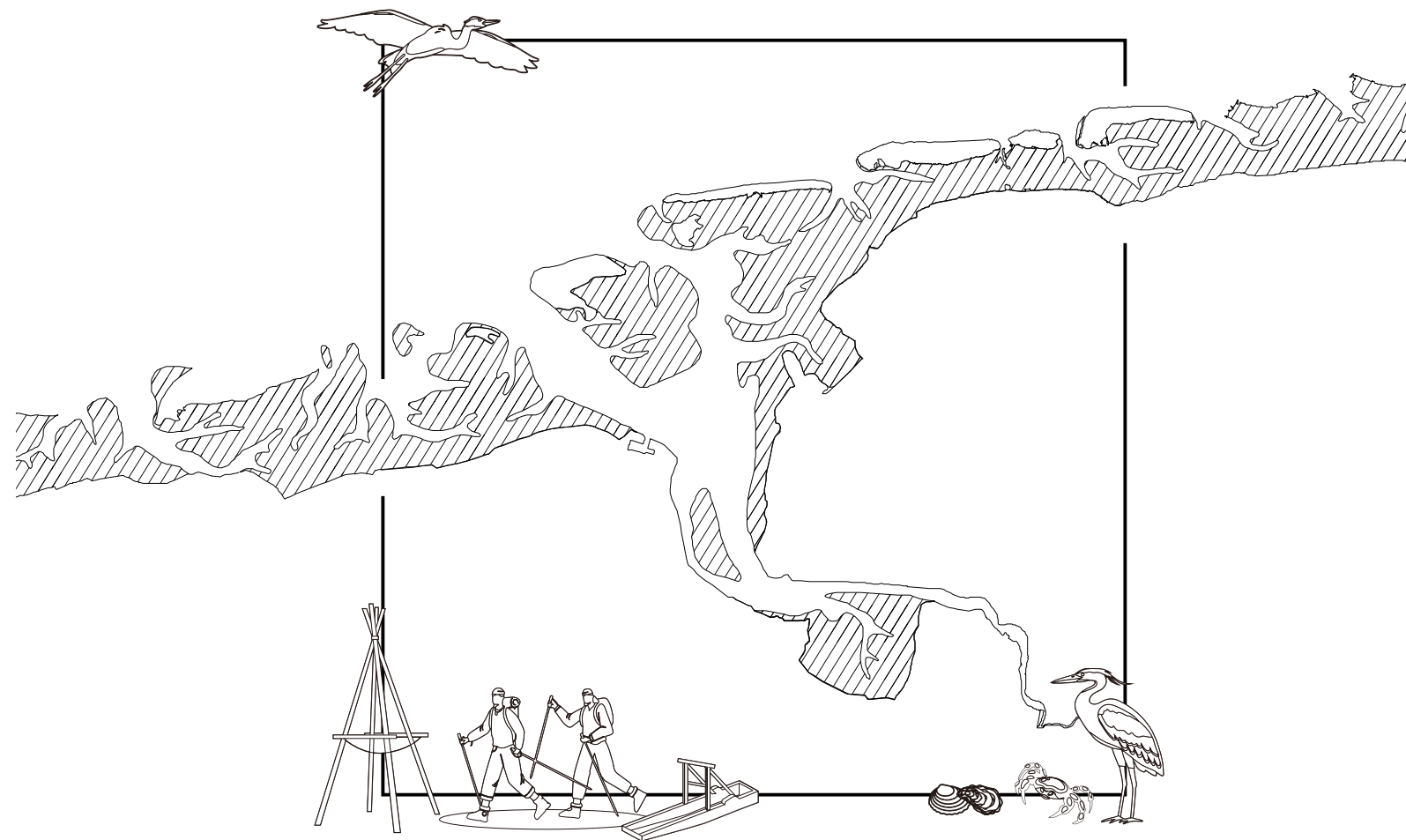


Mudscapes

Embracing Nature, Feeling Culture in the Ems Estuary



Zhaolei Li
2023.06.29

Colophon

AUTHOR

Zhaolei Li

FIRST MENTOR

Laura Cipriani

Chair of Landscape Architecture, Delft University of Technology

SECOND MENTOR

Bram van Prooijen

Associate Professor of Estuarine Dynamics, Delft University of Technology

EXAMINAR

Steven Steenbruggen

Architecture and the Built Environment, Delft University of Technology

AR2LA021 THEORY COURSE

‘Water Crisis and Hope’

Academic Year 2022-23

May 2023

TU DELFT

Architecture and the Built Environment

Department of Urbanism

Section of Landscape Architecture



Introduction



Introduction



Satellite image of the Wadden Sea.
Photo: U.S. Geological Survey.

