosystem services are all goods and services obtained by men from ecosystems [figure 2.12]. This includes: "...provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth." (Alcamo, 2003). And although current levels of technology largely shields the cultural world from the effects of environmental changes it is "ultimately dependent on the flow of these services" (Alcamo, 2003). This concept is basically the attempt to translate ecologic processes and well being into an economic language so they can be measured and given an economic value. The concept itself is mostly focused on ecologic preservation, but its features are used by the concepts of hybrid landscape and landscape machine, which is largely built on two important premises: The first is that nature is a dissipative system, from which goods and services can be gained and waste material can be returned. Second is that economic influence should not be ignored or excluded because of its negative impact, but the influence and positive effects should included in the thinking process.

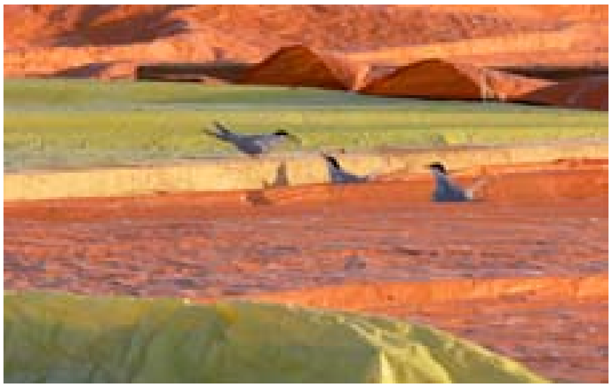

Figure 2.12 | Arctic Terns living and breeding in an industrial site (source: ziltwater.eu).

Figure 2.13 | Shoals of fish are atracted to oilrigs and wind mills, as they provide food and shelter (source: sail.world.com)

2.3.2 Landscape: hybrid and producing

The concept of a hybrid landscape continues from ecosystem services, as it does not aim to divide ecologic functions from economics into monofunctional landscapes, but rather searches for integration. Delbene (2009) says it even goes further than this, for integration is the combination of different elements which form a certain coherence but maintain their individuality. Hybridisation is however: the conscious mixing of different dynamics, and the mixing of elements "that found there origin in different languages". It thereby creates new forms, and possibilities, that "go further than the solving of an individual problem of the present" (Delbene, 2009) [figure 2.12, 2.13].
With this, the hybrid strategy is an answer to the failure of the modernistic ways of regulation and function separation. And is one of the key ingredients for a contemporary landscape (Sieweke, 2010). According to Sieweke, in order to steer away from the regulation of the modernist regime and towards a new paradigm of a 'producing' landscape, three vital changes have to be made (2010):

- From monofunctional to hybrid
  The modernist principle of functional division has led to a strict division of 'green spaces' being either for: agriculture, recreation or nature. This separation of functions and dynamics leads to monofunctional landscapes and problems as described in Chapter 1.

Hybrid

- From linear to cyclic
  The modernist paradigm has led to the 'normalization' of cyclical natural systems for the benefit of linear economic growth. But in order to avert environmental challenges, a system must synchronize with "the cyclical dynamics of nature".

Cyclic

- From produce to producing
  The domestication of landscape has given rise to a romantic view on nature and turned it into an object, rather than a producing and open system. A producing landscape can however be natural as well as productive without them being in conflict.

Producing

2.3.3 Landscape: a machine

The objective of creating a producing landscape forms the basis for the concept of the landscape machine, devised by Roncken (2011). He states that landscape can be seen quite literally as a machine, for it has a certain material input and output and is driven by an energy source [figure 2.14].
An example could be a reed field, where wastewater is pumped in, is cleaned by the reed by the power of the sun and produces fresh water, reed for biomass energy and fish as food. The processes powering the machine can also be steered, accelerated or stimulated, to create a landscape of abundance, not just fit for production, but also increasing safety and creating new habitats.

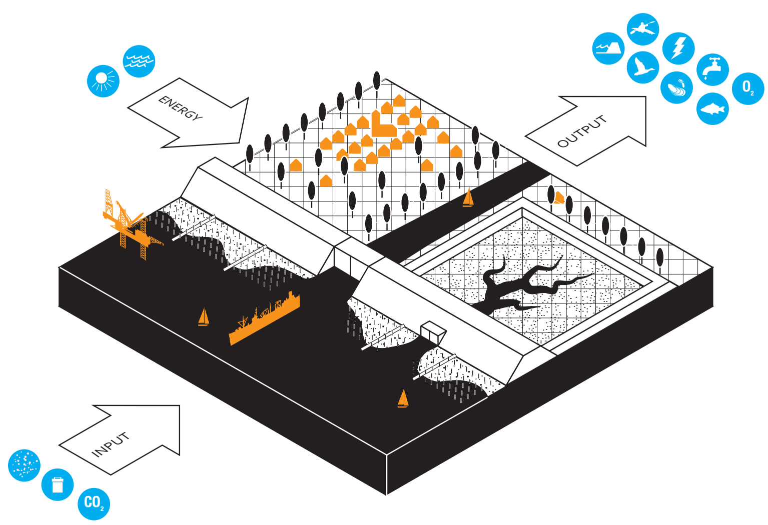

Figure 2.14 | Producing landscape machine
The landscape is a machine that has input, output and an energy source powering it. The processes can be accelerated and create a surplus for use of food, safety, recreation and nature.

The intend of the landscape machine is to cancel the separation of the natural and the cultural world. The dividing of these worlds as has been the modernist fashion, has not only given rise to a less interesting landscape, but also led to a troubled landscape, with constant need of maintenance and control. A landscape machine could revitalizing the life-sustaining processes, by steering away from this mono-functional strategy and be a landscape of many things at the same time (Roncken et al., 2011). In this contra-modernist philosophy, the machine itself is not implemented at once, as the term might suggest, but is grown: The mechanics change and develop over time because of an interaction with other mechanics and physical, ecological and chemical processes. Through these reactions the machine evolves, changing the ways of production and the products as well. The landscape machine thus not expands in a linear fashion, but rather cyclically grows dependent on the natural processes powering the machine. And as these processes are dynamic and inherently uncertain

Growing landscape machine

[paragraph 2.2], the development of the machine is therefore also characterised by a certain level of uncertainty.

Landscape services, landscape machines and hybrid landscapes, use common elements such as ground, water and vegetation. They will not result in an 'alien' landscape [figure 2.16, 2.17 & 2.18], but they will be unlike most existing landscapes and will be more than an integration of nature and economy, it will be a full hybrid. A raw landscape, unlike the landscape of the modernist engineers or our romantic forefathers, but representing the choreography of natural processes (Roncken et al., 2011, Sieweke, 2010).

Figure 2.16 | The adaptive afsluidijk
The afsluitdijk has to adapted to future climate change and instead of tradionally heigthening the dam, natural salt marshes are created to reduce the tidal effect. This has the added benefit, that it creates new habitats and forms a touristic attraction (source: Sperling, 2009).

Figure 2.17 | Generating Dune Scapes
A hybrid landscape example. The dune forming processes of the Dutch coast is used to create a growing landscape, where both nature, living and recreation finds its place. All in the direct vicinity of the Rotterdam industry. (source: Rietveldlandscape, 2006)

Figure 2.18 | Dredge landscape
A landscape machine example. Poluted dredge is collected from rivers and canals in a single place in the Haarlemmermeer. The dredge is hence cleaned with natural processes, resulting in a park which grows and changes as the dredge is processed. (source: Herrebout & de Vries, 2006)

2.4 Conclusion

Based on the theories of hydrologists, ecologists and designers the research framework has presented ways to interpret, understand and work with dynamic processes, and strategies for implementing these in the controlled cultural world. The Framework shows how landscape architecture can be used as a strategy [2.3] and how to deal with uncertainty and dynamic systems [2.2], for:

Landscape is change

- Landscape changes continuously.
- Dynamic systems are under the influence of natural processes and highly unpredictable.
- Environmental challenges concern both the natural and the cultural world.

Although men has largely taken control over the natural system, dynamic processes still occur which causes friction with the attempted controlled state. To move away from this stress situation, it is needed to reintroduce natural dynamics and steer towards a state closer to a natural balance (Jager, 2011, Bos et al., 2012). Hereby should be taken into account that working with these natural dynamics, instead of against it, implies that we first need to understand how this natural system works (McHarg, 1969, Steiner, 1991, Alcamo, 2003).

To work with the system, you must understand the system

The accompanying uncertainty of these natural systems also has to be taking into account while designing. And can be done by making a design for change, a growing strategy able to adjust to the changing aspects of landscape, instead of implementing static intervention.

Paragraph 2.3 continued from this standpoint of working with natural processes, suggesting that if the dynamics of the natural world are reintroduced, they save to be integrated with the dynamics of the present and future cultural world. This requires new attitudes on dealing with landscape, considering that:

Landscape is productive

- Nature is productive and provides services.
- The cultural world is ultimately dependent on the services and processes of nature.
- Mixing culture and nature can generate a whole, which is greater than the sum of its parts.

Thus in order to revitalize a troubled landscape conflicted by environmental challenges we thus have to reinstate natural processes, instead of working against them and reintegrate the natural and cultural world. Thus creating a hybrid landscape or landscape machine, which provide landscape services.

The theories and concepts used in this framework will not always literally return in the rest of this thesis, but they form the basis for how we think about landscape, and how we believe design should work:

- Landscape is not a dichotomy between cultule and nature; it is always a mix of both.
- Landscape is not static. Under the influence of natural and cultural effects it changes over time, never reaching an end state.
- Apparent contradictory elements such as nature, agriculture and industry can and should be mixed, for they are part of the same system.

Landscape is a constant changing mix of things

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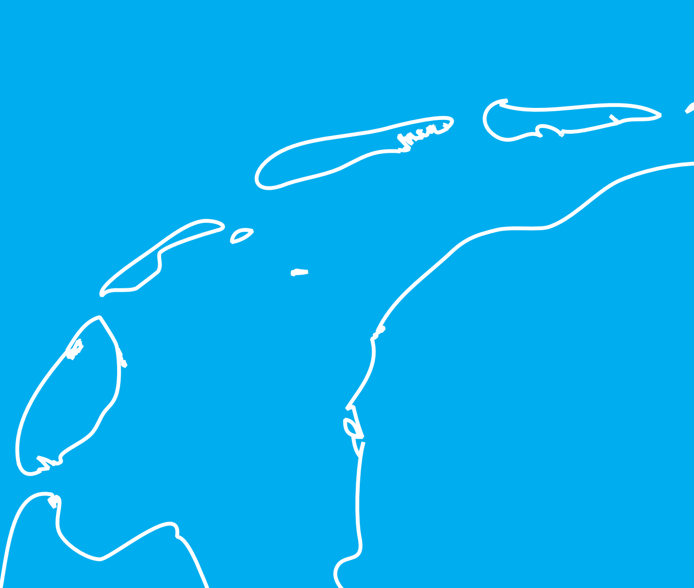


SYSTEM ANALYSIS

3.1 Introduction

From the previous chapter [Research framework] it has become clear that, in order to make changes within a complicated system, we must first understand how the system works. This chapter makes the first step and is build up as follows:

- 3.2 The functions and processes of an estuary, both from a cultural and natural standpoint,
- 3.3 The developments in the Ems-estuary. Clarifying the steps under which the sludge-problem could arise.
- 3.4 Conclusion and consequences of the turbid state.

The analysis of the estuarine system is hence used as the basis for the search of a solution in chapter 4 [Design Strategy]

Figure 3.1| Different stages in the origin of the Wadden Sea.
I: Sea level rise
II: peat formation
III: Breakthroughs
IV:Regulation and Embankment

3.2 The estuarine system

3.2.1 The dynamic Wadden Sea

As an estuary, the Ems cannot be seen separately from its marine connection: The Wadden Sea. Between the Wadden Sea and the connected estuaries is a constant exchange of sediment, nutrients, animals and fresh and salt water, all powered by river discharge and daily tides.

Formation of the Wadden Sea

The formation of the Wadden Sea started around 5000 BC. The last ice age was over and melt water started to fill the oceans again. The Atlantic Ocean filled the North Sea through the English Channel, which still remains as the dominant ocean current along the Dutch coast. Within its rapid stream it takes on sediment from the coast and rivers and deposes it on shallower and quitter grounds in elongated ridges (Blerck et al., 2008). Eventually these sand ridges surfaced and formed a closed off beach wall alongside the North Sea coast [figure 3.1 I]. Temperatures continued to rise and behind this sandy ridge, large peat valleys started to form [figure 3.1 II]. The sea level continued to rise and started to break through the sand ridge at weak spots, mainly estuaries of rivers and streams. These breakthroughs became stronger and more frequent, gradually dividing the ridge into islands, striking away peat and gouging out large pieces of land [figure 3.1 III]. The sea was now fully able to flood the land at the highest tides, and penetrate deep into the main land through the estuarine gullies. Coarse sediment is deposited alongside these gullies and forms creek ridges, further away from the stream the flowing speed reduces and finer sediments settles down. Eventually these ridges silt up high enough, so that even at spring tide they do not flood and become overgrown with vegetation [figure3.1 IV] (Barends et al., 2005). The result is a complex dynamic Wadden ecosystem, which is internationally valued as; one of the last remaining natural, large-scale, intertidal ecosystems where natural processes continue to function largely undisturbed formed by and still subjected to many different geomorphological processes (UNESCO, 2009).

Within this world famous Wadden Sea ecosystem estuaries play an important role. The estuaries can be seen as the life lines of the Wadden Sea, which in turn is important for larger marine ecosystems like the North Sea and as key area within various migration pathways. The Wadden Sea originally had 41 estuaries which connected the sea with the rivers and their hinterland. But due to embankments and dams only 4 open estuaries left nowadays [figure 3.2]. One of those estuaries, which still has an open connection, is the Ems-estuary.

Figure 3.2 | The 41 estuaries of the Wadden Sea.
37 have been closed off, leaving only 4 open estuarine connections.

3.2.2 Delineation of the estuarine system

Definition estuary

An estuary is, shortly said, the seaward section of a river system where saline and fresh water is mixed and receives sediments from both fluvial and marine sources. This area is subjected to marine and riverine processes as tide, waves and fluvial flows and extends from the total area on which both marine and riverine influence is measured (Hijma, 2009). As such an estuary does not have clear or stable borders, but is dependent on the increase or decrease of marine influence or riverine discharge. Within these estuaries there are several archetypes, classified by location, soil and a combination of river, tide and wave influence (Hijma, 2009):

- Lagoonal (Miramichi river, US)
- Partially-closed (Schelde, NL)
- Open-ended (Gironde, FR)
- Tidal (Broad Sound, AU)

Zoning of the Estuary

The Ems river mostly resembles an open-ended estuary because of the large tidal influence and outwards ranging coast line. This tidal influence is however somewhat limited by the Wadden islands in front of the coast line, which function as a barrier. The borders of the Ems estuary starts from the sea opening between these Wadden islands and stretches 105km until the weir at Herbrum. Within this estuary, different subsections can be made out based on salinity and other estuarine processes, which gradually overflow in one another (Bos et al., 2012) [figure 3.3]:

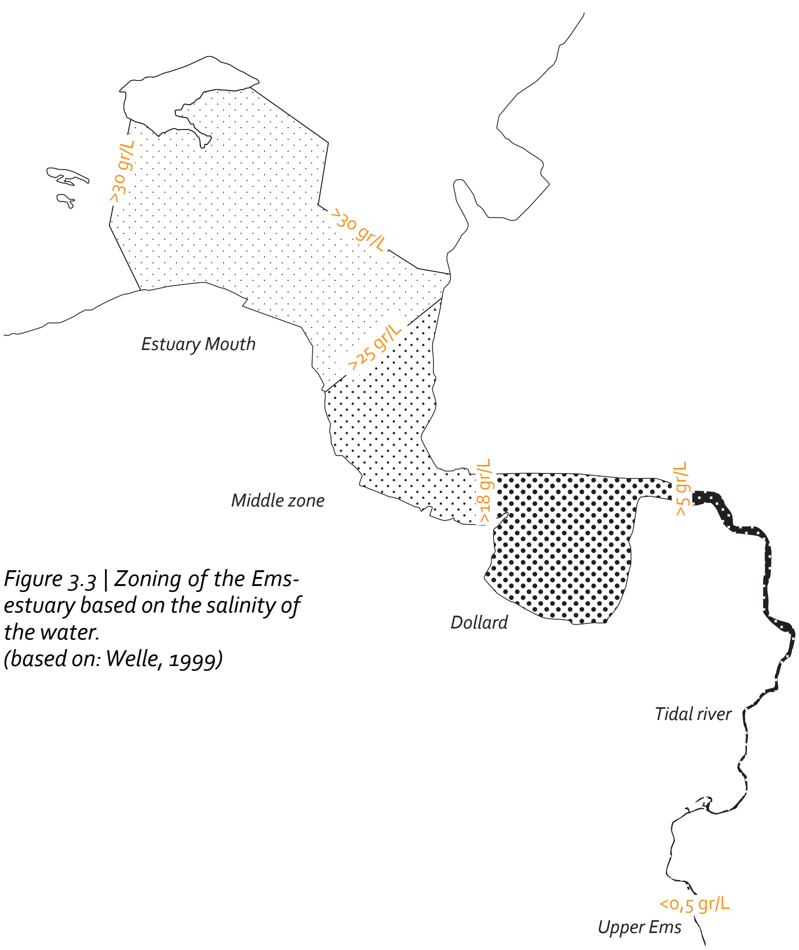


Figure 3.3 | Zoning of the Ems-estuary based on the salinity of the water.
(based on: Welle, 1999)

- *The coastal zone or mouth*

Zone where marine water enters the Ems estuary through the western Ems gully between the Wadden islands Borkum and Rottumeroog. Between the islands and the coast lies a zone of shallow mudflats, where the Ems and smaller gullies, cut through. The water is saline, but has different characteristics than the North Sea because of the influence of the Ems River.

- *The middle zone*

The estuary narrows but the width of the gully roughly stays the same, and thus decreasing the zone where water can slow down. This results in a zone with a natural high turbidity and a relative high flowing speed.

- *The Dollard*

A shallow intertidal region of 100 km2 with silts, flats and saline marshes between Termunten and Pogum. The Dollard and the lower zone are fed by the same gully, but are separated by the Geiseleitdamm, a 12km long breakwater.

- *The lower zone or tidal river*
  The zone stretches 40km from the permeable barrier at Gandersum (Ems Sperrwerk) to the closed off barrier at Herbrum. It forms a gradient of fresh to brackish water and is under the influence of the daily tides.

The fifth section is the Upper Ems, ranging around 250km from the barrier at Herbrum untill the source in Schloß Holte-Stuckenbrock. Even before the construction of the weir, the tides did not reach this river section, but after the barrier the mutual influance has decreased even further. As a result the upper river and the estuary are seen as two seperate ecological sections and the Upper Ems will therefor not be further discussed.

3.2.3 Hydrological and morphological ingredients for an estuary

An open estuary is exposed to a mix of natural forces, which leads to a divers and ever changing landscape. This paragraph explains the phenomena, which shape the estuary and how they still apply to the Ems estuary.

Riverine influence
The riverine influence is highly determined by the size of hinterland and unlike the tides can be very unpredictable because the exact movement of melt water and rain is undeterminable.
The dynamics of the riverine section of the Ems is however negligible. Because of the barrier at Herbrum, the riverine inflow can be controlled and fluctuations are by in large kept to a minimum, averaging to 80-110 m3/s (Jonge et al., 2009) (in comparison: 16,000 m3/s passes through the Rhine at Lobith). However limited, the catchment area does still supply the system with nutrients and fresh water.

Tide and tidal effects
The tidal effect, the daily motion of the sea between high and low tide, is the most defining aspect of the Wadden Sea. The tides are primarily caused by the gravitational pull of the moon and in lesser extent the sun, which pulls on the water surface and moves it around the globe. As a result the tides have a daily rhythm, lasting around 12,5 hours, with high and low tide both lasting around 6 hours.

Figure 3.4 | Catchment area of the Ems and adjacent rivers

Figure 3.5 | Areal photo of the Dollard at high and low tide

Thus there is a set time when water flows into a system and when it flows out. As an estuary, the Ems is strongly influenced by the tides, considering that the tidal-current during flood is 400 times bigger than the river-current (Leeuw, 2006). Due to human interventions this tidal effect has changed and increased dramatically: During the last 40 years the Ems-estuary showed, driven by sea level rise and adjustments in the river course, an average increase of 51 centimetres per century. Near Herbrum, the tidal range even increased from +0 to +2,50 meter over the last 100 years (Leeuw, 2006). And, instead of symmetrical tide, the tidal curve has became a-symmetrical, which means that the flood lasts 40 minutes longer than ebb (Leeuw, 2006).

This increased tidal amplitude and tidal asymmetry is the consequence of the constant dredging activities in the estuary. Due to these activities the natural barriers and retardant meanders have disappeared and has caused a flood dominated importing system. Which means that sediment is easily pushed in, but is not easily pushed out.

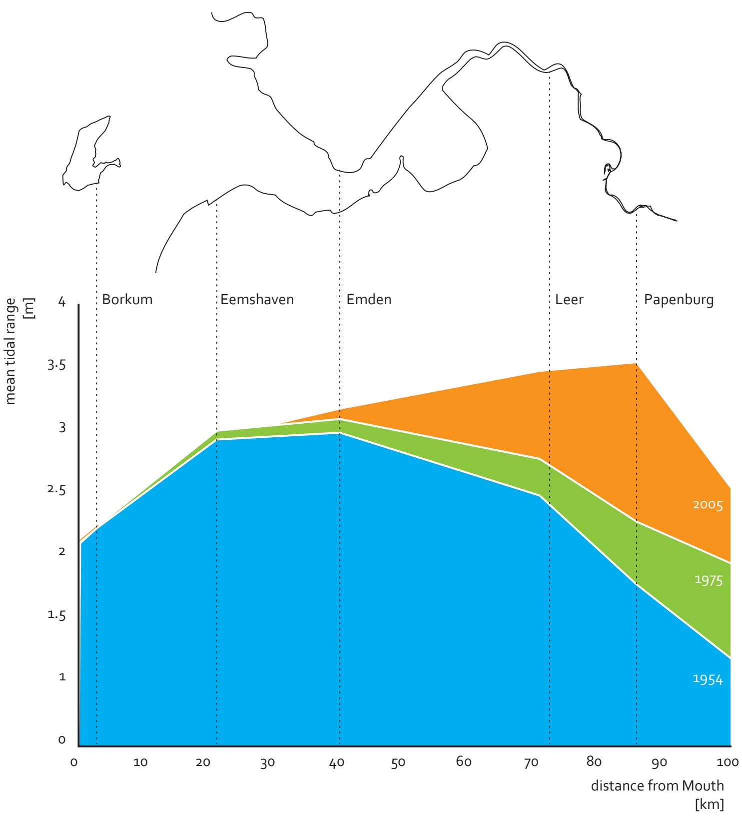


Figure 3.6 | Tidal range in the Ems-estuary. The tidal range has another course due to human interventions in the estuary.

Meandering

In a natural situation, an estuary is characterized by a multiple channel system where the channels are not straight, but meander; very much in contradiction to the current state. Van Veen described the natural channel system of an estuary by its 'popular tree-like' shape: "The trunk is a wide channel that meanders from the left to the right bank, with branches stretching along the banks. Such branches are called flood channels" (1950). Flood channels (Dutch: vloedscharen) are tidal channels which discharge the water during high tide and are relatively shallow. Ebb channels, on the other hand, are tidal channels which discharge the water during low tide and are relatively deep [figure3.7].

Multiple-channel system

The multiple-channel system has two important roles in the morphological functioning of an estuary:

- Brake the entering flood stream. The meanders and the sills at transition between ebb and flood channel provide a lower flow rate of the flood stream (Firet, 2012).
- Sediment transport. Individual ebb-cannels and flood-cannels form together so called short-circuits, where on one side erodes and on the other grows.

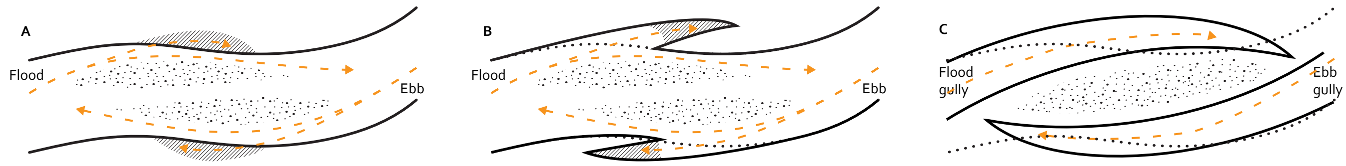


Figure 3.7 | Gully forming processes (based on: Veen, 1950).

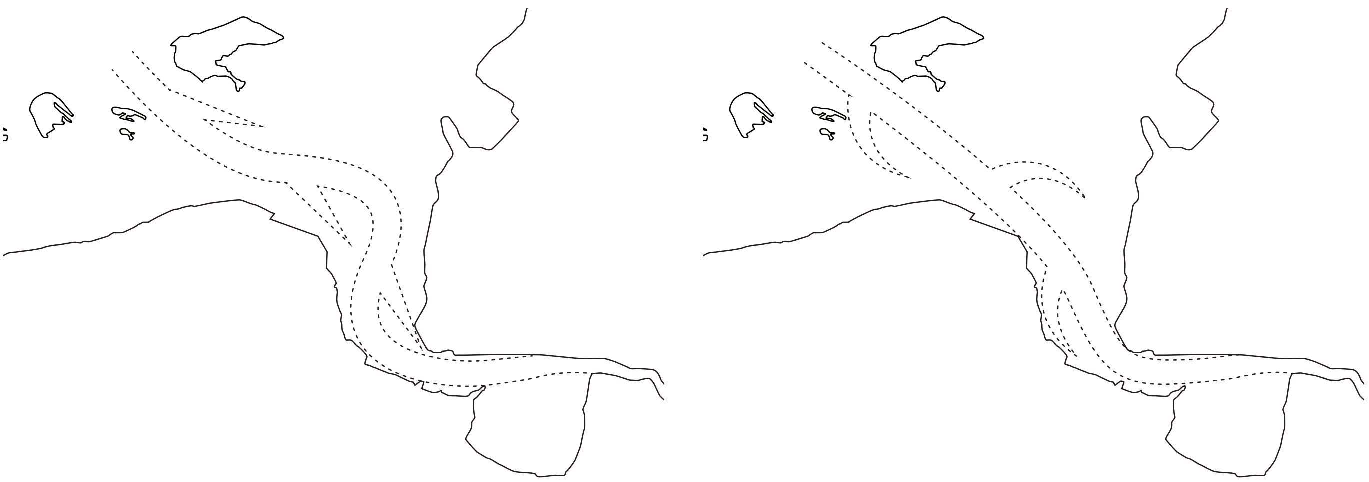


Figure 3.8 | Deformation of the multiple-channel system to a one-channel system (based on: Veen, 1950).

By transforming the multiple-cannel system into a one-cannel system these advantages will fade out, what result in a strong flood stream which takes all the sediment upstream.

A good example of an attractive, meandering, 'popular tree-like', multiple-cannel system is nowadays recognizable in the Scheldt–estuary. A pattern of a meandering trunk shorted by flood-channels is recognizable all the way from the mouth of the estuary till the ports of Antwerp (Veen, 1950). Until recently this pattern was present in the Ems-estuary, but dredging activities forced the Ems into a unnatural one-channel system [figure 3.8], which is as Van Veen describes: very difficult to for every natural channel system of sufficient length has the tendency to split into a multiple channel system. (1950).

One-channel system

Sedimentation

The Wadden Sea, and thereby also the Ems, is subjected to a never ending process of sedimentation and erosion. This dynamic process is, by the many factors that form and influence it, very hard to comprehend exactly and even by the most dedicated scientists still not fully understood (Bos et al., 2012). There are multiple factors determining the level sedimentation, but the basic principle is the following:

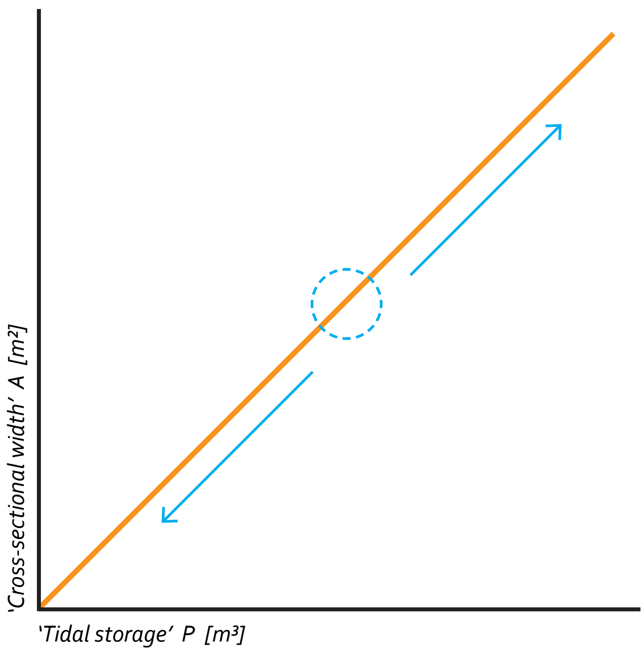
The minimal force that is needed to pick up a particle is always greater than the lowest force that is still able to keep the particle in motion. When the force of the flowing water becomes greater than the downward pull of a particle it is picked up and transported. When the speed drops, the downward pull becomes the strongest and the particle sets down. Heavier particles set down sooner than finer sediment, which has the result that near a gully coarse sediment is deposited and further away clay and silt.

Basic principle of sedimentation and erosion

Relation between the hinterland of the estuary and its depth

In a natural system, erosion and sedimentation are more or less in balance. At places with a high flow rates erosion occurs and at places with a low flow rate sedimentation is predominant. This principle sounds simple enough, but the speed of flows and the volume of water passing an estuary is determined by size and shape of the entire system, thus affecting the level of sediment entering and leaving the sediment cycle. This correlation between the level of erosion and the volume of water passing through the gully during every flood is described by the following equation (Steijn and Adema, 2000, Kemerink, 2004):

$$A=c*P$$

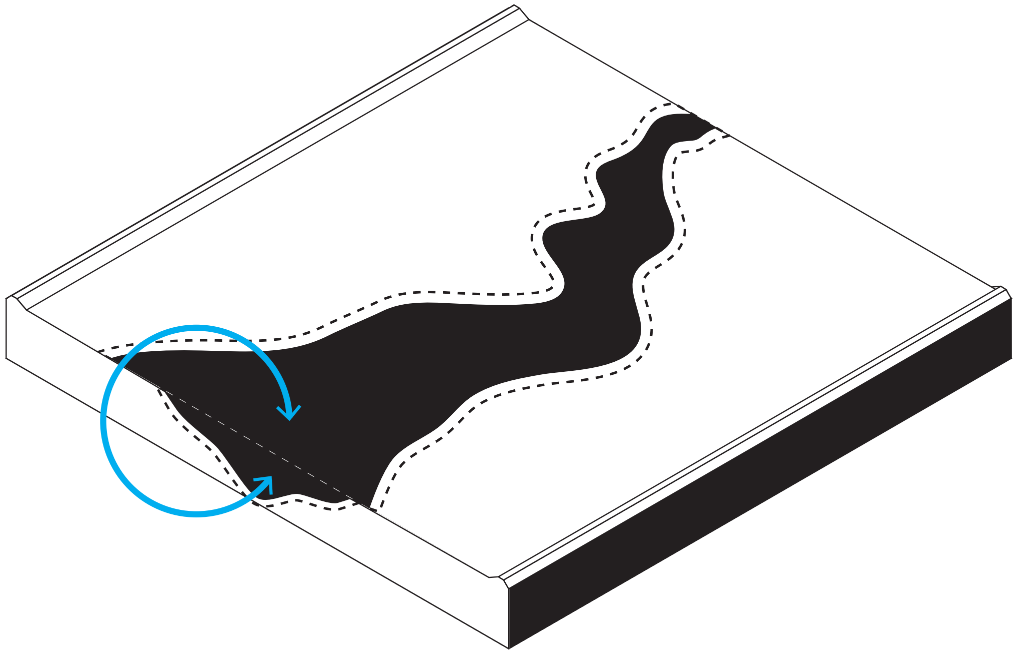


[P] The cross-sectional width of the gully, or the cross-section of the gully in square meters.

[A] The tidal prism of the estuary. The tidal prism stands for the total amount of water passing the gully every flood. The tidal prism is calculated by multiplying the surface of the estuary (tidal basin) with the height difference between flood- and ebb-tide. The result of this calculation is the amount of water [in cubic meters] filling the estuary every flood.

[c] A constant factor which is different for every estuary all over the world, depending on sediment material, tidal strength and other features. The number has the sole purpose of converting the large tidal prism in m3 to the small cross-section in m2, and will not be further used in this thesis.

Figure 3.9 & 3.10 | Relation between the Cross-sectional width of a flood gully and the Tidal storage of the tidal basin.



In practise this relation between the cross-sectional width and the tidal prism means the following:
When the tidal basin of an estuary increases, more water is needed to fill it during the same time, because the flood time in general stays the same. A larger volume of water in the same time means an increase in flow velocity. This increases the level of erosion thus deepening the main gully [figure 3.9]. The inverse is also true. Smaller tidal basin; less water needed to fill; slower flow velocity; more sedimentation with a smaller/shallower gully as result.
The same mechanics can be applied to the cross-sectional width: If the width of gully is narrowed by for example a new bridge, the amount of water able to flow through the gully is reduced; decreasing flow speed; increasing sedimentation and filling a smaller tidal basin (Steijn & Adema, 2000)(Kiezebrink et al., 1996).

3.2.4 Processes and time

The different processes that take place in an estuary can be distinguished on five different levels of space and time [figure 3.11]. The largest scale is the estuary as a whole, morphological changes on this level can take centuries to complete. The medial scale consists of gullies or flats on which changes can be seen in the time span of decades. The smallest scale consists of even smaller entities such as puddles of water or ripples of sand that change every tide (Steijn, 2002).

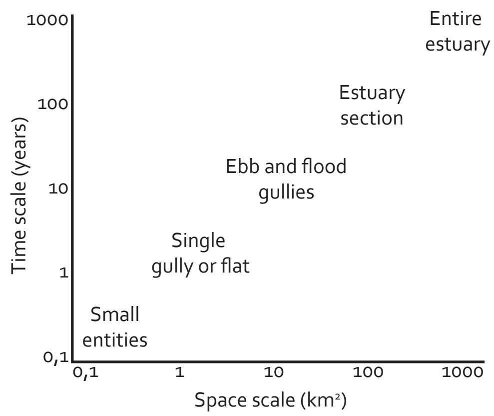


Figure 3.11 | The interconnectedness of scale and time within an estuary (based on: Steijn, 2002).

This interconnectedness between the scale in space and time is important to realise for it means that when a natural system is thrown out of balance, either by human or natural causes, there is a given time for when the system restores this balance or finds a new balance (Steijn, 2002). The engineered Dutch landscape is full of examples, which illustrate this slow processes of natural recovery (Vroom, 1989 and Allersma, 1993 and Steijn, 2001 in Steijn, 2002):

- After the construction of the Haringvlietdam it took 11 years for the outer delta of the Haringvliet to recover (120 km2).
- With the closing of the Lauwersmeer, it took 17 years for the Zoutkamperlaag (gully in front of the Lauwersmeer) to come to a new balance (200 km2 after closure).
- And it took 32 years for the Zeegat of Texel (gully between Texel and Den Helder) to come to a new balance after the construction of the Afsluitdijk (tidal basin of 680 km2).

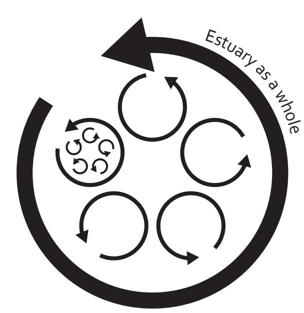


Figure 3.12 | Development on different scale levels within an estuary. Each level has its own dynamic balance and is influenced by higher scale levels (based on: Steijn, 2002).

This research thus confirms the theory that there is interconnectedness between time and area of effect. Secondly if this change occurs on high level (as described by Steijn, 2002), then this will also have a response on lower levels [figure 3.12]. The largest circle stands for the morphological effects taking place in the entire estuary, the smaller circles stand for changes in gullies or flats and the smaller circles for even lower levels. A given rule is that changes occurring on lower levels do not affect higher levels and higher levels set the preconditions or trend for the smaller scale (Steijn, 2002). An observable effect could thus be directly caused on a certain scale, but it could also be caused by changes on a higher scale. For example, local dumping of dredge could cause turbid water, but it could also be caused by the disruption of a gully on a larger scale.

3.3 The estuarine functions

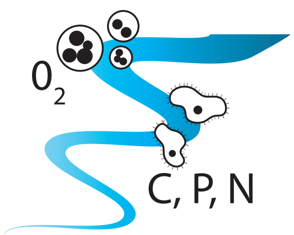
3.3.1 The ecological functions of an estuary

The morphological and hydrological processes form the conditions for the ecological functioning of the estuary. These processes differ largely, thereby creating a wide variety of characterises. There are nevertheless a number of primary ecological functions noticeable, which are present in almost every estuary. These can be divided into four primary functions (Based on: Firet, 2012, Bos et al., 2012):

4 most characteristic ecological functions of an estuary

- Primary production
- Diversity in habitat
- Nursery ground
- Migration pathway

Primary production



The most important function of an estuary is its primary production. This is the processing of waste materials and the production of the basic elements that forms the base of the food pyramid [figure 3.14]. The main cause for this large primary production is the sweet-salt connection. Because an estuary is a passageway from the mainland to the sea, nutrients and waste materials from both sides converge, forming a larger food source. When oxygen is added, bacteria break these materials down to basic chemicals (Firet, 2012). The oxygen that the bacteria need is produced by algae, which in return use the carbon provided by the bacteria and the sunlight that falls on the surface [figure 3.13]. These micro-organisms are hence eaten by larger animals such as mussels and fish and thus make it possible for larger animals such as the avocet (kluut) and the seal to live in an estuary.
The largest part of the primary production takes place in the mouth of an estuary. It is rich in nutrients and has a high ratio of shallow mud flats, which provide living ground for micro-organisms and are well lit by the sun. The predominantly sweet tidal river has a relative low primary production and can be neglected when looking at the estuary as a whole (Bos et al., 2012). The middle section has a relatively low primary production. This is the brackish mix zone and is characterized by a high turbid zone, blocking sunlight and thereby troubling food and oxygen production by algae (Firet, 2012).

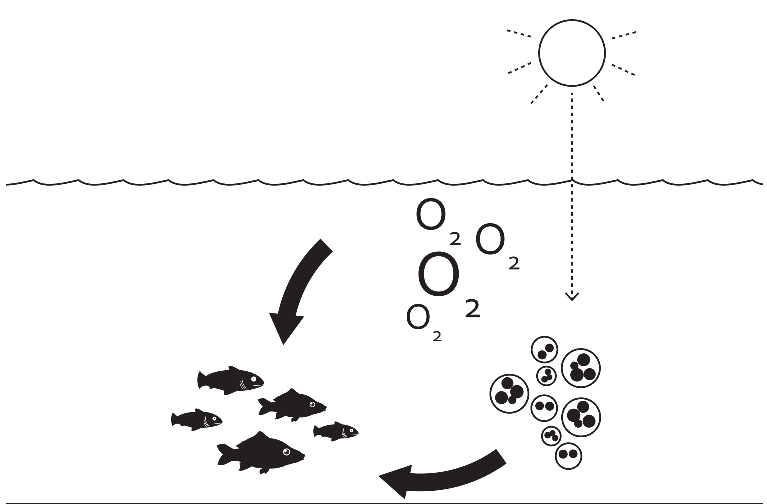


Figure 3.13 | Primary production Sunlight penatrates the water and motivates phoyosynthesis, algea growth, bacteria developent and oxygen production. This forms the base of the food pyramid for an estuarine system.

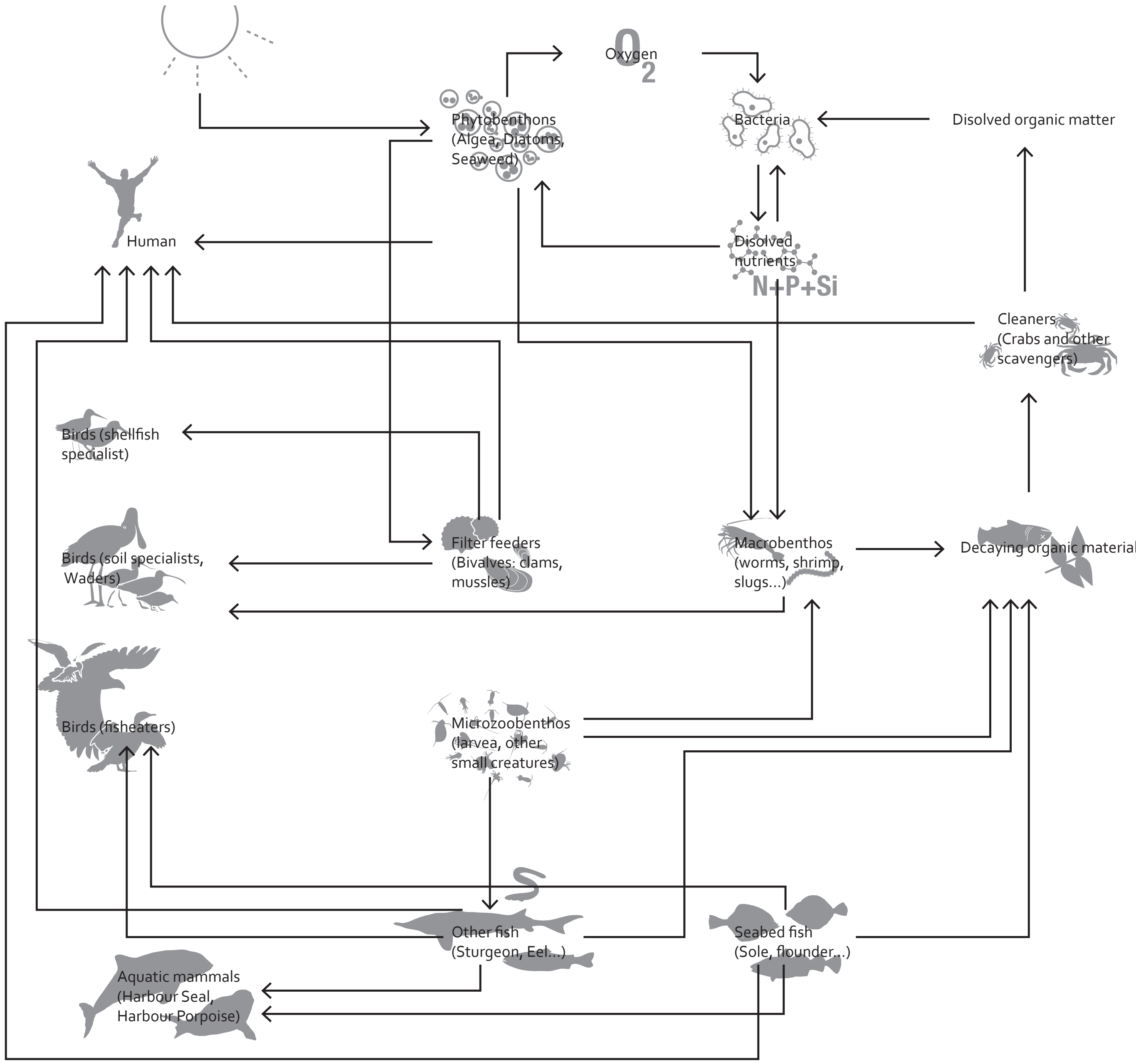
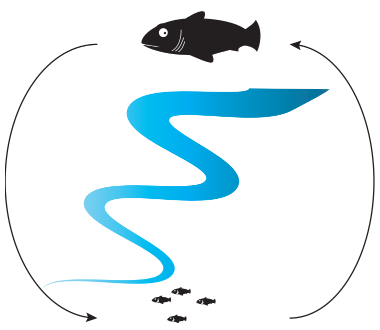


Figure 3.14 | The foodweb of an estuary (based on Groven & Officer, 2009

Diversity in habitats

Due to the existing morphological and hydrological processes the estuary becomes a varied ecosystem with numerous transitions like; fresh-salt, wet-dry, high-low and turbulent-calm. The high diversity in transitions enables a mosaic of marine and brackish ecotypes, with gullies and creeks, literal and sub-literal sandbanks and mudflats, mussel beds, seagrass fields and many others [figure 3.15]. This diversity in the ecosystem is important for the survival of many species, who spend parts of their life-cycle and daily-cycle in different ecotypes or habitats. The diversity in habitats, and the spatial coherence is therefor essential for the biodiversity and the overall quality and functioning of the ecosystem as a whole.



Nursery landscape

Jager describes a nursery ground "as a restricted ground, where young or juvenile individuals of a specie, spend a part of their life separated from older adult conspecifics" (Jager, 1999). Estuaries are part of the top nursery grounds. Its high primary production provides an ample food base for spawning adults and their juveniles, and because of the low number of predators they form a safe haven. Because of this, nursery grounds are important factors for the existence of fish in the Wadden Sea, which makes the estuaries of unparalleled importance for the functioning of ecosystems on a larger scale (Jager, 1999).

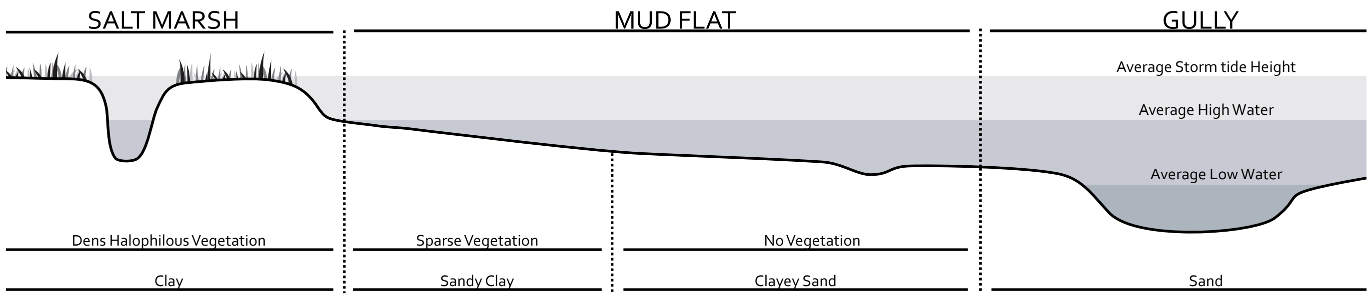


Figure 3.15 | A mosaïc of different ecotopes

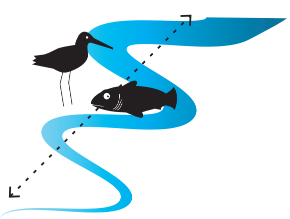
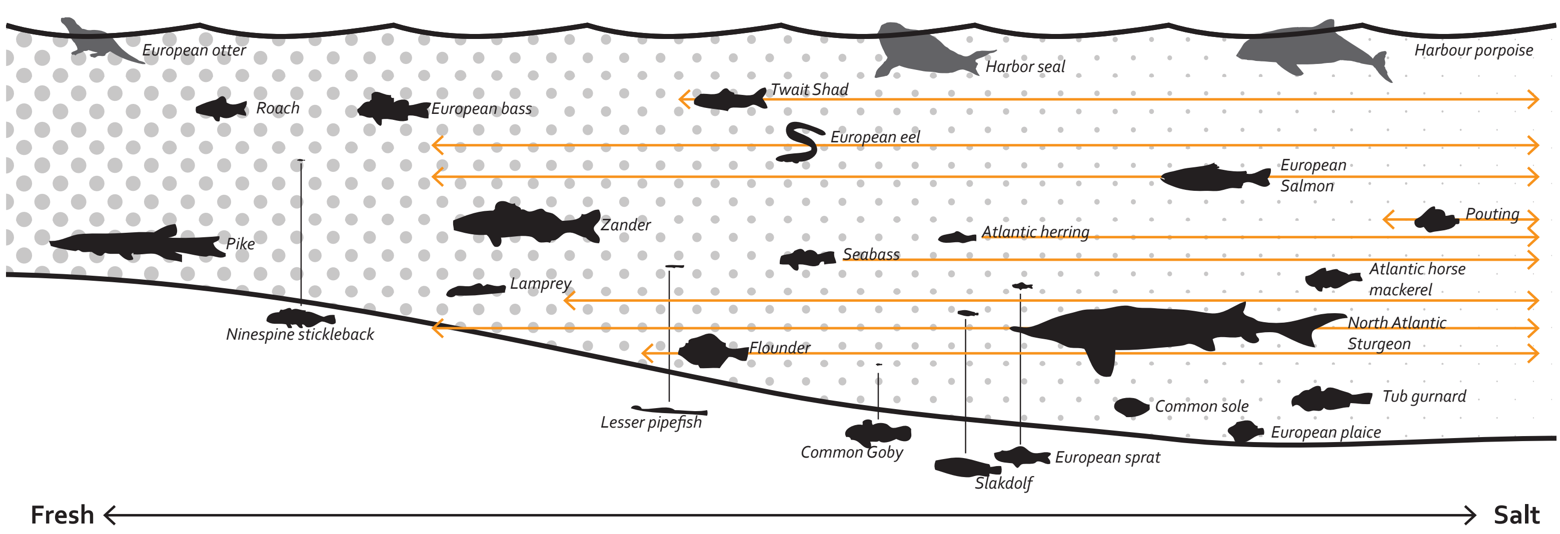


Figure 3.16 | The estuary as hotstpot and migration route for fish. Fish migrate from sea to the river or vise versa for breeding purposes, thereby attracting other fish or top predators such as the otter, seal or porpoise.

Migration ground

The open connection between sea and river is an important estuarine condition for the migration of so called diadromous fish species, which use the estuary as migration routes to their nursery ground. Well known examples are eel and flounder, which spawn at the sea and mature in fresh water (catadrome fish species), and salmon, sturgeon and lamprey, which spawn in the river and grow up at sea (anadromous fish species). These connections have to remain open, for fish need to be able to fulfil their lifecycles and they need to be gradual, to prevent shock and diseases. The presence of these fish is a good indicator for the health of an estuary for it may be assumed that most of the characteristic diadromous fish species are present in an ecologically good functioning estuary (Bos et al., 2012).