Introduction



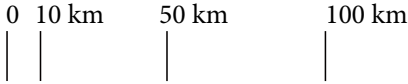
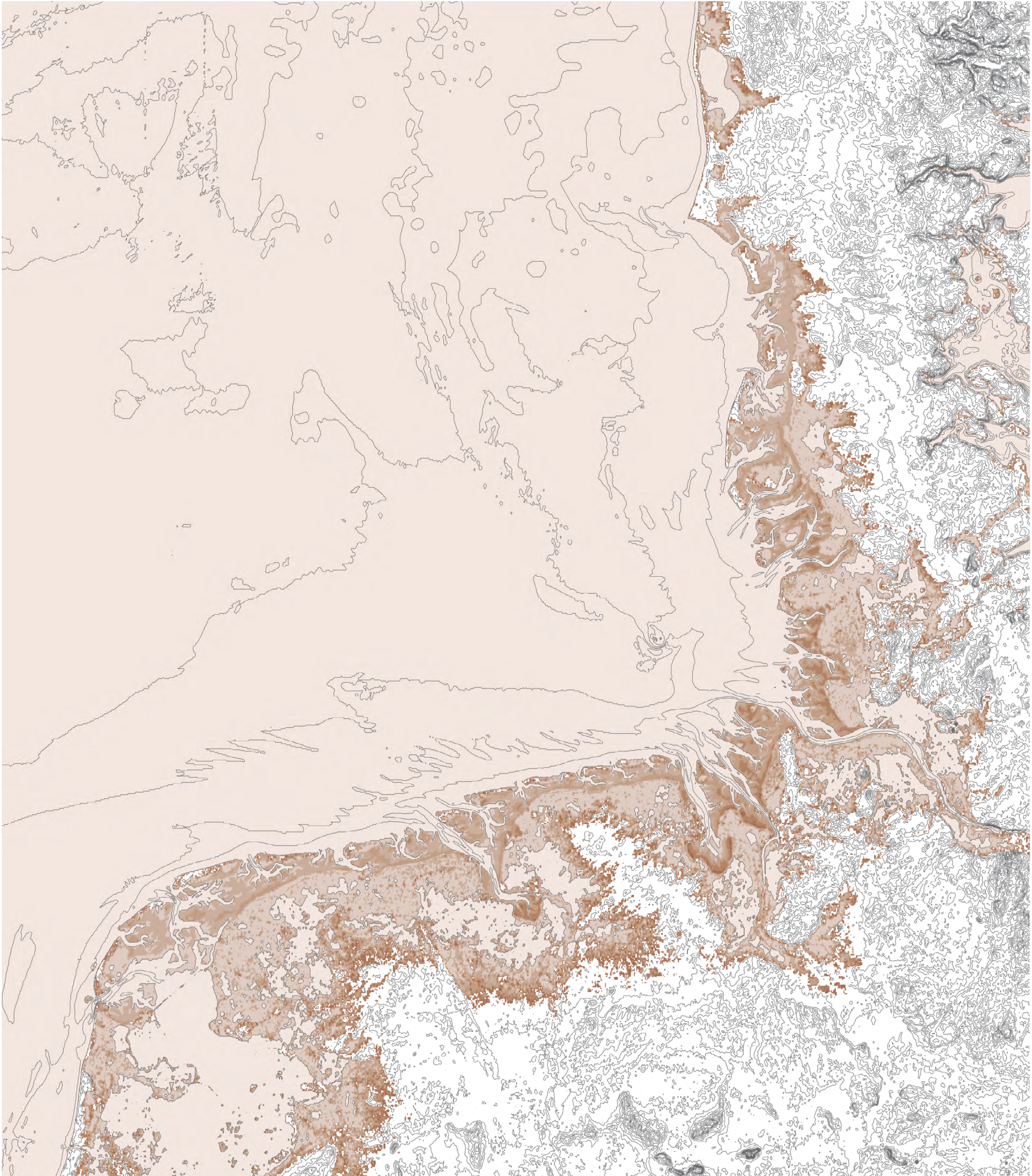
Diverse ecosystems of Wadden Sea
Photo: Klaus Dieter Meinen

Introduction



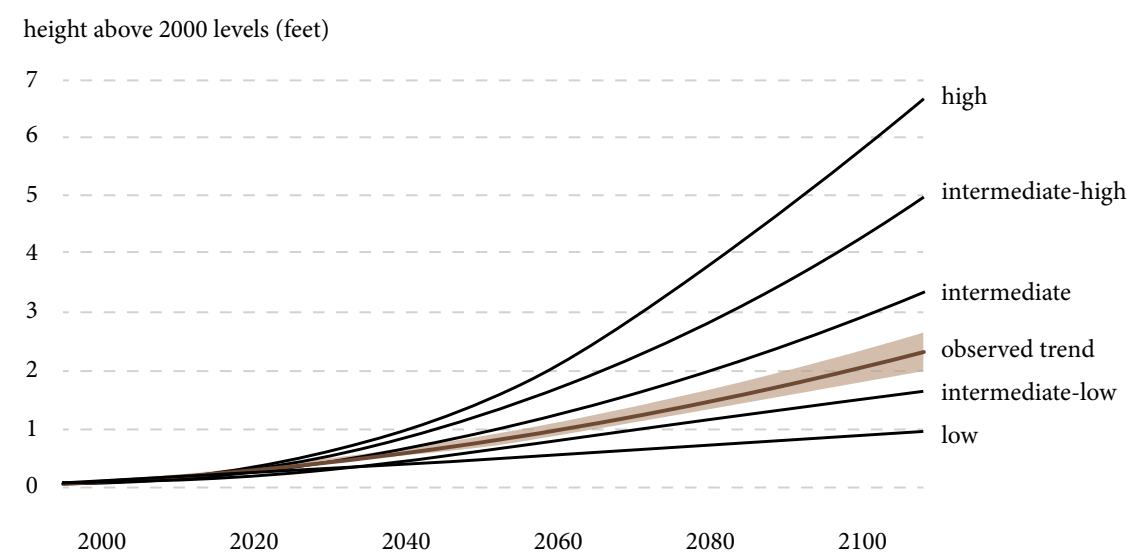
Mudflat walking
Photo: Marketing Groningen

Sea Level Rise

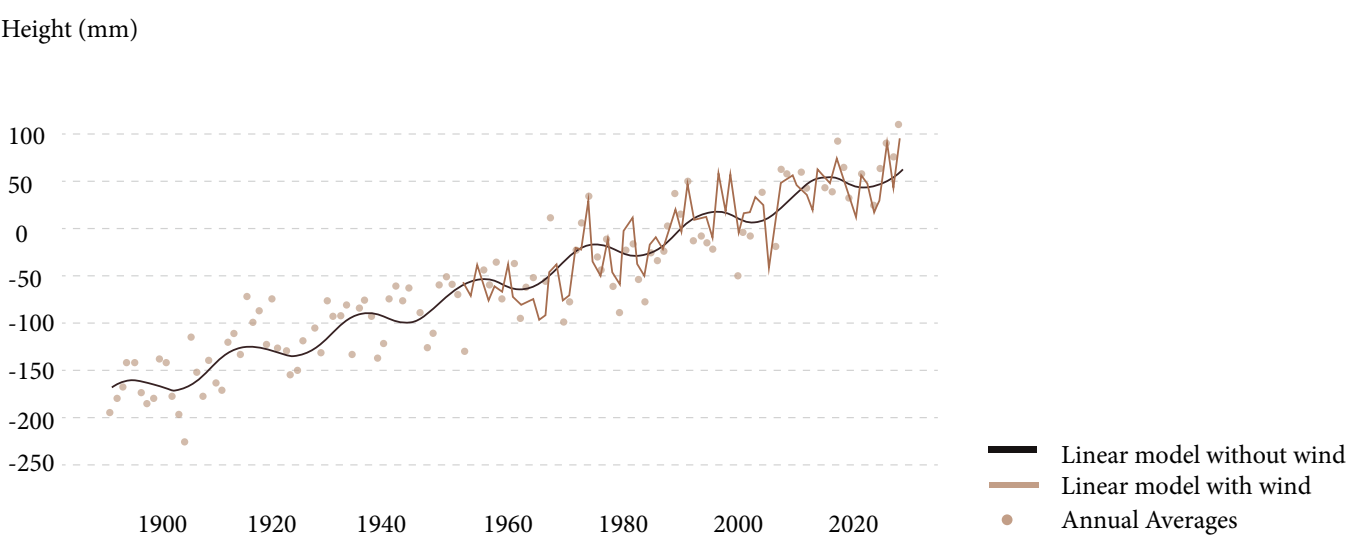


- Height of sea level rise-0m
- Height of sea level rise-1m
- Height of sea level rise-2m
- Height of sea level rise-3m
- Height of sea level rise-4m
- Height of sea level rise-5m

Sea Level Rise



Global sea level rise
Data: NOAA climate.gov, 2022.



Sea level rise in the Wadden sea
Data: Sea level monitor 2018. E Baart et al., Deltares, 2019

Introduction



Magnificent Wadden land.
Photo: www.visitwadden.nl, 2022.

Introduction



Polder near Noard Fryslan Butendyks
Photo: Zhaolei Li, 2022.

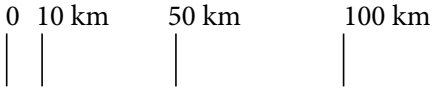
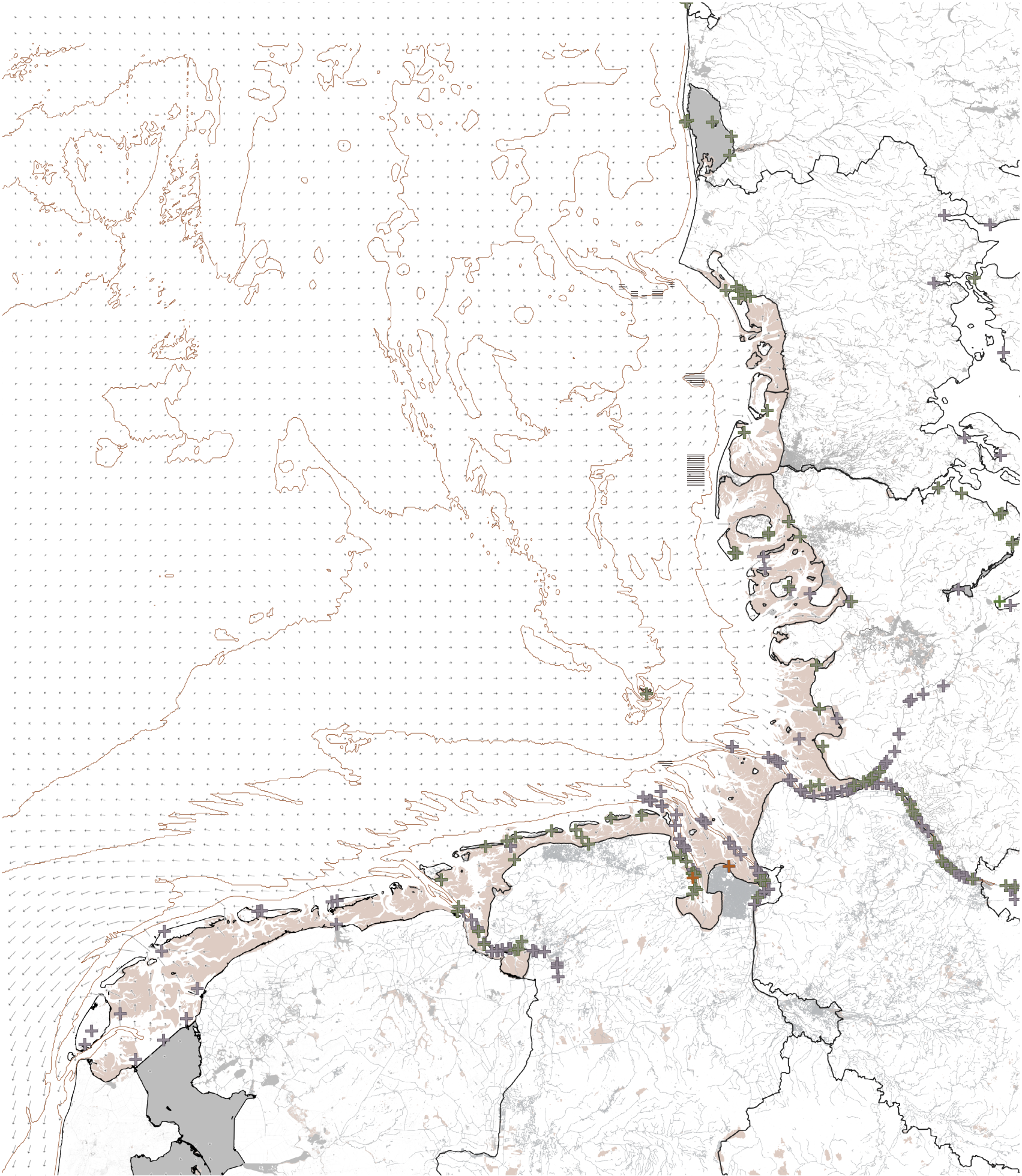
Dredging & Dumping