Because of their rich variety and abundance of food (and fish), estuaries are also highly attractive for birds and form important stops along the East-Atlantic Flyway. The Wadden Sea and its estuaries attract up to 12 million birds every year, and reaching up to 40 species in the Ems-Dollard alone (Bos et al., 2012, Leeuw, 2006).



3.3.2 The economic significance of estuaries

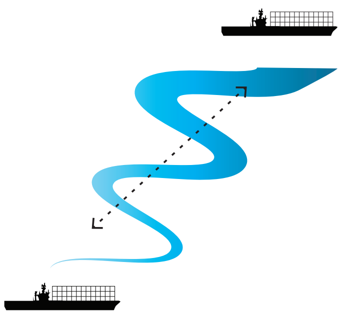
The Wadden Sea region is most known for its ecological qualities and is, besides a large touristic sector, of little economic importance. The estuaries, which form the interruptions in the shallow sea, are an exception, and are junctions for economic and industrial development. Its nutritious grounds and waters, and its strategic location for global trade and manufacturing industries, make estuaries into the most valuable areas of the world (Constanze, et al, 1997 in: Groven and Officer, 2008). Its value can be divided into three functions:

- Food production and exploitation
- Transport route and passageway
- Industry node

Food production and exploitation

A large part of its current and historic value of estuaries is due to the high nutritious conditions, as already explained in the previous paragraph. This does not only result in a high attraction to fish, which in return attract fishermen, harbours and villages. But more profoundly in the richness of the soil. Before the construction of large sea dikes, the land surrounding the estuary flooded several times a year. The sea brought in vast amounts of sediment, which are estuaries are rich in, and deposited them on the land; leading to sea clay soils, high in lime and assumed to be one of the most fertile soils worldwide. Since the 13th century people started to protect the land against these floods and now able to grow crops continuously, able to achieve high yields. Encouraged by these high yield, men started to reclaim more land, increasing revenues even further and leading to prosperous agricultural lands such as the Oldambt in Groningen (Barends et al., 2005, Westerman, 1999).

Figure 3.17 | Endless arable lands and magnificant cloud-scapes are charcteristic for the fertile grounds of the estuary.



Transport route and passageway

The main asset of an estuary is simple: it's a direct connection from sea to the river and its hinterland, and so is a great attraction point to harbours and connected industries. In a period before dredging was widely used, large cargo ships could only reach so far into land, harbours settled at these places to tranship the goods into smaller boats for further up river or over canals. This strategic position turned the estuaries into extremely busy junctions of national and international importance for trading, with big examples such as Hamburg or Rotterdam. Since the beginning of the 20th century most of these industrial estuaries are dredged continuously to maintain and increase the accessibility of the ports for the ever-increasing cargos and other vessels (TIDE, 2010).

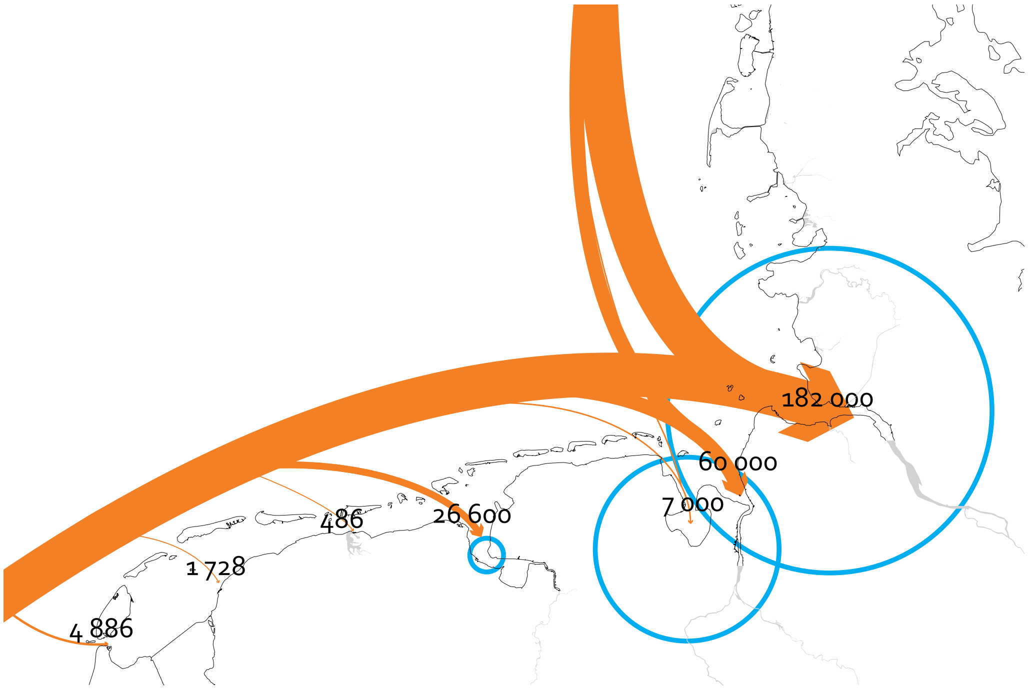
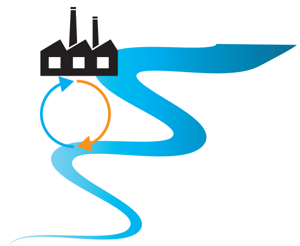


Figure 3.18 | The shipping movements within the Wadden Sea. The Elbe (with the port of Hamburg) receives most trafic; the Ems far less. The blue circles depict the cargo traffic, including ships construction (based on: Cofad, 2009; Destatis, 2011; Groningen Seaports, 2010)

Industry node

The accessibility for large sea freighters and the presence of international important trading junctions turns estuaries into favourable locations for processing and manufacturing industries. It has an immediate access to cheap raw materials and is able to ship products overseas or further inland. The mechanisation added another function: cooling water. Estuaries provide a direct access to large quantities, which can be directly pumped in and out and is continually refreshed and cooled because of natural flows.



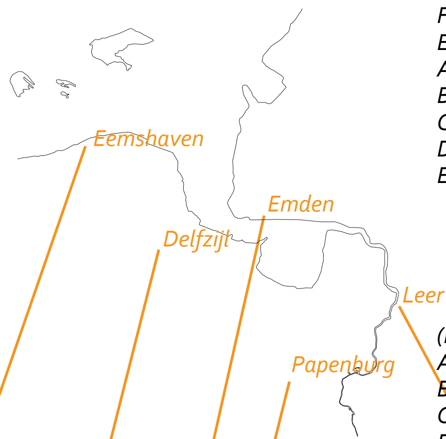


Figure 3.19 A-E | Ports of the Ems
A. Eemshaven- Energy
B. Delfzijl - chemistry, industry
C. Emden - VW, offshore, bulk
D. Leer - Shipping wharfs
E. Papenburg - Cruise industry

(Photos:
A Groningen Seaports
B RWS beeldbank
C commons.wikimedia.org
D kustvaartforum.com)

3.4 The development of the Ems-estuary

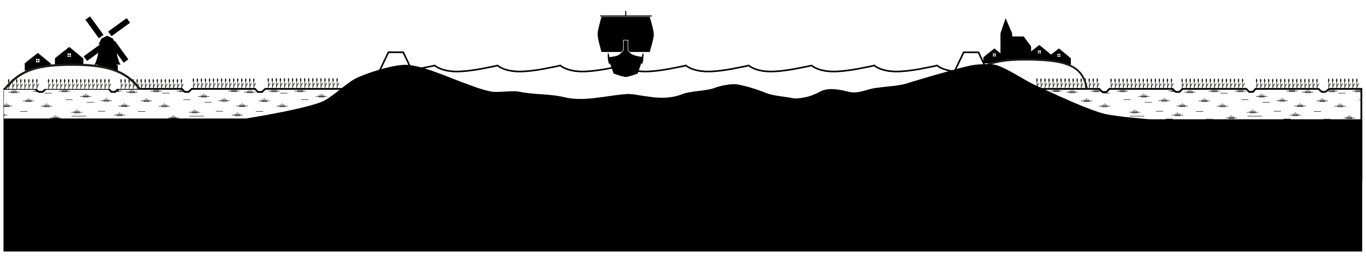
From the above standing statements it could be concluded that indeed estuaries are among the most valuable areas in the world and it could be expected that an estuary like the Ems would flourishes under these conditions. However, the current situation gives another representation. The human drive for economic gain has turned the apparently wealthy Ems-estuary into a dirty and muddy river, which suffers from oxygen deficiency and exponentially growing dredging costs. The coming paragraph will give the answer how the estuarine systems affect the Ems-estuary and how they have resulted in the current problems.

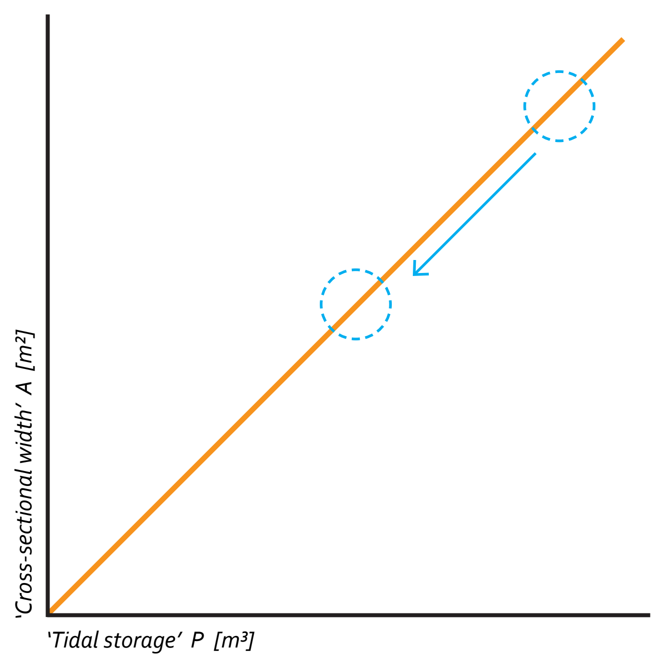
3.4.1 Agricultural expansion: 1100-1930

First inhabitants of the Ems-Dollard region.

For a long time the Ems-Dollard region was to a great extent dependent on agriculture. Being an estuary, the sea would flood the land regularly so people settled on slightly higher sand creek ridges, where they build artificial hills (in Dutch: Wierden or Terpen) to avoid the immediate danger of flooding. They lived of fishing and livestock, but the manner of living changed around the eleventh century. It is then when the people of the north started to construct dikes, in order to not only protect their houses, but also their cattle and crops (Bijhouwer, 1977). This in-diking of land started with smaller plots of land belonging to a single farmer or village, and with low and small

Figure 3.20 | The Ems-estuary around 1300. The natural equilibrium in the estuary has been reduced by diking the shores of the estuary.





summer-dikes. Around 1000 AD the scale of dike building changed significantly. Villages began to work together and small dikes were connected, which in 1200 AD resulted in a fully connected northern sea dike (Barends et al., 2005, Blerck et al., 2008). [figure 3.21] However, this embankment had consequences for the natural equilibrium in the estuary. The reduction of the floodable land meant a reduction of the tidal prism [A], which in turn meant a reduction of the depth or cross-sectional width [P] of the estuary [figure 3.20].

First connected sea dike

Initially these dikes only had a defensive purpose, shielding of high tides. But from the thirteenth century an offensive strategy was taken (Barends et al., 2005). The inhabitants of the Ems-Dollard region gradually started to reclaim the Dollard for arable land. To reclaim this landscape from the sea, they used the dynamics of the Wadden in their advantage. In front of the old dike, small dams were built out of poles and branches. The sea then flooded the dams and left its sediment. After some years the land was silted high enough and a new dike was constructed. This process repeated itself several times and thus formed a layered landscape of parallel dikes [figure 3.20]. This resulted in a landscape of layers, with layers of arable land of around 2 km and a new dike that separates them from each other.

From defence to offence

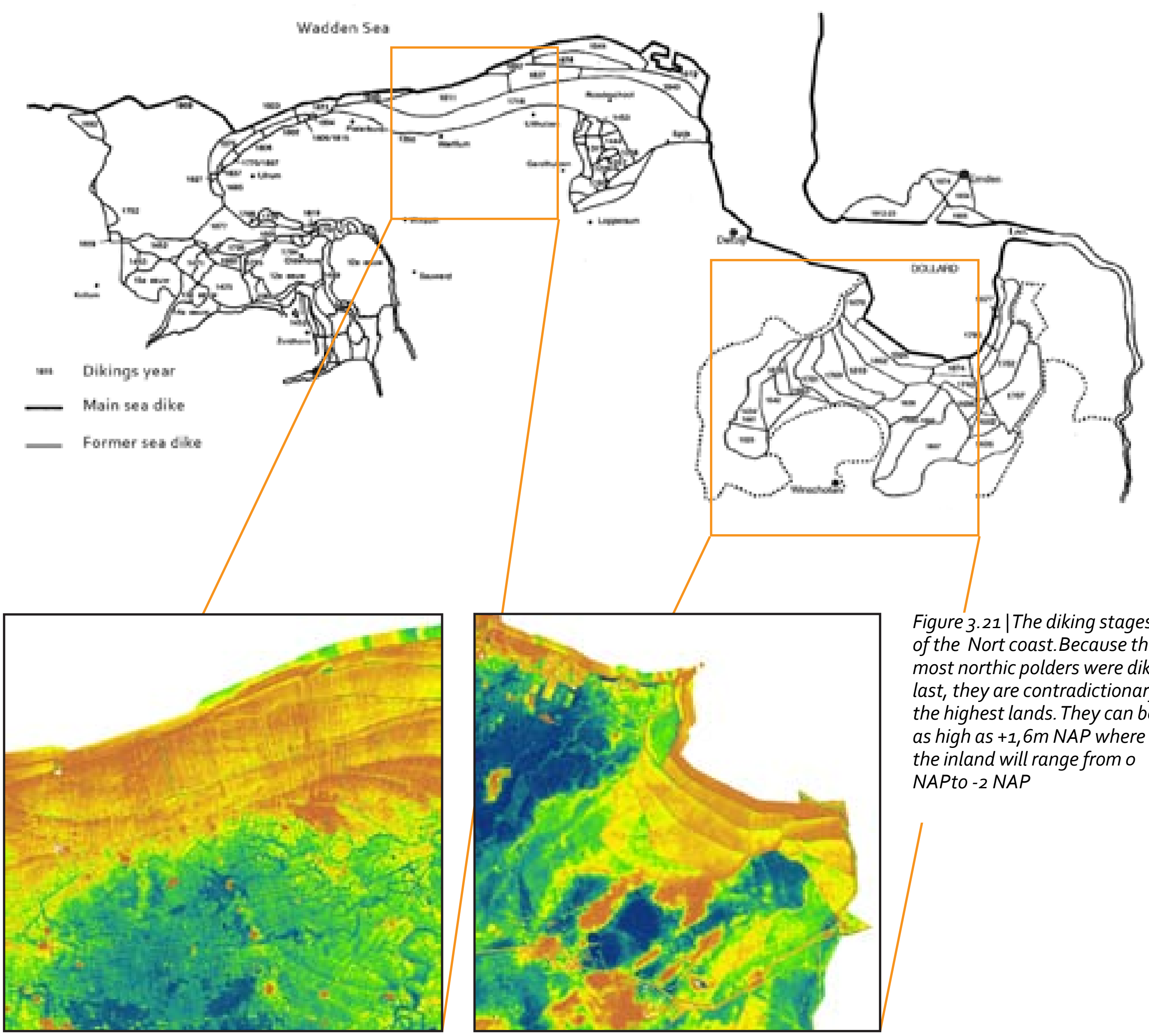


Figure 3.21 | The diking stages of the Nort coast. Because the most northic polders were diked last, they are contradictionary the highest lands. They can be as high as +1,6m NAP where the inland will range from 0 NAPto -2 NAP

At the fresh fertile Dollard-clay castle-like farms arose owned by rich farmers, which were by far the most important employers of the region. Since 1597, when the first land reclamation took place, approximately 250 square kilometres of land was reclaimed. On one hand this huge land reclamation had important consequences for the natural equilibrium in the estuary. The land reclamations meant a further reduction of the tidal prism and the cross-sectional width for the estuary [figure 3.23]. But above all the land reclamations meant an enormous boost for the economy in the region. Based on the average yield rates and prices of wheat per hectares in 2010, the land reclamations provide a gross profit of 48.8 million euro per year (Productschap akkerbouw, 2011, LEI, 2012).

Figure 3.22 A,B | The rich Oldambt, both in soil as in wealth (photo B: RTV Noord)

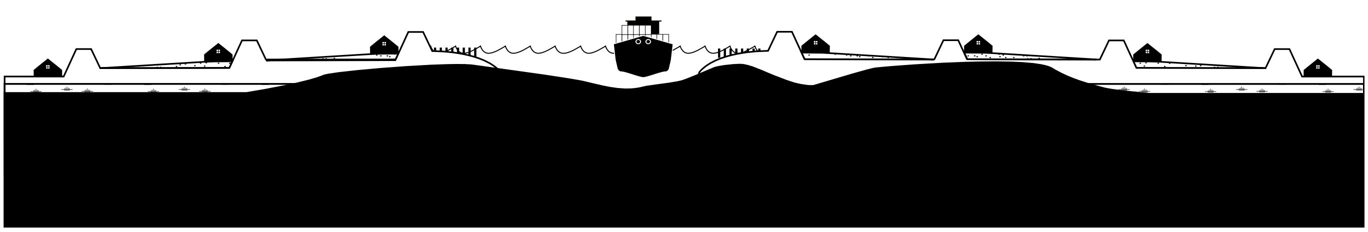
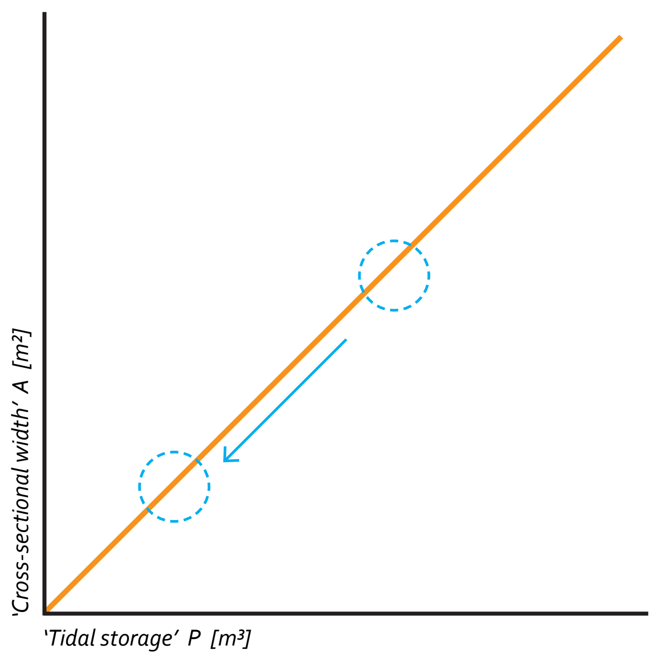


Figure 3.23 | The Ems-estuary around 1900. The natural equilibrium in the estuary has been reduced by large land reclaimation works.



3.4.2 Industrialization: 1930-1970

In 1924 the Carel Coenraad Polder was the last part of the Dollard which was reclaimed for agriculture. New land reclamations, which were initiated in 1937, were stopped in 1953 on advice of the minister of public works (Rijkswaterstaat) (Welle, 1999). The cancelation of the land reclamations is distinctive for the developments in the 20th century. Until the first half of the twentieth century, agriculture was by far the most important employer and source of income for the Ems-Dollard region, but after WWII immense changes occurred. Modernisation and agricultural mechanization provided machines and techniques which could do more work in less time. The farm became a family business again and the staff was forced to move or work elsewhere (Westerman, 1999). The former agriculture employees found new work at the industries. Upstream in Leer and Papenburg settled shipyards, more downstream in Delfzijl, Emden and later on Eemshaven, arose big ports, with large trading and industrial facilities and took over the role as most important employers.

The development of Delfzijl is one of the most characteristic examples of the demographic developments in the Ems-region. After WWII the industrial development in Delfzijl gets a boost after the government decides that Delfzijl is to become the industrial heart of the North. To promote the region, industrials are lured to the region with subsidies and tax cuts and by being somewhat loose in its legislations: "Delfzijl is a unique place. All of the waste water can be dumped right into the Ems" (mayor Roele of Delfzijl in the fifties in: Run and Knol, 2004). This is of course a very dated quote, but it does show the way in which people thought about the Ems, namely as a place for economic use and prosperity; the ecologic importance of the connection to the Wadden Sea was not even considered.

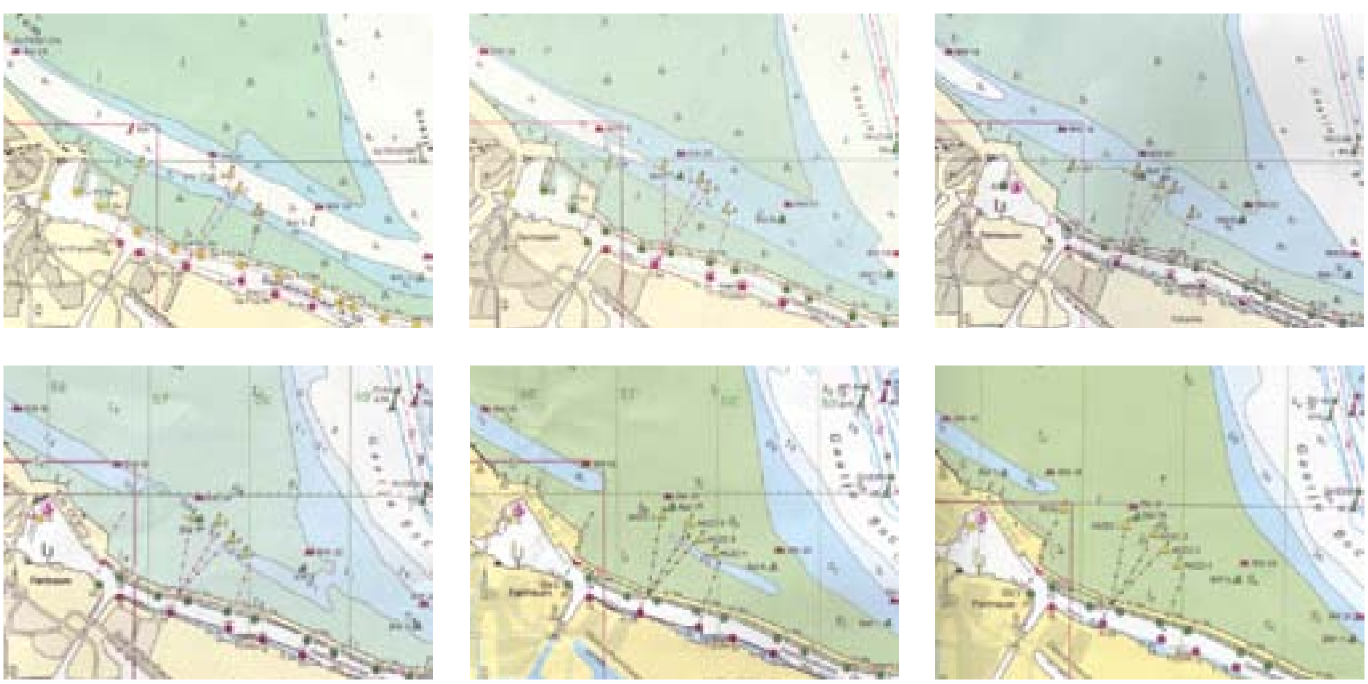


Figure 3.24 | The gradual congestion of the 'Bocht van Watum' in front of Delfzijl from 1986 till 2009. In 1986 the Bocht van Watum was still navigatable for all types of ships. Nowadays the area in fornt of Delfzijl is only accessible for mudflat hikers. (WadgidsenWeb 2.0, 2011)


Figure 3.25


Figure 3.26


Figure 3.27


Figure 3.28 A


Figure 3.28 B


Figure 3.29

Figure 3.25 | The expansion drive of the industry of Delfzijl caused the demolishing of several old wierde villages, this church is standing lonely surrounded by industry.

Figure 3.26 | Oterdum was also demolished for the benefit of the industry of Delfzijl, leaving only the graveyard on the dike.

Figure 3.27 | The demolishing of Oterdum was in vain for most of the grounds have remained barren. The view however would not have been so pleasant.

Figure 3.28 A, B | The style of the new living areas in Delfzijl, grey concrete and now: largely abondend.

Figure 3.29 | The results of the policy of dumping everything in the water. Here dirty industrial water pumped into a canal in Oude Pekela, and from there into the Ems-Dollard (source: Nationaal Archief)

By its proximity to major raw materials like salt, natural gas and process water, a cluster of chemical industries emerged; stimulated and subsidised by national policy. With large companies in Delfzijl such as salt processor AkzoNobel and aluminium processor Aldel (Welle, 1999). Due to this new economy and with the help of the national spatial policy, Delfzijl proceeded to expand, building new large residential areas, most in the typical post-war style: simple, concrete and monotonous. The country had to be rebuild, and not just the cities, but the whole of society. Economical production had to be increased to reach an overall prosperity level for the entire country, Delfzijl included. This modernist belief of make-ability and endless economic growth signifies the beginning of the problems for the Ems-estuary.

The continuing growth of ports and industries instigated a new series of adaptations to the estuarine system. Now not to size of the tidal basin [A], but to the width of gully [P] and the main shipping route. From the beginning of the twentieth century, men started to alter the course of the river by straightening the meanders in the estuary. The first normalizations were initiated in the lower zone of the estuary, where several river bends were cut off and a weir was installed to provide a better passage for the increased shipping down the river. The successes of the normalizations in the river upstream were continued in the mouth and middle zone of the estuary. In 1950, the flood gullies where cut through, thereby removing the meanders and making an end characteristic multiple channel system of the estuary (Veen, 1950). During ebb and flood, the water now flows through the same channel and the cut-off bends slowly changed into congested death-end gullies [figure 3.24 and figure 3.30].

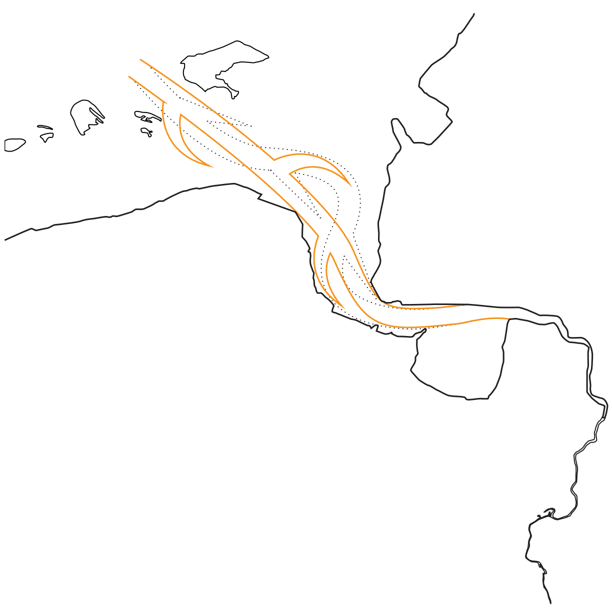


Figure 3.30 | The development of the Ems around 1950. The floodgully were extended and fixated in a straight line by intensive dredging. (Based on: Veen, 1950)

3.4.3 Specialization: 1970-now

Industrial specialization

While the first decades after WWII are characterized by unbridled industrial and economic growth, the seventies and the eighties are characterized by a sharp decline. It results in a stop of the population growth in Ems region and for Delfzijl even turns into a sharp drop (Louter and Eikeren, 2007). It is caused of an overall economic decline with three main features:

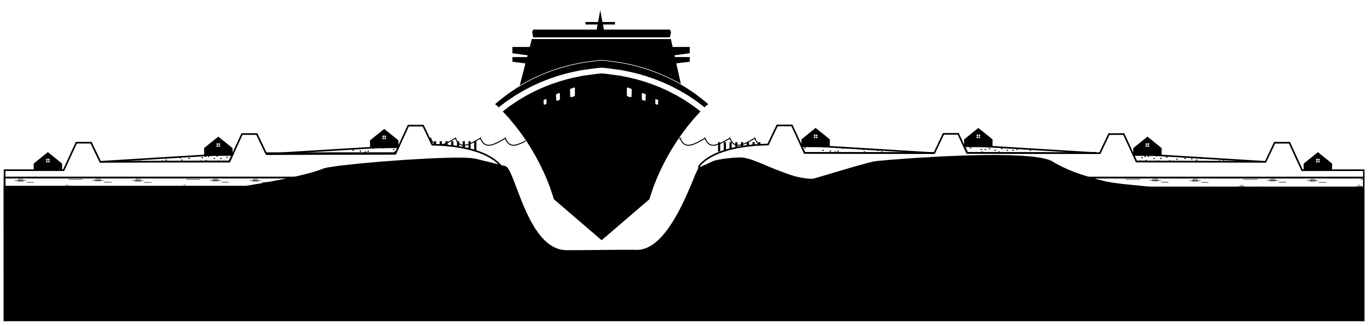
- The oil-crisis in the seventies. New and old investors like AKZO, put their planned developments on hold, which proves disastrous for the new Eemshaven (Knol, 2004).
- On top of that, the main asset of 'unlimited dumping into the Ems' becomes restricted under influence of the rapport 'The limits of growth' by the Club of Rome.
- The final reason for the downfall of the (Dutch) Ems-region was initiated by a change in policy. The Dutch government stopped with their policy of decentralization and cancelled their subsidies for the peripheries (Delken, 2006).

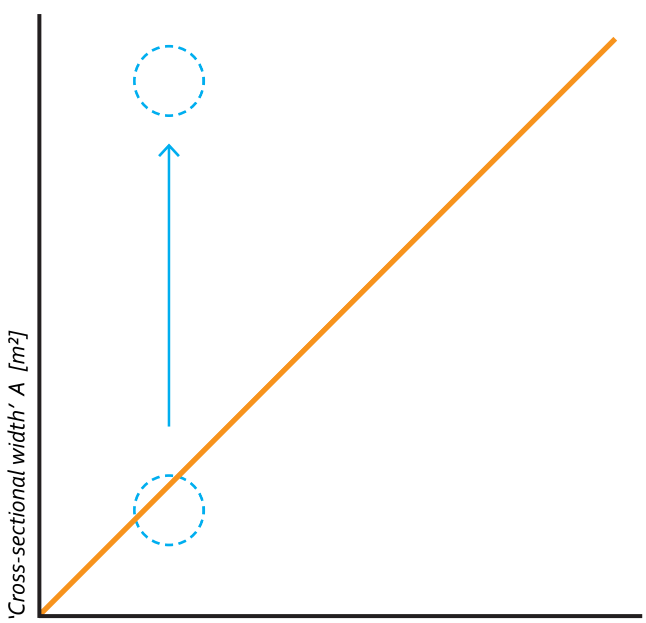
That causes the deathblow for Delfzijl, the most important industry node at the Dutch side of the estuary. Industrial sites are shut down, people move away and the city falls in a declaim, resulting in a shrinkage-prognosis for Delfzijl and surroundings of more than 17% in 2025 (Gemeente Delfzijl, 2009 in: Papenborg, 2012). Both on the German and Dutch side of the border, the Ems-region is now seen as a periphery area, with a declining population and an economy that is originally largely based on agriculture (LancewadPlan, 2007, Noorderbreedte, 1993).

Yet there is hope. Since the beginning of the twenty-first century, the industries of the Ems-estuary changed their focus from common trading and manufacturing, towards the conducting of specialist services and the export of specialist goods. Good example is the rise of Eemshaven. Its renewed focus as energy hub for the Netherlands makes Eemshaven currently the largest construction site in the country (Reformatorisch Dagblad, 2011).

But most iconic for the specialisation of the estuary is the Meyerwerft in Papenburg. 100km upstream in Papenburg, the Meyerwerft shipyard is starting a new specialist profitable business. Since the 1980's the wharf is specialised in the construction of world largest cruise ships for companies like Disney and Holland-America Line. And the future prospective is excellent. Every year the wharf gets more orders and the ordered ships increase in size as well. The construction of the cruise ships means with more than 2.500 employees an important impulse for the employment in the

Figure 3.31 | The Ems-estuary around 1980. The natural system felt out of balance due to unnatural dredging activities.





area. Certainly considering that every job at the Meyerwerft means 5 other jobs in the surrounding (Meyerwerft, 2011). The success of the new found specialisation has however proven to be disastrous for the natural health of the estuary, with a large role played by the growing cruise-ship industry. Until 1980, the relation between the tidal prism and the cross-sectional width of the estuary, was in balance, even though it was heavily adapted [figure 3.23]. However for the main benefit of the cruise-industry this balance was disturbed. Between 1984 and 1985 the upper part of the estuary was significantly deepened up to 5,70 meter [P] and because the estuary was diked, the tidal basin [A] could not grow along, thus creating a misbalance. In 1991 and 1994, the situation was worsened by a further deepening to a minimal of 7,30 meters, bringing the Ems to its current depth and unbalanced state [figure 3.31].

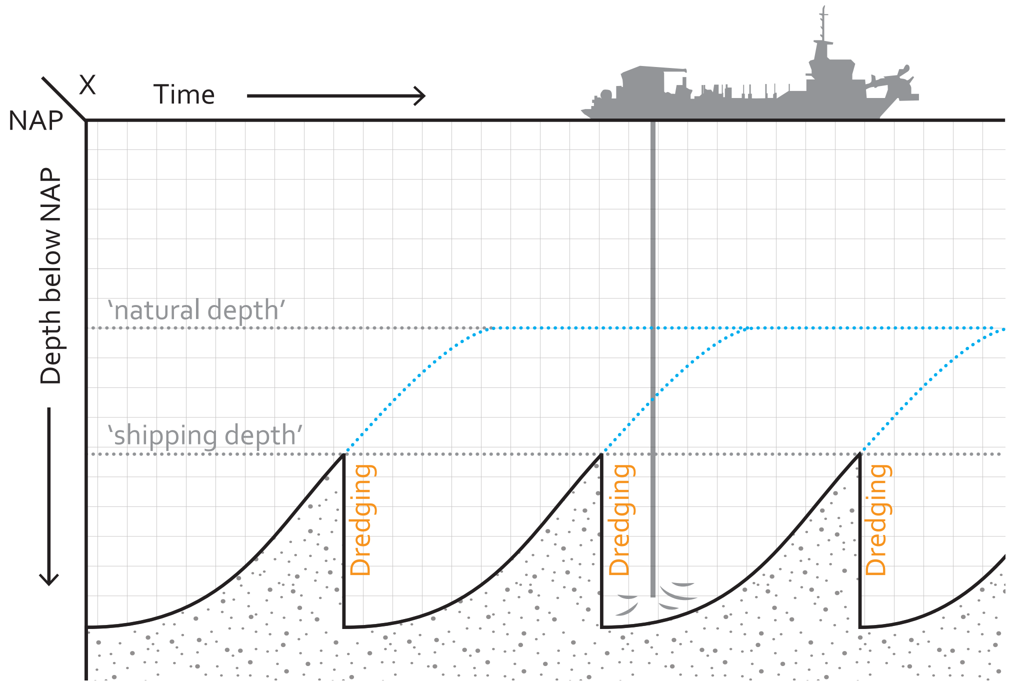


Figure 3.32 | A conceptual representation of the 'depth balance' of an estuary. A natural system moves towards its dynamic natural balance, but this is prevented by dredging procedures. The system again tries to restore itself, but is stopped again.

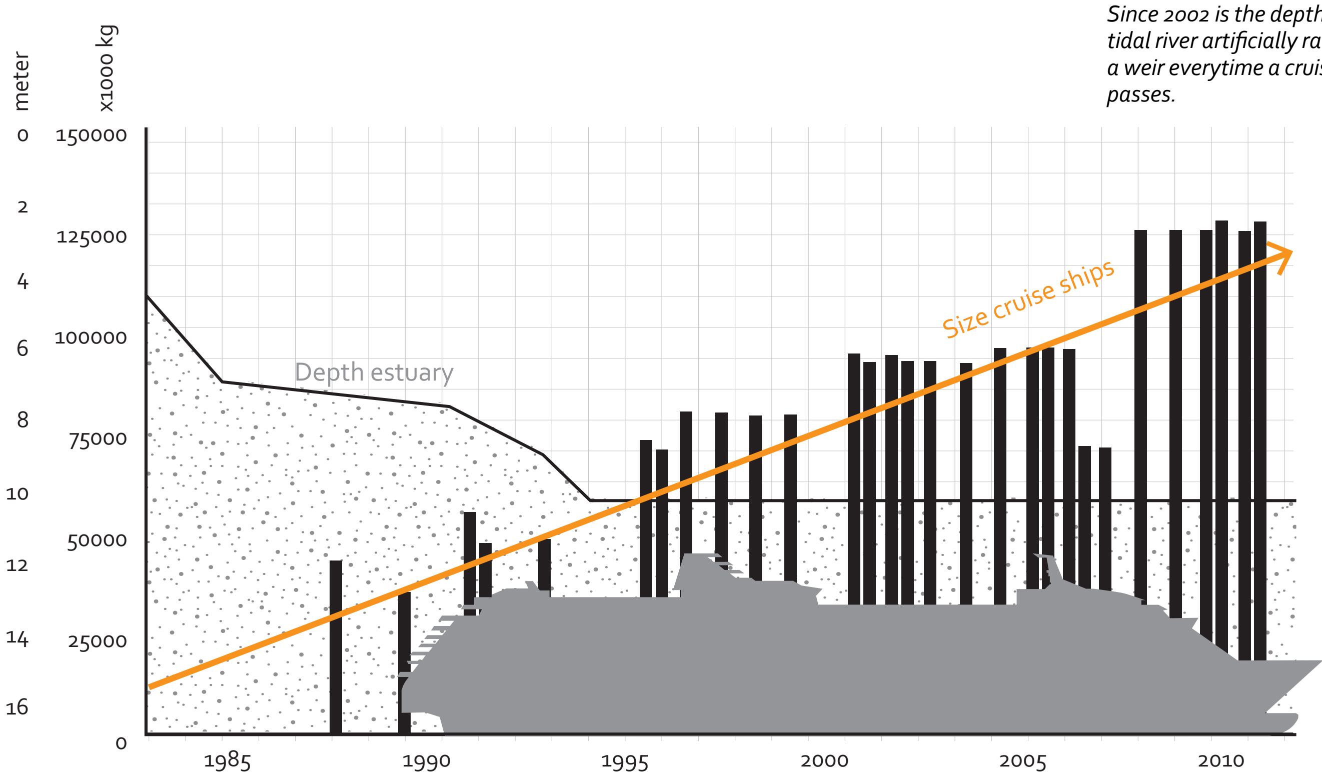


Figure 3.33 | Relation between the increased depth of the estuary and increased size of the cruise ships. (based on: Welle 1999 and Meyerwerft, 2011)

Since 2002 is the depth of the tidal river artificially raised with a weir everytime a cruise ship passes.

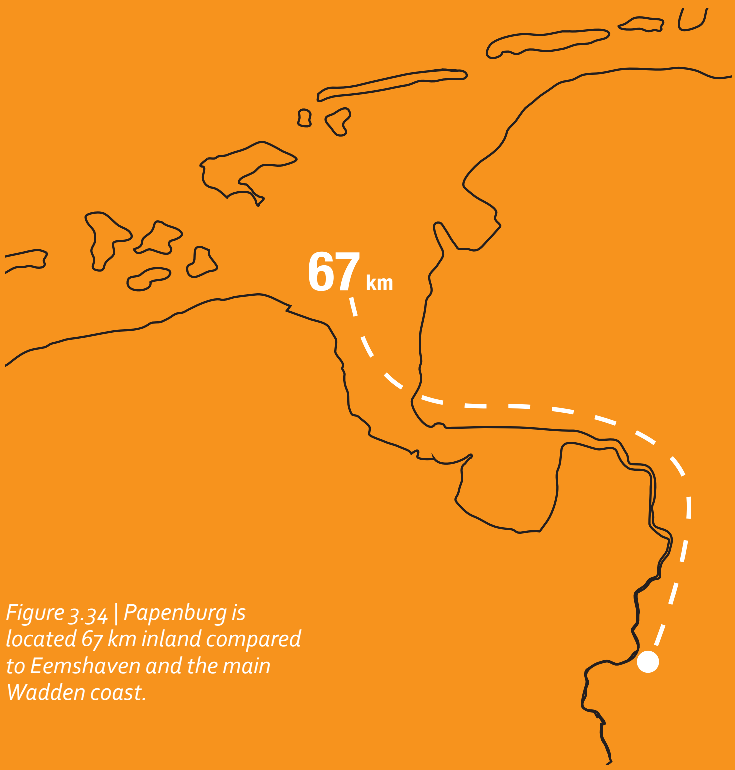


Figure 3.34 | Papenburg is located 67 km inland compared to Eemshaven and the main Wadden coast.

Figure 3.35 | Peat ship as were constructed and used in Papenburg during the 18th and 19th century (photo: schiffbau-papenburg.de)

Figure 3.36 | Cruise ship as are constructed in Papenburg today (photo: shiparade.com)

Intermezzo: The arise of the Meyer Weft

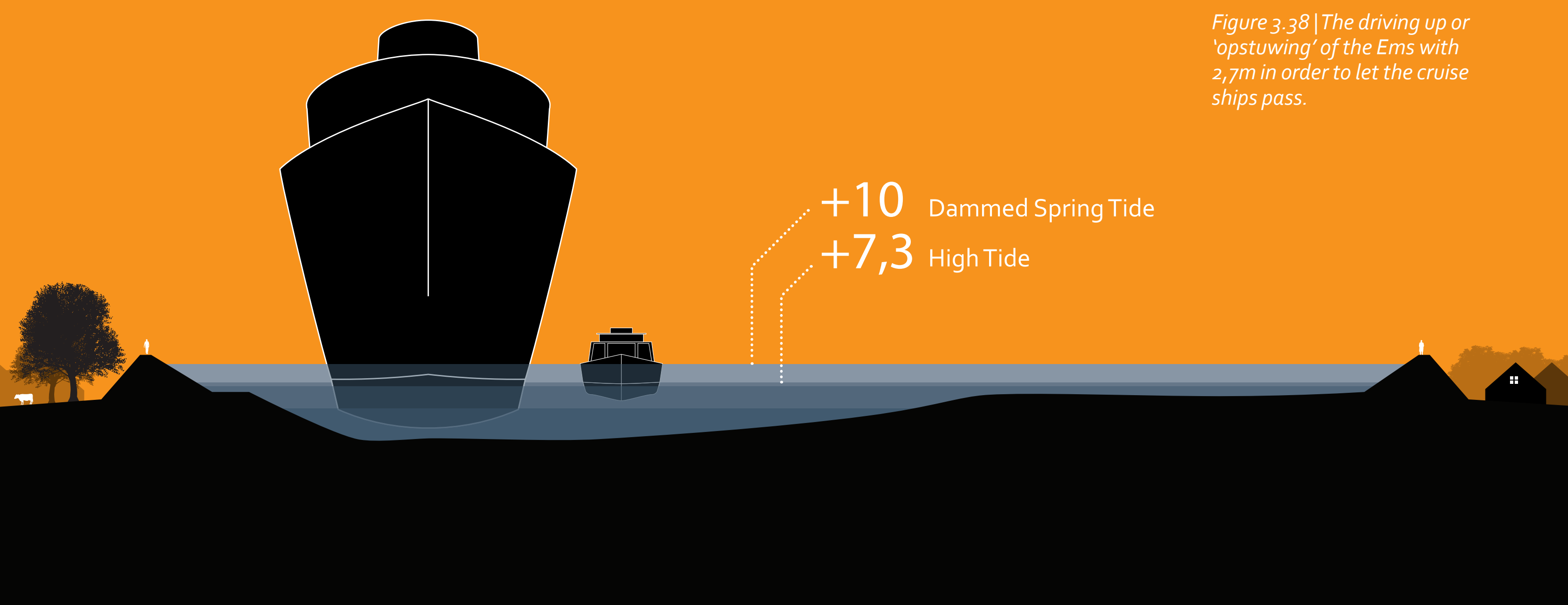
The location of the Meyer Werft is hard to explain. It is the manufacturer of the largest cruise ships in the world but its location is 67 km more inland than the deep-sea harbour Eemshaven. Starting a new large harbour on this location would be folly; large ships with a deep draft could hardly reach it. It is for this reason that Rotterdam (largest harbour of Europe) is expanding towards the sea and not inland. The truth about the Meyer Werft is that it has not started as a cruise ship manufacturer, but it has grown into one.

As its inland position is confusing, the surrounding landscape of Papenburg is clarifying. It lies between higher sand ground in the south and the higher seacoast to the north and with the overflowing Ems as supplier; it is a perfect growing condition for peat. When people first established in the region they lived on the higher soils and only used the peat soils as meadows. With improved techniques they later on began to use the peat soil for crops and on a small-scale used the peat for heating. At the end of the eighteenth century, there comes a change in this small-scale approach. After Dutch example they started to excavate the peat on an industrial scale. Ditches were dug to harvest the peat and canals were dug to transport the peat to the Ems, and from henceforth to Emden or the Ruhr region. For transportation they used wooden boats able to carry around 12 tons of peat [figure x.x] (Schiffbau Papenburg, 2003). The ships were imported from the Netherlands since they already had the knowledge and the shipping yards. As reclamation progressed, the region started to build their own ships, which led to the foundation of 20 shipping yards including the Meyer Werft in 1795 (Meyer Werft, 2011).

Under the competition of coal, the peat market for fuel, collapses and all the shipping yards close down with the exception of the Meyer Werft. This shipping yard was able to survive because of the focus on a new trend: the pleasure boat. In 200 years they transferred from constructing small freighters to building colossal cruise ships reaching up to 340m [figure x.x]. Over the course of time the Ems has been deepened and straightened to allow increasingly larger ships to pass and as a result the Ems now has a minimal depth of 7,3m at high tide until Papenburg (Bos et al., 2012). However from the size and success of these ships rises a problem: they have reached the limit of the Ems and the ships cannot grow any larger. The largest cruise liners have a draft of 8,5m and therefor are 1m short to even float in the river (Meyer Werft, 2011). The solution is simple: just add more water. In 2001 they constructed a tidal embankment, presented as storm surge protection, but mainly for the benefit of the Meyer Werft. During spring tide the embankment is closed off and the river is pushed up with another 2,7m, just enough for a cruise ship to pass [figure x.x] (NLWKN, 2001). This operation takes several days and occurs twice a year when a new ship is finished, it costs several tons and extra dredging is needed to ensure the needed depth. This operation is laborious and would be unneeded if the whole shipping wharf would move to a deep sea location, such as the Eemshaven. The local government however does not want to lose their most important employer (Jonge, 2010), and thus takes every mean to prevent a relocation.

Figure 3.37 | The size of the largest Meyer Werft ship 'The Disney Dream' in comparison with other famous cruise ships and other vehicles.

Figure 3.38 | The driving up or 'opstuwing' of the Ems with 2,7m in order to let the cruise ships pass.



3.5 Conclusion: A troubled system

Over the centuries, economic growth has caused major changes in the natural system and until the eighties, the resilience of natural estuarine system could still absorb the human interventions and move towards a new equilibrium. But from 1980 on, the interventions had a devastating effect on the natural system and continuous dredging activities prevent the system from finding a new balance. The system however always tends to move towards an equilibrium state and thus, at every flood, the natural system imports huge amounts of sediment to reduce the artificial depth of the estuary (Steijn, 2012). This accelerated sedimentation is in return disadvantageous for the large industries who want to sustain the accessibility for large (cruise) ships. The sediment is therefor dredged or kept in suspension to prevent particles from settling down. But because of the created asymmetrical tidal curve [see paragraph 3.2], the low tide is unable to export the excess sediment out of the system. This not only means the sediment cannot leave the system, but more sediment comes in every day and is being whirled around by dredgers 24/7, thus ever increasing the amount of suspended matter in the estuary.

A side effect of this, is the formation of a fluid mud layer of several meters thick located in the tidal river (Talke and Swart, 2005). The mud layer lies on top of the river floor, smoothening it and reducing sedimentation. It acts like a layer of paint, which is unable to solidify because it is kept constantly in motion by the tides and dredgers that stir the layer with oxygen, rather than removing it (Talke and Swart, 2005).

The increased amount of sediment in the estuary is not only disadvantageous for the industries along the estuary, which have to deal with rising dredging costs up to 27 million euro a year (Talke and Swart, 2005), but also has dramatic consequences for the ecological functions of the estuary. Primarily for the level of primary production, the most important function of an estuary. With the presence of the critical factors, sunlight and nutrients, phytoplankton and other microbes produce high amounts of oxygen and food, making it possible for larger organisms to survive (Bos et al., 2012) [figure 3.39 I].

However in the current situation, the increased amount of suspended matter decreases the light permeability of the water. This decreased light permeability causes in turn a decrease of primary producers and oxygen production [figure 3.39 II].