Dredging in the Wadden Sea
Photo: Hayden Burke, 2022

Dredging

Dredging Area
Data: Comune di Venezia, 2008.



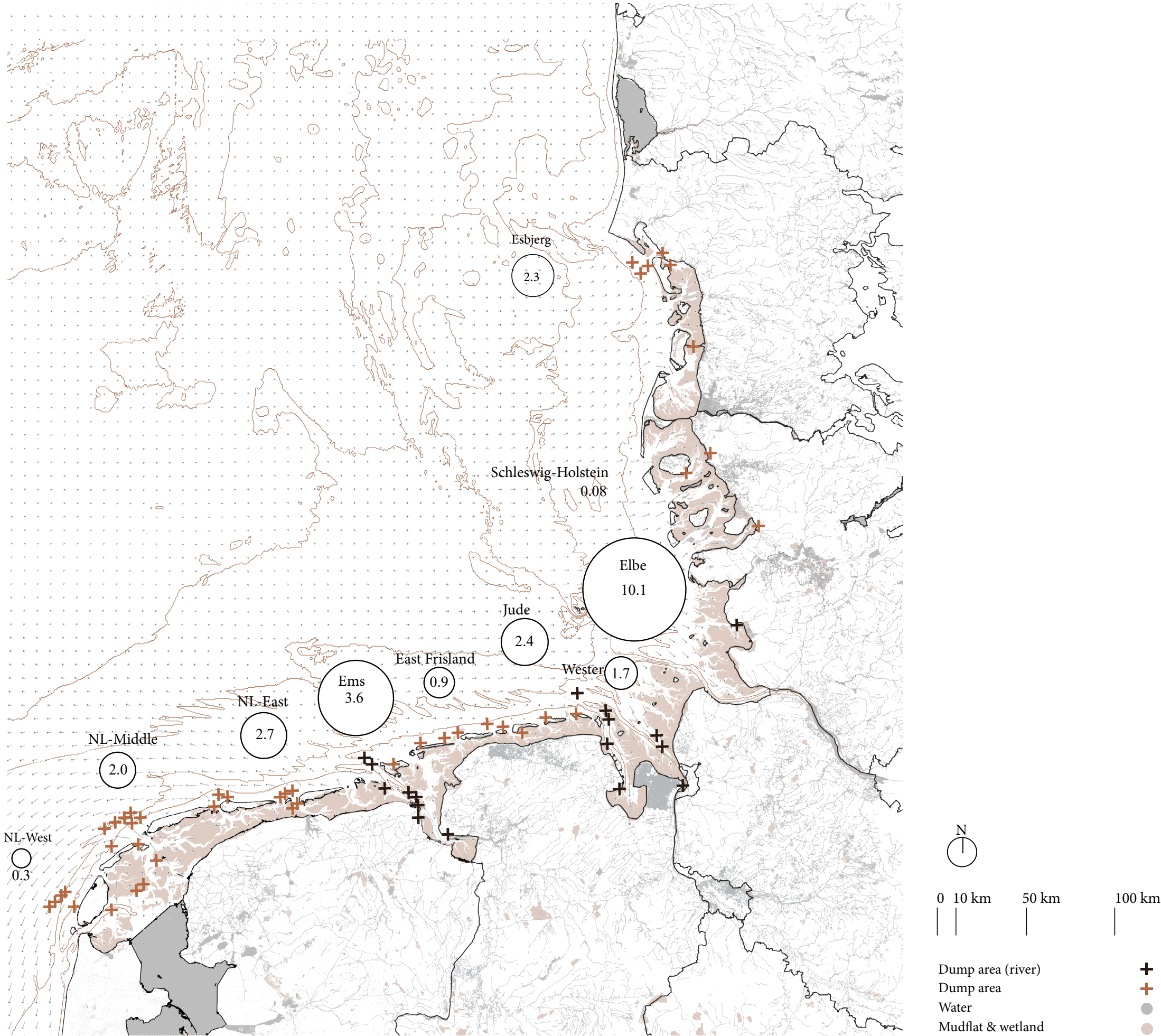
- Water
- Wetland & mudflat
- Extraction area
- Dredging area centroid
- Dredging line midpoint
- Estimated dredging area
- Original dredging area



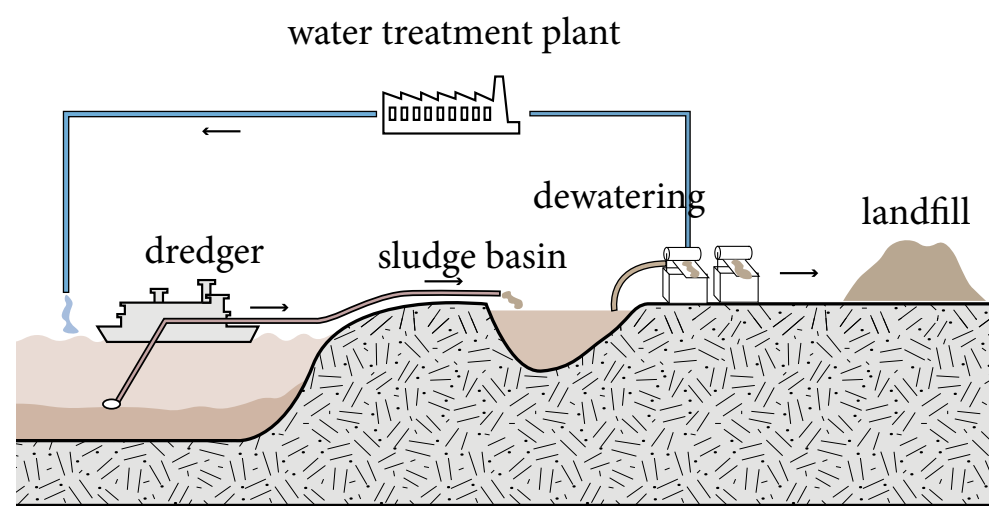
Odyssey of the Seas transits the Ems River
Photo: Royal Caribbean, 2021

Dumping

Dump site
Data: Comune di Venezia, 2008.



Dumping



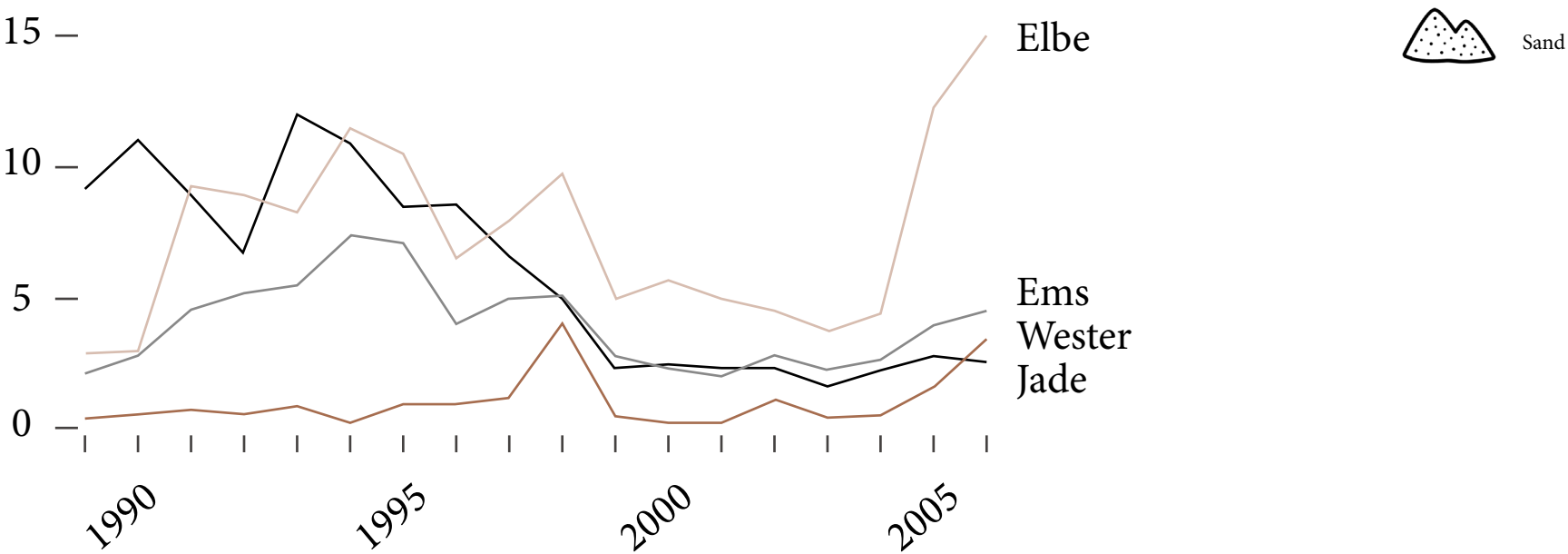
Dredging process



Replenishments, dredging and pumping sand onto beaches.
Photo: Zlatan Hrvacevic, 2022.