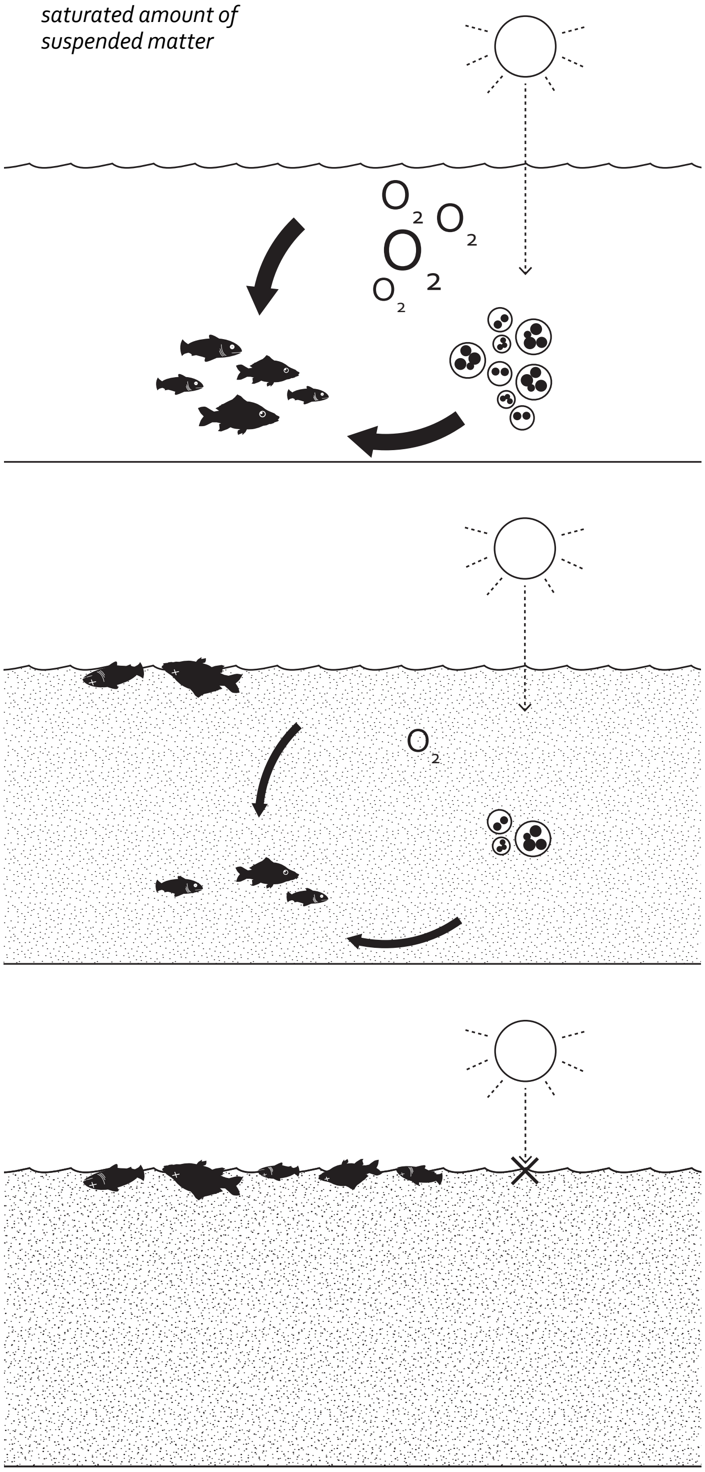


Figure 3.39 | The relation between primary production and the amount of suspended matter in the water:

I: Situation with a small amount of suspended matter

II: Situation with high amounts of suspended matter

III: Situation with a saturated amount of suspended matter

After a while the oxygen level reaches a stress level (4 mg/l) and when it reaches below the critical level (1,5 mg/l) fish are unable live within the system, a point the Ems already reaches regularly (Bos et al., 2012) [figure 3.39 III]

Nowadays, the signs of an ecological disaster are clearly present in the estuary. The increased turbidity, has caused a decrease of the primary production by 50% (Brandtsma, 2011). Which in turn have caused the disappearance or endangerment of seven of the eleven characteristic diadromous fish species in the estuary (Brandtsma, 2011). The normalisation and dredging activities also had a direct effect on the diversity of the estuary: the characteristic estuarine habitat types; tidal flats, shallow depths and salt marshes were respectively reduced with 35%, 42% and 37% (Bos et al., 2012). Most dramatic seems the consequences for some migrating fish species. Where some species have already dissapeared from the estuary, stats show a decline of catchment uptil 90% of the fish species flounder and smelt (Cofad, 2004).

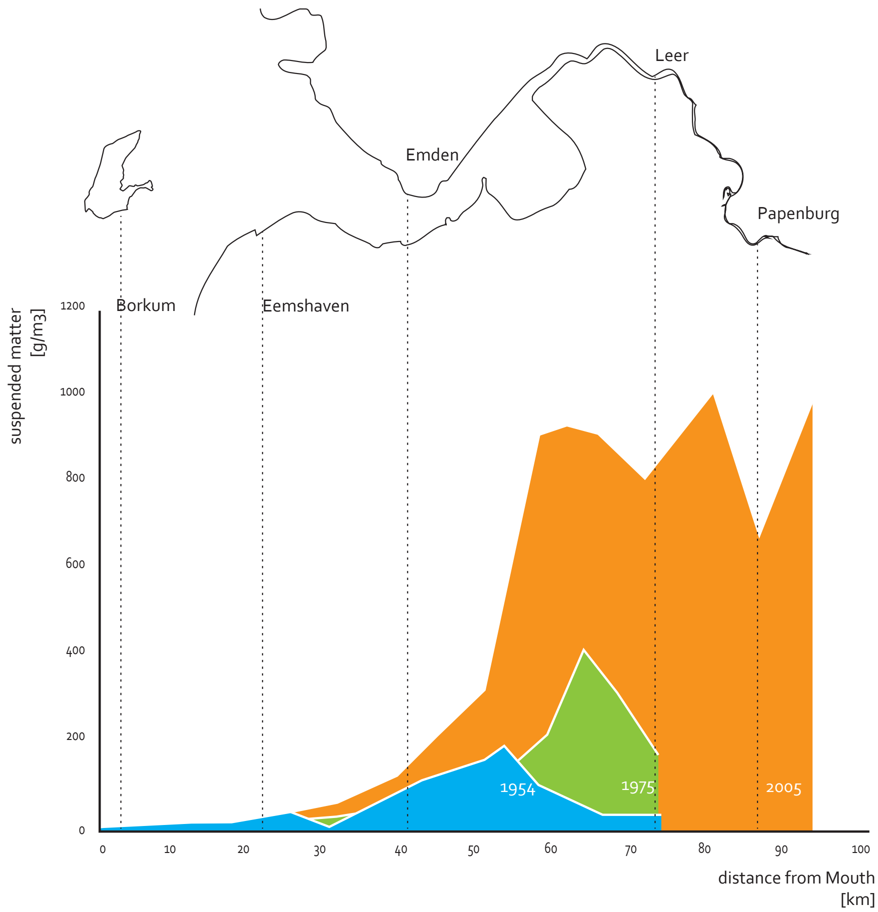


Figure 3.40 | Increased amounts of suspended through the years. Not only the amount of suspended matter incread but also the high turbidity zone, which streches nowadays over a length of more then 30 kilometers. (Based on: Bos et al, 2012)

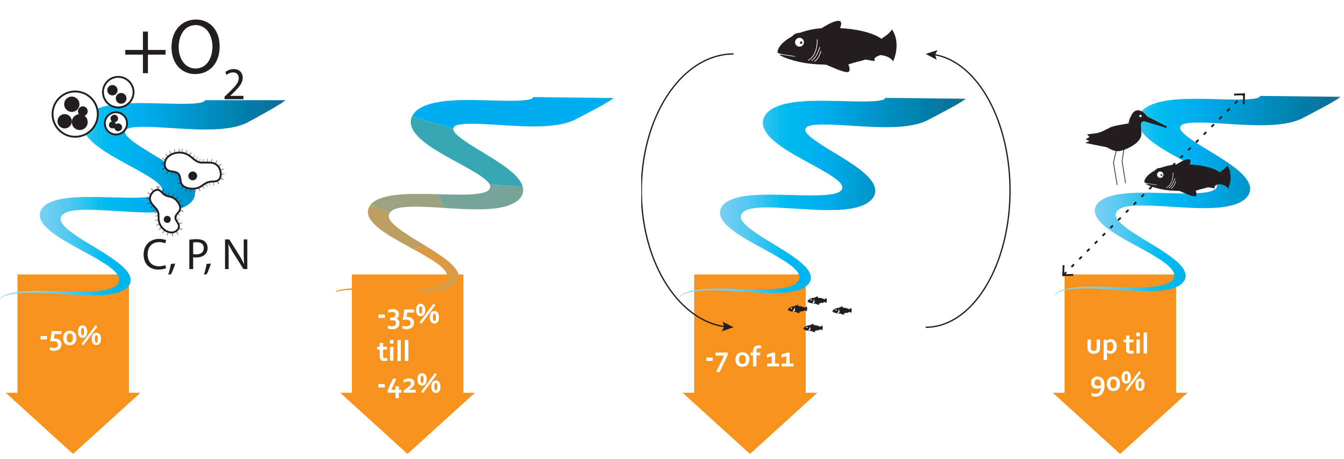


Figure 3.41 | Decrease of the four most important ecological functions of an estuary.

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4

SOLUTION STRATEGY

4.1 Introduction

To this point in the thesis the following has been deduced:
The Ems is dealing with a turbidity problem; large amounts of sediment is continuously pumped into the estuarine system and is unable to settle down because of a high flowing speed and continues dredging. The problem also worsens because the system moves further from its balance, thereby not only damaging the unique ecological functions, but also increasing maintenance costs.
This chapter combines the system knowledge of Chapter 3, with the theoretic statements of Chapter 2. Searching for a growing strategy of problem solving and answering the second research question:

2. How can the estuarine system be changed or steered to avert the current and future turbid challenge?

The end result of this chapter will be a working model that could be applied to the Ems, but also estuaries within a comparable situation, dealing with similar problems. Chapter 5 thus continues from this strategy and adepts it for the specifics of the Ems.
This chapter takes the following steps:

1. Moving towards a new balance and searching for strategies and solutions which could achieve this balance [4.2].
2. Assessing the alternatives and choosing a working model [4.3 & 4.4].

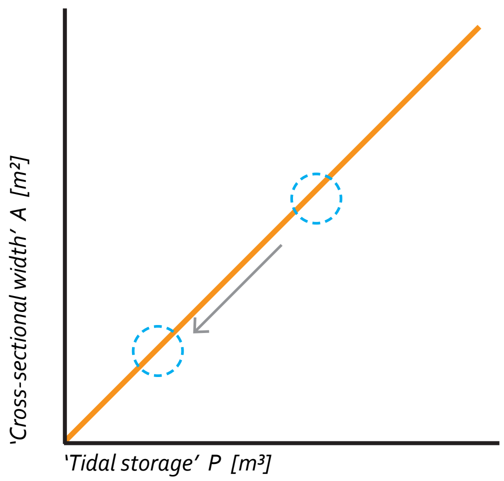
4.2 Finding a new balance

4.2.1 Finding a balance

The balance of a natural system is never stable, and moves constantly in and out of balance (Steijn, 2002) and has the ability to restore itself and find a new balanced state when thrown out of it. The System Analysis has however shown that men has acted against this natural system and continuous to counteract against the finding of a new balance in order to maintain the current economic position. These gradual, but continues interventions have led to a system in dis-balance [figure 4.1]. When reasoning logically, a first rational though would be to cease these harmful adaptions and erase historic interventions. There is however no guaranty that such a recreated historic situation could be maintained by itself. For instance, a recreated two-gully system will most likely move again towards a one-gully system, because the processes guilty of the original shift are still present (Steijn, 2012). Restoring a historic situation would also be unreasonable, for men is largely depended on the current estuarine settings, be it for jobs, food or safety. And even if we were able to dismantle the current system and cancel all dredging and deepening activities, it would be unlikely to restore itself (Jager, 2011).
To restore the system, rather than trying to find an old balance, a new balance must be found, dealing with the historical adaptations. These can be roughly divided into two different directions and periods:

- The first is the long and gradual retrogression of the size of the tidal basin, by damming, closing and diking the landscape from tidal and estuarine influence.
- The second is the relatively quick actions undertaken to deepen the channel, thereby increasing the cross-sectional width.

A new balance can be found by addressing one of these historic changing, while moving towards the estuarine equilibrium and staying true to: A=c*P.
Meaning that if the gully size [A] is maintained, the tidal basin [P] must expand and if the size of the tidal basin [P] is maintained, the gully [A] must decrease in size [figure 4.2].



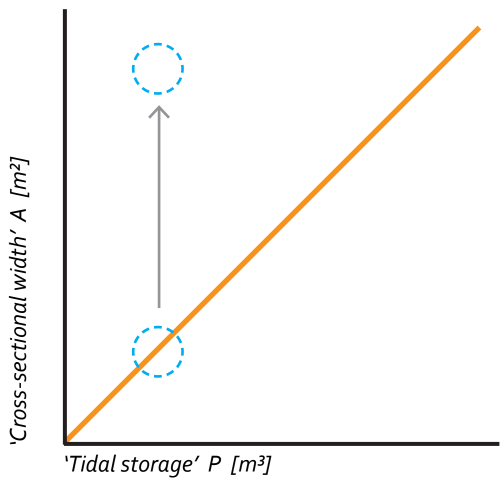


Figure 4.1 A,B | The altered balance of the estuary

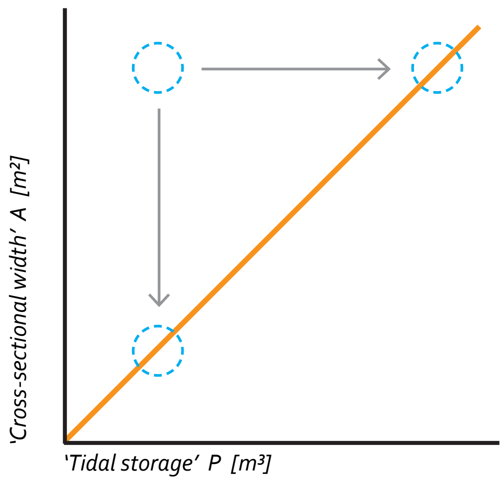


Figure 4.2 | Solution direction Either increase the tidal basin, or decrease the cross-sectional width.

4.2.2 Possible solutions

With a more limited understanding of the system, and before the adaptation of the A=c*P equation, it proved difficult to devise a working solution for the Ems estuary. Suggestions either proved to be: ill-working, not-working or working in a totally different manner than perceived (Steijn, 2012, Winden, 2012). It indeed proved to be a complex and wicked problem.

As a way to overcome the incorporated uncertainty, this thesis has limited itself to the testing of 15 possible strategies. These strategies have been developed by different research teams with the aim of giving a wide scope of possible solutions for the Ems problem (Abrahamse et al., 1974, Schuchardt et al., 2009, Bos et al., 2012, Welle, 1999). This thesis uses these strategies, because they provide a (theoretic) certainty of positive influence on the estuarine system.

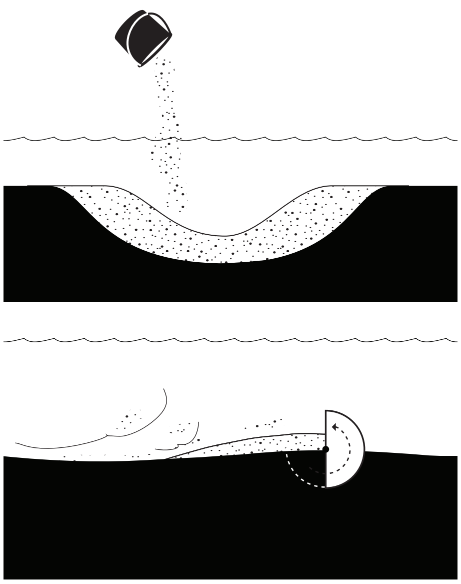


Figure 4.3 A,B | Tidal flow strategy examples. A: Reducing depth waterway; B: Floor barrier

These strategies can be divided into two groups:
- Either reduce the cross-sectional width, thereby reducing the tidal inflow;
- Or increase the tidal basin, thereby giving more space to the tidal pulse.

The strategies are hence divided in the group 'Tidal flow' which focuses on reducing the tidal inflow and the group 'Tidal basin' which largely focuses on increasing the tidal storage:

Tidal flow
- New shallows North Sea
- Closure by dam
- Floor barrier
- Reducing width flood gully
- Barrier between existing barriers
- Vegetation development
- Restoring two-gully system
- Reducing depth waterway

Tidal basin
- Opening summer dike
- Moving winter dike (main dike)
- Deepening foreland (uiterwaarden)
- Tidal polder
- Reconnecting branches
- Moving dam Herbrum
- Canal

A full description, graphic explanation and location of these strategies can be found in the appendix.

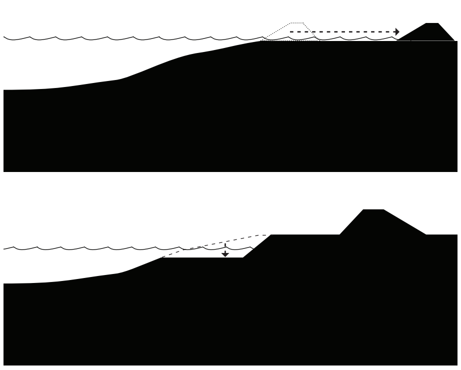


Figure 4.4 A,B | Tidal basin strategy examples. A: Moving winter dike ; B: Deepening foreland

4.2.3 Strategy assessment

On the basis of the publications it can be concluded that all different strategies will have a positive effect on the turbid state in some way. The manner and intensity however varies. To choose the most effective strategy, in general, but more specific for the Ems strategy, all strategies have been assessed on four different points:

1. Solving the turbidity problem (sediment and oxygen production)
2. Towards a new balance
3. Sweet-Salt connection
4. Navigability

Solving the turbidity problem (sediment and oxygen production)

[Assessment acquired from the studies of Bos, et al (2012) and Schuchardt (2009).]
This assessment is acquired in its whole from the above stated sources. These studies remain superficial on the exact quantitative effects on the reduction of sediment levels, but the different options have been graded with a expert review ranking them to relative effect size (Bos et al., 2012) (the experts itself are not named).
The effects and causes of the turbidity problem has been described in detail in Chapter 3. It should be clear that this is the main problem of the Ems and that every solution must address this problem.

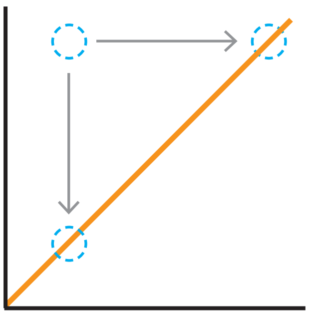


Figure 4.5 | Towards a new balance

Towards a new balance

[Assessment done with educated guesses based on (Winden, 2012, Steijn, 2012, Steijn, 2002).]
The manner of how the problem is to be solved, should logically move towards a new balance. A dynamic system will always search for a equilibrium state; short term adaptations that move away from this state will only generate more maintenance on the long run and will thus not provide a healthy and steady solution.
It is unsure what the exact effects of the different strategies will be, but it is possible to give an indication on which way the equilibrium will move, based on the stated sources above.

Sweet-Salt connection

[Assessment done with educated guesses based on (Bos et al., 2012, Firet, 2012).]
The open sweet-salt connection (as described in Chapter 3) is highly important for the functioning of the Ems estuary in itself, but also for a much larger region. We therefor want to maintain the open connection for the following reasons:

- The importance of a gradual open connection for fauna migration, such as eel and flounder [chapter 3].
- The richness of an estuary, both in ecological sense as in economic sense.
- Open estuaries are scarce, of the 41 Wadden estuaries only 4 remain [figure 3.2] and in the delta renowned Netherlands, only 2 remain. The function that a estuary plays as the basis of the food pyramid and as nursery ground, becomes scarcer and more dependent on the remaining connections. Preserving the ones which are still open, thus becomes more important.
- Closing of estuaries has led to economic progress, but also environmental challenges. These problems have increased to a level that it becomes interesting to reopen the dams again [chapter 1]. The Ems estuary should thus remain an open connection.

Navigability

Within a European perspective, the Ems plays only a minor role within the total mass of freight and number of shipping movements, especially when compared to its Wadden Sea cousins: the Elbe and the Weser [figure 4.6]. But as 3.3 has pointed out, the Ems is a specialty estuary, not focused on bulk and the size of its hinterland, but on specialized goods and its connection to the sea. Industry, the second most important employer in the, is heavily dependent on this connection, with the shipping companies in Leer, Volkswagen in Emden, power in Eemshaven and the cruise industry in Papenburg (Prognos, 2004, Louter and Eikeren, 2007). If this connection is lost or restricted, many of these industries will either have to adept, or more likely move away. A huge potential deficit for an already troubled region [paragraph 3.3].

The Ems must thus stay accessible for industrial shipping between Borkum and Papenburg. Not only for the common freighter, which reaches a draft of 4m, but also for the cruise ships constructed in Papenburg reaching (now) up to 7,5m.

*Figure 4.6 | Port turnover in tons * 1,000 (Based on: Destatis, 2011; Seaports, 2011)*

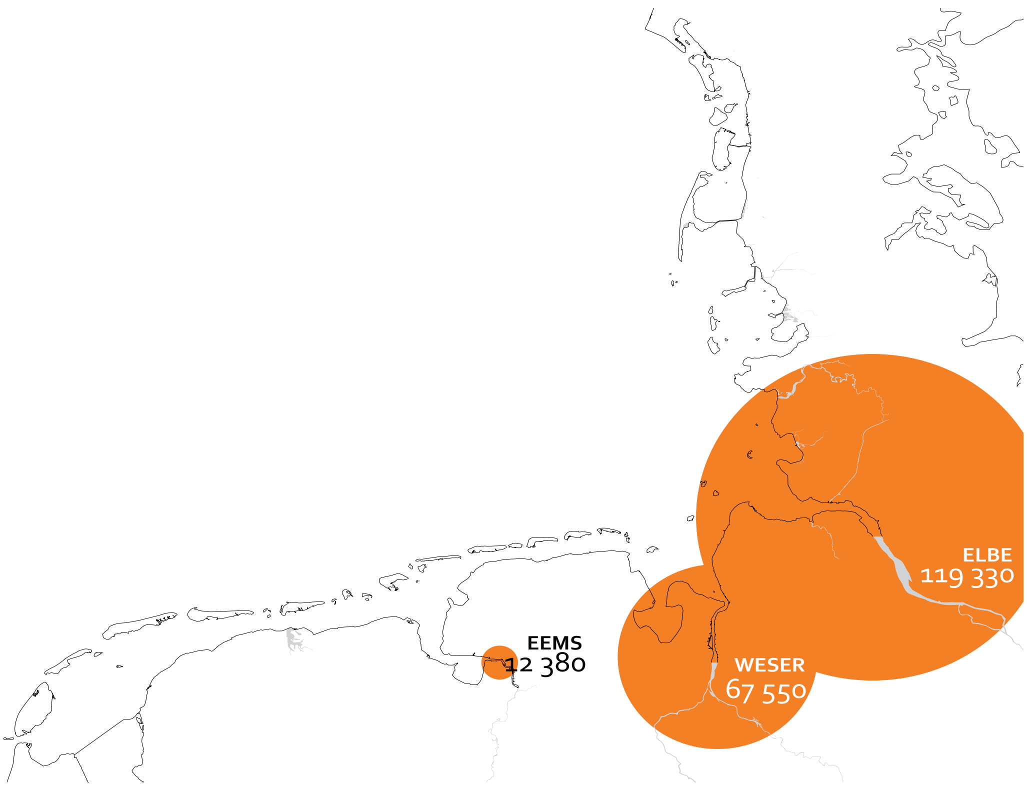
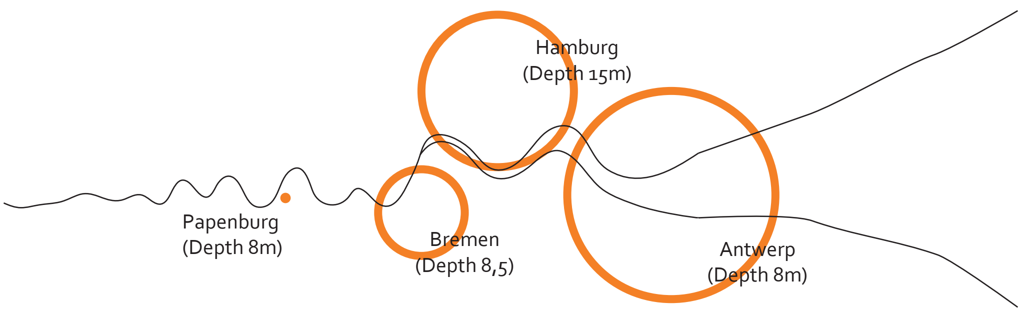


Figure 4.7 | One of the explanations is position of the harbour relative within the size and parts of the estuary. Papenburg and Antwerp have the same depth and are both located around 70 km from the coast line, but Antwerp is almost at the mouth of the estuary and has a much larger potential natural depth.



Assessment table explanation

[Assessment done with educated guesses based on (Winden, 2012, Steijn, 2012, Steijn, 2002).]

With the current knowledge about the turbidity problem, the dynamic system, and the different solutions, this thesis can only give an indication of the relative progress of each strategy. The quantitative effects of each solution would have to be tested in further research.

Strong negative effect	-- or ---
Negative effect	-
No effect	0
Positive effect	+
Strong positive effect	++ or +++

Figure 4.8 | Assessment table for different strategies
The total score indicates the suitabillity of the strategy for the Ems estuary. Light blue indicates suitable solutions, bright blue indicates the best solution within each segment. A full assmentent and description of these strategies can be found in Appendix X.

Tidal flow

	Strategy	In/out of current borders	Region	Reducing/solving dredge problem	Towards estuarine balance	Effect on sweet-salt connection	Effect on navigability	Score	Source
1	New shallows North Sea	Within	Mouth region	+	0	0	0	1	in: Bos et al (2012)
2	Closure by dam (Menkemadam)	Within	Mouth region	++	0	--	-	-1	in: Bos et al (2012); Menkema (2011)
3	Floor barrier	Within	Middle zone/ Tidal river	++	0	0	-	1	in: Bos et al (2012)
4	Reducing width flood gully	Within	Mouth region/ middle zone	++	++	0	0	4	in: Bos et al (2012)
5	Barrier between existing barriers	Within	Tidal river	+	-	-	-	-2	Bos et al (2012); Schuchardt (2009)
6	Vegetation development	Within	Tidal river	0	0	0	0	0	Welle & Meire (1999)
7	Restoren two-gully system	Within	Tidal river	+	+	+	0	3	in: Bos et al (2012)
8	Reducing depth waterway	Within	Entire estuarine zone	+++	++	0	--	3	Schuchardt (2009)

Tidal storage

	Strategy	In/out of current borders	Region	Reducing/solving dredge problem	Towards estuarine balance	Effect on sweet-salt connection	Effect on navigability	Score	Source
9	Opening summer dike	Within/outside	Tidal river	+	+	0	0	2	Schuchardt (2009); Welle & Meire (1999)
10	Moving winter dike (main dike)	Outside	Mouth region/ middle zone	++	++	0	-	3	Schuchardt (2009); Welle & Meire (1999)
11	Deepening foreland	Within	Tidal river	0	+	0	0	1	Schuchardt (2009); Welle & Meire (1999)
12	Tidal polder	Outside	Tidal river	++	++	0	0	4	Schuchardt (2009); Welle & Meire (1999)
13	Reconnecting branches	Outside	Tidal river	+	+	+	0	2	Schuchardt (2009); Welle & Meire (1999)
14	Moving dam Herbrum	Outside	Tidal river	++	+	0	0	3	in: Bos et al (2012)
15	Canal	Outside	Tidal river	+	0	0	+	2	WWF (2011)

4.3 Choice of strategy

Two options

From the assessment we can conclude that the best solution is either to increase the tidal storage by constructing tidal polders, or decreasing the inflow by tightening the flood gully [figure 4.10 and 4.12]. These two different options fall well in line with the historic development of the estuary to its current situation for it has also been changed in two major ways:

- The first was reducing the floodplain of the Ems, by diking in land and cutting of river branches for safety and agricultural gain, which is primarily a factor in the tidal river.
- The second is straightening gullies and deepening the riverbed for shipping and industrial gain, which primarily affects the mouth and middle region.

Addressing to one of these development lines would thus be a wise choice, considering they both achieved the highest assessment score and have the best potential to lead to an economically and ecologically healthy estuary. In theory this holds the truth. In practise however it is not as simple as choosing one of these strategies, we must actually search for a combination of these different strategies, for both of the singular strategies are incompatible with the current land use as this paragraph will make clear.

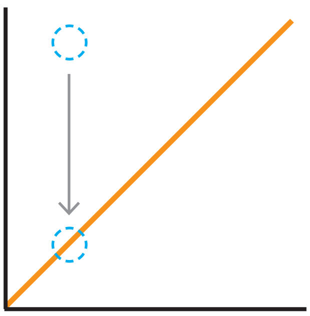


Figure 4.9 | A new balance width a small gully and small tidal basin

4.3.1 Tightening the flood gully [further explained in Chapter 6]

By reducing the width of the main gully, the volume of water able to flow through the estuary system during a single tide, could be severally reduced. A smaller volume of water in the same time frame (flood time stays the same), means a lower flowing speed and less sediment disturbance. This 'squeezing' of the gully is executed by placing a impenetrable layer of boulder clay or groyne structures on the sides of gully [figure 4.9]. This has the advantage over shallowing the gully, for it still allows ships with a deep draft to enter and leave the estuary.

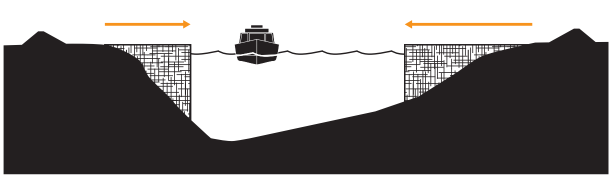


Figure 4.10 | Reducing the width of the flood gully

However, because of all the historic interventions that have taken place, means that tightening the gully at one location would not restore the balance of the system, but rather what is needed are interventions along the entire Ems [further explained in Chapter 5,6].

The hinterland has been decreased by at least 290 km2 when only the Dollard polders are taken into account. This means a decrease in tidal basin of 20% when it assuming that the current basin is 1155 km2 (measured from Delfzijl to Herbrum). Reconsidering the equation A=c*P, in where A is the gully width and P the tidal basin. It should be obvious that a decrease in P, would result in a decrease of A (assuming c is positive). But as 3.4 already pointed out, this

is not what happened in reality. Rather than letting the flood gully develop a natural course, shipping companies started to deepen and widen the gully by dredging. As a result the flood gully reaches depths up to 15 meters where it used to be 7 meters, and up to 8 meters in the tidal Ems, where it used to be only 2-3 meters deep (Leeuw, 2006, Bos et al., 2012, Cofad, 2004). To go back to this historic state would mean a heightening by several meters (Bos et al., 2012). Only width reduction could not achieve such a feat and in order to restore the balance the flood gully would have to levelled by several meters, going back to the historic size and less, because the Ems' tidal storage has also been reduced by 20%.
This would not only severely limit the industrial possibilities for the port of Emden and Delfzijl, but it would also make the cruise industry in Papenburg impossible.

4.3.2 Tidal polders [further explained in Chapter 7]

Instead of moving the main dike to enlarge the tidal basin, a tidal polder creates more room behind the main dike. This is done by building a ring dike behind the dike and constructing an inlet or sluice which allows water to flow through or under the dike. This has the advantage that the in- and outflow can be regulated and closed off and opened when needed. The polder is to be part of the estuarine system and becomes subjected to the daily tides.
With this increase of space, the tidal pumping effect is reduced because the incoming flood is given more space and more time to slow down and set its sediment (Schuchardt et al., 2009). It has the extra effect of effectively lowering the high water levels and thus becoming a measure for flood protection (Welle, 1999).

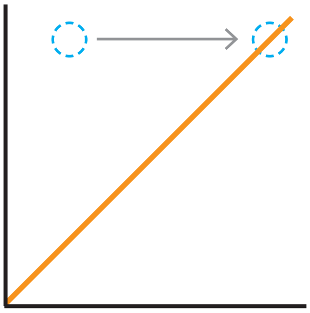
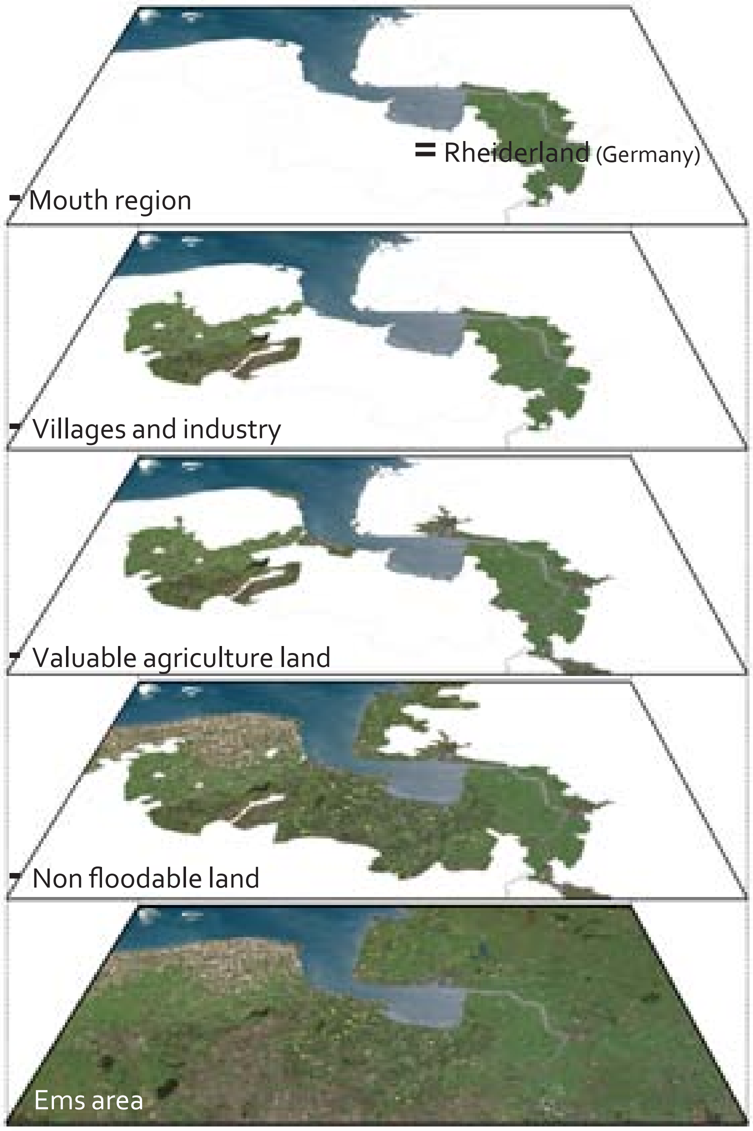


Figure 4.11 | A new balance width a large gully and large tidal basin

Increasing the size of the tidal basin by any size would have a positive effect on the balance of the estuarine system (Kemerink, 2004). For it would mean that, when considering the equation A=c*P, the P grows further towards the heavily altered and increased A. But to fit the tidal basin to the current ratio of the flood gully would require a space of probably hundreds of square kilometres (Bos et al., 2012). And this room is simply not available if you consider that [figure 4.13 (next page)]:

- Only land below 0 NAP is deemed suitable to be flooded (excluding the option of excavating thousands of hectares).
- The higher fertile lands are to be maintained. Although the function of agriculture is diminishing, these lands belong to the most fertile lands of both the Netherlands and Germany and remain important for the production of crops [paragraph 3.5].
- Villages, cities and large industrial sites are excluded from flooding.
- Flooding land upstream has far more effect on the total balance, because of the relative comparison with the current width. Bigger and lower, increases the effect (as long as it remains within tidal reach) (Schuchardt et al., 2009).

Figure 4.12 | Increasing the tidal basin with tidal polders



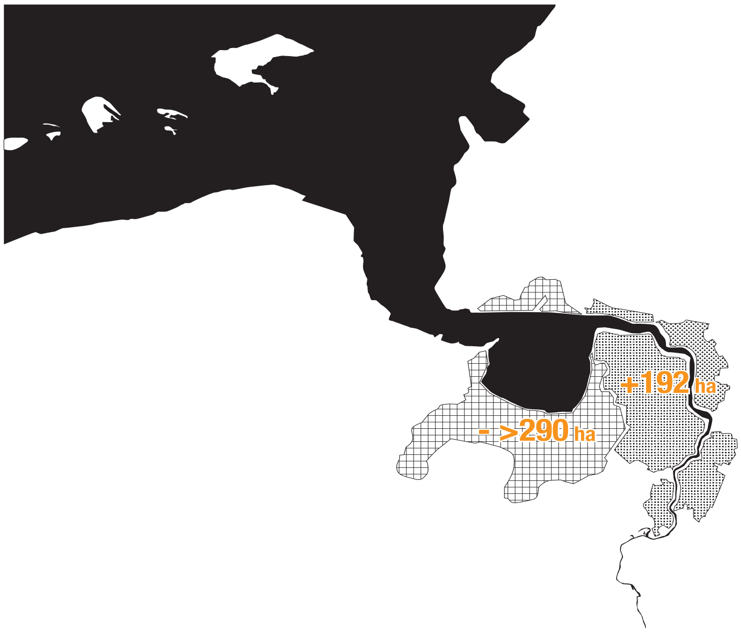
This only leaves the German side of the Rheiderland as suitable location for a tidal polder. But as said above, it is not enough to achieve a balanced estuary:

The total floodable surface of the Rheiderland is 192 km2. Flooding this all will mean an increase of 16,6% in the total tidal basin (measured from Delfzijl to Herbrum). It will however be insufficient when considering that the diked land of the former Dollard alone was already 290km2. Add to this the closed off tidal basin of the Westerwoldse Aa and the Leda and considering that the flood gully is almost twice as deep now, than it was before the Dollard was diked and it becomes clear that the Rheiderland alone is insufficient.

Figure 4.13 | [top left]
Suitable land for a tidal polder

Figure 4.14 | [down left]
The Rheiderland consists of low laying peat land, which is scarcely habited and only used for extensive grazing.

Figure 4.15 | [down right]
The removed area outweighs the new potential area.



4.4 Conclusion

On the basis of the information of the previous paragraph two conclusion could be drawn:

1. Neither of these strategies provides a fitting solution and a new strategy has to be devised.
2. Neither of these strategies can separately come to a solution, but a combination of the two could work.

As the previous paragraph already revealed this thesis has chosen to work towards a combination of the two different strategies. When considering all the facts this would be a logical choice:

- No single strategy has the complete answer to the Ems problem (including the earlier dropped strategies).
- The scale of the solution should fit to the scale of the problem (Steijn, 2012). The whole of the Ems has been adapted and every intervention has added to the rise of turbidity problem, a solution should thus not limit itself to one estuary region.
- Considering the two lines in which the Ems estuary has been altered, deepening the flood gully and decreasing the floodplain, an intervention should address these both.
- Decreasing the flood gully is most effective at the spot where its runs wide and deep (downstream), for a change there will have more relative effect. And an increase of tidal basin has more effective further upstream, because this will result in a relative larger effect (Schuchardt et al., 2009).

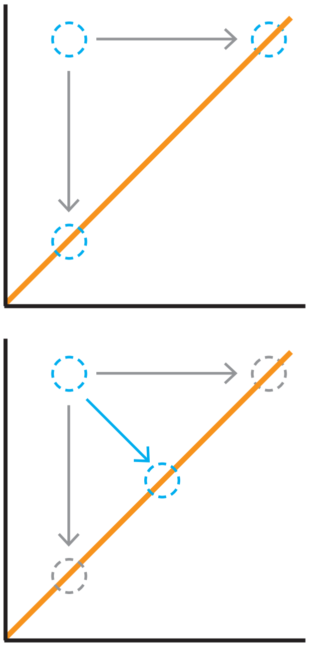


Figure 4.16 A,B | Instead of a choice between the two strategies, it would be more effective to work towards a combination.

Figure 4.17 shows the conceptual combination of the two different strategies, which is to decrease the width of the gully downstream in the middle zone, and increase the tidal basin upstream in the tidal river.

This model could theoretically be fitted to any estuary which has comparable problems, but this thesis want to create a strategy for the Ems. Adapted to its social, ecological and economical needs and fitted to the Ems landscape. Chapter 5 expands on the challenges of the landscape as were largely, but shortly, introduced in earlier parts of this thesis. Chapter 6 and 7 expand further on the two different strategies detailing them into a design.

Figure 4.17 | Ems model
To solve the Ems' turbidity problem the tidal inflow has to be limited at the estuarine mouth while the tidal basin has to be expanded in the tidal river zone.

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5

DESIGN OPPORTUNITIES

5.1 Introduction

In the previous chapters the focus lay on the main problem of the Ems-estuary: An out-of-control sludge problem with a devastating effect on the ecology in the estuary and skyrocketing dredging costs [chapter 3]. Chapter 4 focuses on the solution for this turbid situation and gives answer to the question which interventions are needed to overcome the sludge problem. These interventions are split into two possible solutions. The first solution focuses on the reduction of the cross-sectional width in the lower part of the estuary, while the other solution must be sought upstream along the tidal river. But as the third research question is:

> *How can the interventions be conducted in such a way that they deal with the uncertainty of the system and fit within the Ems landscape*

A solution for the turbidity problem cannot stand on its own. The causes for the current situation lie in the way that men has changed landscape and in the way it is used now. Any interventions must thus find its place in the landscape of the Ems and its surroundings. And as the main research question is:

> *How can the Ems' sludge problem be solved and how can this lead to an economic and ecologic healthier landscape, using a growing design strategy?*

A solution should thus not only confront the turbidity problem, but also aim to strengthen the region itself. Engaging other problems and potentials in the estuary. Making the design, not only an alien intervention to fix the sludge problem, but also an design which is veined with the potentials and problems of the landscape of the Ems-estuary and surroundings.
This chapter will discuss the problems and potentials of the landscape of the Ems-estuary in two sections:

§ 5.2 The downstream landscape, to find which problems and potentials can be connected to the reduction of the cross-sectional width.

§ 5.3 The tidal river, to find connections to realize the task for tidal storage and create added value for the region.

Figure 5.1 | Delfzijl in former times. At the old drawing dominate the Ems and Wadden Sea. Delfzijl is just a small human intervention in the landscape, to provide passage for ships. (Image: Geheugenvan-Nederland.nl)

5.2 The drama of Delfzijl

5.2.1 A city at the estuary

Paragraph 3.5 described, how economic crises have resulted in a quantitative decline of employment and inhabitants, leaving the city of Delfzijl in severe decline. The city is unoccupied, and due to modernistic developments preceding the economic decline, aesthetically one of the ugliest towns of the Netherlands. There are many arguments to underpin this statement, but the main reason is that Delfzijl has lost its identity (Papenborg, 2012). Before its downfall, Delfzijl was a picturesque town at the Estuary, settled around a sluice in the dike which functioned as a transition between the Damsterdiep, the transport route to Groningen, and the Ems. This function even named the city (Old-Dutch for sluice= Zijl or Siel) and is thereby an important identity for the city (Papenborg, 2012). The modern developments did nothing with this story and created placeless and monotonous residential areas.

Former city at the estuary

This potential that that Delfzijl has, as a picturesque harbour city within a transition zone between the inland and the Wadden Sea, is not met in reality. Delfzijl is not, like expected and like in former times [figure 5.1], an idyll city at the estuary, but an introspective modernistic town behind a megalomaniac coastal defence wall [figure 5.2]. Nowadays the Ems-hotel, which rises up out of the mudflats of the Ems-estuary in front of Delfzijl, and a small beach, located at the same mudflats, are the only tangible connections between Delfzijl and the Estuary [figure 5.3].

The real connection between the Ems and the Damsterdiep, is no longer even visible from the city centre, but rather visitors should take a car or a bicycle and drive 6 km direction south-east. Here the harbour has its new access to the Estuary. The reason for these apparent weird interventions can be found, again, in the regulation and the normalization of the Ems-estuary.

Relocation of the harbour entrance

Figure 5.2 | Delfzijl nowadays. The estuary is not perceivable. A hudge flood defence wall dominates the introvert city.

The inner-city of Delfzijl lost its connection with the estuary, by the transition from a multiple-channel system into a one-channel system. This made the 'Bocht van Watum' inaccessible for vessels and the old port a sediment trap, leaving Delfzijl unreachable [paragraph 3.2] A new connection to the shipping channel was found 6 km southeast [figure 5.4], reconnecting Delfzijl to an Ems gully but at the same time marking the cultural deathblow for Delfzijl. Henceforth, tourist and other waterway users have to sail 6 km through wharfs and silos to reach the modernistic, inland orientated Delfzijl.

Figure 5.3 | The Ems-hotel and a small beach are the only tangible connections with the estaury.

Figure 5.4 | The entrance of the its harbour is, from half way at the dike not even visible. (photo: Hank Slagter Panoramio)

5.2.2 Stranded villages

Figure 5.5 | Wierde villages in former times. Orgininally these wierde villages were just small human interventions in the mighty estuarine landscape. (Drawing: Rob van Eerden)

Delfzijl is the largest town in the Ems-mouth region, but most distinctive for the region are the many 'wierde' or 'terp' villages. A wierde is an artificially raised mound, erected by the first inhabitants of the region to protect themselves and their cattle for periodic floods. The wierden were erected in an extensive salt marsh landscape subjected to the vagaries of the Wadden Sea and their estuaries, which stretched from Friesland till Denmark (Bijhouwer, 1977). Figure 5.5 shows how all of this Wadden landscape, and also Ems estuary must have looked a thousand years ago. Big changes came in the 12th century, when with the help of dikes and new draining techniques vast areas were reclaimed (Barends et al., 2005). Monasteries, who mastered the techniques of draining and diking, settled in the area and started to exploit the landscape (Stichting Natuur en Landschap Eemsmond e.o, 2001). The area changed from a salt marsh landscape, subjected to the periodic floods of the estuary, into an agricultural landscape with a limited relation with the estuary.

But the old creeks of the salt marsh landscape remained important in the area, in particular at the Dutch side. After the diking of salt marshes the creeks (Dutch: maren) were used to drain the new arable land. But the drainage of the land via the creeks became more difficult since the coast silted up and also because of the phenomena of the interconnectedness between tidal basin and gully width.

Creeks as connection

Figure 5.6 | The former small harbour of Spijk. From the 16th century till the 20th century, the old creeks functioned as transport routes to the Wierde villages.
(Image: Beeldbank Groningen)

Lost the connection

By reclaiming land and closing of side branches, the main gully became unable to hold a large volumes of water, losing flow speed and ultimately silting up. This was overcome by inverting the traditional drainage. New connections were dug to lose the water and many of the old sluices lost its function. The economy however continued to grow, needing more transportation and so many of the creeks were excavated and the villages along the creeks were accommodated with small harbours [figure 5.6]. In this way, the wierden remained connected with the Wadden landscape (Atelier Fryslân et al., 2011).

However, since the 20th century, transport by road took over the transport function of the creeks, which caused the disappearance of the small harbours in the villages [figure 5.7]. Hereby the 'wierde landscape' lost its last connection with its initial creator: the Wadden Sea and the Ems-estuary (Jong, 2012).

Figure 5.7 | Spijksterriet nowadays. The creek changed into a small anonymous ditch. (photo: agronex panoramio)

Figure 5.8 | Termuntenzijl is a popular touristic place with its marina and fish restaurants.

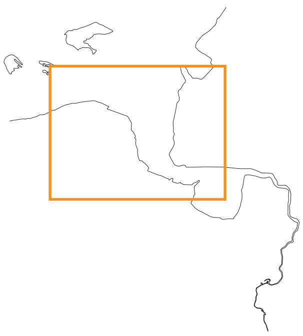
5.2.3 New opportunities for the Ems-mouth

Both the characteristic wierde villages as Delfzijl found their origin in the interaction between man's and natures dynamics of the Ems-estuary. Nowadays, however, all the connections between the villages and the Ems-estuary have disappeared.
The simplest answer to this problem seems to restore the historical connections; the sluices. Plan to restore the sluice of Delfzijl are numerous and Firet (2012) suggests in his guiding document, Spelen met de Gulden snede in het Eems-estuarium, the reconnection of former creeks to the estuary for better fish stocks. Hereby, the old wierde villages can develop into new touristic spots like small harbours of Termuntenzijl and Noordpolderzijl [Figure 5.8]. Delfzijl, in turn, can restore its connection with the estuary like Harlingen or the historical cities along the Scheldt [Figure 5.9].
However, the current silting up of the Bocht van Watum [paragraph 3.2] makes such reconnections almost impossible. The high concentrations of sludge in the gully will silt up a new connections in no time. Therefore the shipping channel has to be shifted towards the Dutch side or the Bocht van Watum, be integrated with the estuarine channel system, and give the landscape and the villages of the Ems-estuary a renewed identity.

New connection possibilties

Figure 5.9 | Plans to re-open the harbour of Delfzijl, like the Municipality initiates, are not possible without restoring the course of the estuary. (Image: GeheugenvanNederland.nl)

Figure 5.10: Actual sitation of the Ems-mouth landscape. The Dutch side of the Em-mouth has orginally a strong relation with the Estuary, but has lost its connection by the land-reclaimations and the shift of the shipping channel course to the german side.