Dumping

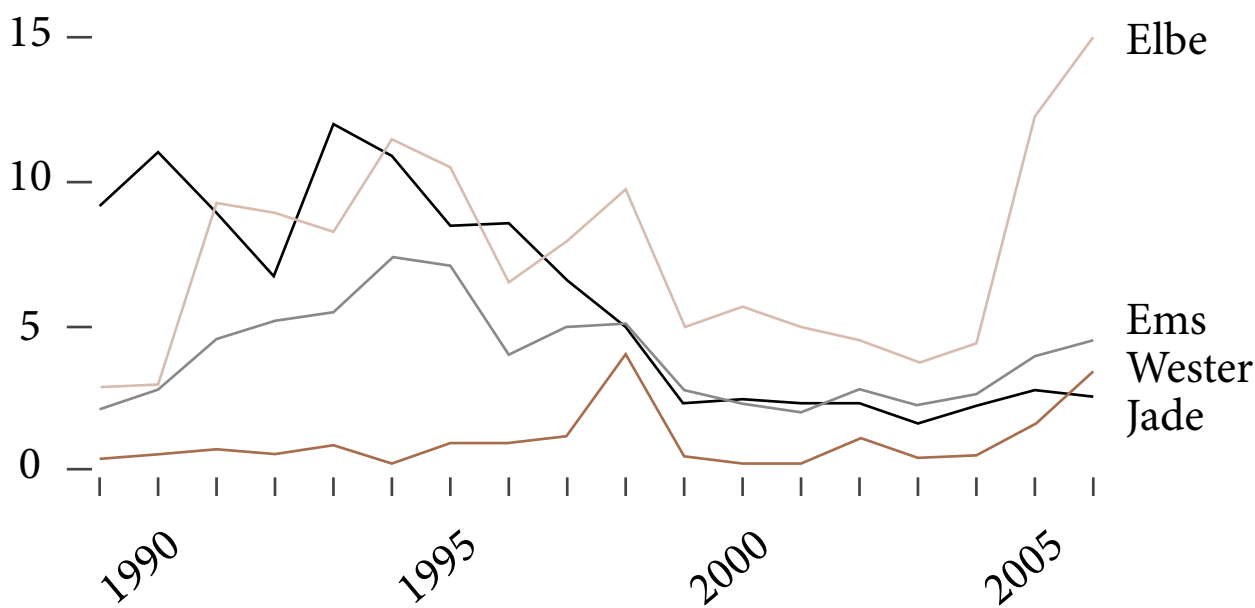
Million tons dry weight



Amounts of dumped dredged material
Date: Wadden Sea Ecosystem Quality Status Report 2009

Dumping

Million tons dry weight



Sand

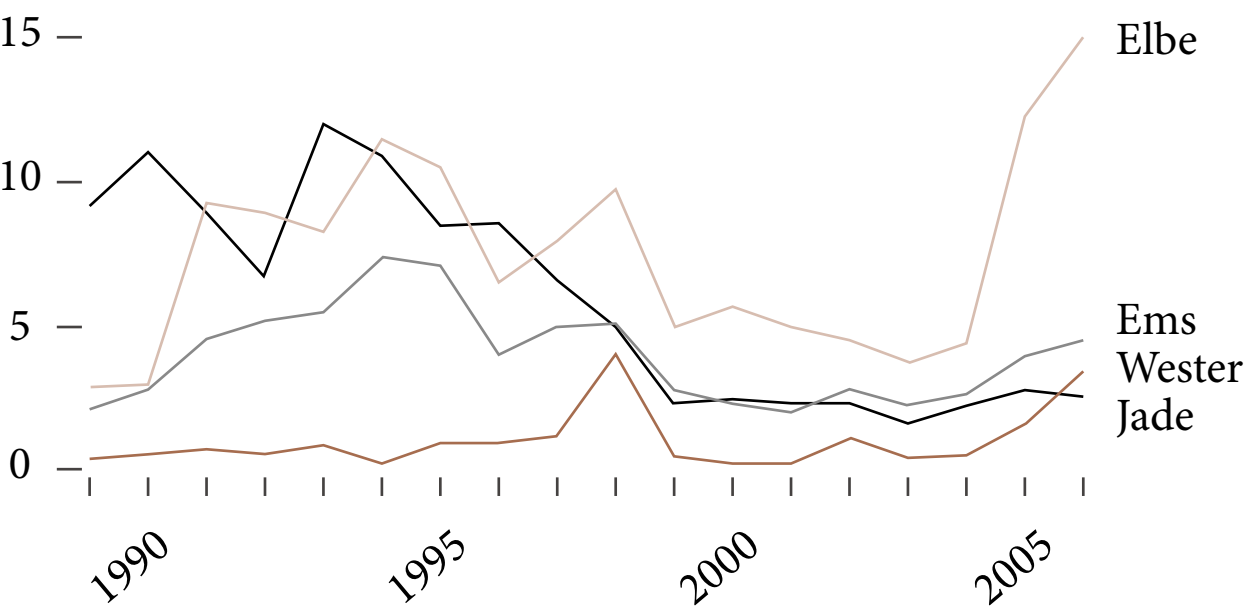


Mud (include clay,silt, organic materials)

Amounts of dumped dredged material
Date: Wadden Sea Ecosystem Quality Status Report 2009

Dumping

Million tons dry weight



Sand



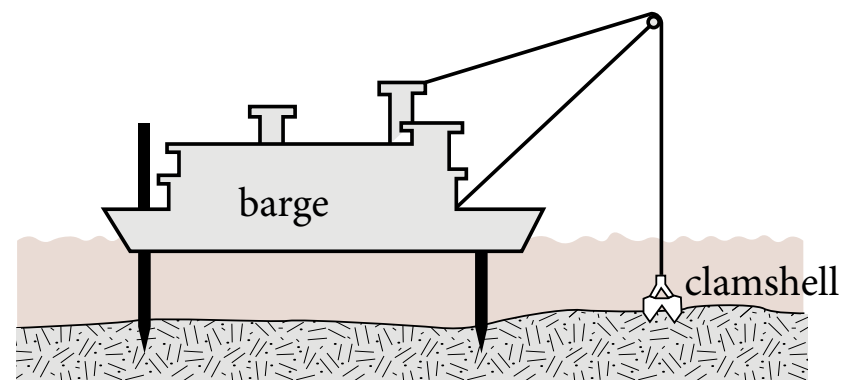
Mud (include clay, silt, organic materials)