LEGENDA

Possible new connection

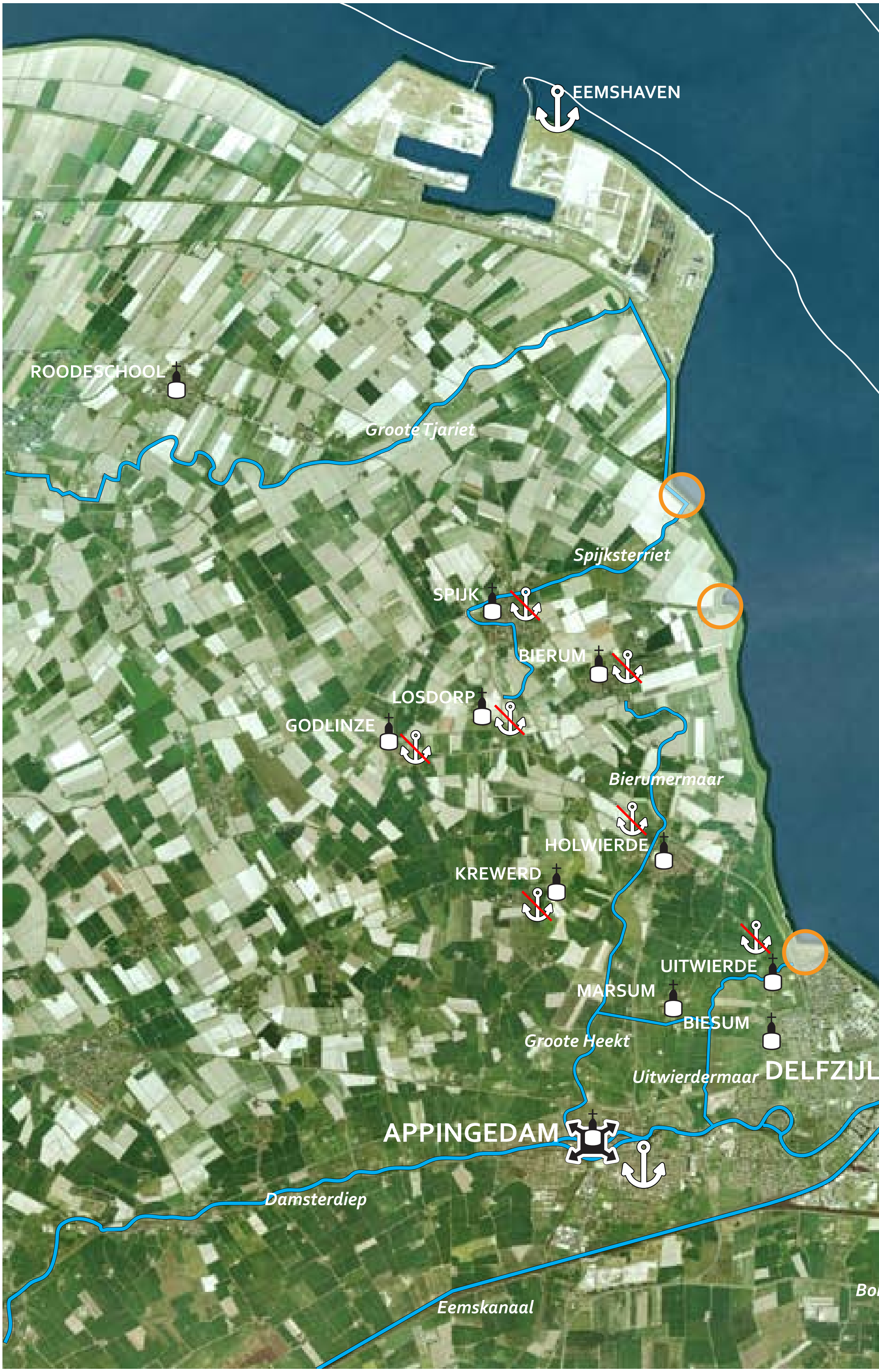
River or Creek

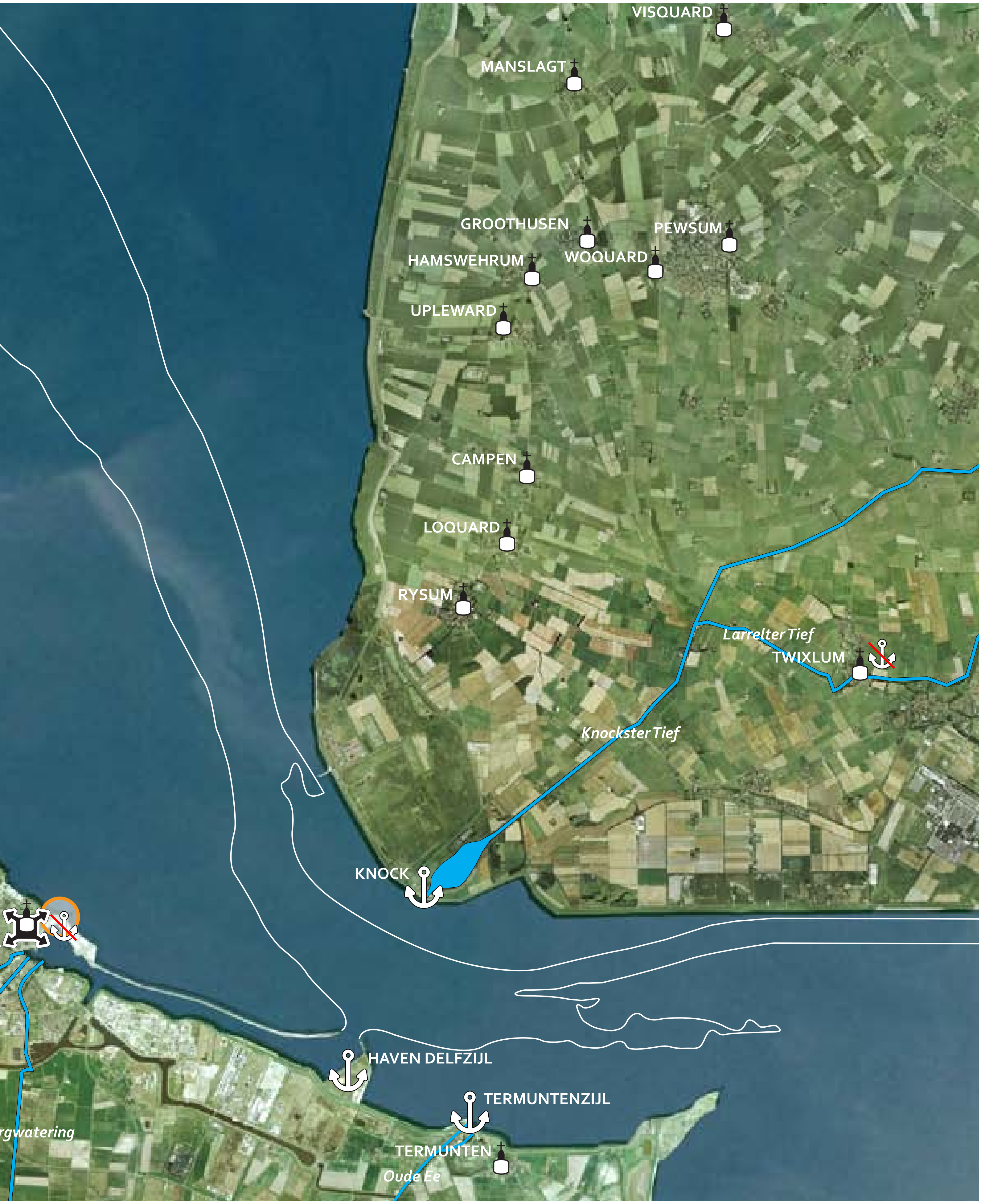
'Wierde'-village

Town

Existing harbour

Former harbour




VISQUARD
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UPLEWARD
CAMPEN
LOQUARD
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TWIXLUM
Knockster Tief
KNOCK
HAVEN DELFZIJL
TERMUNTENZIJL
rgwatering
TERMUNTEN
Oude Ee

5.3 The desolate Rheiderland

5.3.1 The lost Rheider-Ems connection

The historical map below shows the state of the Rheiderland as it was in 1595 [figure 5.11]. Comparable with the landscape of the Ems mouth, there was an open landscape. The Ems could flow over the land, be it either by increase of fluvial or marine water and lay its sediment on the land. People settled on the low levees alongside the Ems, which were slightly higher than the inland which mostly consisted of wet peat soils (German: moors). Before the construction of large dikes, people lived on small dwelling mounds, previously described as wierden. These were not dispersed randomly but were situated at side branches of the Ems where the land was slightly higher, due to more sedimentation, and there was a direct connection to the Ems, the Wadden Sea and even further. This direct connection was lost when higher dikes where constructed around the Ems to (hopefully) permanently keep out the rising water. The side branches were canalised and reconnected to the Ems via small sluices, and as most villages were founded next to these branches, almost every village got its own sluice [figure 5.13]. These operations increased the safety of the Rheiderland, but also excluded the growing capacity of the sediment rich water, thus stopping the elevation of the hinterland. With the new dikes and canal systems it also became possible to reclaim the wet peat soils of the hinterland and grow crops, but focussing mainly on cattle due to the low fertility of the soil (Knottnerus, 1993).

Lost connection: diking

Figure 5.11 | Map by Ubbo Emmius of the Rheiderland in 1595 (source: commons.wikimedia.org/)

With the exclusion of the tidal influence of the Ems and the subsidence of the peat soil due to drainage, the Rheiderland became lower than it was before the Ems closure, ranging currently from 0 to -2 NAP. This resulted in a higher water level and also meant that water could not flow freely into the Ems, and it had to be controlled by pumping station and could only by released into the Ems at low tide. With this the Rheiderland gained a tradition in the way it has dealt with water. Unlike most of Germany, but very common in the Netherlands, Rheiderland has a water board and dike watch. Without having to relay on individual farmers, water boards can decide upon the safety of the entire region but also manage individual sluices when needed.

Waterboards: Unique in Germany

5.3.2 A deserted wasteland

The direct visible and tangible connection to the Ems has been lost by the construction of connected dikes. The sluices conserved this connection in a minor form, but this was diminished again after a new sequences of dike building. This heightened the dikes to 6 meters, losing sight on the villages behind the dikes and vice versa [figure 5.12]. At some places the new dike was even constructed around the old dike, reducing the tidal basin, but also making old sluices functionless [figure 5.13]. The land itself, as already made clear in chapter 4, is almost useless in terms of agriculture. The land is low, wet and unfertile, unsuited for growing of crops and even poorly suited for cattle because of its low carrying capacity.

These attributes are not flattering for the Rheiderland: it is empty and barren. Trees are scarcely placed, leaving an open grass landscape, which is in this case not a positive

Figure 5.12 | The village of Pogum behind the Ems dike

Figure 5.13 | The old disconnected sluice at Esklum

Figure 5.14 [top] |The landscape of Rheiderland is dominated by open infertile grass lands

Figure 5.15 [middle] | Many streets landward from the villages are dead ended.

Figure 5.18 [bottom] | Cross section of the Ems with a 'Emsüberführung'.

quality [figure 5.14]. The landscape is deserted and difficult to reach, especially when traveling away from the Ems' village row and main dike [figure 5.15].

These setting make the region unattractive for tourists and recreationists, while at the same time the number of inhabitants and the employment is also reducing (Hasse, 1993). A revival in industry or trade is not to be expected giving the Rheiderland more opportunity when aiming for tourism, natural development or new sectors when aiming for an economic boost (Hasse, 1993).

5.3.3 New opportunities for the tidal river

There are two times a year when the Rheiderland attracts thousands of visitors in one day. These are days of a 'Emsüberführung', the day when a new cruise ship is finished at the Meyer Werft in Papenburg and is tugged 70 km over the Ems towards the Wadden Sea. It gives an impressive sight as the ships can be as high as 55 meters, towering over dikes and houses and being perceivable from miles away in this open landscape [figure 5.16 and figure 5.17]. Locals and tourists are attracted by this spectacle and gather en mass on the dikes and floodplains of the Ems [figure 5.16]. However, at the moment the ship has passed, the tourists too go away, having remained only in a small portion of the Ems landscape. This is a missed opportunity. The potential that the Meyer Werft has to attract people on to the dike is not to be neglected and there lies an opportunity in using the force of these cruise boats when they travel along the Ems. Using this 'Emsüberführung' within the task for the tidal river of increasing the tidal basin, would also be big turnaround for a company which is seen as one of the largest contributors to the turbid problem (Bos et al., 2012, Leeuw, 2006).

This new modern tradition, the historic tradition of water boards, and the presence of the old sluices are perfect ingredients for the new task for the tidal river and can help regain a lost physical, hydrological connection, but also create a new social, cultural connection.

Figure 5.16 [top] |The 'Ems überfürung ' acctracts many spectators (source: Panoramio).

Figure 5.17 [middle] |The 'Emsüberfürung' seen from the Rheiderland. (source: Panoramio Reinard Kerkeling).

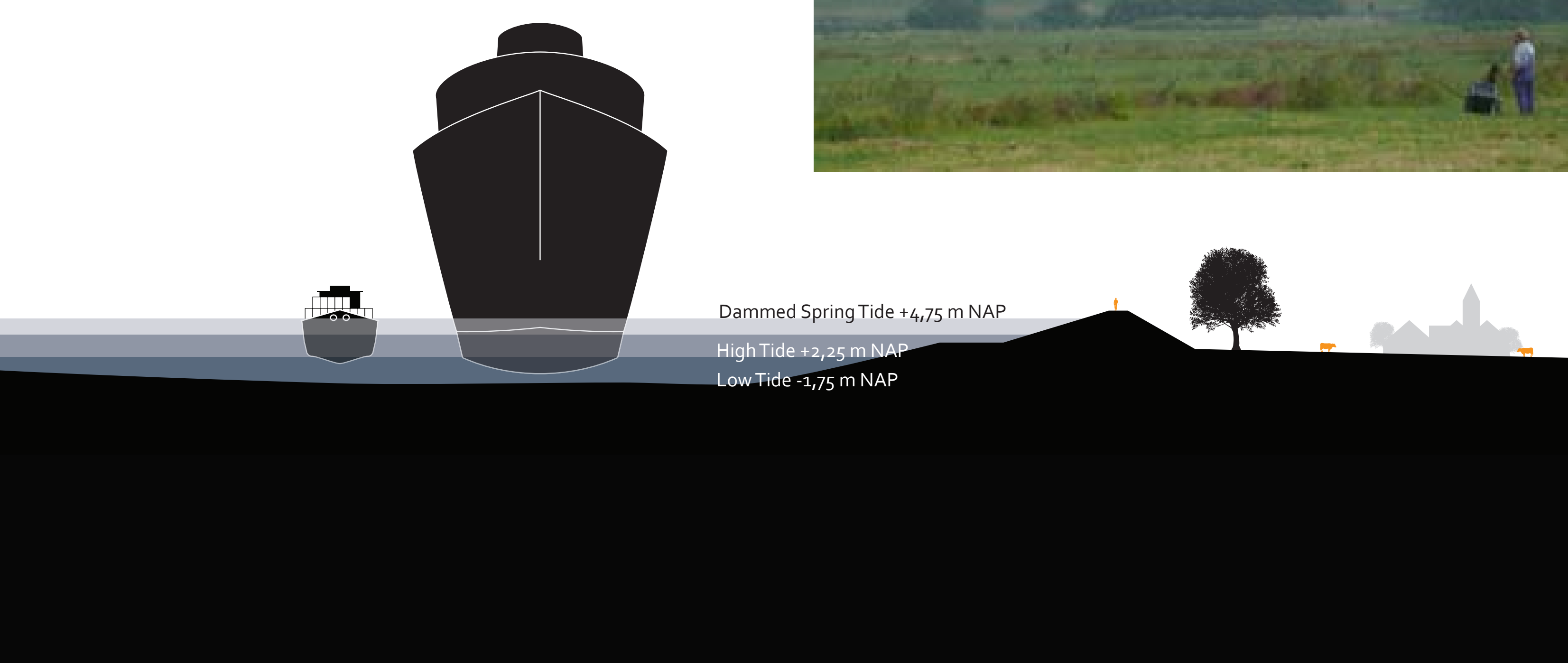
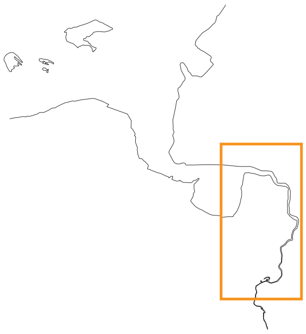


Figure 5.19 | Actual sitation of the Ems tidal river landscape. The wierde vilaages of the Ems are still largely connected to the Ems by sluices and canals. Many however are closed and unused.



LEGENDA

'Wierde'-village

Town

Existing harbour

The Cruise ship Wharf

Former sluice

Sluice for water

Sluice for water and boats

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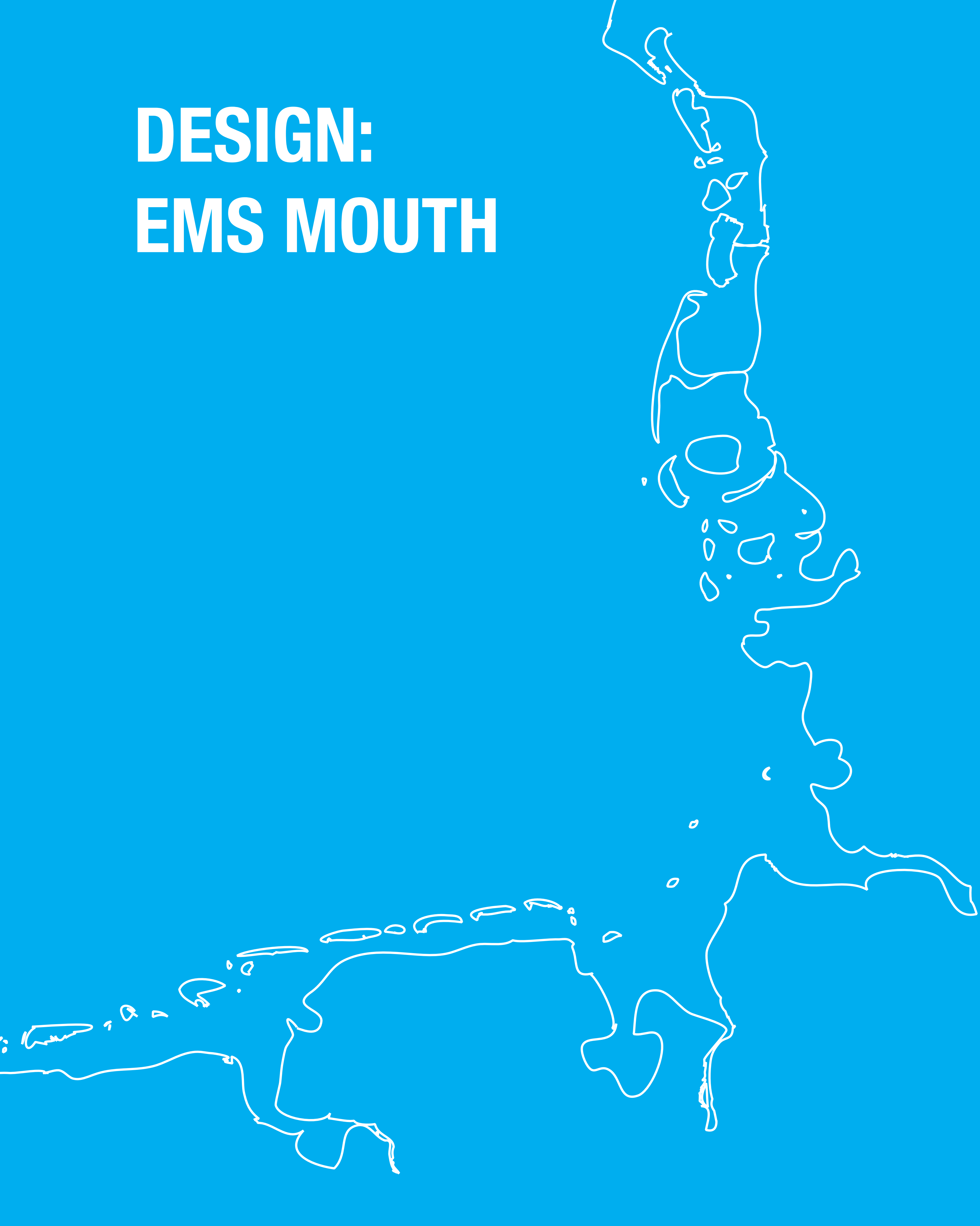
6

DESIGN:
EMS MOUTH



6.1 Introduction

From chapter 4 [Design strategy] it became clear that two strategies are needed in order to restore the balance in the Ems-estuary:

- Reduce the cross-sectional width, thereby reducing the tidal inflow
- Increase the tidal basin, thereby giving more space to the tidal pulse.

Chapter 7 will handle the second strategy, where this chapter will revolve around the first: The reduction of the cross-sectional width of the estuary. The design for the estuary mouth is founded on the technical aspects of the solution, as discussed in chapter 2 [research framework] and chapter 4 [design strategy], which stated that in order to reduce the tidal inflow of the Ems, the best choice is to reduce the gully width in the mouth and middle zone. A landscape architectonic design, however, goes beyond the formulation of a technical solution, but uses the landscape and the reality of the Ems-estuary as is stated in chapter 5 [design challenges]. Therefore this chapter covers both. The first paragraph defines the design principles for the strategy, which would fit the estuarine system the best. The last paragraphs deal with the implementation of the strategy based on the specific characteristics, problems and potentials of the landscape of the Ems-mouth:

§ 6.2 Strategic design: basic principles of tightening the stream
§ 6.3 Detailed design: constructing groynes
§ 6.4 Local design: arrangement of the structures

6.2 Strategic design: Tightening the stream

6.2.1 Basic principles of tightening the stream

The idea of tightening the stream is quite easy to explain. The strategy is based on the reduction of the cross-sectional width from the sides instead of reducing the cross-sectional width from the bottom of the channel. This, in turn, will lead to a more balanced state between the cross-sectional width and the tidal prism of the estuary as is described in chapter 4. As additional outcome, a narrowed channel will cause higher flow rates which prevents unwanted sedimentation and may even provide scour in the middle of the channel, which in turn ensures lower dredging costs.
To tighten an estuarine channel, three varying techniques are eligible:

Longitudinal dam
The most common technique to reduce the width of a channel is the construction of longitudinal dams (Dutch: leidam) at both shores of the channel, in which the water flow is concentrated. Famous are the jetties in the branches of the Mississippi Delta, designed and constructed by the military engineer James Eads. With these jetties, Eads narrowed the main branches of the Mississippi to allow year-round navigation. The jetties are constructed out of wood, clay and stones and were successful in the past and still prevent the southern branch of the Mississippi from silting up nowadays (Mathur and Cunha, 2001) [figure 6.1].

Figure 6.1 | Painting of Eads jetties at the mounth of the Mississippi.

The Ems-estuary also features a longitudinal dam. In 1872 German authorities started to construct the 'Geise Leitdam', as separation between the Dollard and the shipping channel in front of Emden. The motivation for the construction of the Geise Leitdam was to preserve the shipping lane from silting up, by fixing the adjacent sand banks and mudflats at the edge of Dollard and the shipping channel (Duits-Nederlandse Eemscommissie, 1990). It is important to notice that by the implementation of a longitudinal dam to tighten the channel, the area at the shore side of the dam should silt up. There is a risk that the longitudinal dam will only split instead of tighten the channel. [figure 6.2] The attachment of the longitudinal dam to the shore or the construction of small side dams, perpendicular to the dam, will eliminate this problem (Steijn, 2012).

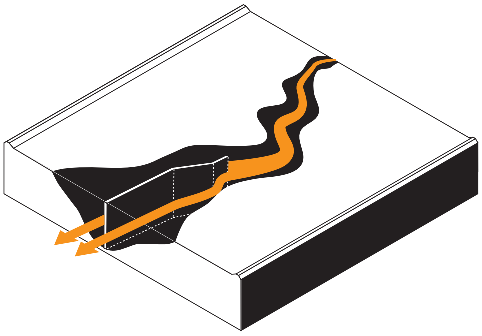


Figure 6.2 | The construction of a longitudinal dam can lead to the split of the stream instead of the pinch of the stream.

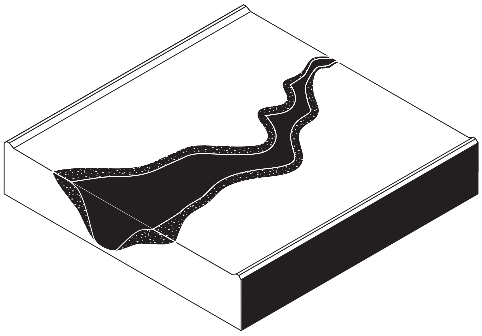
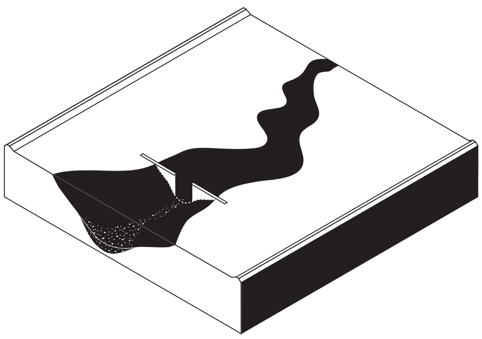


Figure 6.3 | Boulder clay can reduce the cross-sectional width of a channel, cause it endures an steeper angle of inclination than sand.



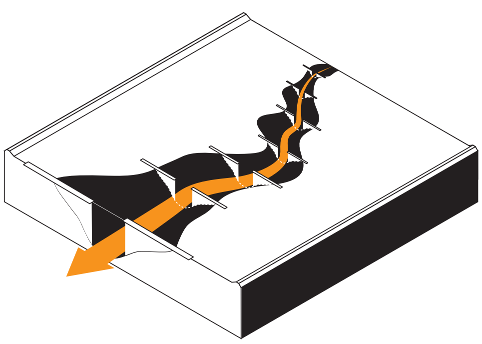


Figure 6.4 & 6.5 | Pinching the stream by a single couple of groynes lead to a congestion of sediment downstream the groynes.
A range of groynes can avoid this problem.

Boulder clay supplementation

Another technique narrows the channel by the supplementation of the channel sides with boulder clay. Boulder clay has the characteristic, in contrast with sand and sludge, to remain stable under a relatively large angle of inclination. This means that the cross-sectional width of the channel can be reduced, by spraying boulder clay on top of the relative gentle sandy shores of the channel [figure 6.3]. Currently the technique is mainly used to reinforce the channel sides to prevent erosion from undermining the coast (Provincie Zeeland and KNDW, 2011). However, plans are made to deploy the technique of boulder clay supplementation to reduce the tidal range in the Ems estuary (Waddenvereniging, 2011).

Groynes

The last technique is derived from the river training works, where groynes are used to ensure depth and to prevent unwanted sedimentation in the river. Van Staverden describes groynes as: "artefacts, made of stones, soil, poles or a combination, constructed at a certain angle to the river" (Translated from Dutch: Staverden, 1983). Groynes have to be implemented in a range, to prevent unwanted sediment congestion downstream of the groynes [figure 6.4]. The assembly of groynes in range ensures a guiding of the stream and prevents thereby the congestion of sediment in the shipping channel (Winden, 2012). [figure 6.5]

The above described techniques may differ in shape and material, but the basis stays the same. Three general principles can be established for the implementation of the structures in the estuary:

- Tightening ensures a reduction of the cross-sectionalwidth from the sides of the channel.
- The structures should be attached to the shore or to higher sandbanks to prevent the channel from splitting.
- The structures should be implemented in a long range to prevent congestion of sediment downstream.

Based on the width reducing effect of the intervention, all techniques are suitable for implementation in the Ems-estuary, considered that they meet the above stated requirements. Nevertheless, the usage of groynes is most preferable in this situation. Where the longitudinal dam and the boulder clay supplementations have to be implemented at once to be effective, the groynes can be constructed in phases, as it consists of multiple freestanding components. Therefore utilizing the groyne-technique fits best in the growth strategy described in chapter 2.

6.2.2 Understanding and using hydrologic processes

Restoring diversity

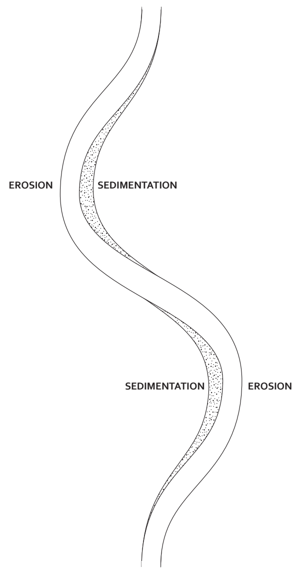
The biggest disadvantage of tightening the estuarine channel, with one of the above described techniques, is the poor connection with the surrounding mudflats. The new constructions raise a barrier between the channel and the surrounding mudflats, similar to a highway crossing the landscape encased by sound walls. This results in an impoverishment of the estuarine ecosystem, due to the loss of the characteristic habitats of the transition zones. This means a great loss of one of the four important functions of the estuary: habitat diversity.

Lost of habitat diversity

In addition there is another problem to tackle. The tightening of the stream only solves the problem of the lost balance between the depth of the gully and the size of the hinterland. But during the 20th century men also altered the course of the estuary. The normalization of the tidal river and the transition from a multiple-channel system to a one-channel system has caused large tidal asymmetry, which in turn makes it even harder for sediment to leave the estuary [Paragraph 3.2].
As a result of these new considerations the technical principles need to be extended with two guide lines:

- The interventions have to preserve or expand the current habitat diversity.
- To reduce the tidal asymmetry, the meanders and the multiple-channel system have to be restored.

Figure 6.6 | Theoretical meander with a sinuous shape. The outerbends of the meander are conducted to erosion, while the inner bends are conducted to sedimentation.

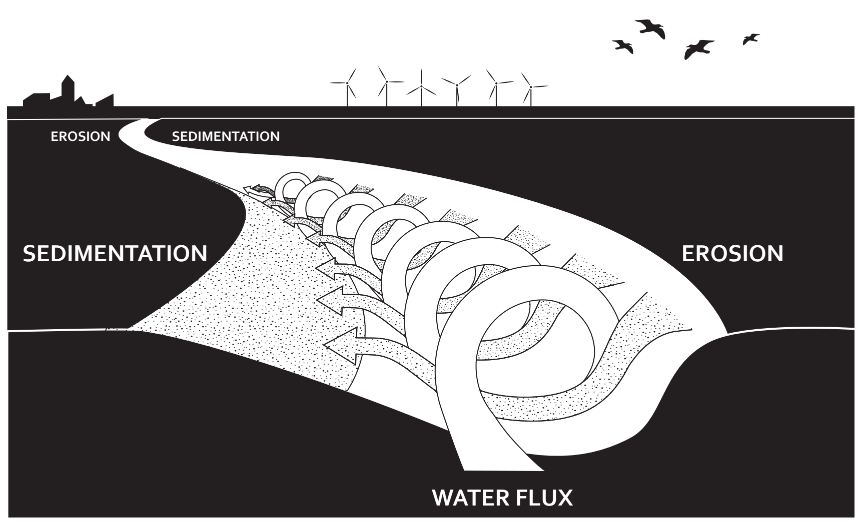


Using the natural characteristics

The implementation of groynes in the estuary appears as a modernistic measurement because of the direction towards a more heavily fixated regime. However instead of implementing a cultural regime founded by the demands of men, the groynes are employed to use the natural characteristics of the estuarine system and create a growing solution:

From chapter 3 it can be learned that the channel system of an estuary has the tendency to meander [Paragraph 3.2]. A meander is a sinuous watercourse consisting of multiple convex inner bends and multiple concave outer bends [figure x.x]. These are formed because the flow velocity of the water is much higher in the outer bend than in the inner bend, which results in erosion in the outer bend and sedimentation in the inner bend (Kleinhans and Brinke, 1998) [figure 6.6]. This process can be explained by the first principle of erosion and sedimentation, discussed in chapter 3 [paragraph 3.2], which explains that sediment particles are picked up at high flow rates and are deposed at low flow rates. These differences are also perceptible on a local scale, caused by the water current which is not following the middle of the channel, but has the tendency of spinning out. The centrifugal forces

Figure 6.7 | Basic priniciples of erosion and sedimentation. Under unfluence of different flow rates occurs erosion at the outer bend of the river, while sedimentiontake place at the inner bend of the river.



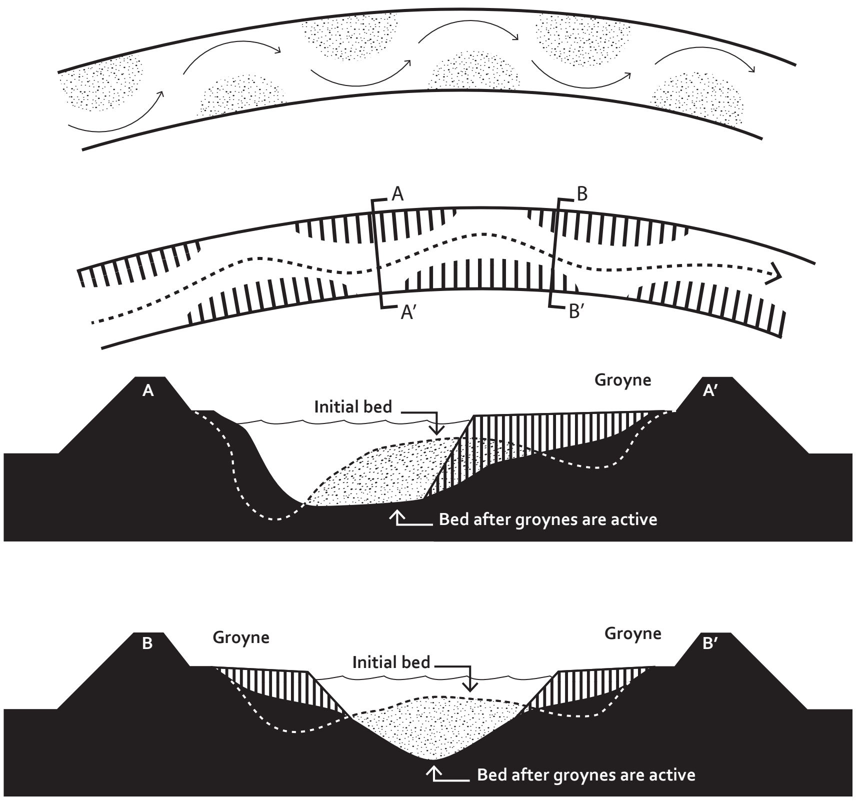


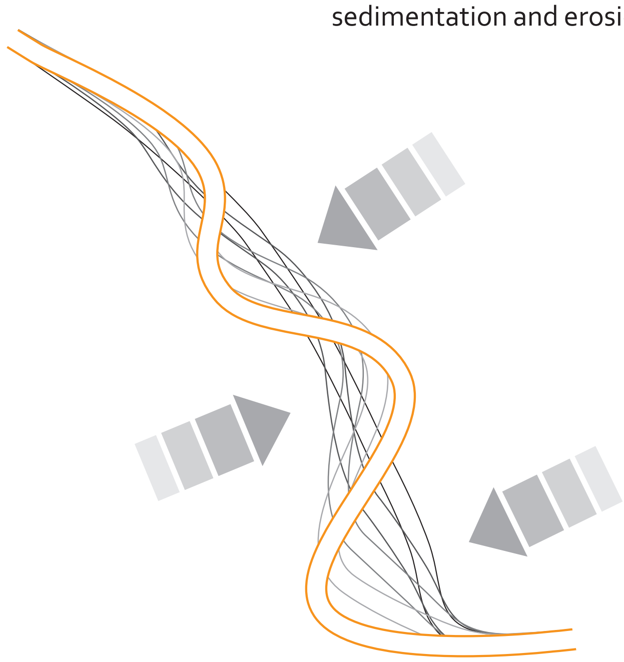
Figure 6.8 | The working of groynes.
Groynes at the inner bend ensure scour and depth at the outer bend, while groynes at both side of the channel ensure scour and depth in the middle.
[based on: Janssen, 1979)

ensure high flow rates and erosion of sediment in the outer bend and low flow rates and sedimentation of this sediment in the inner bend (Kleinhans and Brinke, 1998) [figure 6.7]. This difference in flow speeds and sedimentation rates forms a steep in the outer bend and a gentle slope at the inner(Przedwojski et al., 1995) [figure 6.7].

This means that narrowing interventions are best implemented at the inner bend of the meander. On one hand, because the reduced area is bigger at the gentle inner bank than at the steep outer bank, on the other hand, because the sedimentation at the inner bend will strengthen the narrowing effect while the erosion at the outer bend will nullify the narrowing effect. An added benefit is that one side of the channel will always retains a unobstructed connection with the surrounding system.

These principles are also used by river regulations and normalizations. Normally the inner bend is enhanced by groynes to narrow the profile, while the outer bend is left untouched (Przedwojski et al., 1995) or is reinforced with bank protection or longitudinal dams to prevent erosion (Staverden, 1983). This method ensures not only the narrowing of the profile, because the gentle sandy slope is replaced by a steep and stable groyne, but provides above all natural scour, which ensures a deep and obstacle free shipping channel profile (Przedwojski et al., 1995) [figure 6.8].
The next principle of tightening the stream based on the natural characteristics of sedimentation and erosion implies:

Figure 6.9 | Principle of a growing system.
Extending the groynes in the inner bends forces the estaurine stream to meander.



- Interventions which reduce the cross-sectional width of the channel should only be implemented at the inner gentle bank of a meander, because of the larger reducible area and the strengthened narrowing effect by sedimentation.

6.2.3 Growing system

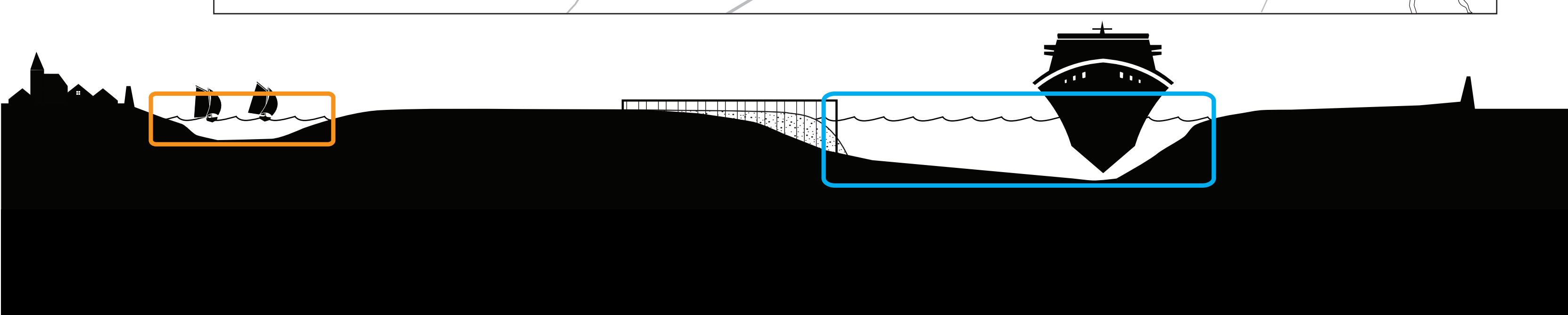
With the above stated principles the cross-sectional width of the channel can be reduced by narrowing the profile on tactical locations in the inner bends of the shipping channel [figure 6.9]. Which would not only greatly significantly restore the estuarine balance, but also maintain an obstacle-free connection with the surrounding mudflats because of the unilateral application of the groynes. However, the quality of these transitions may be questioned. The once highly diverse estuary, with altering small, deep ebb-channels and shallow, broad flood channels (Veen, 1950) has degenerated into a monotonous shipping channel flanked by monotonous high-lying mudflats (Menkema, 2012). The establishment of groynes at the gentle slopes of the shipping channel does not change this problem, but seems to maintain the rigid separation.

Nevertheless, the groynes offer a solution for this problem. The key lies in the approach for implementation. Instead of treating the modernistic fixation and narrowing of the channel as the ultimate final solution for the problem, the arrangement of the groynes should be seen as the starting point to return to the initial multiple channel system.

A growing strategy: Extending groynes

From this starting point new segments can be added to extend the groynes [figure 6.11]. Water will follow the path of the lowest resistance, finding its way around the groynes. As a result the gully will slowly start to meander again [figure 6.10 compared to figure 6.11] and his effect can be strengthened by repeating the extension of the groynes multiple times [figure 6.10 to 6.15].

Figure 6.10 | Pinching the stream as first step in the growing system.



A new meander

After a lapse of time, the meander will again break through in the outer bends. This in turn implies the restoration of the original multiple-channel system, which both reduces the tidal inflow and provides a comeback for numerous, site-related habitats. The manual extension of groynes-structures makes that the re-meandering can be steered. Restoring the course of the meander in the shipping channel, may imply a new impulse for the villages and cities along the estuary. Since the cutting off of the Bocht van Watum and other vital curves in the estuary, many villages along the estuary are no longer connected to navigable gullies and meanders. Most dramatic is the current situation of Delfzijl, where the entrance of the harbour has moved 6 km south east from the inner city, to connect to the present main gully [Chapter 5]. Therefore, the new meander is steered and developed in such a way, that the main shipping channel will pass the centre of Delfzijl again and the flood channels will make a connection with the villages and old river branches along the Bocht van Watum possible again. This makes the re-meandering of the Ems not only an improvement of the ecology, but also gives the landscape surrounding the estuary an impulse.

The reconnection of Delfzijl and the stranded villages

Figure 6.11 | Fase Ib. The water and thereby the course of the river searches a new course around th e groynes.

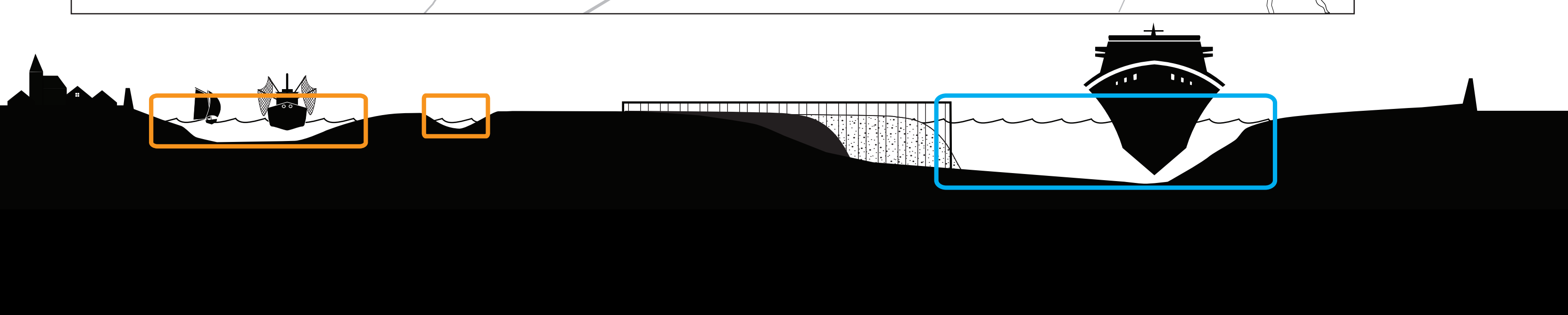


Figure 6.12(above) and 6.13(down) | Fase II. Extending the groynes ensures: a more intense meander, narrowing of the shipping channel and a broader side channel.

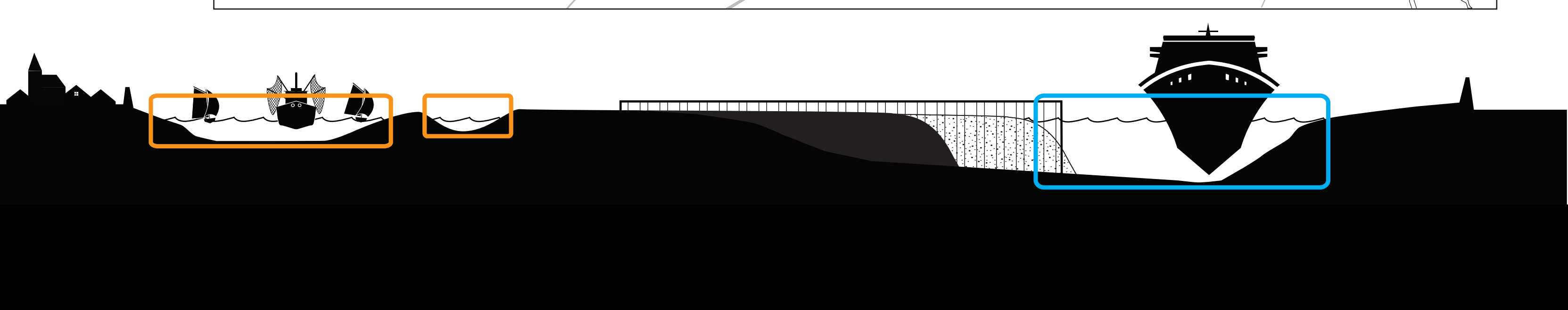
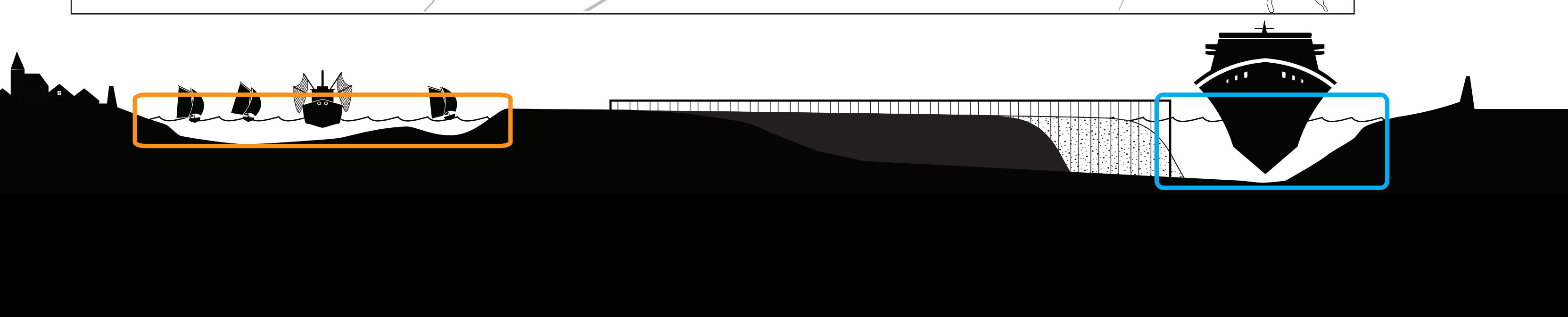


Figure 5.14(above) and 5.15(down) | Fase III. Extending the groynes ensures: an even more intense meander, further narrowing of the shipping channel and a broader side channel.



6.2.4 Monitoring and adjusting the dynamic landscape

Thus, the growing system ensures the comeback of the multiple-channel system and many specific habitats. But in addition, the growing system ensures the possibility to monitor the process and thereby to adjust the implementations to obtain both geomorphologic and ecologic better results. This heuristic strategy, in where results are made by doing, fits excellent with the dynamic and capricious landscape of the Wadden Sea. The first steps within the growth can be based according to present knowledge and literature, which suggest a ratio between 1:1 and 1:4 of groyne length and distance towards the next groyne(Staverden, 1983) (Przedwojski et al., 1995). The next step is uncertain, for nobody has the exact knowledge on how the system will respond to the initial changes. This gives the intervention an erratic course, which may differ quite a lot from the initial drawing table design. And where the beginning may follow the textbook and have a static regularity of groynes all at the same distance, but over time may lead to a densification of the number of groynes at places where the groynes are not effective enough and a decimation of the number of groynes at places where a more gradual transition of habitats is wanted.

Theoretical start

Experimental finishing

The uncertainty and unpredictability makes that the maps above are based on a theoretical ideal situation derived from literature, however, it could be expected that the actual situation will differ significantly from the illustrated maps.

Figure 6.16 | Aerial impression of the restored estuary. The re-meandering and tightening of the channel system constitute an enrichment for the whole estaurine system

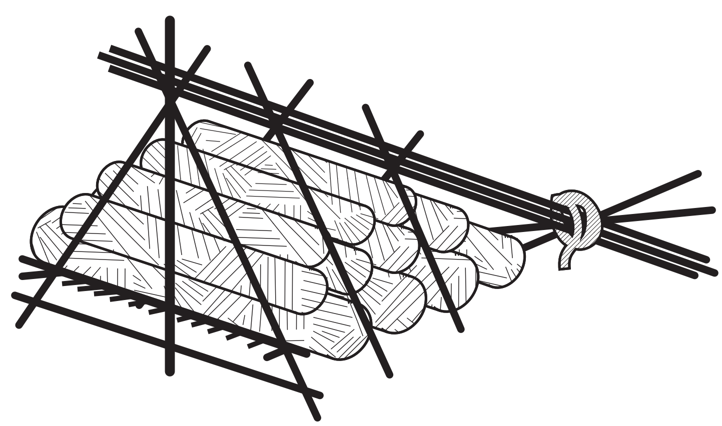
6.3 Detail Design: Constructing dams

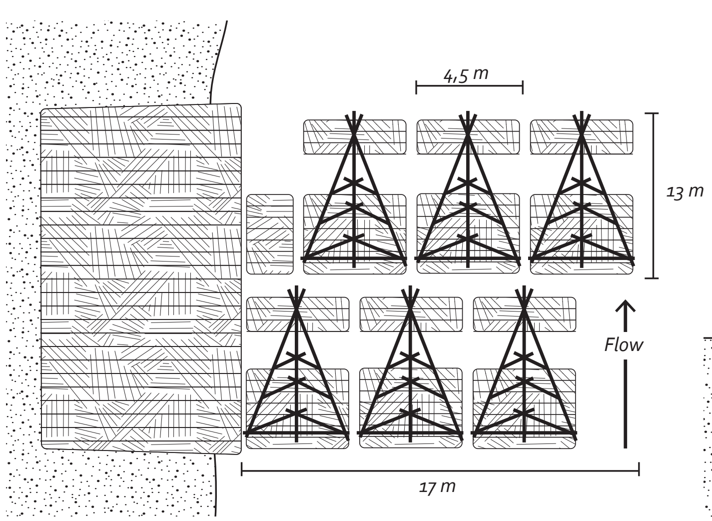
6.3.1 Conventional groynes

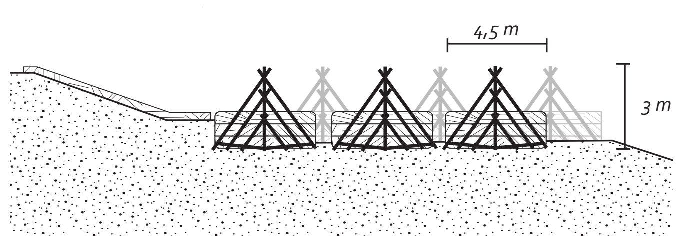
An important asset of the proposed groynes is that they can be build up out of a series of individual objects. This makes the intervention easily executable in phases, which in turn implies a better monitoring and adjusting of the intervention.
Conventional groynes, as used for river normalizations in the Netherlands, are made out of boulder clay and basalt blocks. These groynes block the water flux for the full 100%, whereby the water has to find a new path. These groynes are mainly used to get the deepest possible scour in the middle of the channel (Staverden, 1983). Sometimes full blockage of the stream is unwanted, certainly when the channel is dominated by suspended sediment in the water, like the Ems-estuary. The construction of semipermeable groynes is in these situations more suitable. Semipermeable groynes slow the water down instead of diverting the stream, which will enhance sedimentation between the groynes and in turn narrow the profile of the channel (Staverden, 1983).

Most common used semipermeable groyne constructions are made of pole rows, wherein the distance between the poles defines the degree of permeability. These structures, however, are relative vulnerable to damage by ice, storms or collision by ships. A more stable semipermeable groynes-structure can be found in Japanese rivers. The so called 'Sacred Cow' consists of a framework of stable bamboo triangles reinforced with wire mesh cylinders filled with stones [figure 6.17]. The length of a single 'Sacred Cow' however, is with 13 meter, limited. Which is why the 'Sacred Cow' is often placed in rows. Because a dam of 'Sacred Cows' exist of multiple elements, the construction is very easy to adjust and adapt to the environment. On top of that, the permeability of the 'Sacred Cow' can be modified, by doubling the rows or changing the amount of stones in the construction [figure 6.17].