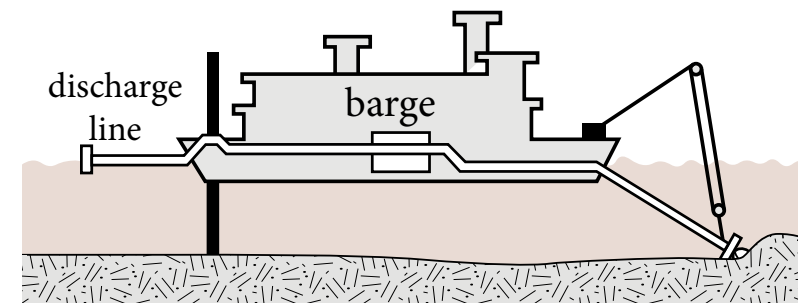
Shell

Amounts of dumped dredged material
Date: Wadden Sea Ecosystem Quality Status Report 2009

Dumping



Mechanical dredging



Hydraulic dredging

Schematic of dredging techniques and processes
Data: Federal Remediation Technologies Roundtable, 2020.

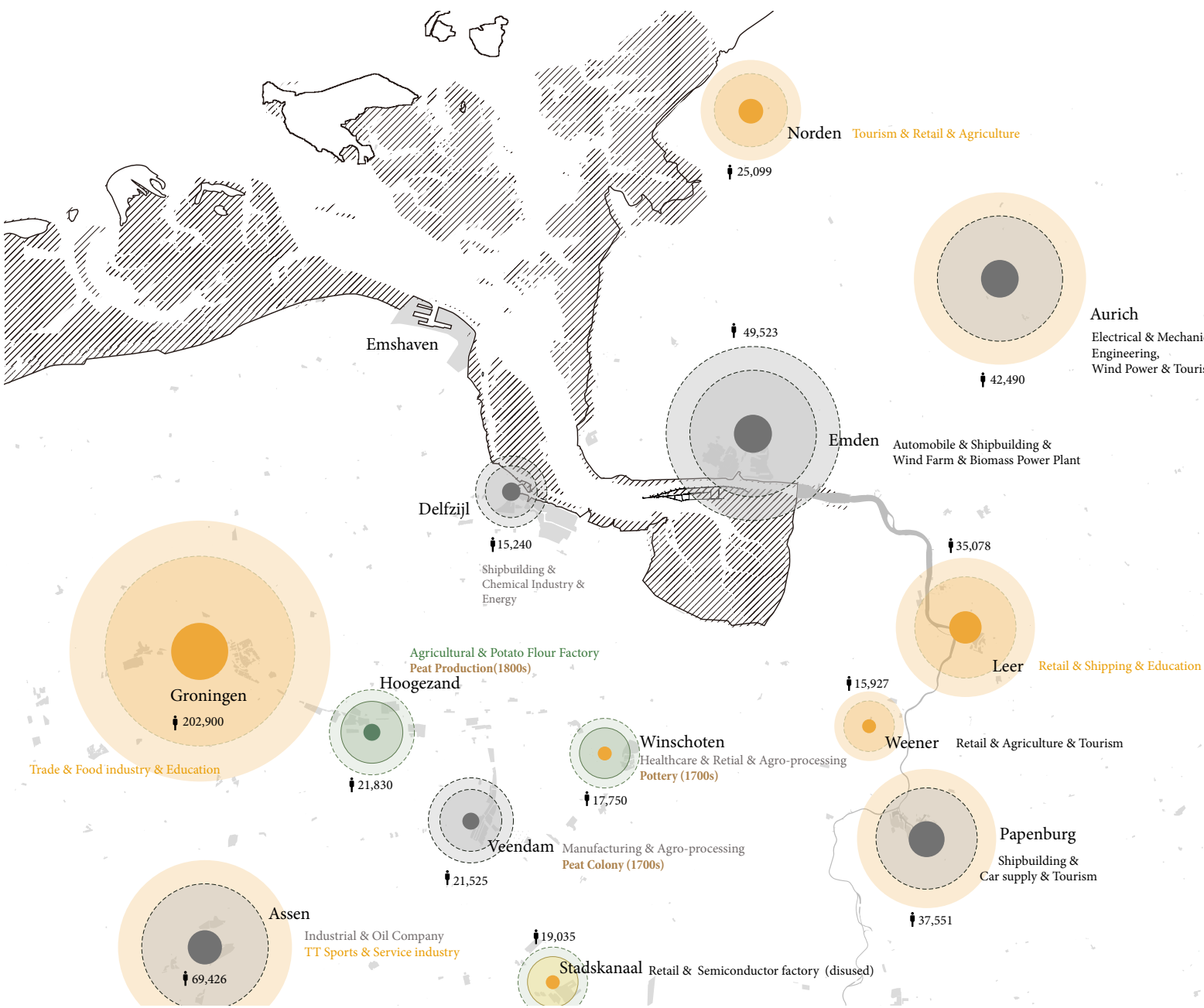
Poor Ecology



Liquid mud in Ems estuary.
Photo: Henk Schuttelaars, 2021

Ems River is currently being called the “yellow river” of Europe

Poor Economy



- Agriculture
- Industrial
- Tertiary sector

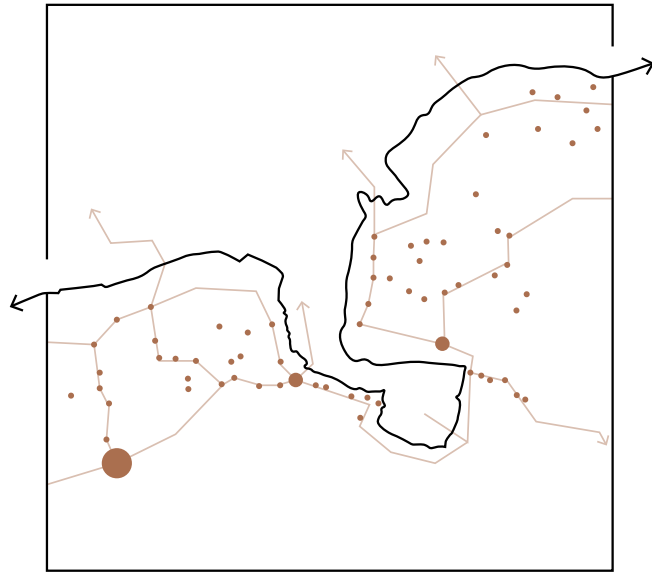


- Climate extremes
- Human activities (Dredging & Dumping)