Figure 6.17 | The Sacred Cow;. Impression and technical drawings (based on Staverden 1983)







6.3.2 Abandoned oilrigs as 'Sacred Cow' for the Ems-estuary

Just like Japan has its 'Sacred Cows' as identification for the river works in their country, a construction which suits the local characteristics of the Ems-estuary is needed. Obvious are the brushwood pole rows (Dutch: rijshoutdammen) used during the land reclamation of the salt marshes. There are, however, some practical disadvantages for these pole rows. In the first place the pole rows are quite vulnerable. As stated above the pole rows will not survive a collision by a ship. But most restricting is the depth of the shipping channel. To narrow the shipping channel, constructions with a length up to more than 10 meters are needed. Poles with these lengths are rare, especially considering that they need extra length for a solid foundation. The replacement of the wooden poles by concrete ones may solve the problem, but the construction of these concrete poles will be expensive and the construction is still delicate.

Oilrigs as solution

The solution for this problem lies north of the Ems-estuary; in the North Sea. For years, the North Sea was a paradise for oil companies like Shell and BP. The soil under the North Sea contains an enormous amount of natural gas and oil. But this is slowly depleting and some oilrigs, which have been standing there for decades, are starting to collapse (Deiters, 2010). The oil companies, which own the platforms, are obliged to remove the unused platforms from the sea out of concern for nature and safety of the shipping industry. This implies that in the upcoming years, hundreds of abandoned oilrigs have to be dismantled and be brought ashore for further recycling, and Eemshaven is one of the Dutch harbours in race for this new industry.
Would it not be great if these platforms could be used as the 'Sacred Cows' of the Ems-estuary? Thereby not only restoring nature in the estuary but also stimulating the economy in the Ems-estuary.

Figure 6.18 | Retired oilrig UK sector 49/4a Chedwick is drawn to Eemshaven for dismanteling.(photo: Flying focus)

Intermezzo:
The abondoned oilrigs of the North Sea

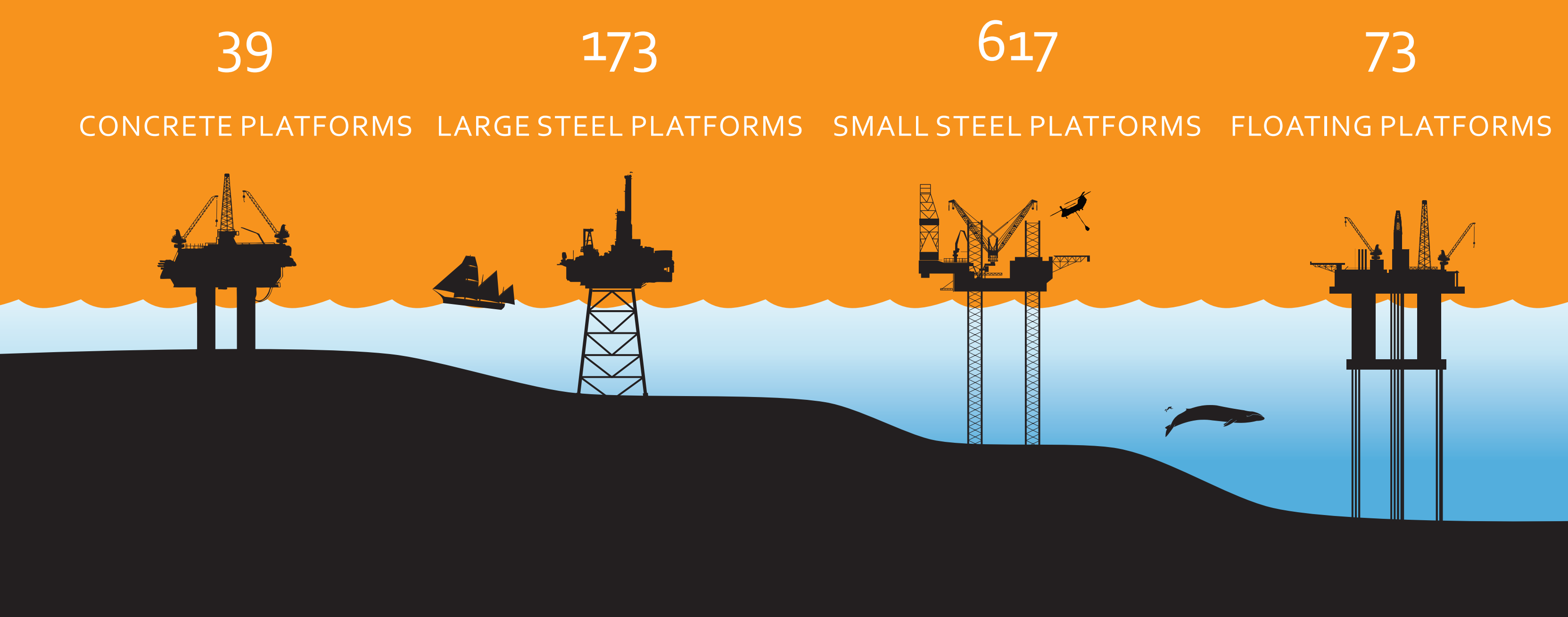
Figure 6.19 [(right] | Position and ownership of the oilrigs in the North Sea

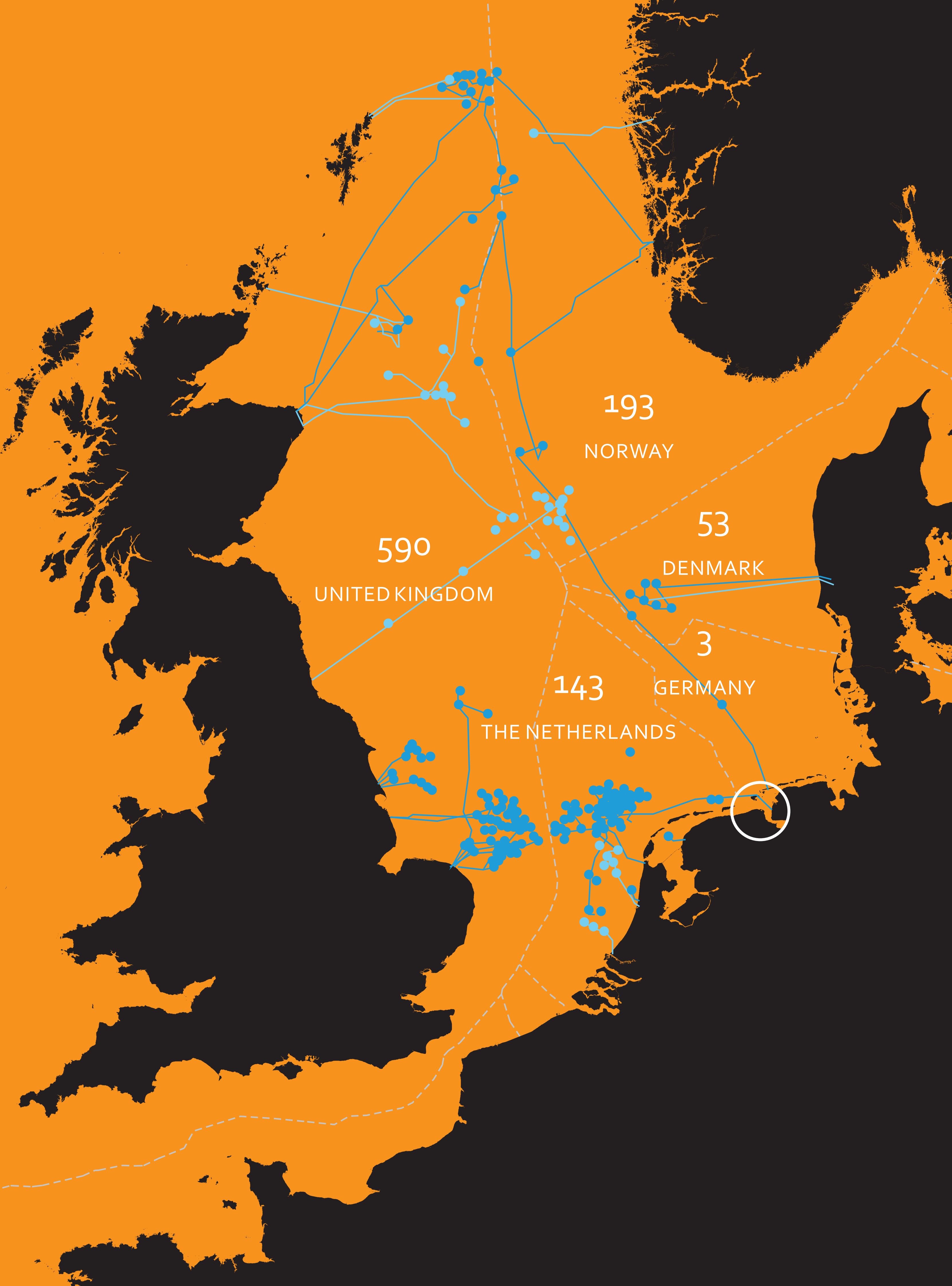
The first oilrig of the North Sea was settled in 1969, which was soon followed by many more. This, despite of the relative high exploitation cost of the North Sea oil due to the required off shore technology. The quality of the oil, however, is outstanding, which results in a total of 982 oilrigs settled in the North Sea nowadays. Most of these platforms belong to the United Kingdom (590) and Norway (193), but also the Netherlands (143), Denmark (53) and Germany (3) profit from the oil and natural gas reserves in the North Sea. In particular the centre of the North-Sea, where the borders of the North Sea nations come together, contains large amounts of oil (Ecomare, 2012).

In the North Sea there are various types of oilrigs, each suited for different depths and types of soil and the accessibility of the underground oil. The most common types are: floating platforms (73) small steel platforms (617) large steel platforms (173) and concrete platforms (39) (O'Donnell, 2010).

Most of those oilrigs were settled at the end of the last century. Assuming that an average oilrig lasts approximately 15 years, implies that a large part of the oilrigs in the North Sea have reached the end of their life, and currently 54% of all the rigs need to be replaced (Zee, 2011). The business which is engaged with the removal of old platforms is undergoing substantial growth. And this is necessary, because next decennia, only from the Dutch part, 15 till 25 oilrigs have to be decommissioned every year. The costs for the decommissioning of the shunted oilrigs in the whole North Sea is estimated, by energy-consultancy firm Wood MacKenzie, up to 39 billion euro's (Deiters, 2010). These costs have to be divided into the construction of dismantle vessels, the real decommissioning job and the recycling of the platforms onshore. And it may be ascertained that acquiring one of these business implies a boost for the investments and employment in the region.

Figure 6.20 [down] | Types of oilrigs present in the North Sea




193
NORWAY
53
DENMARK
590
UNITED KINGDOM
3
GERMANY
143
THE NETHERLANDS

6.3.3 Benefits of the oilrigs groynes

Economic impulse

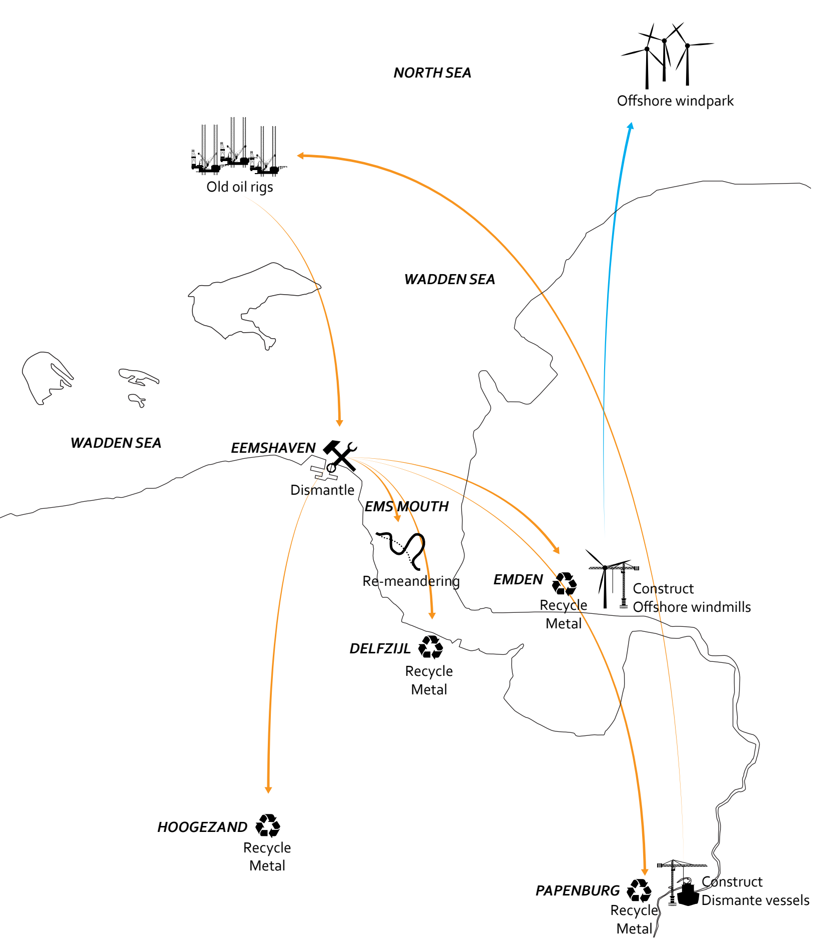
As stated in the Intermezzo, the decommission sector will flourish coming years. Many ports along the North Sea try to acquire parts of this billion euro industry. To assign the ideal location for this industry a couple of parameters are decisive (Eijgenraam et al., 2001):

Establishment conditions decommission industry

- In the first place a sea harbour is needed to ensure enough depth for the towing and dismantling vessels.
- The second criterion is distance; the further away the oilrigs have to towed, the higher the total cost for decommissioning will be. Therefore, the location of the Eemshaven, at the border of Germany, the Netherlands and the North Sea, is ideal.
- The last criterion is the presence of recycling industries in the vicinity of the harbour. Eemshaven has, with metal processing industries in Hoogezand, Delfzijl, Emden and Papenburg, enough hinterland for the recycling of old materials [figure 6.21].

Besides the recycling industry, the Ems region can contribute to the construction of large dismantling vessels. Its specialisation in the construction of cruise ships and utility vessels, like containers ships and gas tankers, makes that the Meyerwerft has the knowledge and the ability to construct these massive ships. In conjunction with the production of cruise ships the Meyerwerft in Papenburg can specialize in the construction of dismantle vessels, thereby stimulating the employment in the Ems-region.

Figure 6.21 | Offshore network for the Ems-region.



The last and perhaps most important economic benefit using 'oilrig'- groynes are the costs for placement. Based on data from 'rigs to reefs' projects in the United States, the placement of 'oilrig'-groynes will costs $15.000 per meter (Velazquez, 2010), while conventional dams will cost almost €200.000 per meter. This means a cost-difference of roughly factor 10, taking into consideration the less required length using conventional dams (Stronkhorst et al., 2010).

All together, the Ems-region thus has a huge potential to specialize further in the offshore sector. The combination of new offshore opportunities, like the placement of 90 new wind parks in the North Sea coming years (Wadden Sea Forum Secretariat, 2011) and the withdrawal of the old offshore oil industry and its related decommission industries creates enormous changes for the Ems-region coming years.

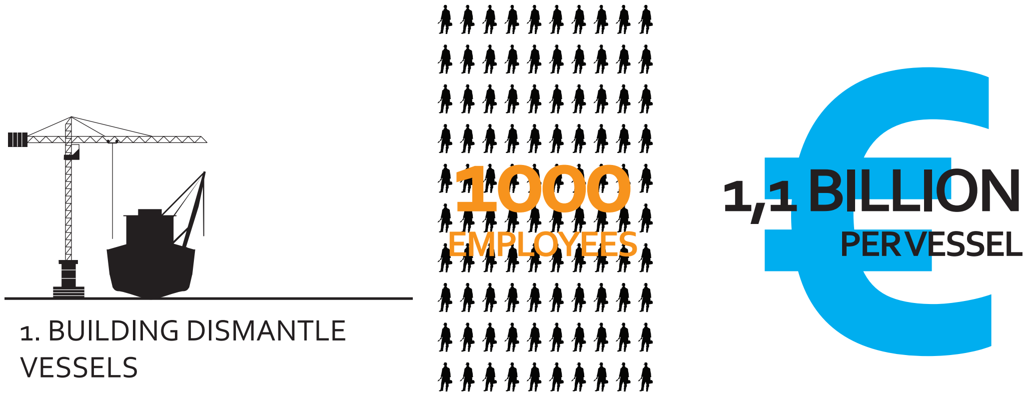


Figure 6.22A | Building dismantle vessels. Based on data All Seas for the construction of dismantle vessel Pieter Scheltes (De Ingenieur, 2011) and employment rates of the Meyerwerft (Meyerwerft, 2012)

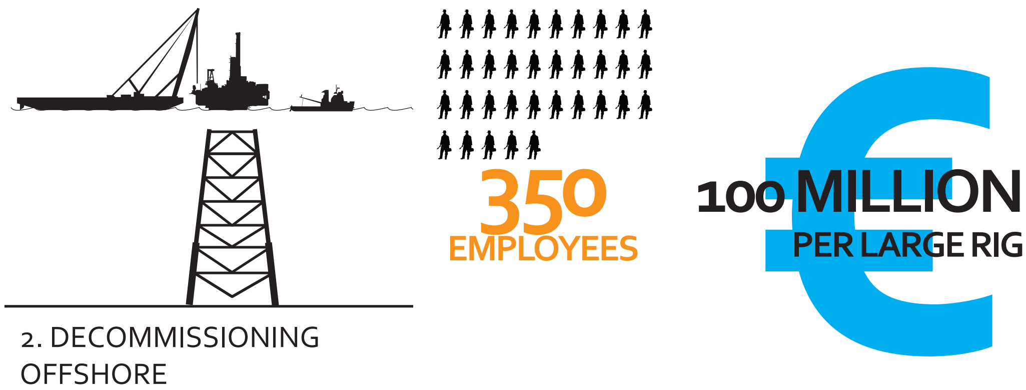


Figure 6.22B | Decommissioning offshore. Based on information Heerema about the decommissioning of large oilrigs from the North Sea. (Deiters, 2010)

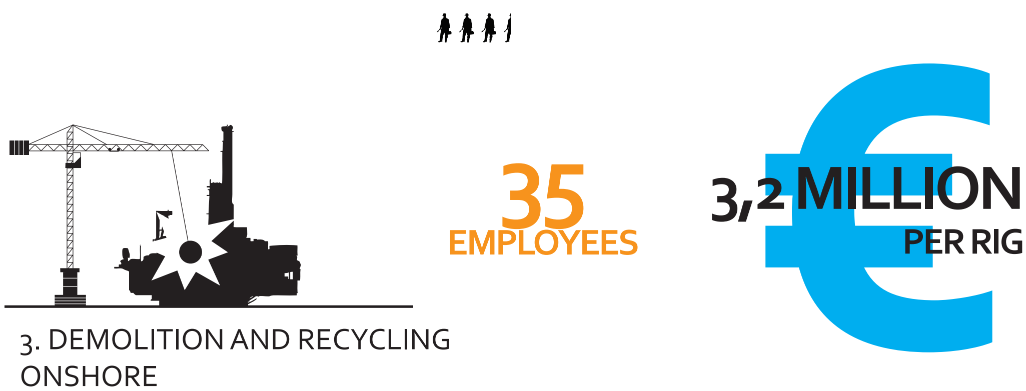


Figure 6.22C | Demolition and recycling onshore. Employment rates based on information Veolia about the demolition of oli rigs onhore in Scotland (Scrapmonster,2012) Costs based on cost-benefits anlysis of the European Commission on 'green-demolition' of oil tankers. (European commission, 2004)

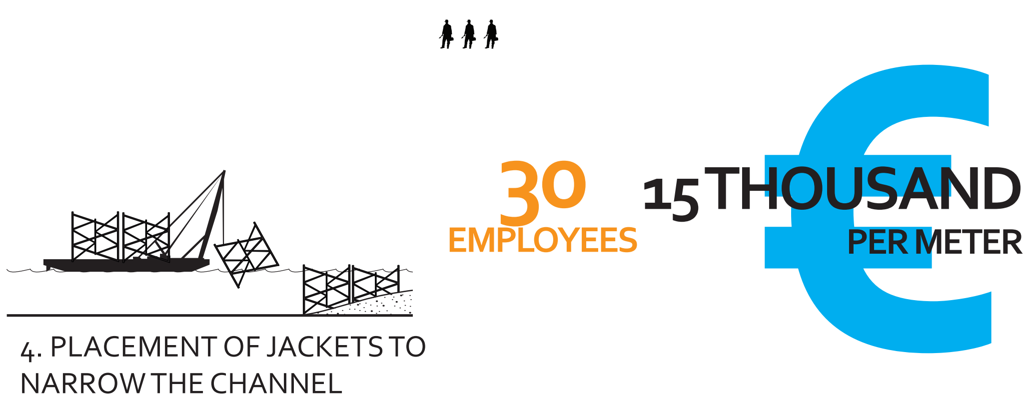


Figure 6.22D |Placement of jackets to narrow the channel. Based on information Rig-to-Reef programs in the Gulf of Mexico. (Velazquez, 2010)

Ecologic impulse

The use of abandoned oilrigs for the construction of groynes to narrow the stream seems mainly to ensure economic gain for the Ems-mouth, but the oilrigs also bring new biodiversity to the Ems-mouth. Looking at the ecology of the North Sea an interesting fact stands out. The highest biodiversity in the North Sea is found around the oilrigs and wind parks. The reason is simple. In the first place the oilrigs and the wind parks ensure shelter ground for all kind of fish and other sea life. Researchers discovered, for example, that the concentration of codfish is relatively high around wind parks. The most likely reason for these high quantities of fish is the absence of fishery in the wind parks (Reformatorisch Dagblad, 2012). [figure 6.23 & 6.24]

Solid substrate

The next reason for the high biodiversity around the oilrigs is the presence of artificial solid substrate by the jackets of oilrigs. Originally, shellfish banks like mussel and oyster beds form the most important source of solid substrate, but due to overfishing, large parts of these natural substrates have disappeared (Bouma et al., 2009) [figure 6.25].This is disadvantageous for the marine ecosystem, because the solid substrates are characterized by a high biodiversity, offering a habitat for various species, like oysters, mussels, anemones, barnacles and starfish which cling to the solid substrate. These solid substrate-biotopes serve in turn as food source for fish, like pout or codfish, crustacean species, like crab and lobster, and birds, like cormorants, which forage around the solid substrates (Bouma et al., 2009). The importance of the solid substrate is best noticeable at the mussel beds in the Wadden Sea. Although the mussel beds cover just 3-4% of the Wadden Sea, they provide food for 25% of all bird species in Wadden Sea (Dankers et al., 2004).

Rigs-to-Reefs

Artificial substrates, like old oilrigs, may contribute to the restoration of characteristic old substrate biotopes. The American research program 'from Rigs to Reefs', which was introduced in 1979, showed successful results in creating new habitats by sinking old oilrig jackets. Within 6 months the toppled rigs off the Louisiana coast, were turned into "thriving reef ecosystems completely covered with marine life", which attracted new invertebrates, fish species and other organisms which made the food web even more complex (American Petroleum Institute, 2011).

All together the use of old oilrigs as groyne-structure implies not only an impulse to the economy of the Ems-mouth, but generates ecological profit as well. It means the restoration of the Wadden Sea's most important habitat hotspots, the boosting of food production and the attraction of new species (Dankers et al., 2004, American Petroleum Institute, 2011).

Figure 6.23 | The jackets of oilrigs attract may fish for shelter and food. (EDF, 2012)

Figure 6.24 | Codfish flock together at windmill park Prinses Amalia in front of the Dutch coast. (Photo: Ruud Moerkens)

Figure 6.25 | Biodiveristy Hotspot.
Anemones and star fish cling to an componend of an ship wreck in the North Sea, which in turn attracts other species like fish. (photo: denoordzeeschoon.nl)

6.4 Local design: Arrangement of the structures

6.4.1 From oilrigs to groynes

Not every type of oilrig is equally suitable for the construction of groynes. Most ideal are the ‘small steel platforms, which are, like the ‘Sacred Cows’, relatively small open constructions and available in large amounts [figure x.x]. Not the whole oilrig is useful for the construction of groynes. The topside has to be dismantled, because of its pollution by crude oil and chemicals. The jackets, however, are very useful for the construction of groynes [figure 6.26].

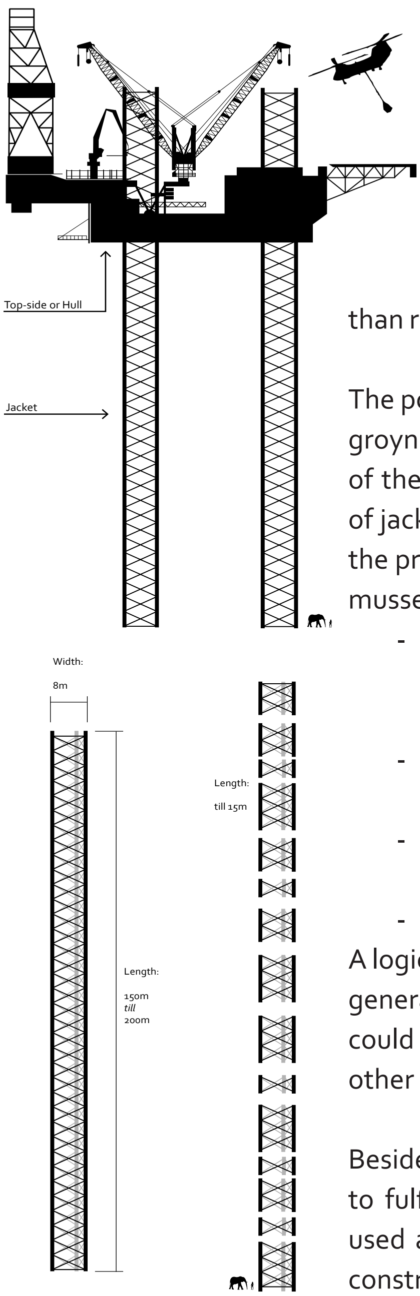


Figure 6.26: From the oilrigs which are withdrawn to the shore, only the jackets are used to build groynes.

Cutting the jackets into small pieces results in small elements, which can be set in rows to form groynes-structures comparable to the structures of the ‘Sacred Cow’ [Paragraph 6.4.2]. A standard small steel platform, with 3 jackets of 150 meters, is sufficient for 75 single structures with a height of 10 meters and 8 meters long. This means that one oilrig provides enough material for 360 meter of groynes. At the moment 333 small steel oilrigs are waiting in the North Sea to be dismantled, taken into account a discard rate of 54% (Zee, 2011), this implies enough material for almost 120 km of groynes, far more than required in the Ems-estuary.

The positioning of the structures determines to a large extent the permeability of the groynes. The standard arrangement of the structures is based on the arrangement of the ‘Sacred Cows’. Whereby, the standard rig-groyne is build up as a double row of jacket-elements to ensure the largest sedimentation effect. As became clear from the previous paragraph, the jackets will function as genuine magnets to shellfish and mussels, which will quickly overgrow the entire element. This holds several benefits:

- You can eat them. Mussels are a delicacy in western-Europe and a booming business in the Scheldt estuary, while they actually extract mussels from the Wadden Sea and sell them as ‘Zeeuwse mussels’.
- Mussel communities generate an even higher biodiversity and biomassality, because they provide shelter and food for smaller and larger animals.
- With a denser mussel population, the permeability is reduced, reducing flow speed and thus increasing sedimentation.
-

A logical step is to accelerate the settlement of mussels and oysters and increase their generated benefits. Using wire mesh, ropes and starting populations a jacket fragment could be a fully closed mussel structure within a year, ensuring sedimentation as any other closed element would.

Besides wire mesh filled with mussels, other elements can be added to the structures to fulfil new functions within the estuary. In the first place the structures can be used as shellfish cultivation elements. Fresh mussel spat settles on the wire mesh constructions and will grow into adult mussels which can be sold in the surroundings or exported abroad. The cultivation of mussels and other shellfish may revitalise the lost fishing industry and provide new opportunities for the coastal ‘wierde villages’, which lost their connection with the estuary [chapter 5].

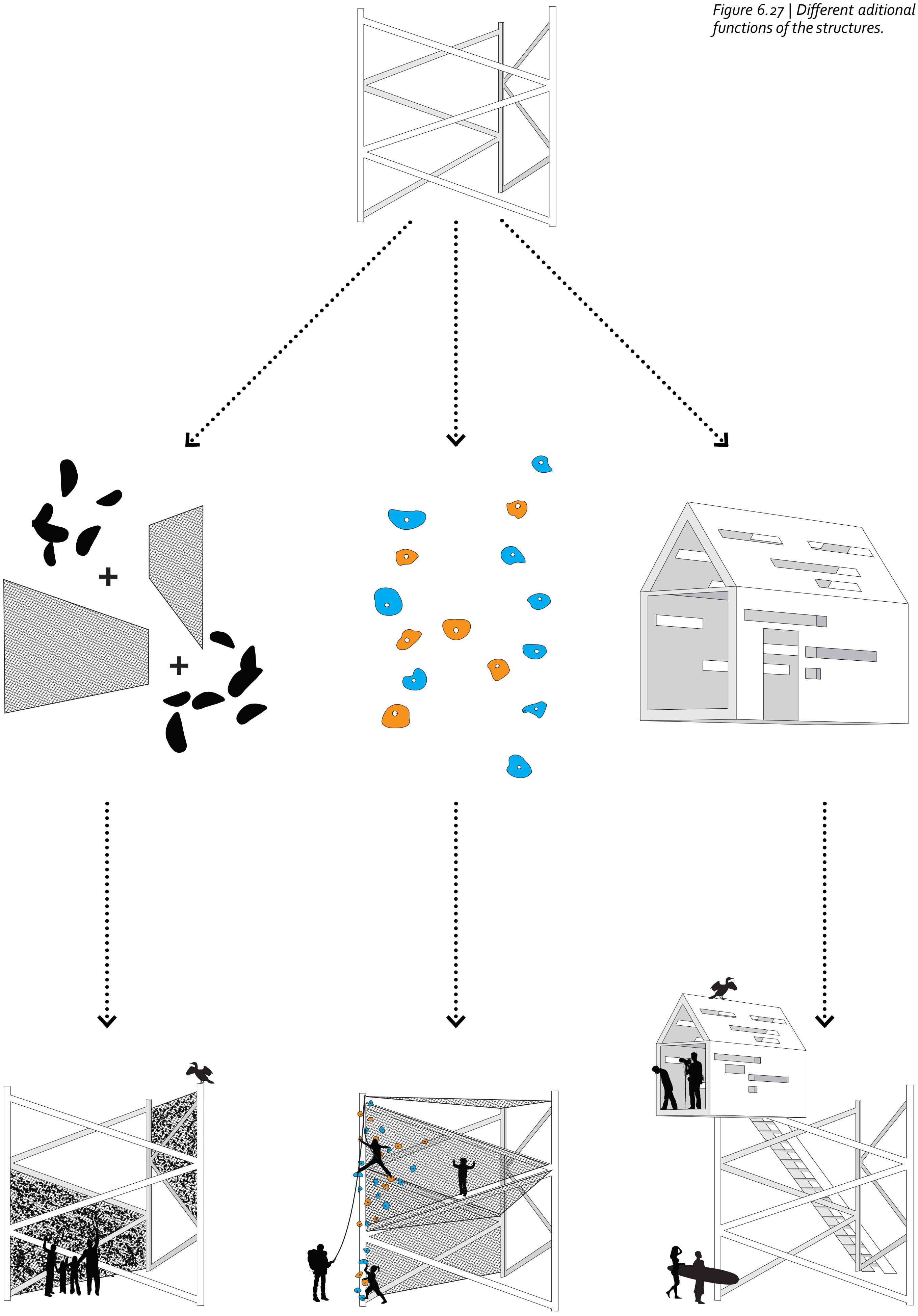


Figure 6.27 | Different aditional functions of the structures.

Fascination for the jackets

But apart its technical, ecological and economical functions, the cut up jackets also have social meaning. When walking over the mudflats, which is made possible by the jackets, it is impossible to not be fascinated by these elements, which fit well within the character of the industrious estuary, but also seem very out of place. You want to see them, touch them and especially climb on top of them to get even a better view of the Ems estuary. Certain jackets can be equipped with extra features to give these 'jacket-tourists' a place to wait out the tide or a helping hand to climb on top. [figure 6.27]. These features should be rare and should signify a special location, like the last jacket in the inner bend of a meander.

6.4.2 Arrangement variety

Local variety of the structures can be reached by the addition of different features, as stated above, or by a different arrangement of the structures. Varying the arrangement of the structures creates groynes with different characteristics. A variety in sedimentation patterns arises, by assembling the structures closer or further apart, or by attaching more or less wire mesh to the structures. These differences in arrangement have consequences for the extent of sedimentation and the amount of mussel yield [figure 6.28]. At places where large and stable sandbanks are desired, the structures have to be placed close together [figure 6.29 & 6.30]. At places where a more gentle and erratic shore is wanted, the structures can be placed with more irregular distances, which results in a more divers morphological pattern, with more transition an thereby a higher biodiversity [figure 6.31 & 6.32]. Finally the highest mussel yields are achieved when the structures lose their inter-connectedness. The open arrangement makes a coherent sedimentation impossible, whereby the largest possible surface remains available for the cultivation of mussels [figure 6.33 & 6.34].

Figure 6.28 | Relation between sedimentation rate, mussel yield and spacing between the structures.
More spacing implies less sedimentation but more mussel yield because the structures less covered with sediment.

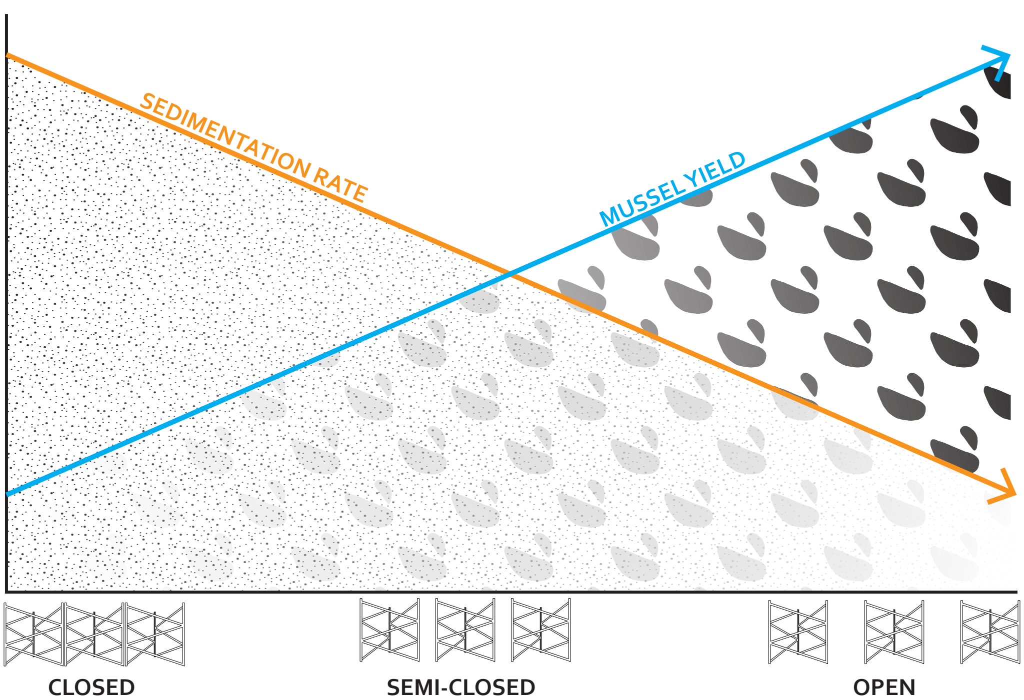


Figure 6.29 | Model study for the arrangement of 6 groynes. More length with the same amount of groynes implies more permeability and thereby less sedimentation.

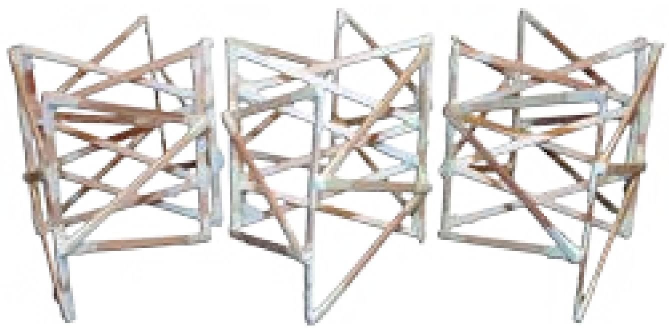


Figure 6.30 | 'standard' arrangement of the structures. To ensure th highest possible sedimentation and the largest surface available for mussel cultivation.

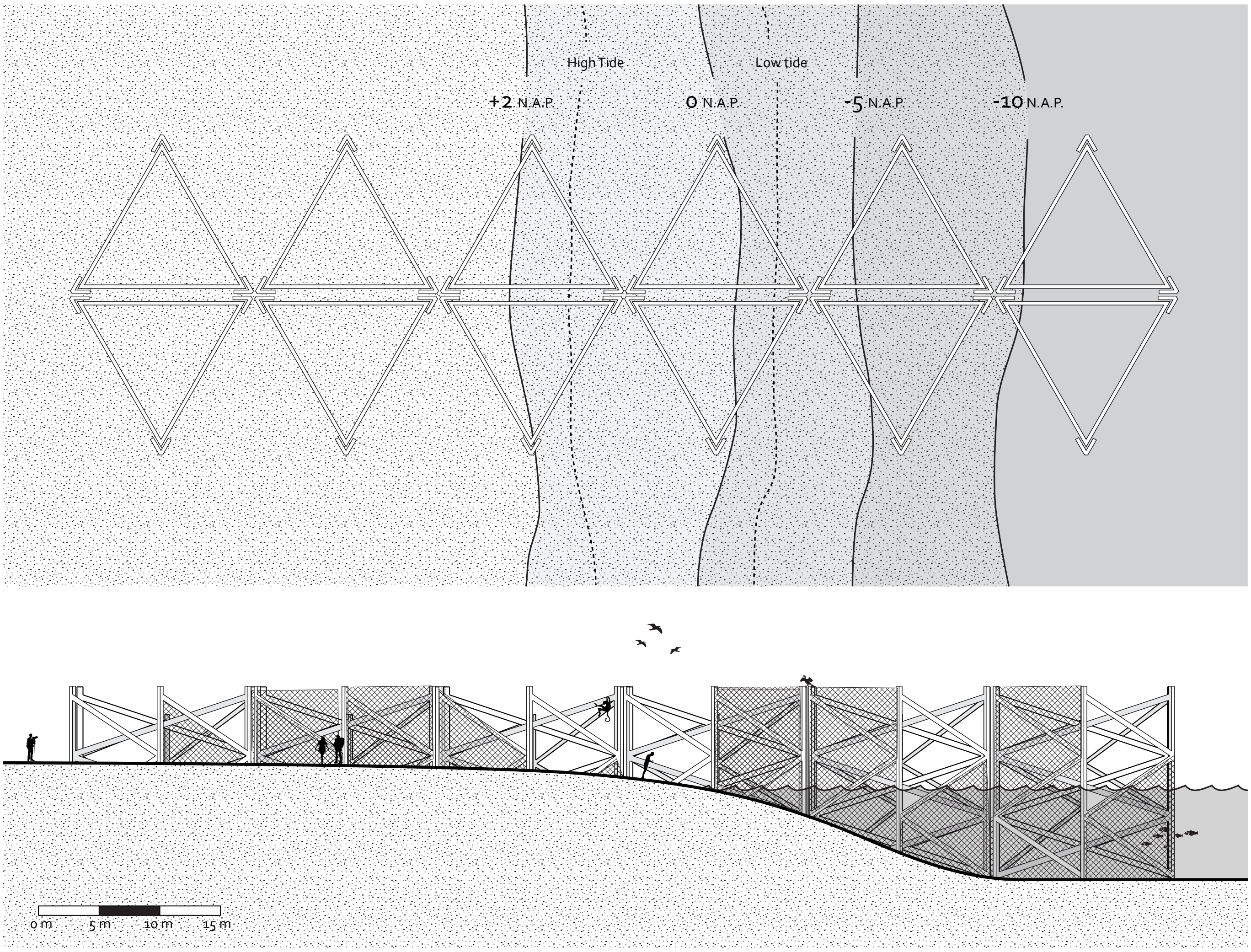


Figure 6.31 | Model study for the arrangement of 6 groynes. More length with the same amount of groynes implies more permeability and thereby less sedimentation.

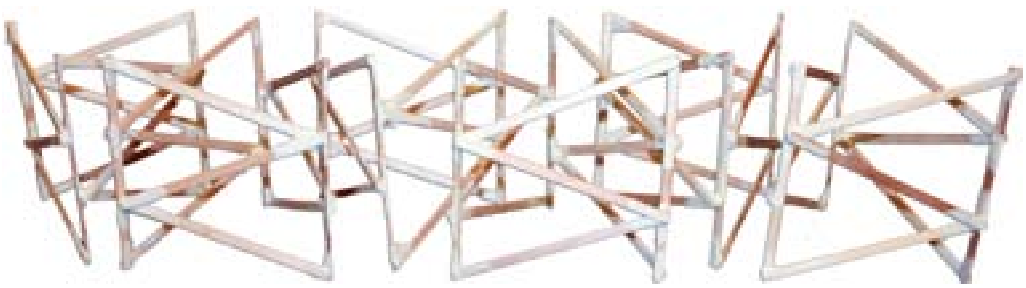
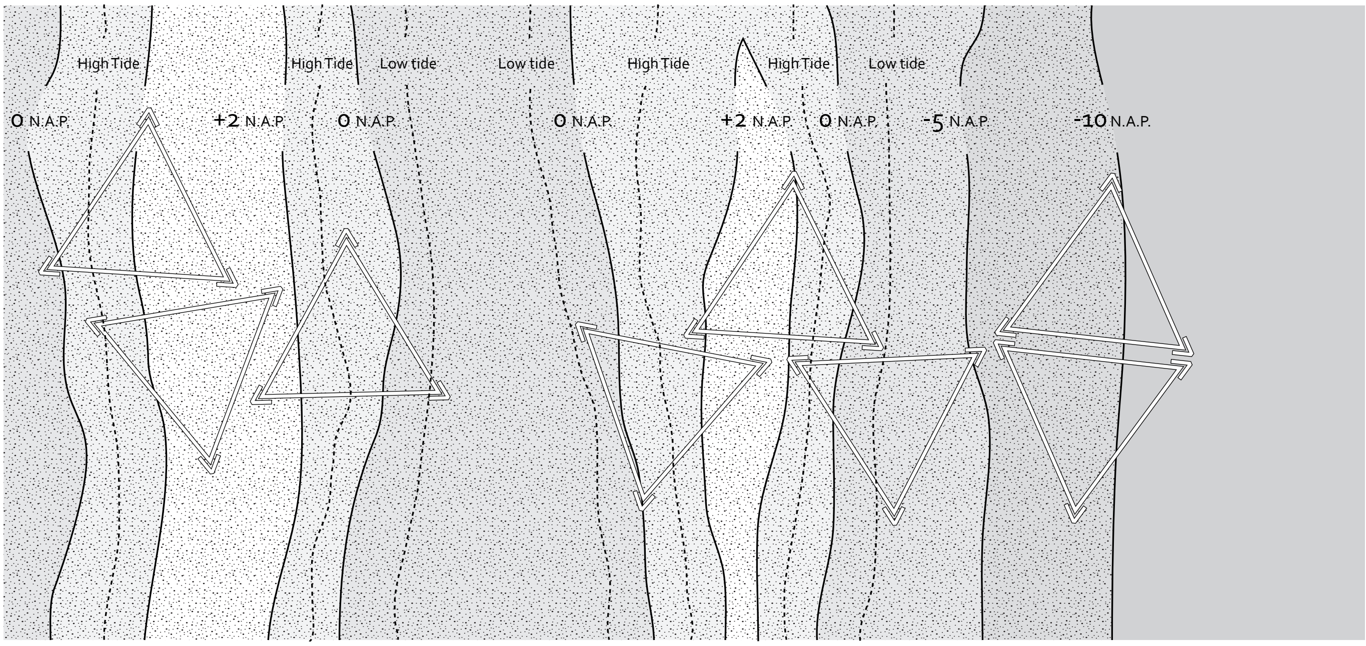


Figure 6.32 | 'irregular' arrangement of the structures. To ensure variety in sedimentation patterns which implies a higher biodiversity.



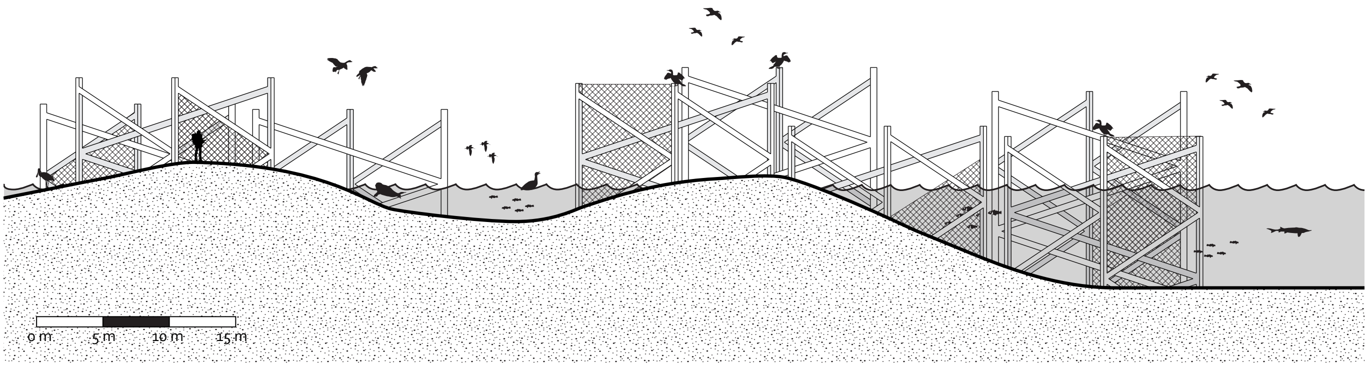


Figure 6.33 | Model study for the arrangement of 6 groynes. More length with the same amount of groynes implies more permeability and thereby less sedimentation.

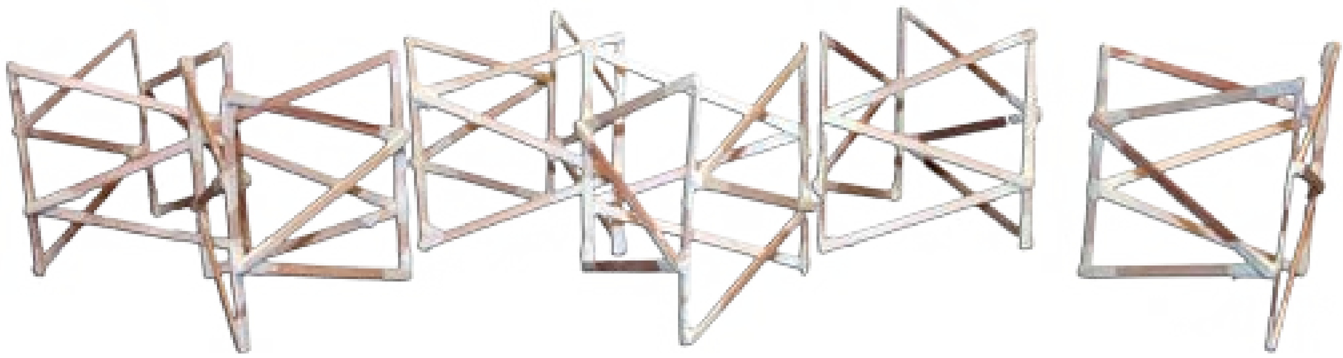
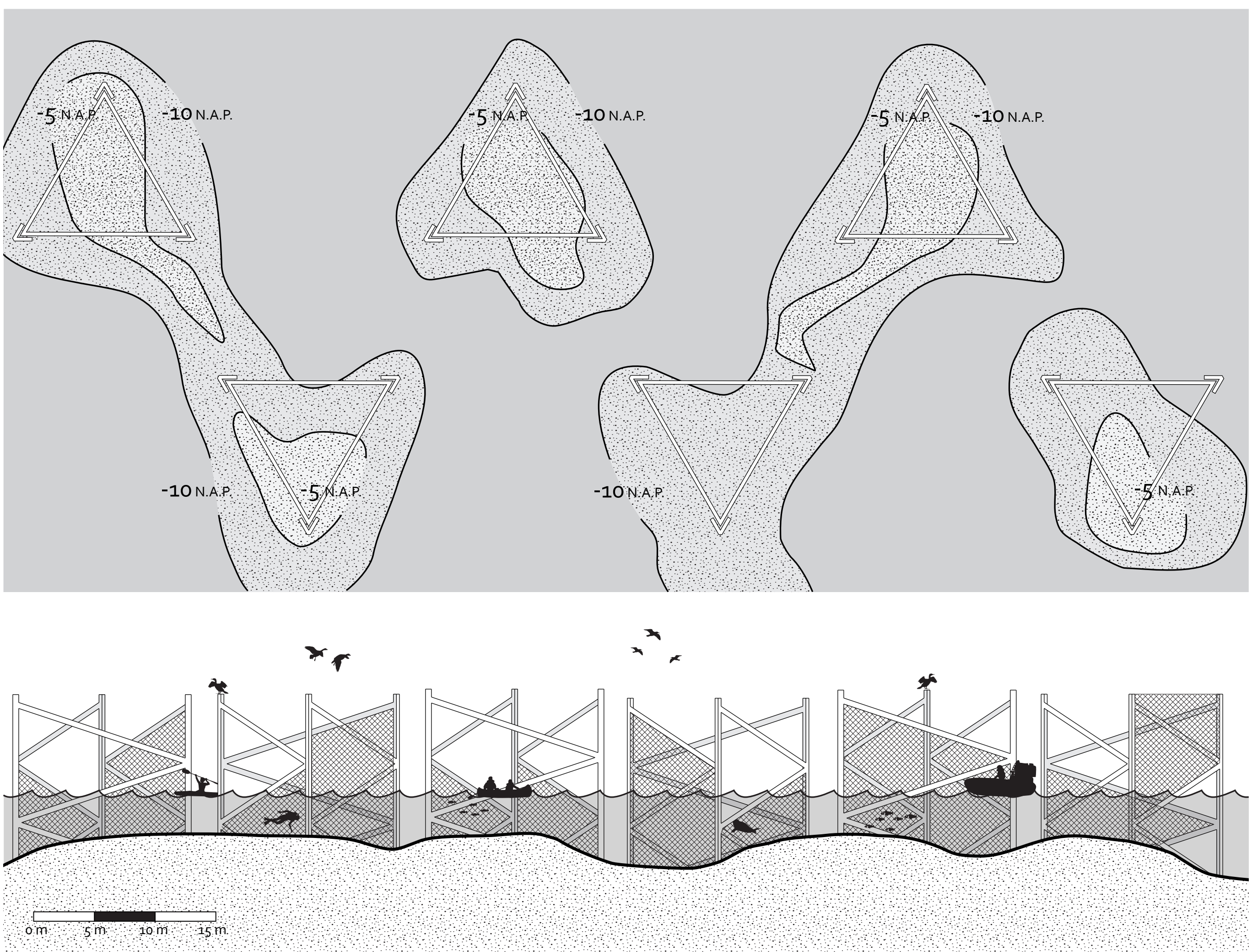
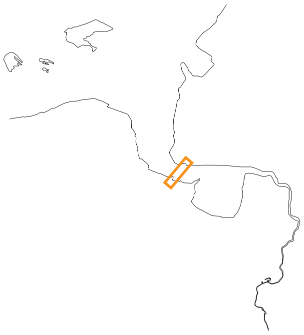


Figure 6.34 | 'Open' arrangement of the structures. An open arrangement results in less sedimentation but on the other hand in higher mussel yields.





Delfzijl: City at the Ems-estuary

In contrast to the estuary city that Delfzijl formerly was, it has now become an inland orientated city lying next to an inaccessible and unattractive bathtub with mud, formed by adaptations in the shipping channel and the erection of a massive defense wall [Chapter 5].

The new interventions, proposed in paragraph 6.2, will tighten the gully and lead it again along the inner city of Delfzijl, while the interventions themselves become exciting visiting places, formed by multiple lines of groyne-structures, where you can and want to go.

The structures ensure a high level of sedimentation, which results in high and outstretched sand banks, attracting wild life and new forms of estuarine recreation. The structures itself can be used as climbing elements or other adventurous activities. Finally, a number of old oilrigs will be towed to the shore as a nesting place for birds, urbex location or hotel to accomplish the connection between Delfzijl and the estuary.

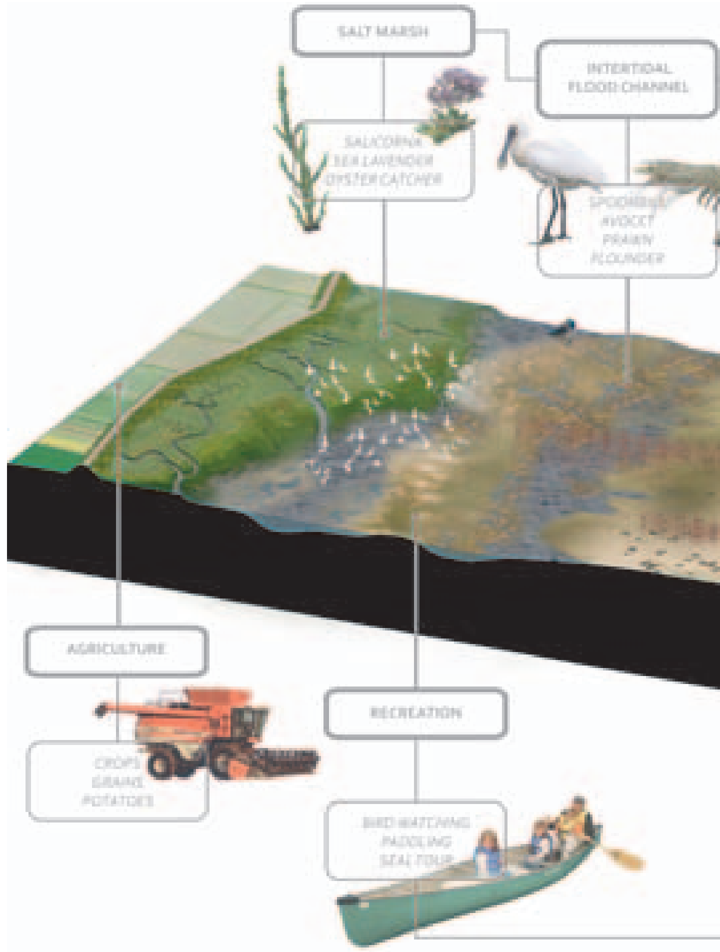


Figure 6.35 | Artist impression New 'estuary front' opposite Delfzijl

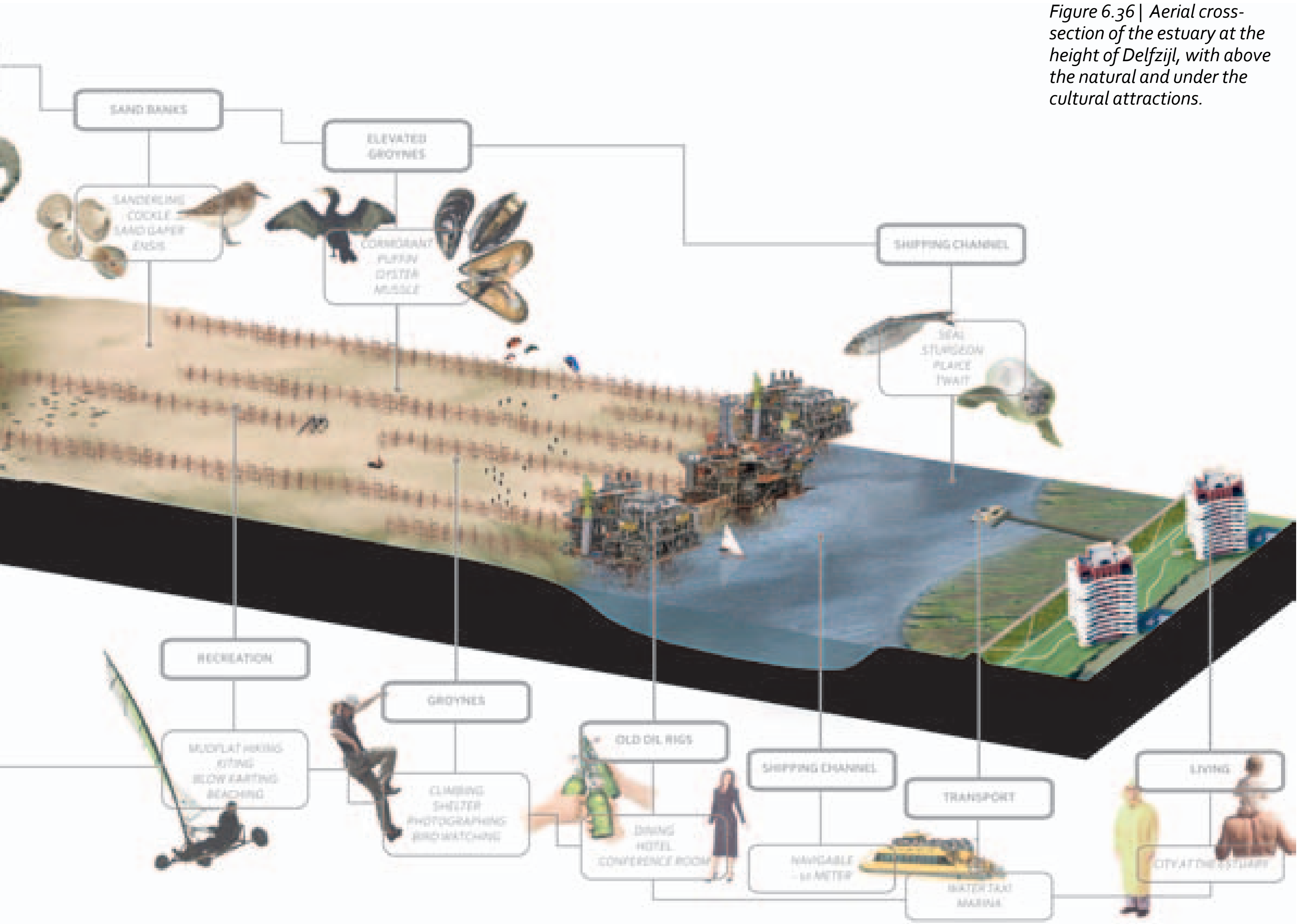
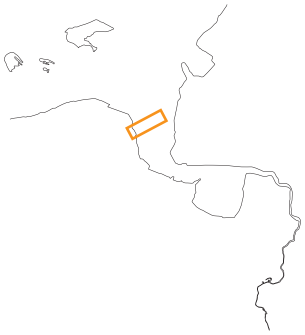


Figure 6.36 | Aerial cross-section of the estuary at the height of Delfzijl, with above the natural and under the cultural attractions.



Fishing grounds 'Bend of Watum'

Since the fifties the Bocht van Watum (Bend of Watum) has been disappearing, but thanks to the re-meandering of the shipping channel, the bend is resurrected as an important flood gully in the estuarine channel system [Chapter 6.2]. This new flood channel allows former creeks, along which villages like Spijk arose, to reconnect with the estuarine system [Chapter 5]. This should enable an ecological revival and give new possibilities to the many 'Wierde villages' along the dike.

The groynes-structures are placed alternative in a number of long and multiple short rows. This creates small bays along the flood gully, which are perfect for the cultivation of mussels and other shell fish on freestanding oilrig elements. These peaceful bays and the presence of mussel farms could reinstate sea grass fields, a rare habitat, now completely disappeared from the Ems.

With this the local ecology is given a boost, while at the same time providing new opportunities for local businesses for many Wierde villages.

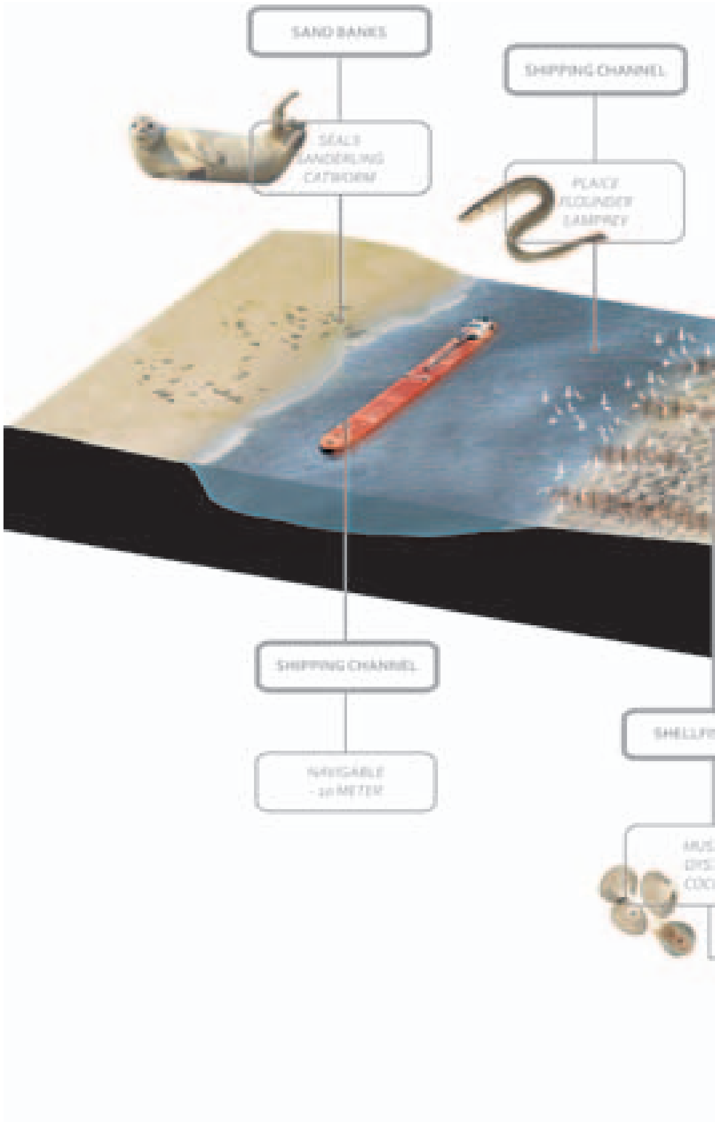


Figure 6.37 | Artist impression. New fishing grounds for the 'wierde villages'.

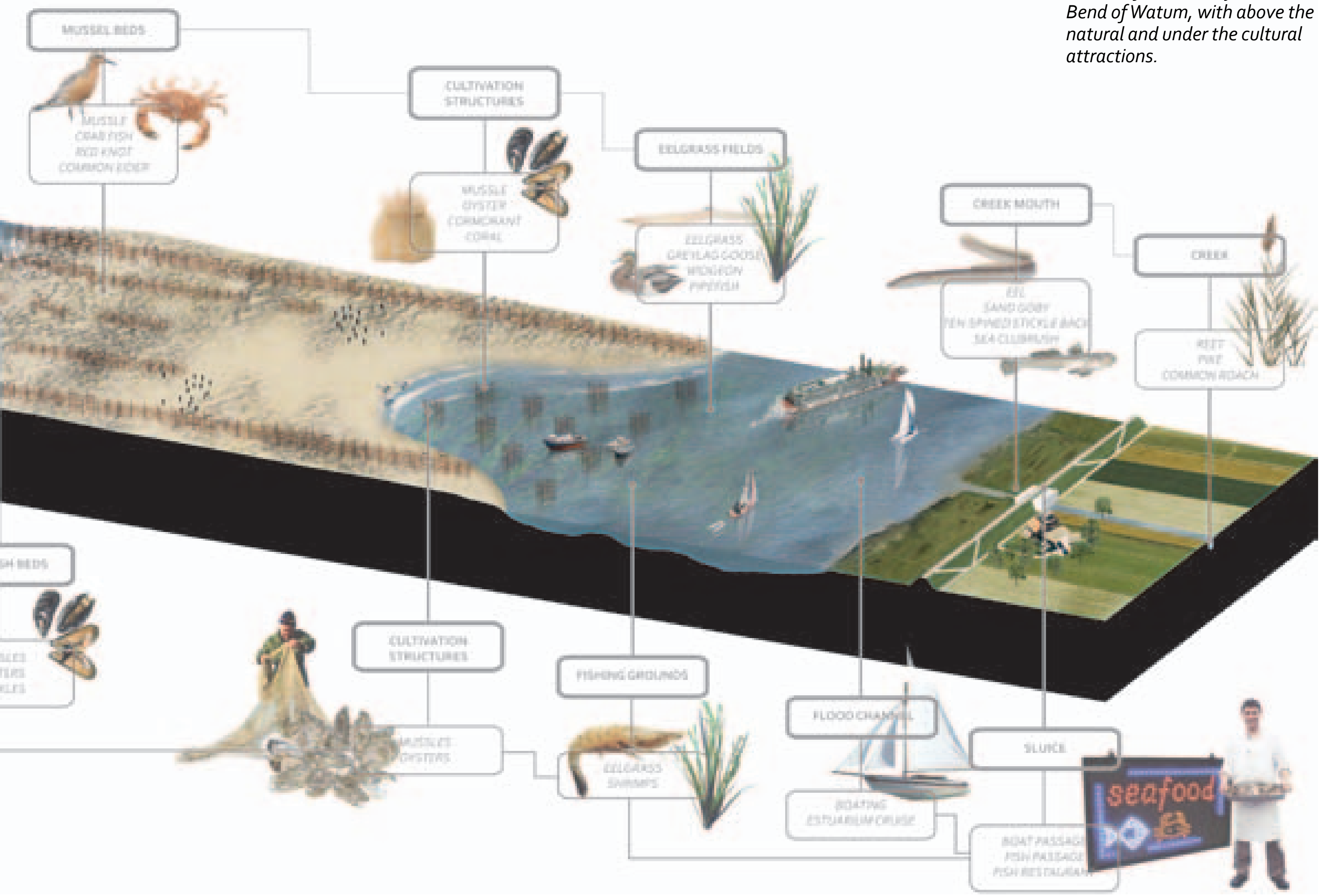
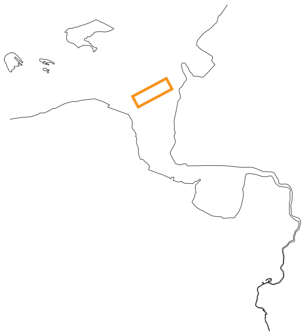


Figure 6.38 | Aerial cross-section of the estuary and the Bend of Watum, with above the natural and under the cultural attractions.



Nature at the Ems mouth

To the east of the Eemshaven lies the upper part of the intervention in the estuary mouth. At this spot the estuary broadens and flows into the seemingly endless Wadden Sea. This transition used to be a fluid one, but the normalization of the shipping channel has led to a sharp edge between channel and mudflats.

This transition is restored with a scattered addition of groyne-structures, fitting to the typical erratic pattern of the Wadden Sea. These structures are constructed with a modest height, because they could easily disturbs the delicate sublimity of the endless mudflats. At the edge of the shipping channel there is a relative high amount of groynes-structures, while further into the mudflats the amount of structures decreases, thereby accentuating the smooth transition between the estuary and Wadden Sea.

In contrast to the lower sections, this landscape is more open and deserted, leaving room for birds and seals to take over, with the occasional lost mudflat hiker looking for a place to wait the upcoming tide.

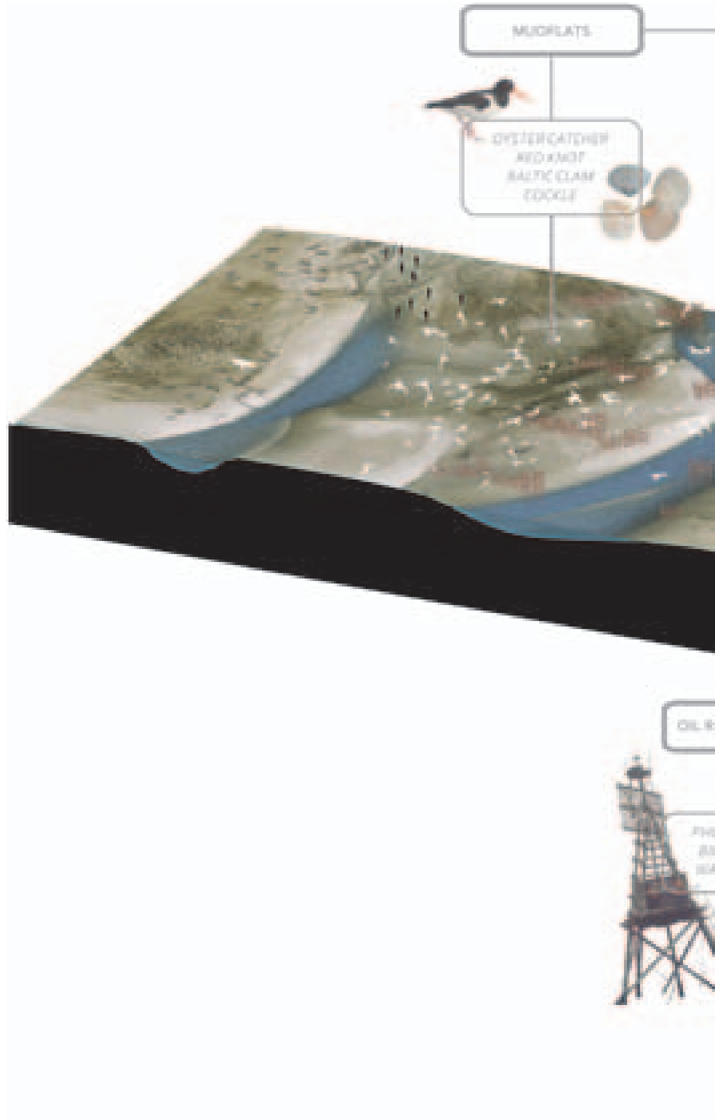
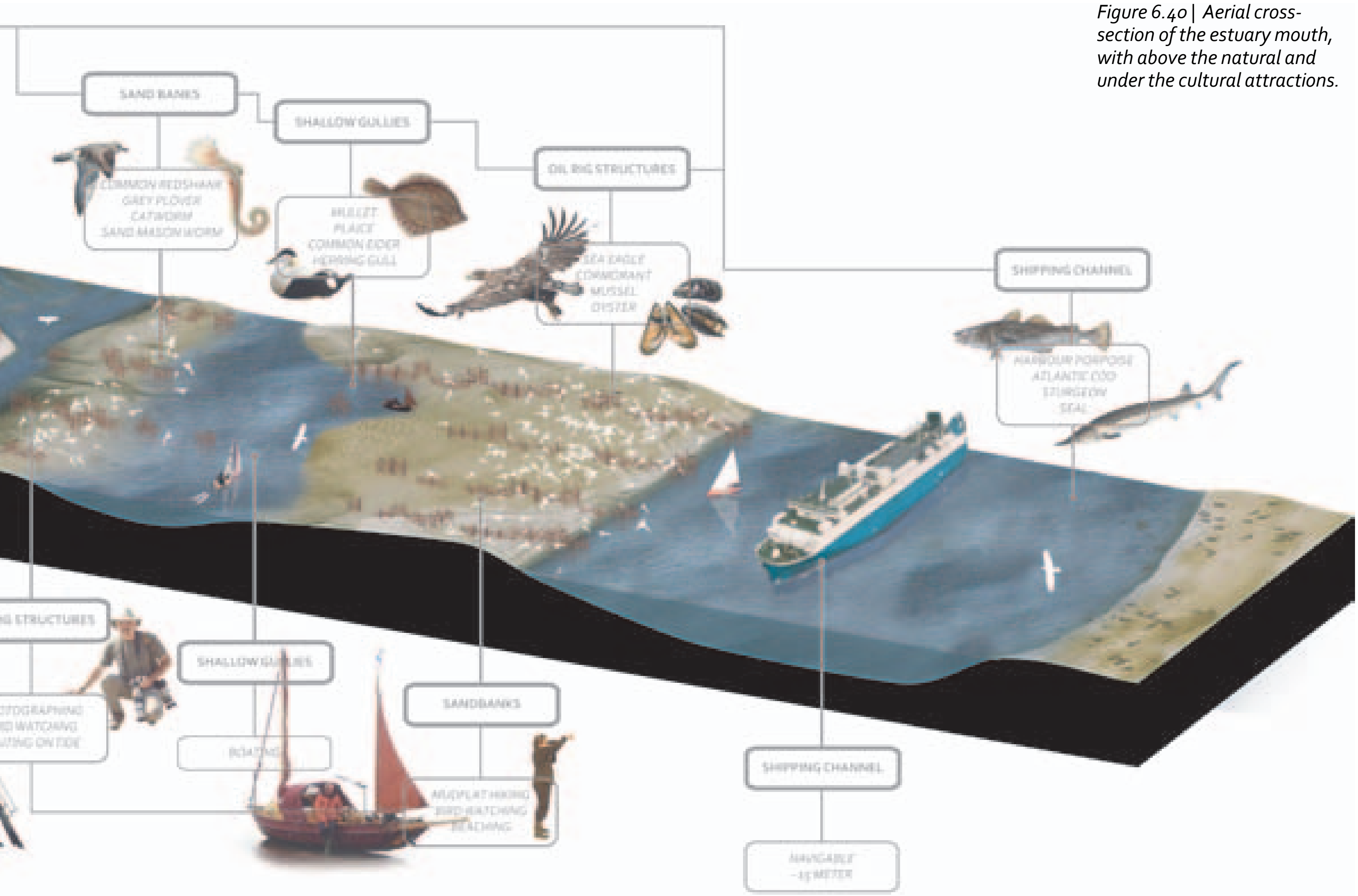


Figure 6.39 | Artist impression. Dynamic nature at the estuary mouth.

Figure 6.40 | Aerial cross-section of the estuary mouth, with above the natural and under the cultural attractions.



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7

DESIGN:
THE TIDAL RIVER

7.1 Introduction

From chapter 4 [design strategy] it became clear that two strategies are needed in order to restore the balanced situation in the Ems-estuary:

- Reduce the cross-sectional width, thereby reducing the tidal inflow;
- Expand the tidal basin, thereby giving more space to absorb the tidal pulse.

Chapter 6 has handled the first strategy, this chapter will revolve around the second: expanding the tidal basin. The design of the tidal basin is founded on the technical aspects of the solution, as discussed in chapter 2 [research framework] and chapter 4 [design strategy]. A landscape architectonic design is however more than a technical solution and to create a workable solution the design has to be fitted to the Ems landscape, as introduced in chapter 5 [design challenges].

Chapter 4 concluded that in order to increase the tidal storage of the Ems, the best choice is to create tidal polders in the tidal river zone and focus on the weak Rheiderland region. This would not only create a technical solution, but by using the cultural aspects it can give an impulse for the degrading region. The construction of the polders, the characteristics, placing, mechanics and effects will be discussed in this chapter and is divided the following:

§ 7.2 Strategic design: The tidal polder
§ 7.3 Detailed design: Placement and growth
§ 7.4 Local design: Polder dynamics

7.2 Strategic design: The tidal polder

7.2.1 Introduction

The goal of expanding the tidal basin is to increase the total tidal storage of an estuary. This gives the incoming water more room and more time to slow down, which will ultimately mean that sediment will have the chance to settle instead of being in constant motion, thus decreasing turbidity. Chapter 4 has given a short overview of the different measurements that could be taken to increase the tidal basin in the lower Ems. These strategies can be summarised into three types:

- Deepening floodplain (increase the room [m3], but maintaining the same area [m2])
- Increasing floodplain (increase the room [m3] by increasing the outer dike area [m2])
- Tidal polder (increase the room [m3] by increasing the inner dike area [m2])

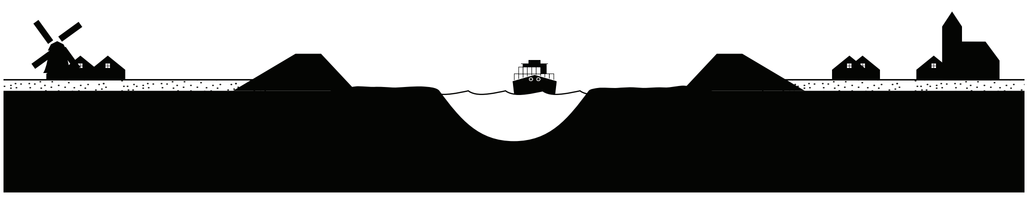


Figure 7.1 | The basic model of the Ems river. A deep shipping channel, shallow floodplains and dikes on both sides.

More outer-dike space (deepening floodplain):
Increasing the tidal basin by deepening the floodplain is a workable method with limited impact on the surrounding landscape. The impact which it potentially has on the total tidal storage is however limited, as the floodplain is already small in size. Any considerable impact would have to considerably change the floodplain, damaging large parts of a now valued habitat and decreasing the important water braking effect.

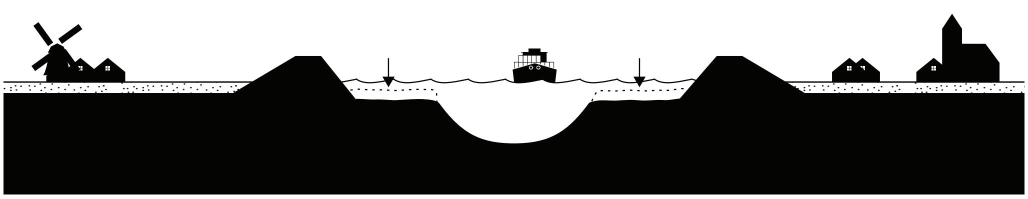


Figure 7.2 | Increasing the tidal basin by deepening the floodplain.

More outer-dike space (move the dikes):
Moving the dikes to increase the floodplain of the river is a successful method applied for instance in the Room-for-the-River projects in the Netherlands. It is a logical countermeasure for the historic pattern of gradually decreasing the floodplain by several diking phases. By moving the dike back, the physical and psychological distance between the Ems and the hinterland is increased. This has as counter side a decrease of the already limited relationship.

The downside of both of these measurements is the incompatibility with the Meyer Werft. Every time a new cruise ship has to pass through the Ems, the water has to be

pushed up on top of the normal flood level by 1,5m [CH3]. Increasing the floodplain would require a larger amount of water to be pushed into the Ems, increasing costs and negative effects on the Ems and is unwanted by the Meyer Werft (Schuchardt et al., 2009).
This in itself should not be a reason to cancel these operations, but taking in the previous arguments and the obvious incompatibility with the cruise industry, which we want to maintain, measurement in the floodplain are far from perfect.

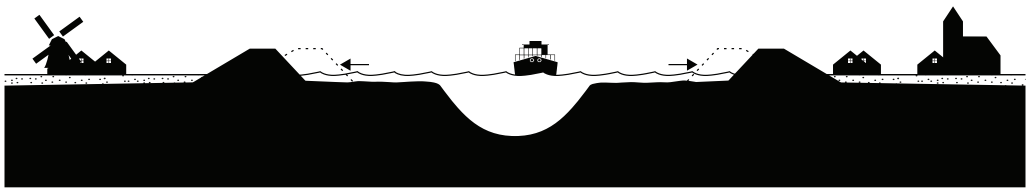


Figure 7.3| Increasing the tidal basin by moving the dikes.

More in-dike space (tidal polder):
The advantages of the tidal polder over the other strategies have already been introduced in chapters 4 and 5. Its ability to control, its growing capacity and its ability to reconnect the villages of the Ems with the estuary via the sluices are some of its benefits. Although the construction of tidal polders implies the same loss of land as with the relocation of the dikes, the consequences for landowners are different. For they will not lose their land to the Ems, but the function will have to change. The controllability of the tidal polders makes them suitable for new types of land use, like aquaculture and biomass production, while the relocation of the dikes only produces extra nature.

Based on technical, ecological, social and economical arguments, the tidal polder is the best strategy for the tidal river. This chapter continues from these statements and elaborates this strategy of the tidal polders for the tidal Ems-river.

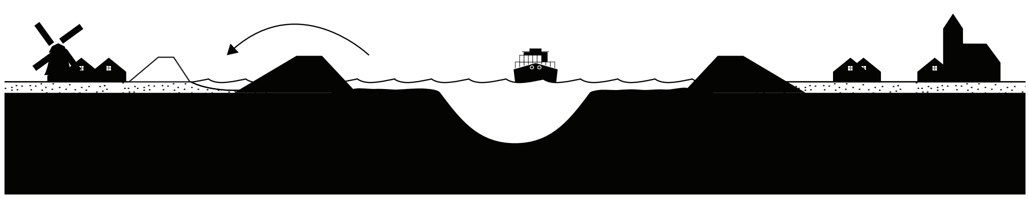


Figure 7.4 | Increasing the tidal basin building a tidal polder and thus more inner-dike space.

7.2.2 Basic principles

Instead of moving the main dike to enlarge the tidal basin, a tidal polder creates more room behind the main dike. This is done by building a ring dike behind the dike and constructing an inlet or sluice which allows water to flow through or under the dike (Welle, 1999, Schuchardt et al., 2009). This has the advantage that the in- and outflow can be regulated and closed off or opened when needed. To effectively increase the tidal storage of the Ems, the tidal polders have to be in direct connection with the river and always open during flood. If the tidal polders would only be opened during storm surges, it would only act as a safety measurement, and not increase the tidal basin.

The tidal polder affects the tidal basin in two ways:

Direct and indirect effect

- Direct; with an increased shallow floodplain, the surface on which water can slow down and settle its settlement is highly increased. This directly decreases the floating particle content of the water and diminishes the turbidity level (Schuchardt et al., 2009).
- Indirect; the turbidity level would quickly restore if the measurements did not permanently increase the total tidal storage. And although the larger the better, a tidal polder of any size will increase the tidal storage and thus move towards a more natural balance between tidal basin and cross-sectional width (Kemerink, 2004).

The theoretical basis for the tidal polders is supported by the results of two example from practise, which provide valuable case information for the new tidal polders in the Ems:

Hedwigepolder

Located in the Westerschelde, next to the Ems the only remaining open estuary in the Netherlands, the Hedwigepolder is already a famous or infamous example within the Dutch politics. The Hedwigepolder is small polder of 300ha in Zeeuws-Vlaanderen close to the Belgian border. It is to be 'ontpoldert' (flooded after being reclaimed in the past) to function as nature compensation for the deepening of the Scheldt river, which is needed for the accessibility of the port of Antwerp (Belgium). But due to political and social indifference, the polder has not been flooded yet although the earliest plans date before 2004 (Kemerink, 2004).

Like the Ems, the Westerschelde has also reached an unbalance between tidal storage and cross-sectional width, which is even going to be increased due to planned deepening in favour of economic drivers. The 'ontpoldering' of the Hedwigepolder is therefor needed to create a larger tidal basin and reduce this unbalance. The Hedwige differs from a typical tidal polder in that it does not have a sluice, but the main dike is removed and becomes fully connected to the Westerschelde, and able to develop freely [figure 7.5]. And although the mechanics varies for the Ems polders, because of its shared objective, the Hedwige polder is used as a reference.

Figure 7.5 | Artist impresion of the planned Hedwige Polder. (source: Dienst Waterwegen en Zeekanaal, 2011)

Figure 7.6 | Polder Breebaart
A working example of a tidal polder in the Dutch Rheiderland region.
(Source: https://beeldbank.rws.nl/)

Polder Breebaart

Located at the same Ems estuary, polder Breebaart (60ha) is an excellent example for the new tidal polders, for it is already functioning as one since 2001 [figure 7.6]. The polder is actually the remainder of the Dollard werken, which were introduced in the Dollard plan Intermezzo in Chapter 1.

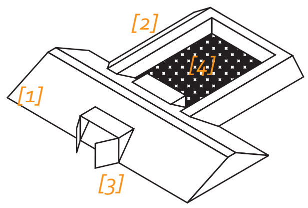
After parts of the Dollard were reclaimed and diked, a large sluice was constructed for the beginning of a broad canal. The government however came back on their former decision and decided to cancel the plans for the Dollard plan. The former tidal area thus remained barren region from 1979 until 2000, when a large gully was dug and reconnected to the Ems-Dollard via a concrete culvert (Dutch: duiker) (Esselink and Berg, 2004). The culvert can be opened and closed when needed and is used for flooding regime experiments, to test effects of different height, durance and intensity of floods (Esselink and Berg, 2004). After the reconnection with the Ems, mudflats and saltmarshes formed again, rapidly increasing the biodiversity and bio-massiveness, among which the Avocat (Recurvirostra avosetta), a key-specie for the Ems estuary (Esselink and Berg, 2004, Tydeman, 2005).

The objective of this polder is not to expand the tidal storage, but its development in sedimentation and biodiversity also applies to the Ems polders, and is used as a reference.

This paragraph has given an overview of the reasons for a tidal polder and two examples, the next paragraph continues with the tidal polder, and describes its dimensions, properties and placement.

7.3 Detailed design: placement and growth

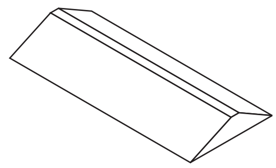
7.3.1 Building blocks



The basic ingredients for a tidal polder consist of:

- The existing main dike [1];
- A newly constructed ring dike [2];
- A sluice or inlet system [3];
- The inside of the polder: the tidal area [4].

Main dike



The dikes along the Ems are generally uniform in size from Emden until Papenburg. They are lower and narrower than the sea dikes which start after the weir at Gandersum (Emssperrwerk). Figure 7.7 shows the model of the Ems-dike that is around 6m high and is comparable with the other dikes in the Wadden Sea, for it has a tapered top. The Ems dikes therefor also lack roads and paths on top of the dike, unlike many Dutch counterparts that often function as a main road or recreational route.
This is illustrative for the Ems-dikes, for people are not warmly welcomed on the dikes; paths are absent and apart from some rare and minor entry points [figure 7.9] the access is fenced and not stimulated [figure 7.10]. This all does not stop people from climbing over fences to enjoy the Ems, but it is a rare sight and most paths are formed by sheep rather than people [figure 7.8].

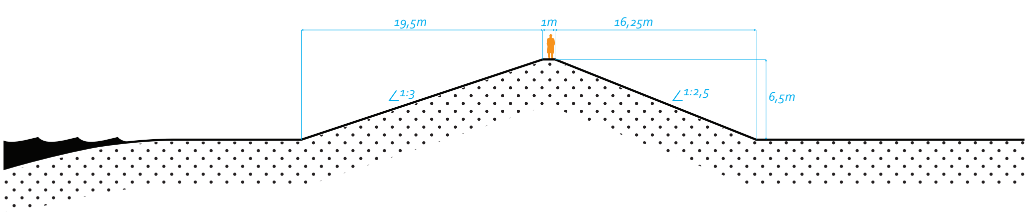


Figure 7.7 | Cross-section of a typical Ems dike.

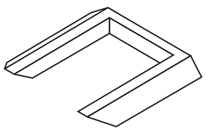
Figure 7.8 | The tappered dike

Figure 7.9 | Rare connection to the Ems dike

Figure 7.10 | Fenced dike

The dikes itself need little alteration to be used as a tidal polder and mostly at the inlets of the system, where canals can be dug to facilitate in- and outflow and concrete or stones can be fitted to prevent erosion (Esselink and Berg, 2004).
Occasionally there are double dikes, where a new dike was constructed in front of the old dike, which can be used as a ring dike for the new polder.

Ring dike



Apart from the occasional double dike, the ring dike has to be newly constructed. Because the ring dikes do not have a water breaking function they can be relatively low. Storms can be kept out by closing the sluices, but the dikes have to be high enough to hold the monthly spring flood, so a height of 3m would suffice, increasing to 4m at the most downstream polders, where the tidal difference is the largest. The dikes are kept deliberately low to retain a difference with the main dike and to prevent the ring dike from being an visual obstruction. The top deck is level and 2m in width; enough for a comfortably walk and to pass other people, but still keeping the impression of a narrow dike [figure 7.11,A]. This effect is strengthened by tailoring the dike, which does not lessen the strength of the dike, but enhances the 'dike experience' (Feddes and Halenbeek, 1988).
A difference is made between the perpendicular dikes and the dikes that run parallel to the main dike. The parallel dikes are given a much fainter slope that fades into the landscape and again prevents a visual competition with the main dike when seen from outside [figure 1.11.B]. The inside slope and height is constant and should strengthen

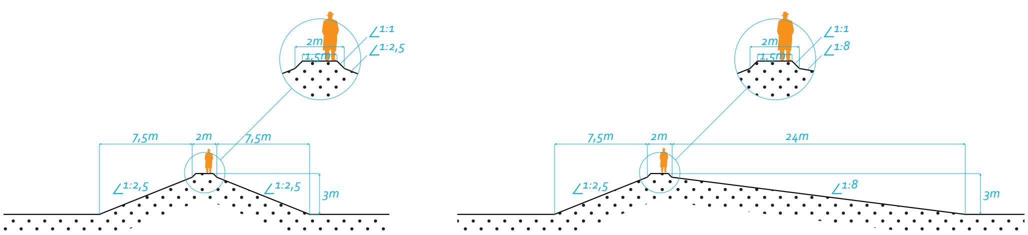
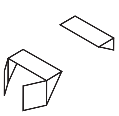


Figure 7.11 A,B | Cross-section of a ring dike.

the feeling of being inside the polder, and closed off from the outside world.

Sluice (in- and outlet)



Where possible, the tidal polders should make use the present sluices of the Ems [figure 7.14 & 7.15], as an efficient use of materials, but foremost to make a connection between the Ems and the villages behind the dikes. Most of these villages have their own sluice, because they were founded at a side branch of the Ems. The construction

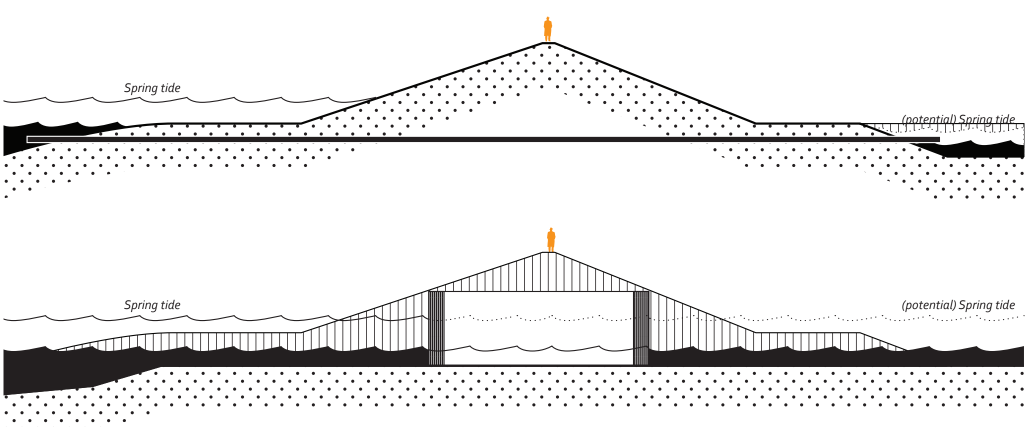


Figure 7.12 A,B | A: Cross-section of main dike with culvert.
B: Crooss-section of main dike with sluice

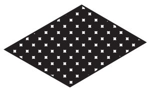
and heightening of dikes reduced this connection to a point that it is almost non-existent, but creating the tidal polders at these places can revitalize the estuarine connection.

When former sluices are not available there lies the choice between two options:

- Constructing a culvert [figure 7.12 A] is the easiest and cheapest solution. Concrete piping is put through the main dike, where water can flow through during high tide. The amount of water which is led through can be controlled, but is limited due to its minor size (Esselink and Berg, 2004).
- Creating a new sluice complex [figure 7.12 B] is a more expensive option, but when possible more preferred. Larger sluices provide more controllability and could allow the migration of larger animals or even small boats and canoes. The sluices could also act as physical and visual connection points and give the dike itself more attractiveness, something that it presently highly lacks.

Tidal area

The volume of the tidal polder is the section that needs least interventions and is largely dependent on the intensity and frequency of flooding and its location along the Ems. Facilitating the in- and outflow of the polder by digging can increase the effectiveness of the polder. It is however not necessary for the functioning of the polder as most of the Rheiderland lies from 0 to -2m NAP and the normal flood level is around +1,75m NAP. The excavation of the tidal area could however be a clever way to reduce the costs of the total operation and try to achieve a closed soil balance (Dutch: gesloten grond balans). Excavating the tidal area and using the soil, supplemented with sand and clay, can construct the new ring dikes more efficiently [figure 7.13], and could also be used to construct the next polders.



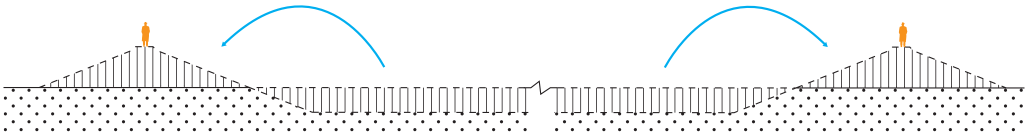


Figure 7.13 [top] | Cross-section of a tidal polder with a closed soil balance. The excavation of the soil is used for the construction of the new ring dike.

Figure 7.14 [bottom left] | The former sluice of Esklum

Figure 7.15 [bottom right] | A culvert going under the dike at Kloster-Muhde. A possile connection is fenced.

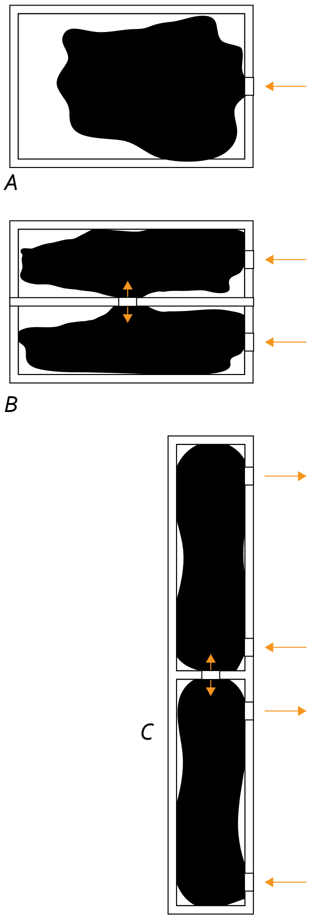


Figure 7.16 A-C | The most efficient orientation of a tidal polder is to be relatively small in size and with multiple inlets: thus C (after: Kadlec and Wallace, 1996, Walker, 1998 in: Johnson, 2002).

7.3.2 Size and dimensions

On the basis of chapter 2 and 3 it was determined that the Ems is a dynamic, constant changing estuary and in order to deal with the uncertainty that rises from this continuous change, any solution must be a growing one. This rule applied to the mouth region and also applies to the tidal polders along the tidal river. Rather than growing from one single point to one large polder, the strategy is to grow from multiple polders, which could eventually form a large connected polder zone.

For the size of a polder we can look at the examples as were named in the introduction. Polder Breebaart is with 60 ha relatively small, fully functions as a tidal polder and has shown general success. The planned Hedwigepolder is 5 times larger than polder Breebaart and is nearly 300 ha. This should also be a target size for the polders along the tidal river. They are small enough to remain manageable and floodable from one flood direction, but large enough to have an impact on the tidal basin (Kemerink, 2004). In practise, the tidal capacity of a polder will vary, depending on the local situation such as form of the main dike, existing infrastructure or soil depth.
As described in paragraph 7.3.1, deepening the polders is not necessary for the functioning of the polders, but could be applied to increase initial success. Because the total basin [P], as described in the tidal prism formula A=c*P (Steijn and Adema, 2000, Kemerink, 2004), is described in m3. A deepening of the polder will subsequently lead to a larger water storage ability and a larger tidal basin.

To achieve the best results in water irrigation and sediment distribution the orientation should be as described in figure 7.16 C (after: Kadlec and Wallace, 1996, Walker, 1998 in: Johnson, 2002). This placement avoids dead corners as much as possible and by connecting polders together with multiple sluices, the in- and outflow can be controlled to a much larger extent and create a string of polder beads (Kadlec and Wallace, 1996).

7.3.3 Growth and placement

As became clear of the theory in chapters 2 and 3, any solution must be a growing one, start small and experimental and grow gradually to the scale of the problem [CH 2.2, 3.2.4]. For the case of tidal polders this has the added benefit of connecting these polders to an existing phenomenon along the Ems: the old sluices [CH5]. This growing polder strategy also has several advantages over one large tidal polder:

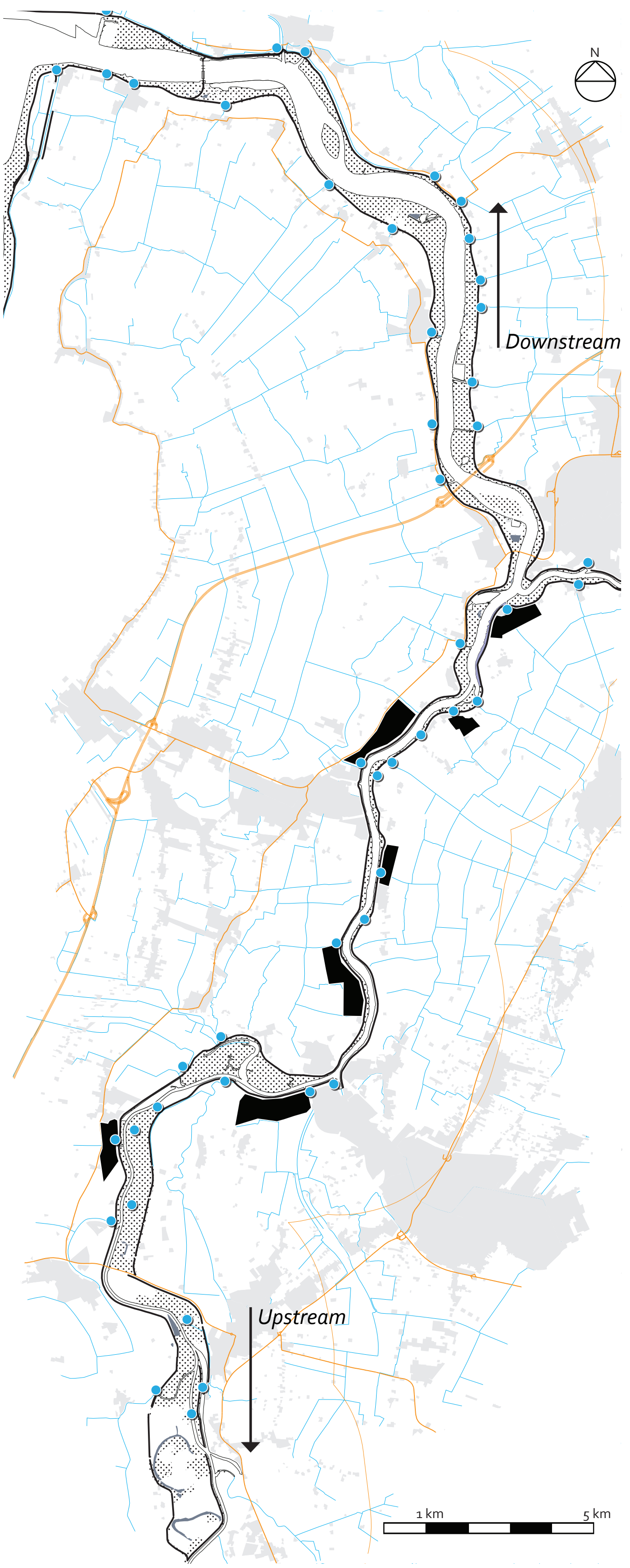
A growing polder strategy

- A string of polders with multiple inlets is more effective than one large area (Kadlec and Wallace, 1996).
- Starting small needs only a small investment with a limited risk, opposite to a large investment without a guaranty of success.
- Small, local polders give villages a new connection to the estuary.
- With multiple tidal polders, there lies the opportunity to experiment with settings, either to improve the effectiveness of the polders, or to create a colourful variety of biotopes and forms of land use.

The placement of the polders and the growing strategy is guided by the rules that determine the effectiveness. In its simplest form it states that: the strength of the effect on the tidal basin increases upstream (Schuchardt et al., 2009, Kemerink, 2004). A small tidal basin upstream can therefor be as effective as a large polder downstream and is an important reason why the Hedwigepolder [7.2] is located at the end the estuarine zone, just before the port of Antwerp. To achieve the biggest effect a polder should therefor be large in size and placed upstream just within the reaches of the tidal effect. However, as became clear from research on the Humber estuary, the tidal storage of upstream polders will decrease over time due to their effect on the tidal basin (Kemerink, 2004). Downstream polders, on the other hand, have a stable effect and even grown in strength over time (Kemerink, 2004).

The second guideline is the theory of inner- and outer-bends as introduced in 6.2.2. A gully or river has the tendency to meander, moving faster and eroding in the outer-bend, and moving slower and silting up in the inner-bend (Kleinhans and Brinke, 1998). As a result, the outer bend of the Ems sometimes rubs along the dike, while the floodplain in the inner bend can reach up to 800 meters. To achieve the strongest inflow and avoid silting up of the sluice and flood channel, the most effective polder is placed in the outer bend of the Ems. Placing a polder at the outer bend also recreates the meandering of the Ems, not in the historic tradition but in a new way.
With these two guidelines the placement of the tidal polders follows the following priority line:

	Place along the Ems	*Bend*	*Infrastructure*
1.	*Upstream*	*Outer*	*Sluice and village*
2.	*Upstream*	*Inner*	*Sluice and village*
3.	*Downstream*	*Outer*	*Sluice and village*
4.	*Downstream*	*Inner*	*Sluice and village*



Following this priority line, a growth proposal is formed as shown from figure 7.17-7.21.
In practise, straying from this path is of course possible.
This only represents the priority in effectiveness for tidal polders. Polder Breebaart for instance is located 13 km upstream from the further proposed polder in this plan, but still functions as a tidal polder and has a high biodiversity. However due to its smaller size and location far downstream its added effect to the tidal storage is limited. Straying from this path could therefor be to achieve other goals or for experimentation purposes [see paragraph 7.4].

Figure 7.17 | Step 1
The first polders are constructed downstream of Leer for the strongest early effect. Priority lies at location at villages with existing or former sluices and the outer bends of the Ems.

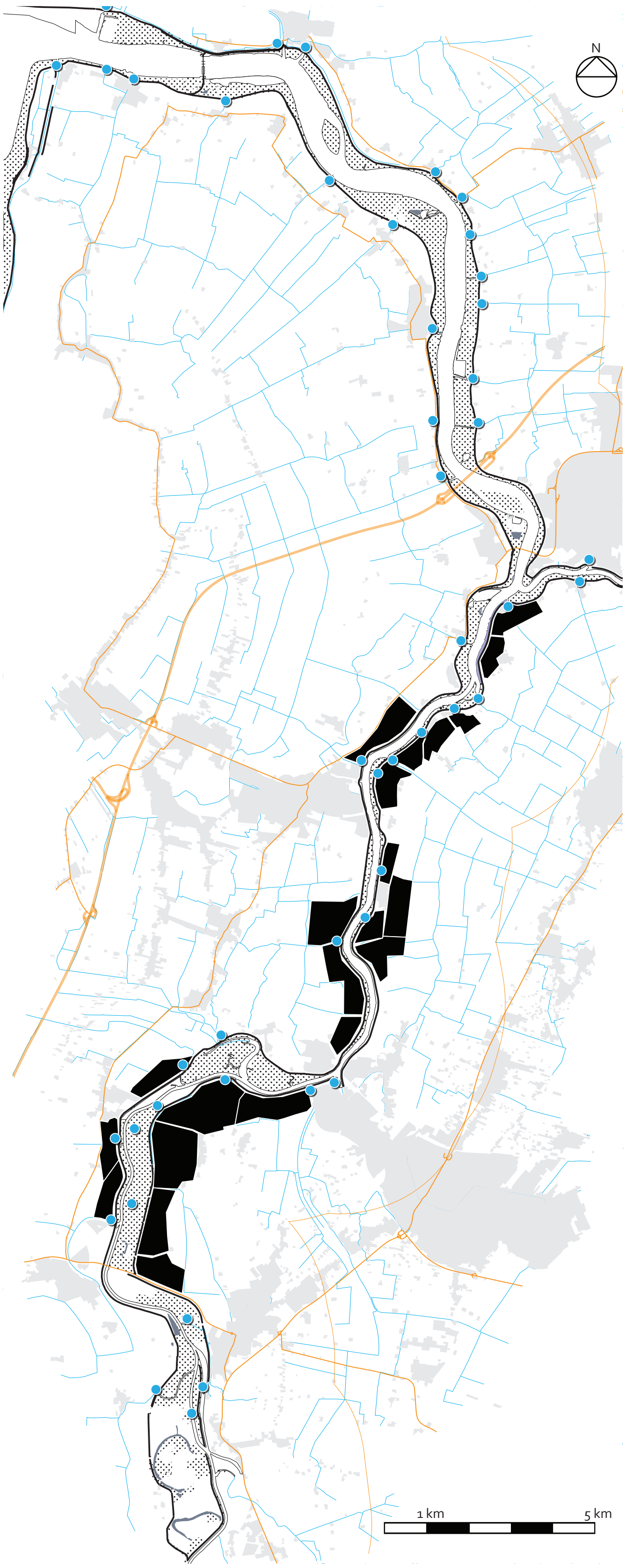


Figure 7.18 | Step 2
The polders are extended in the upstream region for the strongest effect. Priority lies at location with sluices and villages and existing polders are connected.

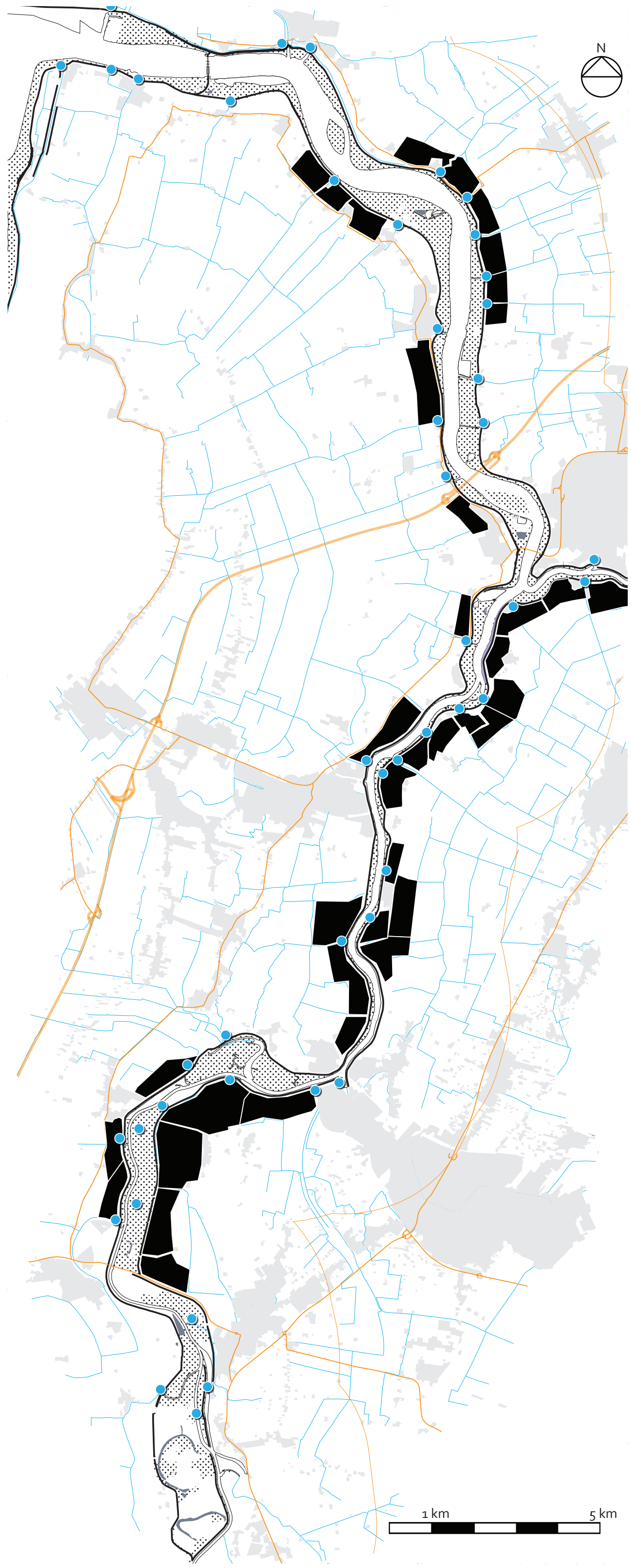


Figure 7.19 | Step 3
After the strong focus upstream, the growth moves downstream where the first polders are constructed at the outer bends and connected to old sluices.

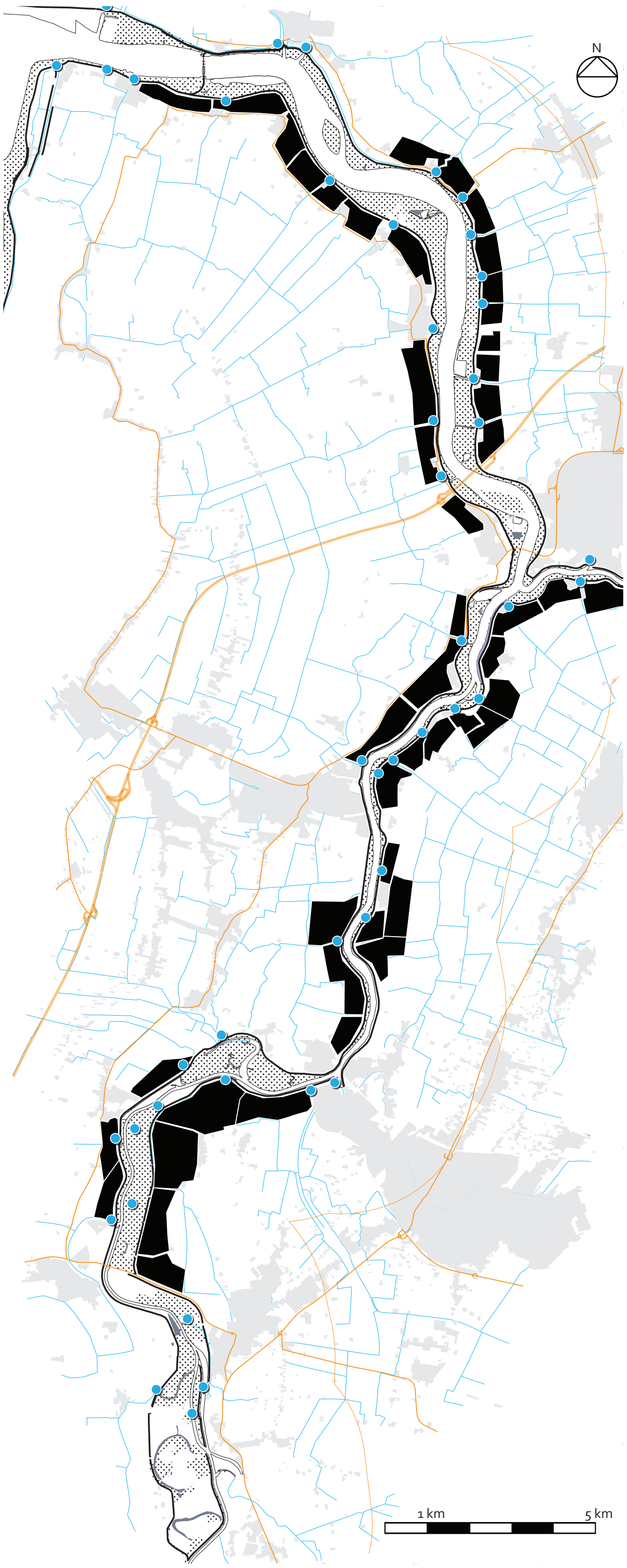


Figure 7.20 | Step 4
The polder growth is along the whole length of the Ems, located at inner- and outer-bends but close to the Ems and existing sluices and polders/

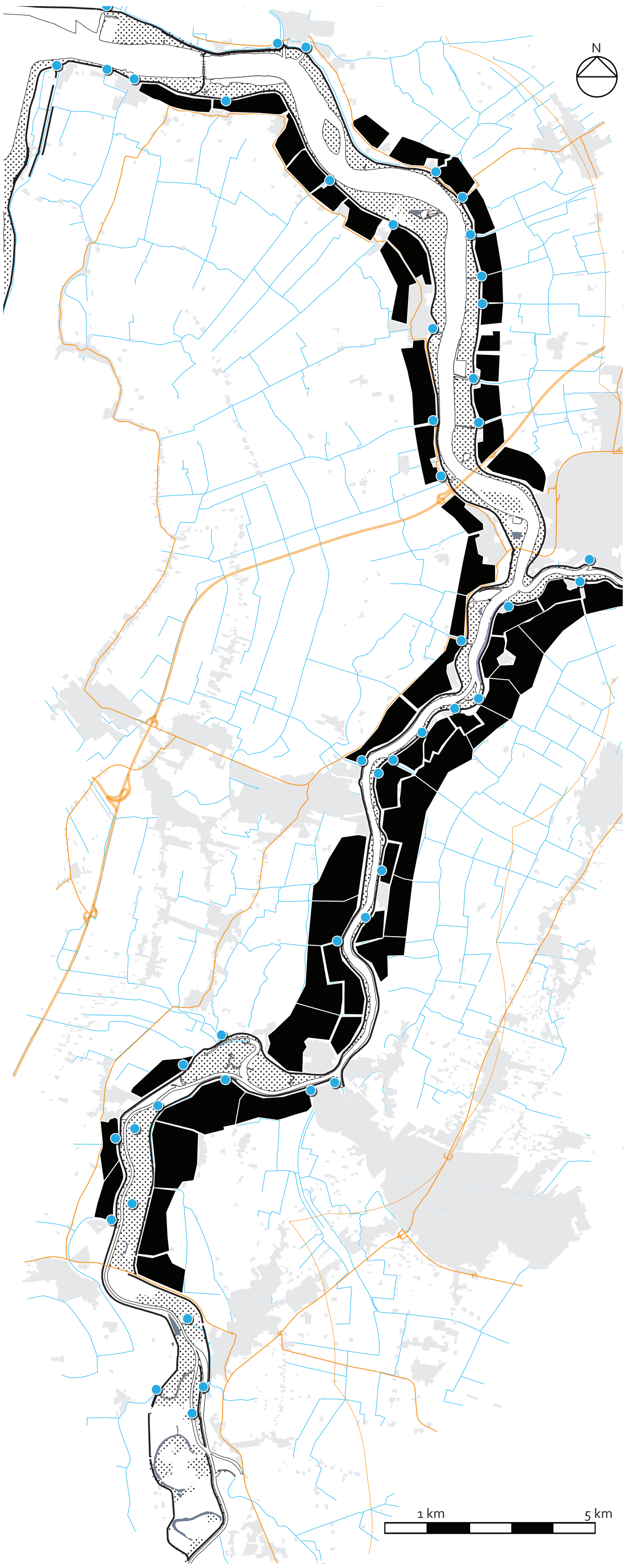


Figure 7.21 | Step 5
The final step can be divided into several sub-steps depending on past results in older polders. The main goal is connect polders to each other, increasing their efficiency and expanding the tidal basin.

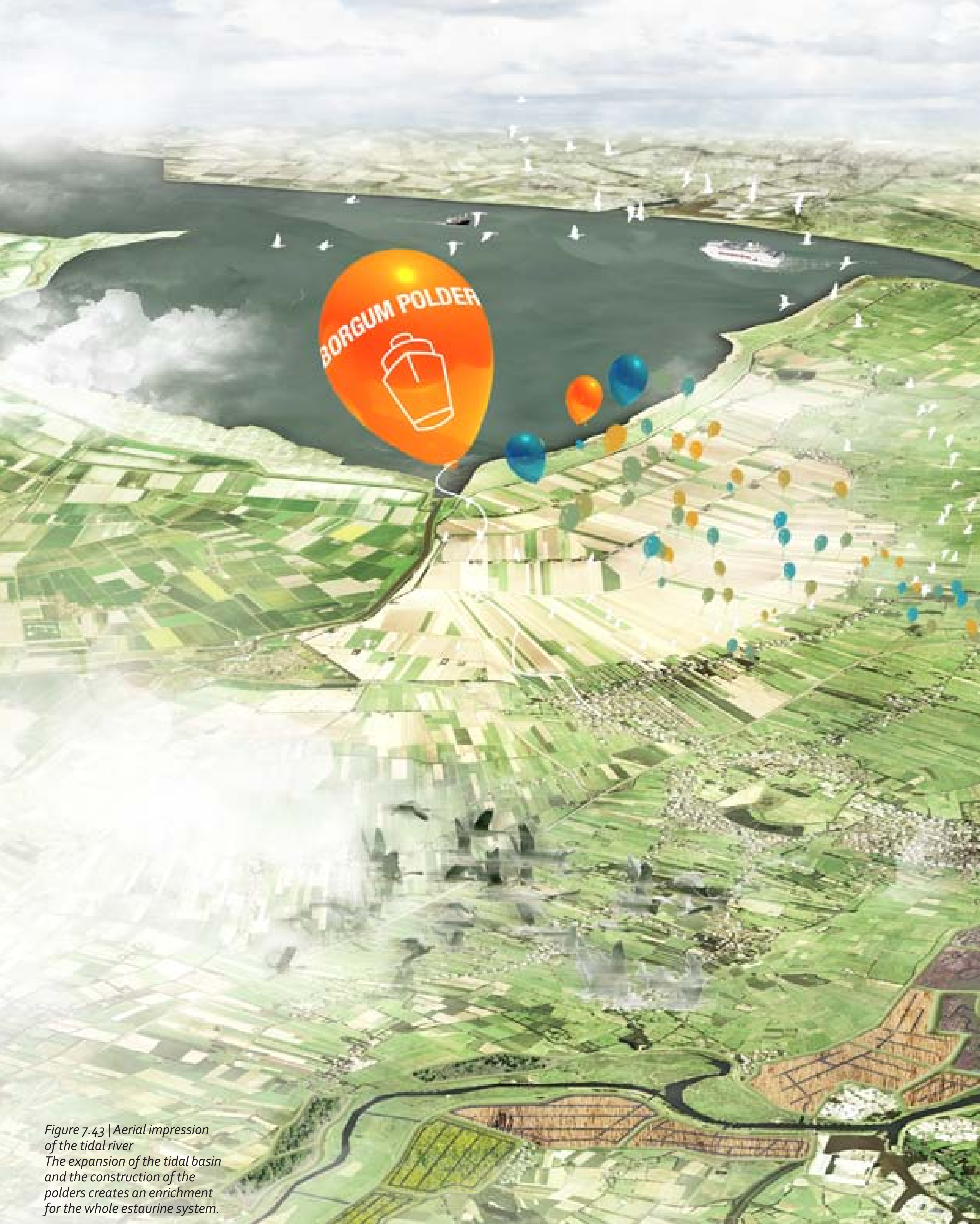


Figure 7.43 | Aerial impression of the tidal river
The expansion of the tidal basin and the construction of the polders creates an enrichment for the whole estaurine system.

7.3.4 Monitoring and adjusting

With this growing strategy, the tidal storage of the Ems can be increased polder by polder, and with it reconnecting estuary and the land behind the dikes. In addition, this growing system provides the ability to monitor results and adjust settings if needed. With many polders it also becomes easier to test different setting and experiment, which is not uncommon for polder Breebaart (Esselink and Berg, 2004). But with many polders, the result can be a varied polder landscape, a tidal experimental ground, attracting ecologists and scientist on a global scale.

Growth and uncertainty

The heuristic strategy, in where results are made by doing, fits excellent with the capricious and dynamic landscape of the Wadden Sea. The first steps within the growth can be based according to present knowledge and literature, which suggest relatively large polders far upstream (Schuchardt et al., 2009, Kemerink, 2004). But the next step in practise is undetermined for there is no certainty on how the system will react to these initial polders. This will give the next steps an erratic course, which may differ highly from the propositions presently sketched out. The polders upstream may for example have only limited effect, while the downstream polders will have a far greater effect thus changing the priority line. It may also be the case that already after the construction of several polders, the turbidity has dropped to such a level that no further polders are needed. In contrast it may also me the opposite and this growth proposal is only the first step, and the whole of Rheiderland is needed to restore the tidal balance.

7.4 Local design: Dynamics and disturbance

7.4.1 Silting polders

By opening up the hinterland to the Ems, the effects of the estuary are also reintroduced, bringing in brackish water, new species, but more importantly the main focus point of this thesis: sediment. The polders are lee places where water has the opportunity to slow down, and away from the direct influence of the Ems, sediment will settle down and will gradually level up the surface. The speed of this sedimentation can be up to several centimetres a year, but due to the turbid situation of the Ems, this could initially be much faster as reports are made of a 30cm increase after a single tide near Papenburg (Talke and Swart, 2005). Ultimately, this is dependent on the floating particle level of the water and the structure of the polder. In polder Breebaart for example, 40% of the yearly sediment that enters the polder remains in the polder (Esselink and Berg, 2004). This number could be increased if the polder was designed to be a sediment-importing-machine. A strategy that was also used in historic times by constructing brushwood dams (Dutch: rijshoutdammen) in salt marshes to accelerate the sedimentation and reclaim the land after a number of years.

That the sedimentation process of the Ems is strong and ever apparent is shown by the photo series below. These photos are taken at a small canal 5 km inland from the Ems, and is only fed by a small sluice and narrow canal from Jemgum. Considering this phenomena kilometres away from the source, the effects on a direct connection can be imagined. And although the sedimentation process creates new transitions and diversifies the habitat, gradually it will decrease the effectiveness of the polder as a tidal polder. The polders silt up due to imported sediment, decreasing the capacity in m3 of tidal storage. This process does not only affect its physical function, but also tempers its biological function as the biodiversity will decrease over time [Intermezzo: loss of diversity].

More sediment = less effect

Figure 7.22 A-C | Sediment accumulation in the innerland of the Rheiderland

Intermezzo:
Loss of dynamics, loss of diversity

Although natural systems are constantly changing, they have the tendency to move towards an equilibrium state where change is limited. Nature conversation can accelerate this momentum by increasing protection and thereby preventing disturbances. This however leads to an unexpected discrepancy within nature conservation: the biodiversity will diminish with a lack or absence of disturbances (Pulliam, 2002) [figure 7.23]. According to the Intermediate Disturbance Hypothesis, the greatest biological diversity occurs at intermediate levels of disturbance, or events that change the structure or resources of the physical environment (Pulliam, 2002). For example when an old tree falls over within a thick forest, the sudden open space and excess of sunlight will stimulate germination of countless of other species than the one single tree.

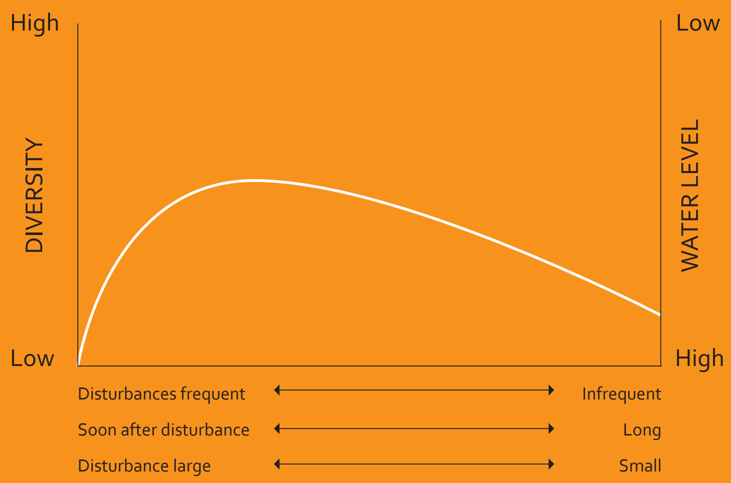


Figure 7.23 | The Intermediate Disturbance Hypothesis (source: Pulliam, H. R., Johnson, B. 2002)

This disturbance hypothesis is constructed on two assumptions:

- In the absence of disturbance, a few superior competitors will prevail.
- Only a few species can endure extreme or constant disturbance.

Discrepancy of modern nature conservation

As a result, the highest diversity is found between these two extremes of constant or no disturbance. To conserve certain species and this high level of biodiversity it is therefor essential to keep a certain disturbance regime. Modern nature conservation is therefor not singularly aimed at conserving the natural dynamic, but conserving the species which result from this dynamic. And rather than doing nothing it is maintaining, constantly mowing, grazing and pulling out unwanted species in order to keep a specific ecosystem (Metz, 1998) [everything has to change, in order for everything to stay the same]. This brings in a discrepancy to modern nature protection, that when you are extremely successful at the protection of a natural area, preventing disturbance and human influence the more likely it is that the habitat will change and most likely with a lower biodiversity.
Frans Vera recognizes this problem in the Oostvaardersplassen, where the lack of dynamics is leading to an uniform and aging swamp, attracting common and damaging fauna and scaring off rare and wanted fauna (Frans Vera in: Nijland, 2012).
This would not be a problem if the ecologists decided they rather have the common goose than a rare type of heron, but consequently this is not the case. And measurements, like controlling the water table and introducing large grazers, are implemented to maintain a certain habitat and stopping the natural transition.

The previously introduced polder Breebaart is also experiencing these same effects. Due to the natural tidal effects the polder is silting up at a rapid pace, which in return effects the biodiversity. This sedimentation rate has in some places led to an increase of 52,7 cm in two years (Esselink and Berg, 2004), roughly leading to a sedimentation rate of 20 cm in the deepest parts and staying relatively stable at the highest sections. This amount is however most likely underestimated and is even increasing (Esselink and Berg, 2004). This causes a decrease in gullies, mudflats and the total floodable area, thereby decreasing the area most valuable for the very specific habitat of the tidal region. The avocet for example was found in large numbers right after the opening of the tidal polder in 2001-2002 with up to 774 breeding pairs, but had dropped to 10% of this number in (Tydeman, 2005). Other rare birds species, like terns and Lapwings (Vanellus vanellus) are also decreasing, where as the very common Black-Headed gull (Chroicocephalus ridibundus) has doubled to 3362 breeding pairs from 2003 to 2004 (Tydeman, 2005).

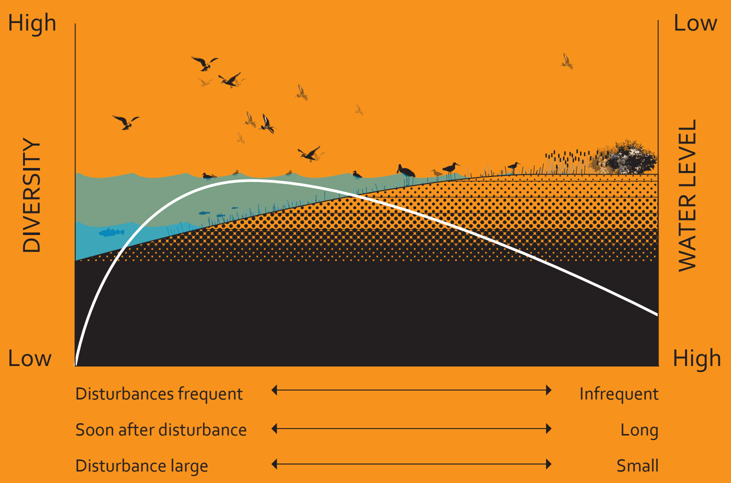


Figure 7.24 | The hypothesis applied to a tidal polder situation. The polder silts up, with increasing land which lies out of the tidal reach, resulting in a decreasing biodiversity.

From this case it can be concluded that although the tidal polder is a good initiative with relative quick effects and a rapid increase of biodiversity, over time it effectiveness of the polder, both in physical as in biological aspects decreases [figure 7.24]. And as Esselink and Berg say a development which "seems unpreventable considering the current sedimentation management of the region" (2004).

What is needed to revitalize and energize the region is to reintroduce disturbances which has the potential to break through the current levelling pattern. This was also experimented in the Oostvaardersplassen 20 years ago where a part of the swamp was drained for a number of years and after re-flooding it caused an explosion in the number of special nesting birds (Nijland, 2012). The tidal polders need this too, a massive disturbance, a deus ex machina to turn things around. What they need is the help of one of the largest causes of the sludge problem to begin with: they need the power of the cruise ships of the Meyer Werft.

7.4.2 Cruise ships: Deus ex machine

The previous paragraph and the intermezzo have shown, that in order for the polders to remain successful, new disturbances have to be introduced within the system. Grazing, mowing, or digging can simulate these disturbances, but most efficient is to use mechanics from within the system to generate these disturbances, rather than implementing new ones (Pulliam, 2002).

We therefor propose a 'reversed flushing basin'. Along the coast of the Wadden Sea and the Ems you find small tidal basins which are filled with water at high tide and are opened at low tide to 'flush-out' a gully or harbour and remove settled sediment. This principle can function as disturbance mechanism for the tidal polder, with the difference that the Ems itself will function as a flushing basin. Remembering the Intermezzo: 'the origin of the Meyer Werft', which stated that in order for the cruise ships to travel over the Ems, the river is dammed and the water pushed up to reach a draft of 10 meters. With this, the Ems has becomes a giant flushing basin! Presently this 'Emsüberführung' is now a large expense for the Meyer Werft, for it has to close off the river for several days, disassembling bridges and making other large adjustments, just to get the boat out in open water. But if the damming of the Ems could be seen as an advantage, and an investment in both economic and ecologic sense, it could even be beneficial to have more 'Emsüberführungen'.

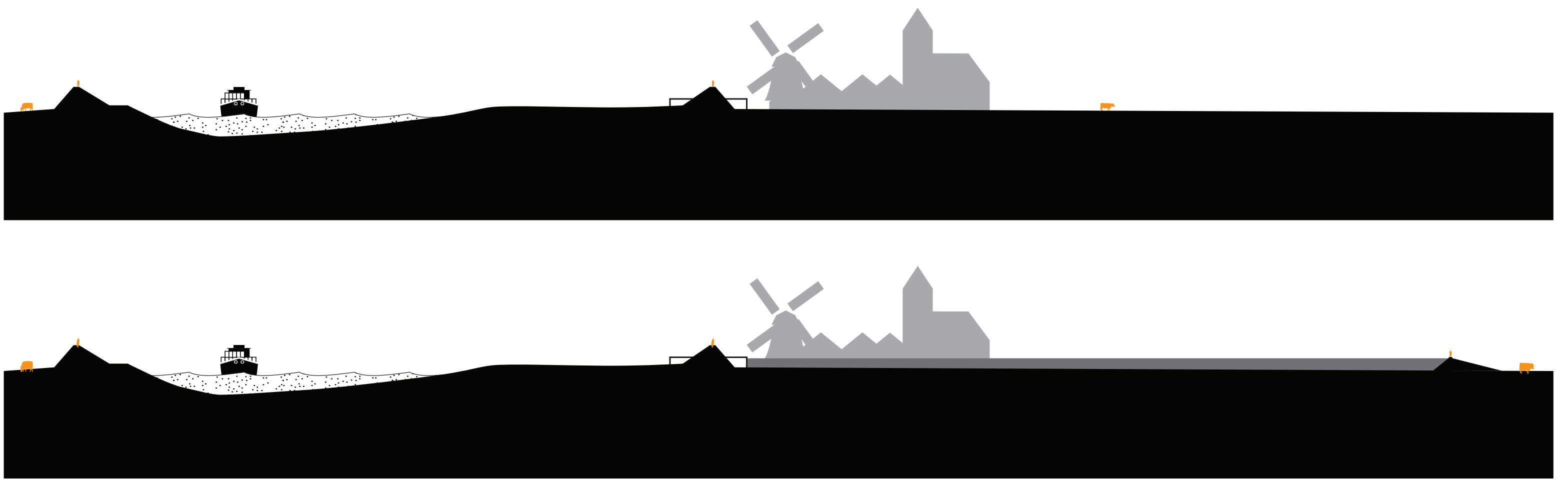


Figure 7.25 A,B [top] | Cross section of the principle of a tidal polder, opening the sluice and letting in water and sediment.

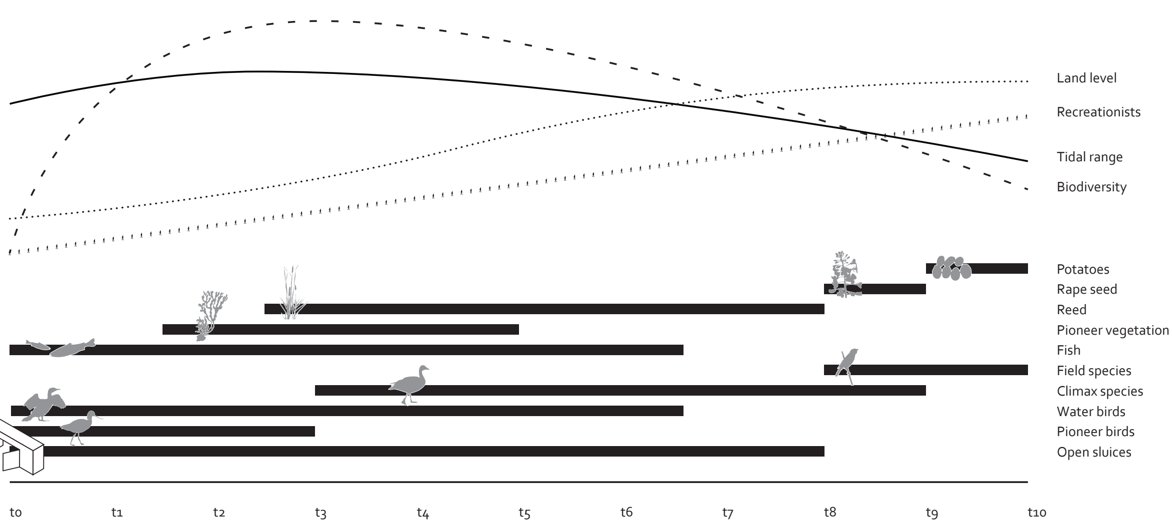


Figure 7.26 [bottom] Dynamic development of a standard polder. When left in standard operation, the ground level will increase, the diodiversity will decrease and climax species will take over.
(based on: Pulliam,2002. Kemerink, 2004)

This gives the tidal river two mechanics to slow down, accelerate and steer the polders in a certain direction:

Open sluices

A polder with open sluices is the main mechanic, which enlarges the tidal basin and makes it a tidal polder. If the sluices are kept open it will likely follow the developments as the polder Breebaart and move towards a stable situation with a lower diversity [figure 7.25, 7.26]. By playing with the mechanics, this process can be accelerated or slowed down, by allowing more or less water and sediment to flow in. By having more sluices or by creating obstructions this sedimentation can also be steered in a certain direction.

Reset phase

The use of the force of the 'Ems flushing basin' gives the polders disturbance, which resets its settings and maintains a higher biodiversity [figure 7.27, 7.28]. This option is available two times a year every time a cruise ship passes and allows diversification: When a ship passes the sluices can be kept closed, opened up every time or only once every few years. The opening of the sluices becomes a spectacle to behold and results in an ever interesting and changing landscape [figure 7.29 to 7.34].

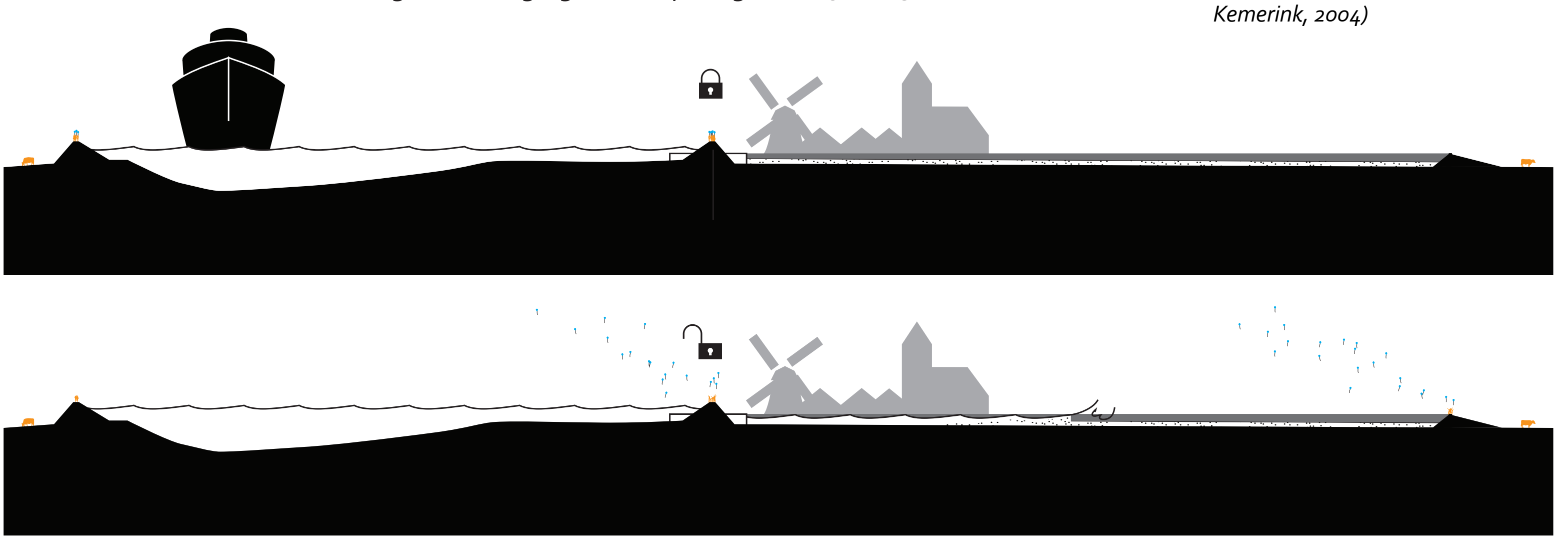


Figure 7.27 A,B [top] | Cross section of the resetting procedure: The sluices are closed, water is pushed up and when the ship has passed the sluices open ones disturbing the polder and reorganizing the sediment

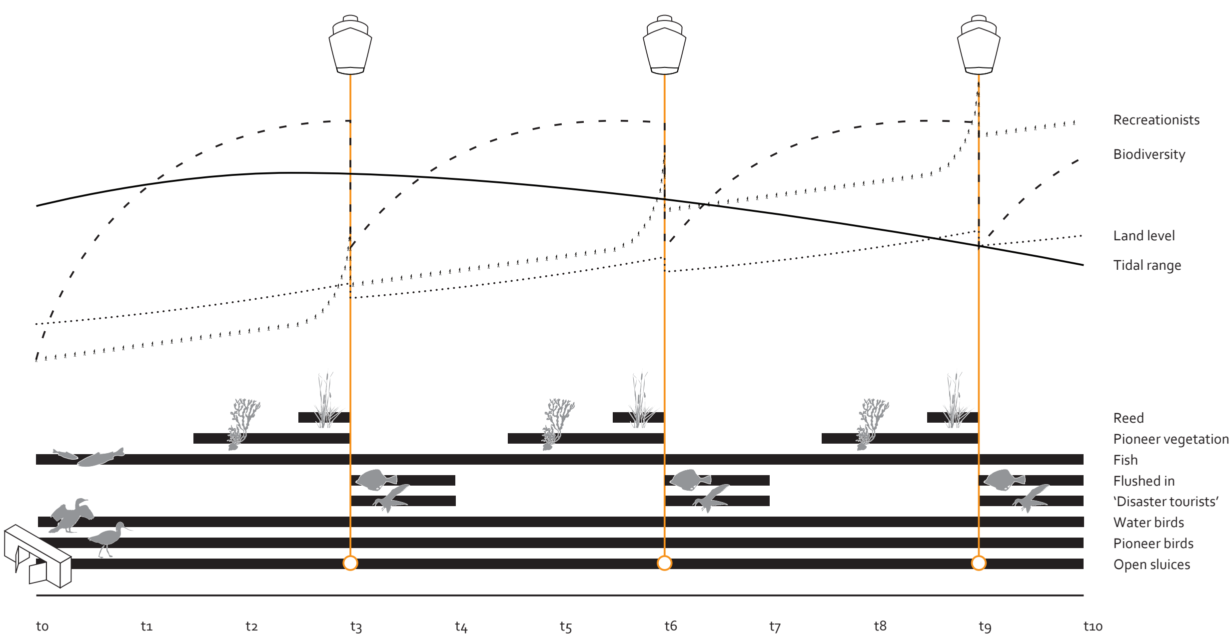


Figure 7.28 [bottom] | Dynamic development of a 'resetting' polder. When a polder is reset, its settings change and has the ability to move back to a pioneer stage, keeping constant change and high biodiversity (based on: Pulliam,2002. Kemerink, 2004)

Figure 7.29 | Step 1
Behind the current dike a parallel dike is constructed and closed of with perpendicular dikes, thus creating dike compartments.

Under the influence of the incoming tide the meadow slowly becomes a brackish polder with a high diversity of plants and wildlife. The polders are open to the public and attracts hikers, birdwatchers and other eco-tourists.

Figure 7.30 | Step 2
Under the influence of the daily tides, the tidal polders behave as sediment importers (Tydeman, 2005). Slowly the ground level rises, diminishing the tidal effect, thus decreasing the diversity of life and the tidal storage.

Twice a year a new cruise liner passes the Ems and each time the decision can be made to open the sluices, either creating something new or 'resetting' an overgrown polder.

Figure 7.33 | Step 3
After the cruise liner has past the tidal river which happens twice a year, the sluices are opened and the full power of the dammed Ems is released on the tidal compartment. The crowd drawn in by the passing of the ship gets a second show at a village that has a 'Siel Fest' with beer and bratwurst and a sluice opening.

Figure 7.34 | Step 4
The water recedes and reveals a renewed and very unpredictable polder with trenches formed by the power of the Ems. The diversity of before could be restored, but could also be very different, making each polder unique and ever changing.
The sequence of polders creates a dynamic polder-landscape and also makes the Meyer Werft, now one of the main causers of the Ems problem, the perfect boost for life and diversity.

Figure 7.35 | *The opening of the flushing sluice in Termunten. The opening is rare and spectacular as water crashes in the sluices at great speed and force attracting many visitors to view this spectacle (source: museumgemaalcremer.nl)*

Figure 7.36 | *The festive opening of a sluice follows right after the 'Emsüberführung' and could become the occasion for the annual village festivities.*

7.4.3 Polder functions

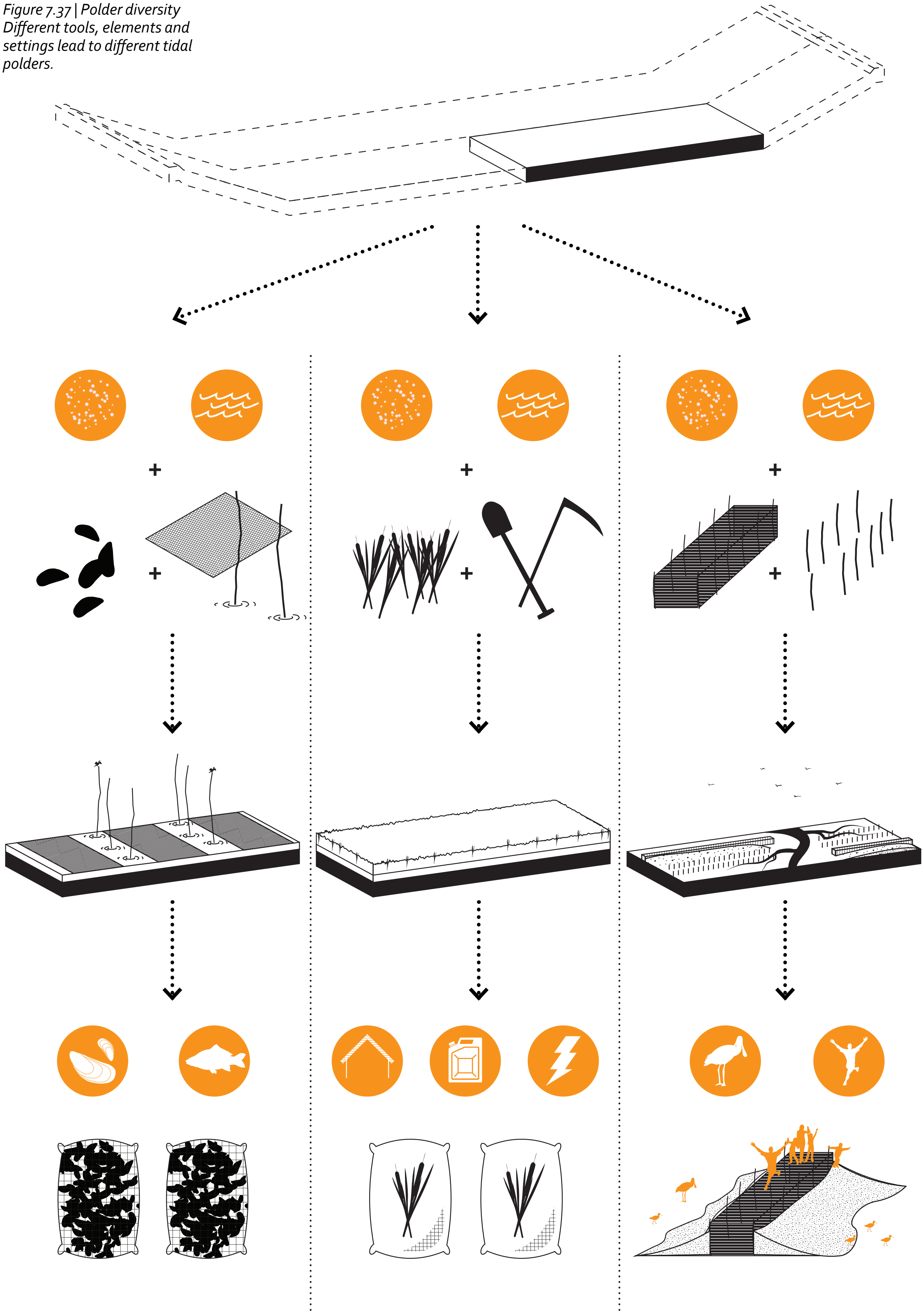
The flushing spectacle

The opening of the sluices is a sight to behold; millions of litres of water start to gush in, forming new landscape patterns and attracting people to see this spectacle [figure7.35]. Every six months, every sluice has the ability to fully open and let in the water of the dammed Ems. This could be yearly festival for villages, which now all have their own polders, and so during the town meeting, there could be a vote for the next festive opening [figure 7.36].

Polder diversity

Because the Ems is an estuary and connected to the Wadden Sea it forms a transition from fresh to salt. The same transition will form in the tidal polders, where the upstream polders will be fresh and the downstream polders brackish. The tidal effect will also vary and will gradually increase towards the Dollard. Under these settings different polders will form, all with slightly different settings because of their specific size or location on an inner- or outer-bend. By using different tools and deploying them on different polders, this polder diversity can be increased and the formation accelerated [figure 7.37].

Figure 7.37 | Polder diversity
Different tools, elements and settings lead to different tidal polders.



Downstream: Producing polders

Most of the villages dispersed along the Ems are former fishing villages. With new draining techniques and a declining fish population the Rheiderland became a cattle region. The current forms of agriculture are however unprofitable in terms of production and maintenance. Therefore new forms of production are needed. The tidal polders can provide this opportunity. The upstream section of the Ems holds brackish water and is high in nutrients, perfect for the breeding of shellfish and farmed fish. The polders will work in cooperation with the estuarine mouth, which focuses on catching and breeding, while the polders can focus on growth, packaging and sales, similar to the strategy as used in the Oosterschelde. Eventually polders can grow together to create a saline landscape, producing fish, its food, cleaning waste products and resulting in an attractive landscape (Molpheta and Wonderen, 2009).

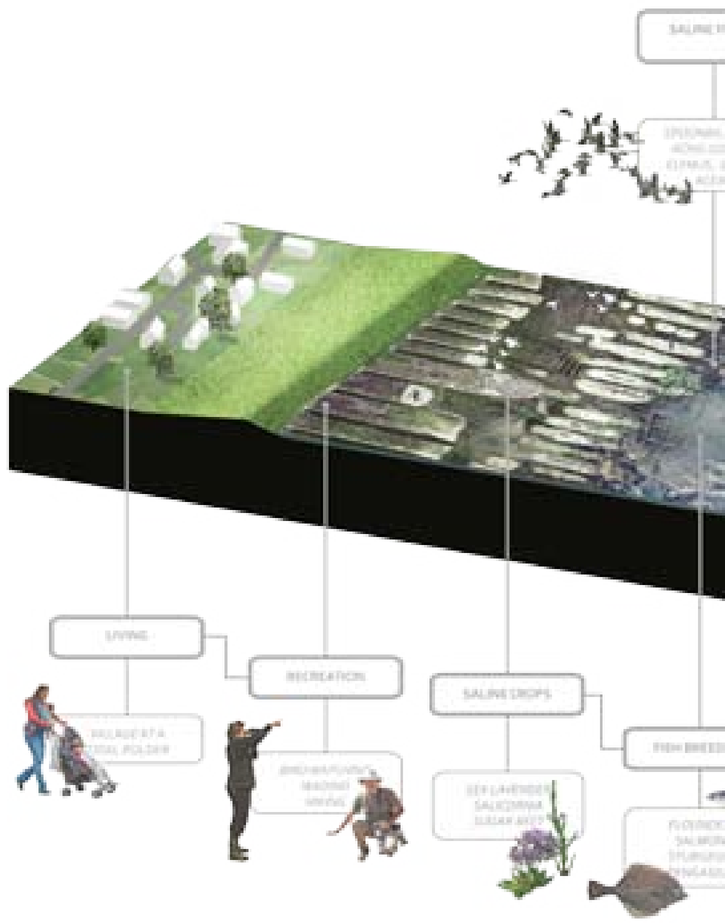
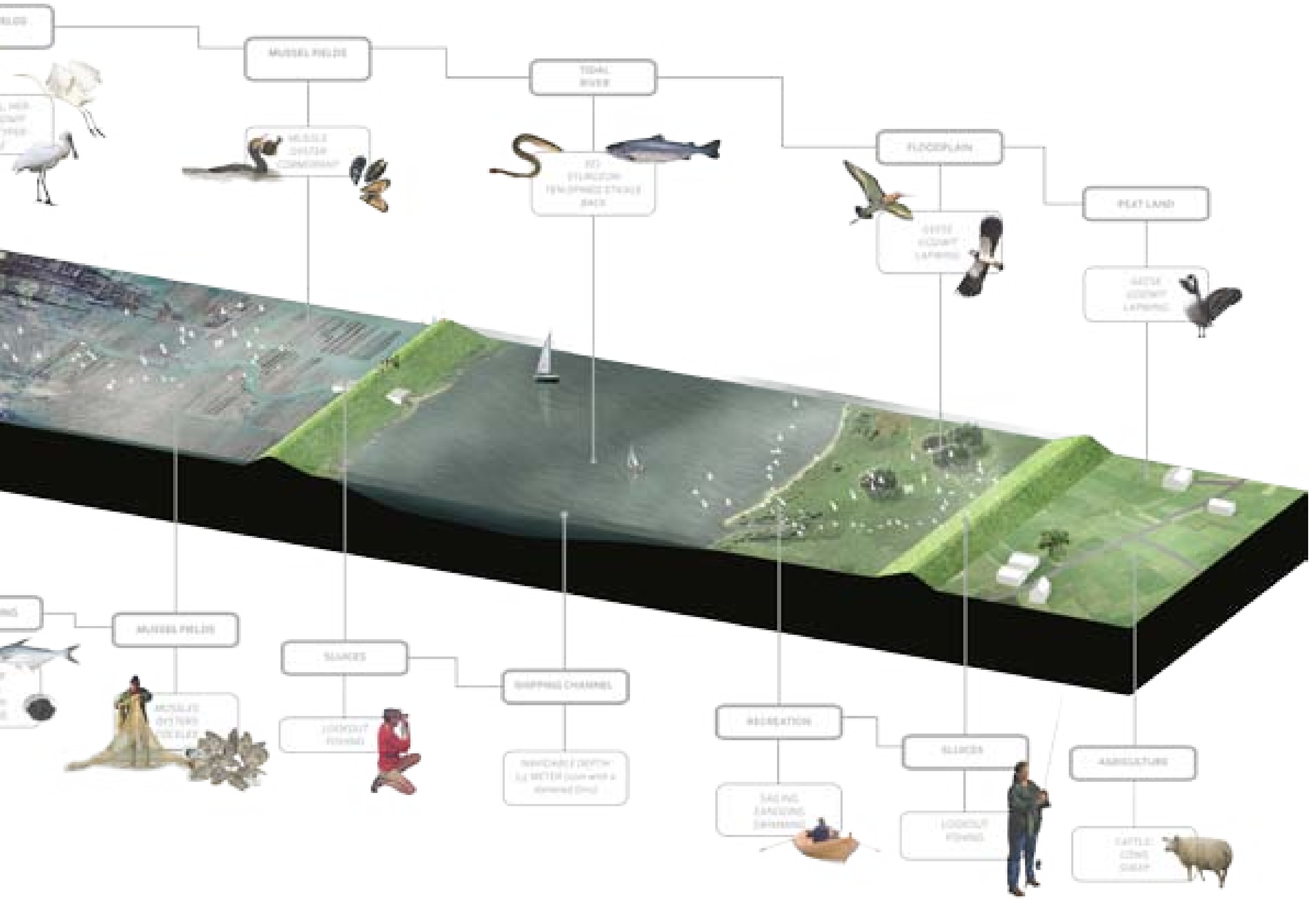


Figure 7.38 [bottom] | Artist impression: mussel cultivation in saline polder.

Figure 7.39 [right] | Aerial cross section: Ems with saline cultivation polder


MUSSEL FIELDS
TIDAL RIVER
FLOODPLAIN
GEESE
GODWIT
LAPWING
PEAT LAND
GEESE
GODWIT
LAPWING
MUSSEL FIELDS
MUSSELS
OYSTERS
COCKLES
SLUICES
LOOKOUT
FISHING
SHIPPING CHANNEL
RECREATION
SAILING
SWIMMING
SLUICES
LOOKOUT
FISHING
AGRICULTURE
CATTLE
COWS
SHEEP

Middle stream: Ever changing polders

Along the tidal river arises a wide variety of polders which will all differ from the next, due to its polder structure and its place connected to the Ems, leading to a different tidal influence, salinity level and sedimentation speed. This diversity can even be accelerated by employing the mechanics of opening the sluices and resetting with the 'Emsüberführung'. This leads to an open ornithology zoo, where different polders attract different kinds of birds in huge numbers and with them attracting bird spotters from a wide region to the Ems using the dikes as routes and podia to spot them. This touristic attraction is only surpassed by the Meyer cruise ships, which, like many wetland birds, migrate the Ems two times a year. This passage and the linked opening-of-the-sluices events are a rare and impressive sight, and the dikes and sluices are excellent platforms to spot these happenings.

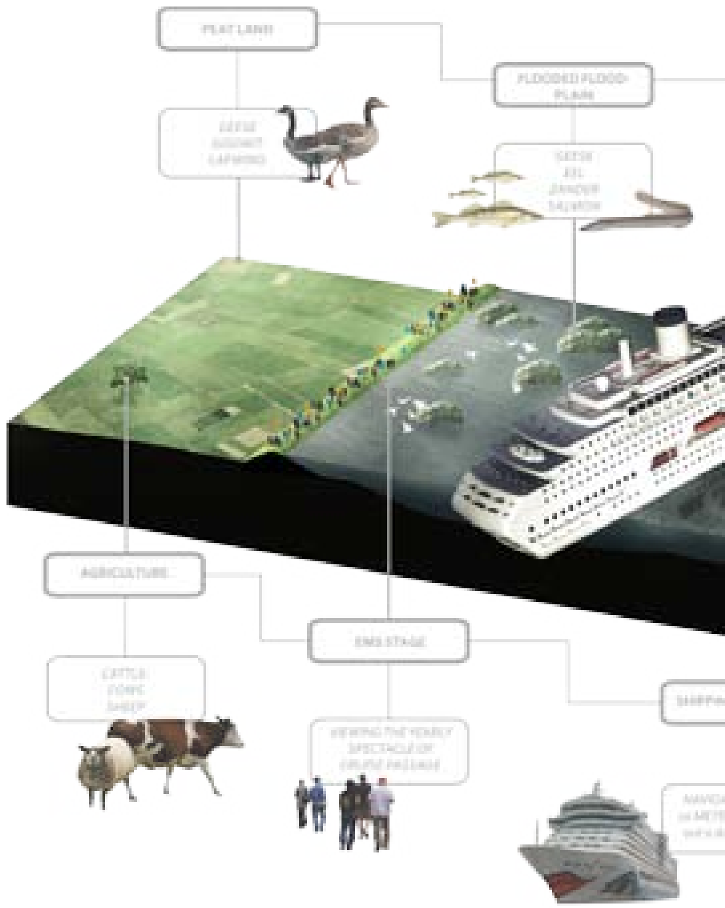
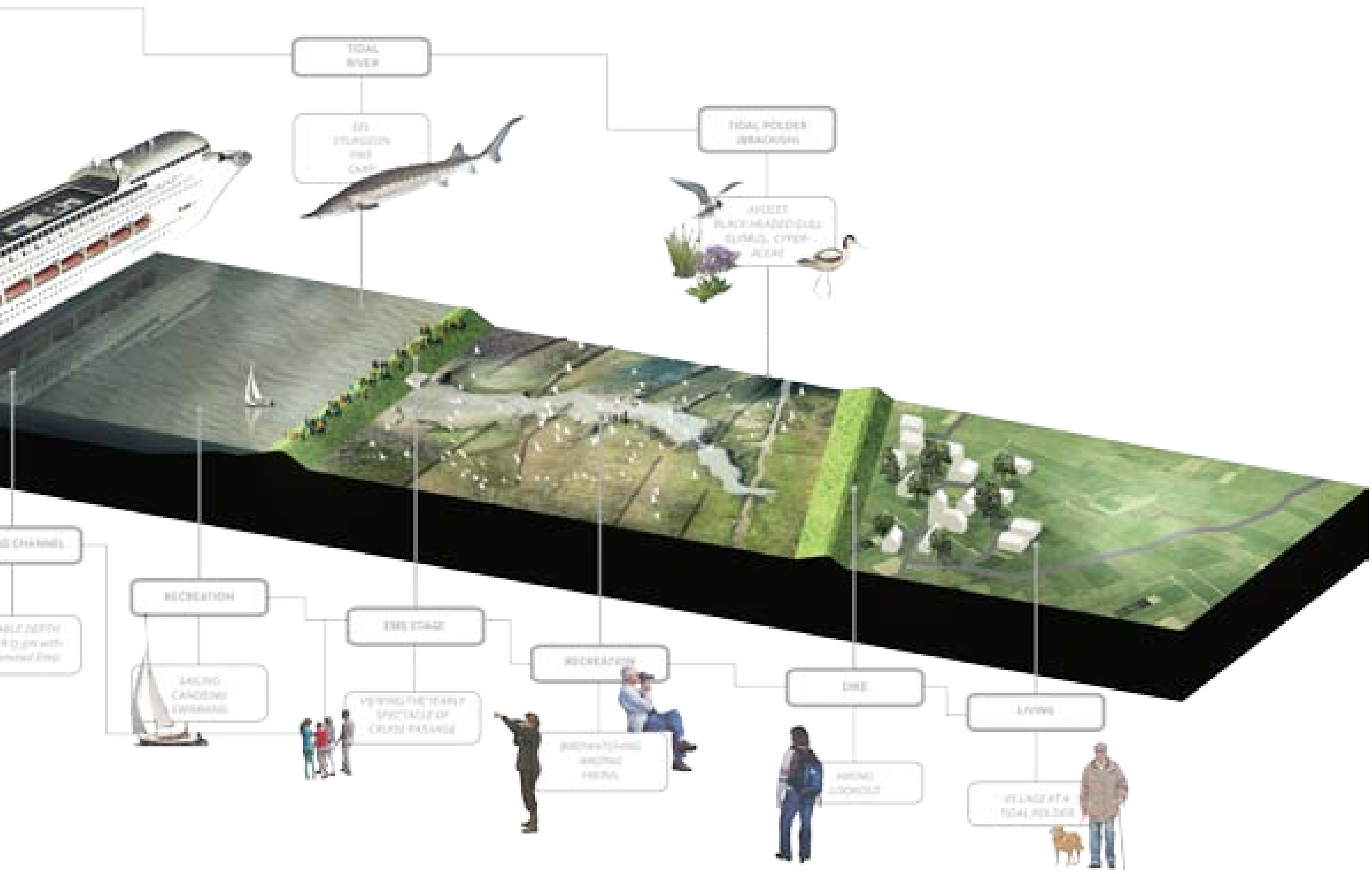


Figure 7.39 [bottom] | Artist impression: A tidal natural polder during an 'Emsüberführung'

Figure 7.40 [right] | Aerial cross section: A tidal natural polder during an 'Emsüberführung'


TIDAL RIVER
TIDAL POLDER (BRACKISH)
RECREATION
EMS STAGE
RECREATION
DIKE
LIVING
SAILING CANOEING SWIMMING
VIEWING THE YEARLY SPECTACLE OF CRUISE PASSAGE
BIRDWATCHING ANGLING HIKING
HIKING LOOKOUT
VILLAGE AT A TIDAL POLDER

Upstream: Biomass and bio-massiveness

In the most upstream region, the tidal influence and the salinity level is lowest, but due to their increased effect over the tidal basin, the tidal polders are here more common and largest. Due to these settings, these polders can focus on the cultivation of vegetation for biomass energy. The polders are nearly closed systems, hydrological controllable and have wet and fertile soils, perfect for the growing of poplar, willow or reed. After harvest the biomass products can be transported to the nearby power plant in Emden or the power plants in Eemshaven providing them with the mandatory biomass ratio.
The biomass crops, a low salinity level and a regular flushing of the 'Ems reset button' will lead to very different natural setting as exist presently, also very different from the saline polders, and very different from the estuary mouth.

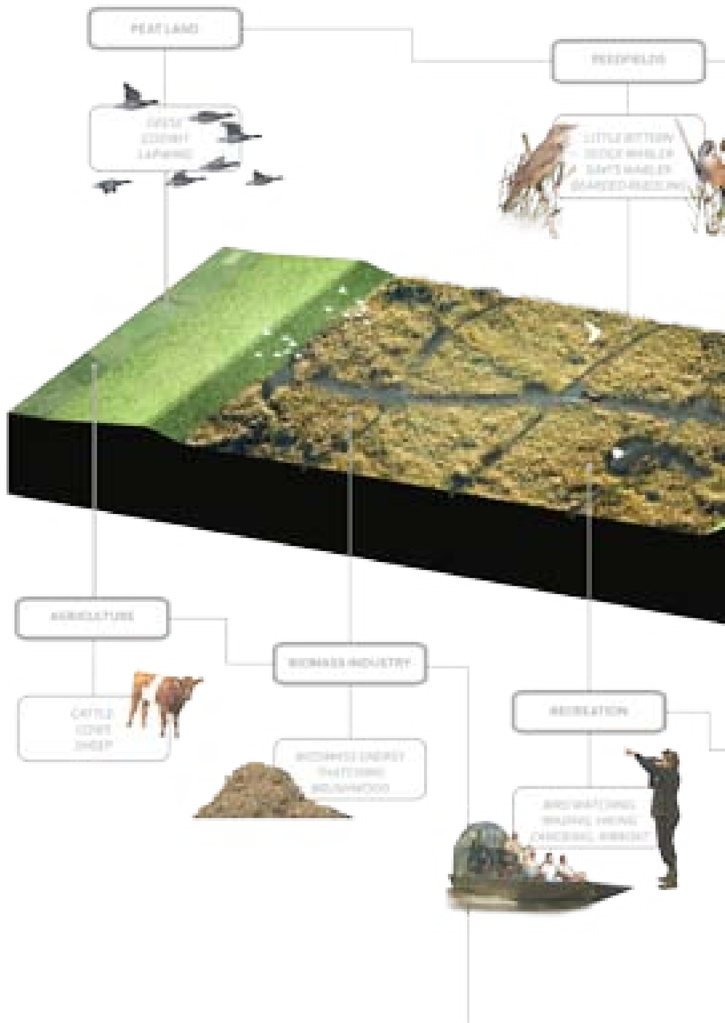
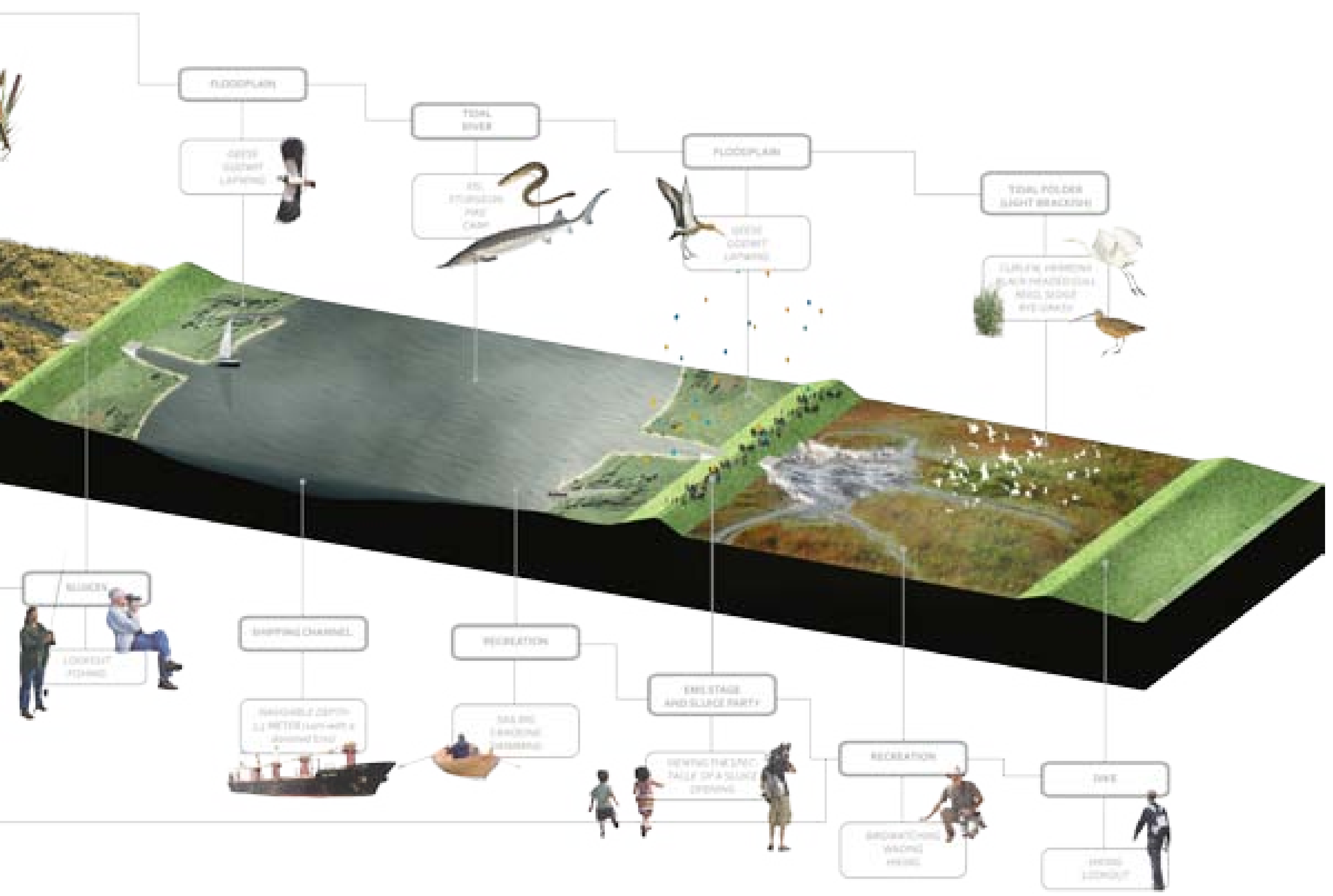


Figure 7.41 [bottom] | Artist impression: A biomass polder

Figure 7.42 [right] | Aerial cross section: A biomass polder and a natural polder after the opening of the 'Ems flushing basin'



FLOODPLAIN
GEESE
GODWIT
LAPWING
TIDAL
RIVER
FLOODPLAIN
GEESE
GODWIT
LAPWING
SHIPPING CHANNEL
RECREATION
RECREATION
DIKE

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8

DESIGN:
CONCLUSION

8.1 Introduction

This chapter concludes the design section of this thesis, with the focus on chapter 6 [estuary mouth] and chapter 7 [tidal river]. It gives a quick overview and consists of:

- A recap of the applied design principles
- Results and effects of the design strategy
- Interaction of the two different design strategies

8.2 Design overview

Tightening of the estuary mouth

The tightening strategy is based on the reduction of the cross-sectional width from the sides instead of reducing the cross-sectional width from the bottom of the channel. This limits the amount of water able to flow into the channel, thus reducing flowing speeds and sediment import. This 'tightening of the gully' is conducted by constructing groynes along the channel to reduce its width; the placement is determined by the following basic principles:

Mouth design principles

- The structures should be attached to the shore or to higher sandbanks to prevent the channel from splitting.
- The structures should be constructed in a long range to prevent congestion of sediment downstream.
- Interventions, which reduce the cross-sectional width of the channel, should only be implemented at the inner gentle bank of a meander, because of the larger reducible area and the strengthened narrowing effect by sedimentation.

Instead of a single and finite intervention, the groynes grow in phase. This is done, to deal with the uncertainty of the estuarine response, but also to gradually steer the channel back into a meander, which in turn solves the asymmetrical tidal curve.

The groynes itself can be made anew, but more effective and more rewarding is to use decommissioned oilrigs for this job. The deconstruction of these elements brings in a new industry to the Ems, the placement of the elements ensure a new habitat and a boost for biodiversity and biomass and the placed elements itself provide economic possibilities because of potential seafood harvest and the attractiveness of the objects.

Expansion of the tidal river

The goal of expanding the tidal basin is to increase the total tidal storage of an estuary thereby restoring the balance between the cross-sectional width and its hinterland. Expansion of the tidal river gives the incoming water more room and more time to slow down, which enables sediment to settle, thus decreasing turbidity. The 'expansion of the tidal river' is conducted by constructing tidal polders alongside, but inland from the Ems river. These polders are connected to the Ems via sluices that allow water to flow freely through the dike. The placement and dimensions is determined by the following principles:

River design principles

- To allow a better and more even spread of water and sediment, multiple smaller polders are preferred over a single large polder.
- Placing a polder upstream will increase the effect on the tidal basin due to the relative increase in size.
- Polders should be prioritized at the outer-bend of a river.
- To recreate the lost connection between estuary and old villages, polder should be placed at existing sluices where possible.

With these principles and with the uncertainty of the dynamic system in mind, the polders are also constructed in a growing process. The quantity of polders grows, but also the quality of the polders changes over time. Due to changes in sedimentation, salinity, tidal force and maintenance, each polder will be in constant change and will also differ from each other, resulting in a varied polder landscape.

8.3 Design results

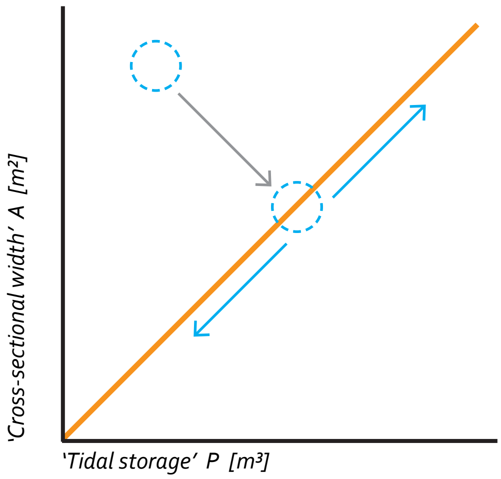

Figure 8.1 | The new to be found dynamic balance.

Turbidity solution

In chapter 4 it was concluded that in order to restore the balance of estuarine system, the two proposed strategies have to be combined [figure 8.1], to maintain at the same time shipping draft and preserving fertile arable lands. Both of the strategies have a direct effect on the turbidity as they reduce the level of floating particles, both by creating calm places where sediment gets the time and space to settle instead of being constantly forced around. The indirect effect of the two measurements is however most concerned with uncertainty. Reasoning from the applied theories both of the methods will affect the balance between cross-sectional width and tidal storage, but the scale of the effect makes the influence of the interventions uncertain and thus needs more study, and more importantly, more experience from practice.

Therefore an experimental start of the implementation is suggested. By beginning with the first experimental polders and groynes, new lessons can be learned for further expansion and future interventions. Already during this growth process the following effects probably will be seen (after: (Bos et al., 2012, Firet, 2012, Talke and Swart, 2005) [figure 8.3]:

- If the tidal basin is increased and the cross-sectional width is decreased the estuary will successfully move towards a more stable equilibrium.
- The flood will decrease in strength and reach less far. The tidal polders will therefor not flood as high and the ebb flow will be stronger and thus erode more in the estuary mouth.
- The suspended matter content of the water will decrease, thereby also decreasing the sedimentation rate. The polders will therefor silt up slower, and the mudflats in the mouth section will not expand as quickly.
- The turbidity maximum will move from the tidal river towards the middle section of the estuary

A hybrid strategy

The starting point of this thesis was to investigate the Ems' turbidity issue and search for possible solutions to get rid of this largely ecological problem. However through the process of the thesis is became clear that a singular solution, issued from only one viewing point, would not provide a real solution, because there were already parties doing just this and have been unsuccessful by a lack of support from other parties.

A real solution should thus restore the ecologic health of the system, while preventing negative effects for industry. But the interventions will lead to more than this. It transcends the discussion between ecology ór industry and goes further than ecology ánd industry; it is via-via (Roncken, 2012). This emerges clearly from the design for the Ems-estuary, wherein new harvest is realized via new ecologic polders, and new habitats are realized via the new oilrig industry. Thus doing more than restoring an old ecologic situation and to save on dredging costs.

Interventions are via-via

Interaction between the interventions

The two proposed interventions are located at different sections of the Ems, but are part of the same strategy and of the same estuarine system. The growth of the polders and the groynes should thus interact, whereby the first experimental implementations will start simultaneously. The further growth pattern will however not be linear and equivalent, but rather will follow and anticipate on the estuarine effects and grow accordingly [figure 8.2]. Despite of the uncertainty of the development and thereby the uncertainty of the implementation, a basis pattern for implementation can be reasoned based on the different characteristics of the two interventions. The groynes structures benefit from high amounts of sediment, which results in a quick tightening effect, while the polders benefit from low amounts of sediment, so they will silt up at a much slower pace, which is beneficial for maintaining their tidal storage role.

Interdependent growth

Based on these different characteristics, first needs to be anticipated on a fast growth of the groynes. The level of floating particles will drop significantly which will start the growth phase of the polders. After a quick start, the groyne growth slows down to slowly start to steer the shipping channel back into a meander. The polder and groyne growth continues until the proposed final step, which will restore the natural balance. Sedimentation will continue and after a certain period the level of the floating particles will decrease and the turbid Ems will be no more [figure 8.3].

Figure 8.2 | Growth and development of the Ems interventions and anticipated sedimentation and dredging development.

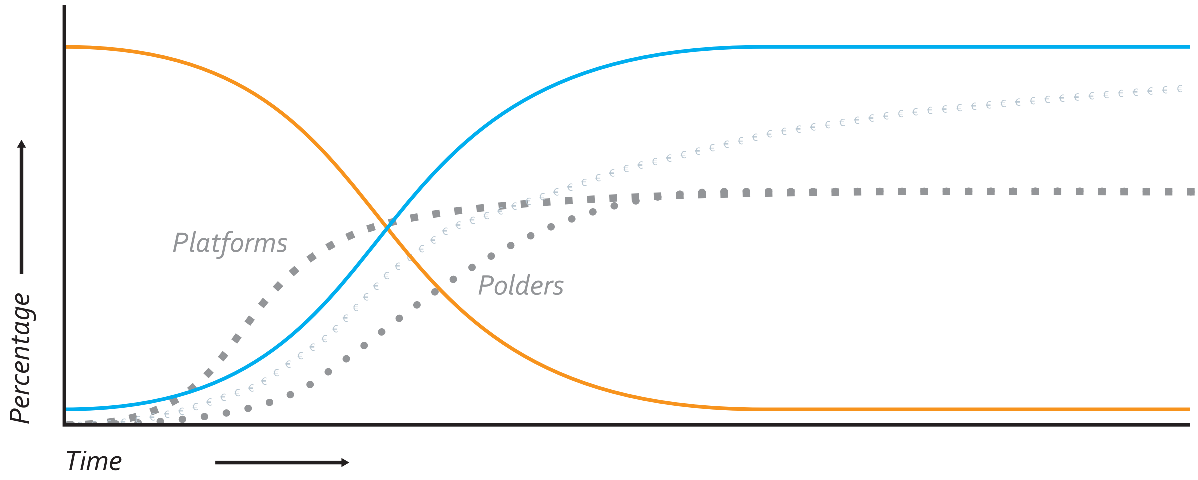

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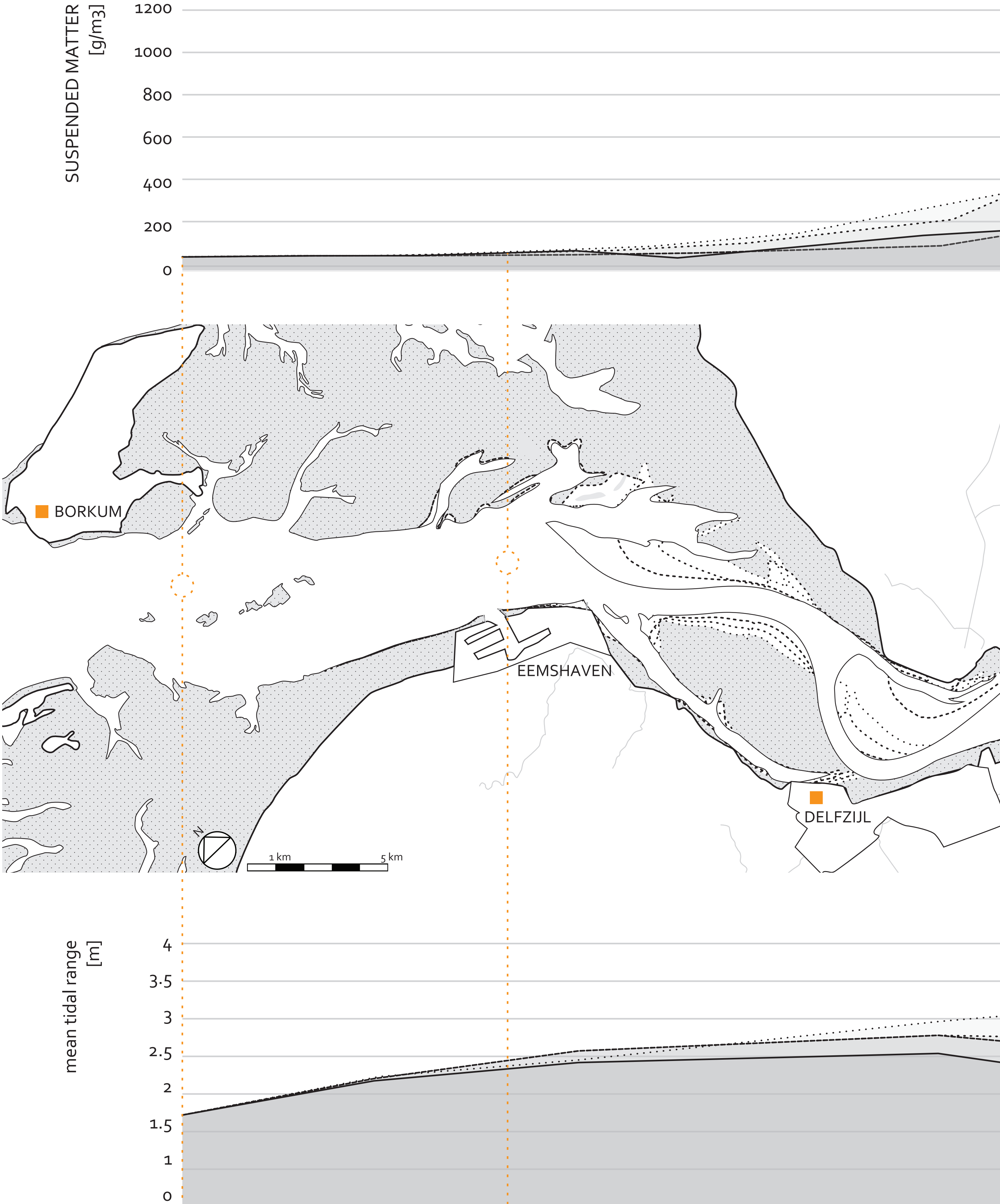
Figure 8.3 [next page] | Through the growing process of the two interventions, the tidal influence and turbidity level will drop. The time for the estuary to fully recover may be a hunderd years, but slowly and gradually the estuary will move towards a new equilibrium (based on Bos et al, 2012).


SUSPENDED MATTER [g/m3]
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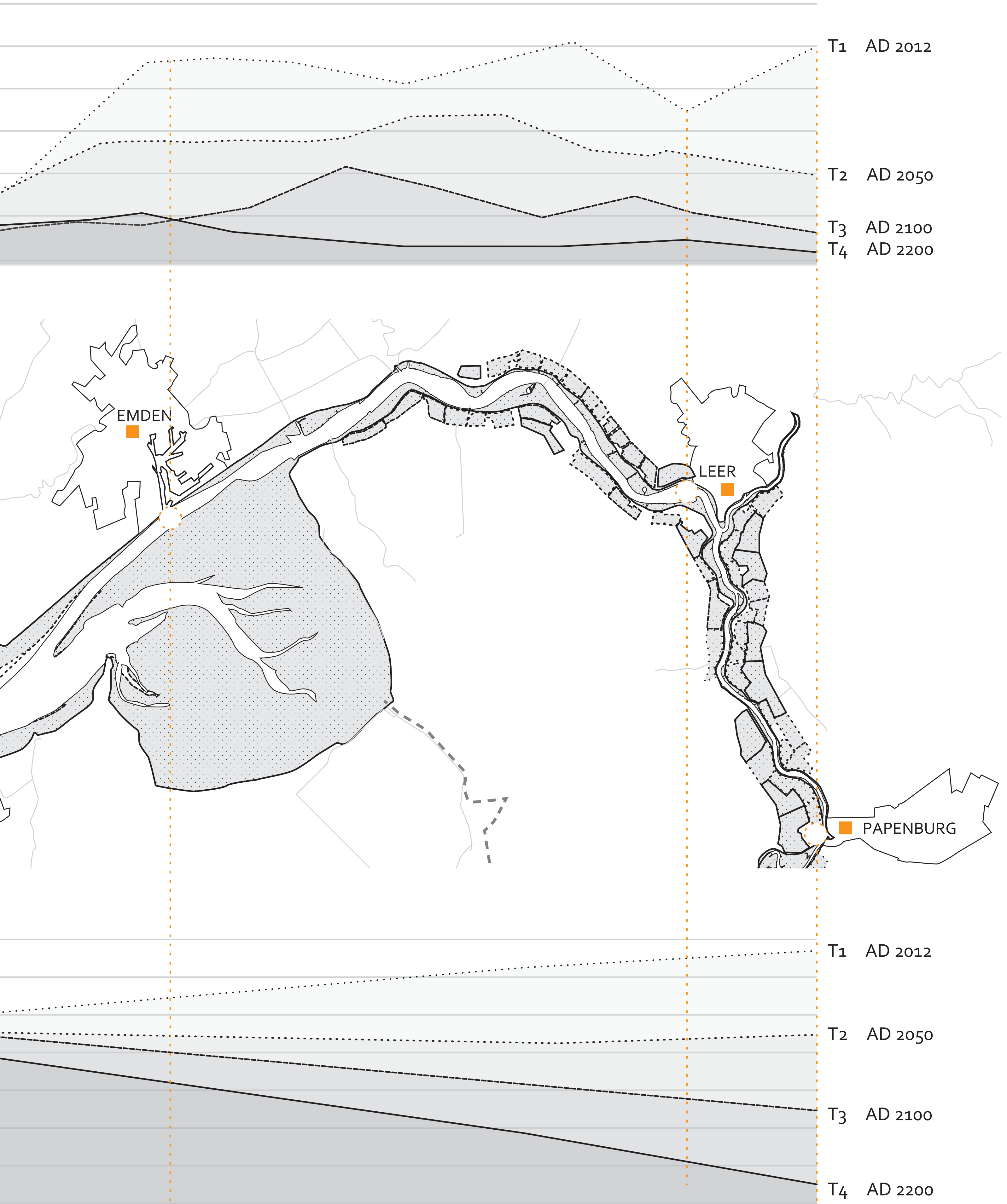
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9

CONCLUSION

9.1 Introduction

This chapter reflects upon the thesis, its questions, its answers and the process that lay behind the understanding of the dynamic Ems system. It is divided into two sections:

9.2 Conclusion
The conclusion answers the research questions as established in the first chapter of this thesis. Thereby showing how we, as landscape architects, can deal with wicked and dynamic cases like that of the troubled Ems-estuary.

9.3 Discussion
The discussion on the end product, its relevance and usefulness, but mainly focussing on the future possibilities of this thesis. We do not consider this thesis as a final step, but a first step in the involvement of the Ems case. This paragraph therefor considers how a landscape architectonic approach, like this thesis, can contribute to the stuck discussion on the problem of the Ems estuary.

9.2 Conclusion: New ways to a recovered Ems-estuary

The problem of the Ems

The Ems suffers from a huge but quite unknown problem. That is what became clear after the first conversations with ecologists and other concerned who have studied the estuary for years. Where once the estuary was inhabited by a massive number of fish and even the prehistoric sturgeon, the estuary nowadays suffers lifelessness for several months a year, caused by an extreme low oxygen level. The cause of the problem, as became clear, lies with the continuous dredging activities in the estuary, which results not only in a loss of oxygen but also in extreme dredging costs up to 27 million euro a year.

Cause of the problem

This case is an example of many environmental challenges that are the result of a constant struggle against the natural system. For many decades man altered the courses of rivers, dammed estuarine connections and drained swamps, replacing the dynamic natural ways for the solid system of man. This however leads to conflicts, as the natural system continuously tries to find balance and can result into friction and eventually a clash with the controlled system. This asks for new technical interventions, which only led to more friction and more interventions; a vicious circle without an immediate solution. Many ecologists have a simple answer and that is to reduce human influence and remove economic activity. The naivety is that men and their land use cannot simple give up his place that it has claimed over time, for its demands and numbers by far exceed that of 500 years ago.

The nature vs economy dichotomy

For the Ems estuary, this dichotomy has led to an impasse between economy and nature. New technical interventions, which would stimulate economic progress, are halted by countless of ecologic studies, while at the same time nature preservation is halted because of a lack of support from economic and political drivers. Any real solution must thus deal with both of these sides, and landscape architecture as holistic discipline, has the ability to counter this dichotomy. The main research question revolving around this, states:
'How can the Ems' sludge problem be solved and how can this lead to an economic and ecologic healthier landscape, using a landscape architectural approach?'

To answer this question four sub questions are compiled:

1. How should dynamic systems like the Ems-estuary be handled argued from a landscape perspective?
2. How does the dynamic estuarine system work and in what has caused the current troubled state in the Ems system?
3. How can the estuarine system be changed or steered to avert the current and future turbid challenge?
4. How can the interventions be conducted in such a way that they deal with the uncertainty of the system and fit within the Ems landscape?

1. How should dynamic systems like the Ems-estuary be handled argued from a landscape perspective?

Dynamic landscapes, like the Ems-estuary are continuously subjected to dynamic processes, like tides and floods, which make highly unpredictable and thereby hard for man to deal with. To overcome this, the uncertainties of the natural system are replaced with the believed certainty of technical and human control. But because natural processes like the tides cannot be stopped, dynamic processes still occur, which causes friction with the attempted controlled state. To move away from this stress situation, natural dynamics need to be reintroduced and there should be worked natural system instead of against it. Natural systems are inherently uncertain. Therefore any interventions must thus be based on the understanding of how this systems works and new solutions must be adaptive, changing and growing to deal with the large insecurity of these dynamics systems.

Landscape is always a mix beteen biotic, abiotic and anthropogenic factors

Besides, the dichotomy between nature and culture does not exist in landscape, it is always a mix between biotic, abiotic and anthropogenic factors. This implies that, when the natural system needs to be healed, it has to be integrated with the contemporary economic landscape. This requires a new attitude towards landscape, which states that: nature can be productive and provide services, and where both ecology and economy benefit from this.

This leads to three strategies which are leading for handling a dynamic landscape like the Ems-estuary:

Strategy deduced from theory

- The natural system should be understood, to integrate the intervention with the natural system instead of opposing the natural system.
- To deal with the uncertainty of the dynamic system, the design needs to be a growth strategy instead of a blue print design.
- To break through the impasse between ecologist and economists, it needs to be understood that nature can be productive and economics can produce nature.

From this, continues the first step in solving the Ems' turbidity problem. This means that needs to be understood how the system works:

2. How does the dynamic estuarine system work and in what has caused the current troubled state in the Ems system?

The Ems-estuary is subjected to many different natural processes which define and change its state. Most dominant in this is the process of net sedimentation and erosion regulated by the relation between the cross-sectional width of the estuary and its hinterland. This states that they are in balance with each other and that changes in width will generate equal changes in the hinterland and vice versa.

Over the centuries, cultural expansion significantly altered the natural system. Until the eighties, the resilience of natural estuarine system could still absorb the human interventions and move towards a new equilibrium. But from 1980 on, the system collapses. Dredging and deepening activities, for the benefit of the shipping industry and cruise ship manufacturing, affect an increase of the cross-sectional width while the corresponding growth of the hinterland is restricted by dikes.

Unbalance between tidal basin and gully-width

In response, the tidal force, strengthened by the normalization of the channels, imports huge amounts of sediment which would normally settle to reduce the width and tidal basin and restore its equilibrium. The sediment, however, is kept in constant suspension by industries to maintain an unnatural deep draft. These floating particles in return cannot leave the estuary because of the increased tidal curve. The result is worsening turbid system, with exponential dredging costs, almost no oxygen production and a strong decrease of all important ecological functions of an estuary.

3. How can the estuarine system be changed or steered to avert the current and future turbid challenge?

To resolve the Ems' sludge problem, the system has to move towards a balanced state. This can be achieved by a reduction of the cross-sectional width of the channel or the enlargement of the floodable hinterland. However, individually they are unpractical, for it will either result in a shipping- channel to become too shallow or narrow for shipping or for valuable arable land to be offered. A combination of both however, has the potential to reduce the turbid state, restore the ecology and fit within the context of the economic system.

A combination of reducing the width and expanding the basin is the solution

This strategy is adapted to the Ems estuary by connecting this new task to other problems and potentials of the area, and focussing on how this could create the largest added value, rather than focussing on doing the least damage.

4. How can the interventions be conducted in such a way that they deal with the uncertainty of the system and fit within the Ems landscape?

With reflection to the theory, rather than implementing a blueprint design, the new proposed adaptations will be growing in size and strength to deal with the capricious character of the estuary.

Growing strategy

In the estuary mouth, this is employed by growing groyne-structures made from old oilrigs. These enforce sedimentation and erosion and slowly steer the gully back into a meander, restoring the multiple-gully system and restoring lost historical estuarine-human connections. But rather than restoring historic conditions, through local variety in arrangement of the structures, new habitats and new economic possibilities are formed.

In the tidal river, the strategy translates itself into the construction of tidal polders, which are flooded by old sluices to increase the floodable hinterland of the Ems. These polders become part of the estuarine system, but will quickly silt up, losing influence and its high biodiversity. The polders can then be reset with the power of the Ems, which is pushed up to allow the Meyer cruise ships to navigate the Ems. This not only restores the effectiveness of the polders, but also gives an important ecologic function to the large cruise ship manufacturer.

Extra ecological and economical benefits

The complete design shows that, by using elements of different nature, technologic, economic and natural, the Ems estuary can be revitalized in both economic as ecological aspects. With this in mind, the main research question can be answered:

'How can the Ems' sludge problem be solved and how can this lead to an economic and ecologic healthier landscape, using a landscape architectural approach?'

Smart interventions within the margins of the natural system enable dynamic systems like the Ems-estuary to house both human activity and ecological diversity. However, to reach such a hybrid landscape a paradigm shift is needed. Economic and ecologic players need to be aware that they are dealing with an ever changing, and unstable system, and that man and its economics are also a part of this. Landscape architecture, as holistic discipline, has the capacity to force a breakthrough, by designing hybrid strategies wherein economic gain and ecologic prosperity can be "guided along a natural infrastructure of landscape-related conditions and potentials." (Sieweke, 2010) With the important and surprising role for oilrigs and cruise ship in the design, this thesis reveals such a paradigm shift, wherein nature can be productive and economics can produce nature.

Nature is productive, economics produce nature

9.3 Discussion

This thesis is the result of a landscape architectural approach to the problematic situation of the Ems estuary. This paragraph will reflect critically on the feasibility and the usability of the various aspects of the thesis. Thereby revealing the gaps and limitations of the proposed design, but also reflect on how this thesis can actually function as a breakthrough for the current impasse of the Ems estuary.

Usability

Uncertainty of proposed interventions

The interventions in the Ems estuary are conducted to a high level of uncertainty. In the first place because the functioning of the system still has many secrets and uncertainties for researchers. The suggested strategies of reducing the cross-sectional width and increasing the tidal basin are based on general assumptions made by hydrologist and other researchers. The actual effect remains unclear. A clear example is the functioning of the tidal polders to enlarge the tidal basin. Similar interventions in other estuaries, like the Hertogin Hedwige polder in the Scheldt estuary, show a positive effect on the increase of the tidal basin. But site-specific conditions make the absence of unwanted additional effects uncertain. Where the same strategy may result in a positive effect for the Scheldt river, it may increase the tidal pumping effect in the Ems estuary. These effects, however, stay unclear until the first leap is taken. Changes in dynamic systems like the Ems estuary, cannot be understood by model study only, real life test cases are needed to get to know all uncertainties.

This high level of uncertainty is amplified by the proposed elaboration of the strategies. The purposed interventions go, with the introduction of oilrigs and cruise ship driven tidal polders, beyond traditional measurements. The functioning of these new introduced designs elements may be questioned. In the case of the groynes build out of oilrig jackets, it is unclear if these structures ensure the appropriate rate of sedimentation. The use of other techniques that actually proved their functioning, may be a solution. However, for the groynes the same applies as for the tidal polders.

Tests and experiments are needed

As long as the effects are unclear, real life tests are needed to prove their right. Hereby, the oilrig-structures have the advantage, that their flexibility makes them easily adaptable for a better functioning.

Feasibility

Endless research to try to understand all uncertainties of the dynamic Ems estuary seems to be a never-ending story. While ecologist and hydrologist produced more than 150 documents about the poor state of the estuary and ways to recover the estuary, the ecological conditions in the estuary have continued to drop. The uncertainty of the estuarine landscape makes that the impasse between nature and economy holds. Where both parties do not dare to take action as long as the effects are uncertain. We

Action is needed

want to emphasize that action is needed and that the purposed actions will not alter the entire estuarine environment immediately but that effects will build up slowly and are part of a growing strategy. Instead of endless research on the functioning of the whole, the purposed interventions can be initiated small scale, then the intervention can be adapted to the uncertainties by doing.

The first step

We like to see our thesis as an inspiration to look in a new way to the jammed discussion on the Ems estuary. We do not pretend that our solution is the only working one to solve the wicked problems of the Ems. Instead with our suggestions we want to inspire and start a discussion that helps all parties involved in the Ems-region to think beyond their own goals. We want to invite all parties to start a landscape experiment and together with their opposing party, to grow towards an estuary which is healthy both in ecological as economy perspective. Therefore we challenge all parties to take a gamble and start importing an abandoned oilrig to Eemshaven and start with the construction of the first tidal polders. Taking the first steps to break through the impasse and start with the growth towards a healthy Ems estuary.

Thesis as inspiration

Growth towards a healthy Ems estuary

APPENDICES

Glossary

Barrier
Structure to block water, either incoming or outgoing. The structure could be permanently closed with sluices, or permeable with the ability to fully close off when needed.

Breakwater
A dam like construction perpendicular to the coast, constructed to prevent erosion or control water flow.

Cross-sectional width (= Natte doorsnede)
The cross section of a gully or river in m2, measured from the sides and bottom until the water surface.

Dredge
The produce of dredging activity.

Dredging
Removing the top layer of soil from the bottom of a water body with the goal of maintaining water depth or increasing depth. The soil could be sucked up and later on dumped elsewhere, or blown in suspension to ensure temporary navigability.

Erosion
The process in which wind, ice or water tiers down geological formation and moving the remains as sediment (the inverse of sedimentation).

Estuary
The seaward section of a river system where saline and fresh water is mixed and receives sediments from both fluvial and marine sources. This area is subjected to tide, wave and fluvial processes and extends from the total area on which both marine and riverine influence is measured.

Flat
Low lying area of mud and sand surrounded by water. A flat overflows during high tide and as a result has limited or no vegetation.

Groyne
A dam like construction perpendicular to the coast, constructed to prevent erosion or control water flow.

Gully
The (natural) channel in de midst of shallower areas through which the main body of water flows.

Intertidal zone
The region that overflows during high tide, and falls dry at low tide.

Saltwater marsh (= kwelder)
Outer dike zone that only overflows at high tide or springtide. Saline resistant vegetation is able to grow here, which has the potential to speed up the process of sedimentation

Sedimentation
The process of sediments, which are carried by the flow of wind, ice or water, settling down and thus heightening land (the inverse of erosion)

Silt
Low-lying area of mud and sand connected to the coast and/or a dike. A silt overflows during high tide and as a result has limited or no vegetation.

Turbidity
The haziness of water caused by tiny individual particles. A high turbidity causes limited light penetration, diminished vision or even troubled intake of oxygen by organisms.

Tidal basin or tidal storage
The total area that is fed by a single gully. As a rule: a large basin needs a great volume of water to fill and as a result has a large gully to process the water.

Tidal range
The vertical difference between high and low tide.

Tidal volume / Tidal prism (= getijprisma)
The accumulated volume of high and low tide; the total sum of water flowing in and out of a system during a single tidal sequence. Calculated by the difference between high and low tide multiplied by the surface of the tidal basin.

Wad
Collection of silts and flats located between the Wadden islands and the North coast.

Weir
See: barrier.

Ratio tidal basin / cross sectional width
There is a strong correlation between the size of a tidal basin the cross sectional width of the gully that supplies it with water. As a rule it states that when increasing the tidal basin, the tidal volume increases which will erode the main gully and thereby increasing the cross-sectional width. The reverse is also true: When the cross-sectional width of a gully decreases, the potential tidal volume decreases and the tidal basin is reduced in size (Steijn, 2002, Louters and Gerritsen, 1994, Kemerink, 2004).

This law is described by $A=c*P$
A: cross-sectional width in m2
P: tidal basin in m3
c: a constant different for every estuary (for example 0,03)

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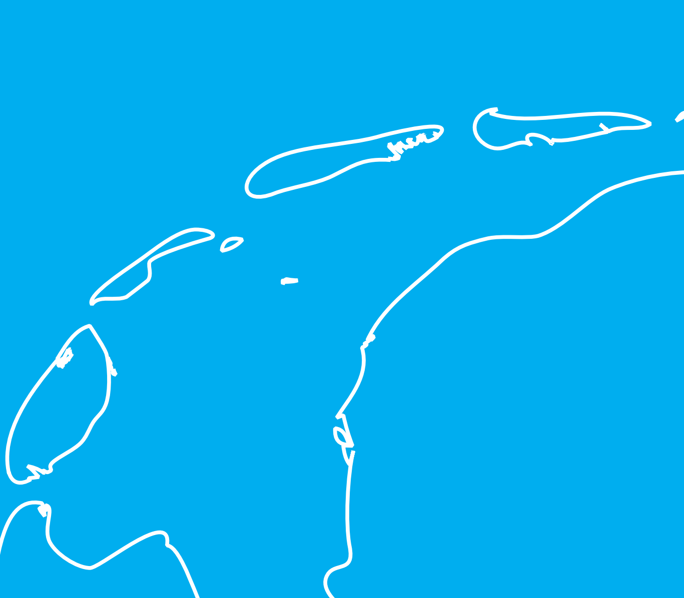

DIGITAL APPENDIX

THE EMS FULL HYBRID
a Landscape Design for a Troubled Estuary

MSc thesis Landscape Architecture | Wageningen UR | 2012

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