- Poor ecology and economy
- Loss of identity

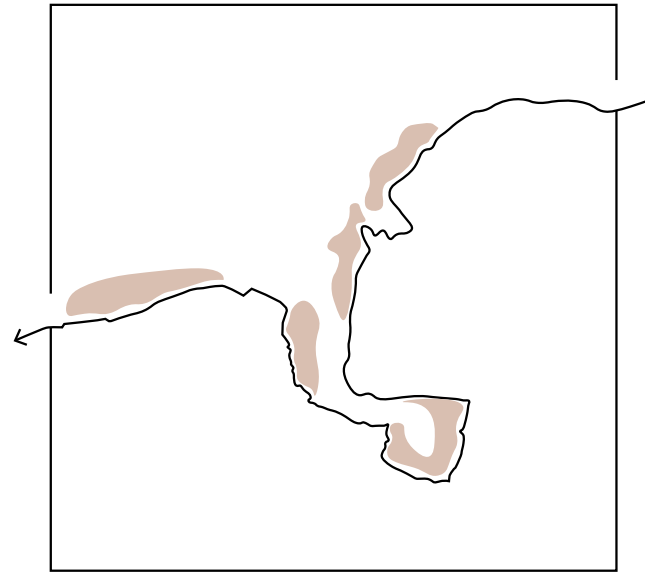
Mud in the polder.

Photo: Programma naar een Rijke Waddenzee, 2020

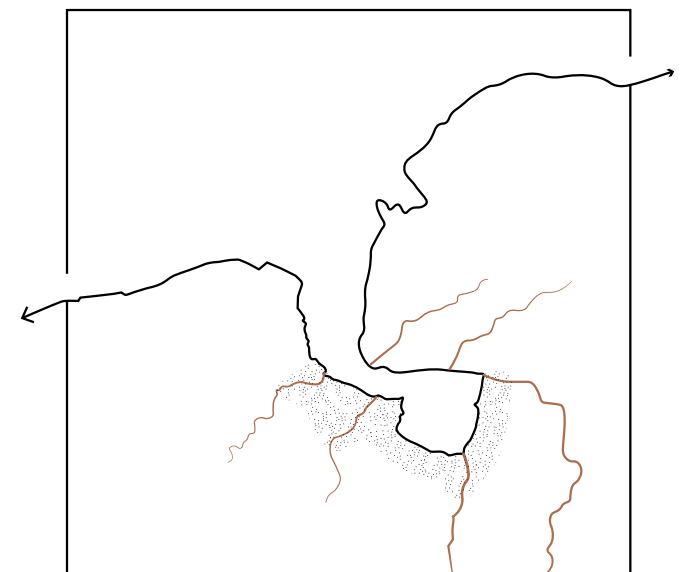
*How can mudscapes contribute to
integrating and promoting
economic, ecological, and cultural development
in the Ems-Dollard region?*



Mud as Socio-Economy Booster



Mud as Ecology Enhancement



Mud as Climate Adaptation



Mud as Socio-Economy Booster

Mud processing to improve agricultural soils.

Mud as material for ceramic handicrafts.

Memorial landscape in the mudflats.

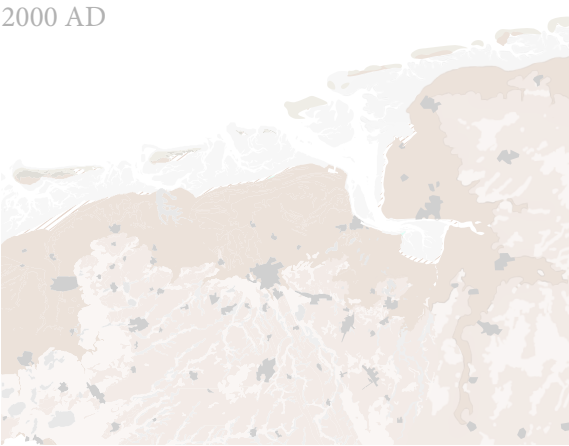
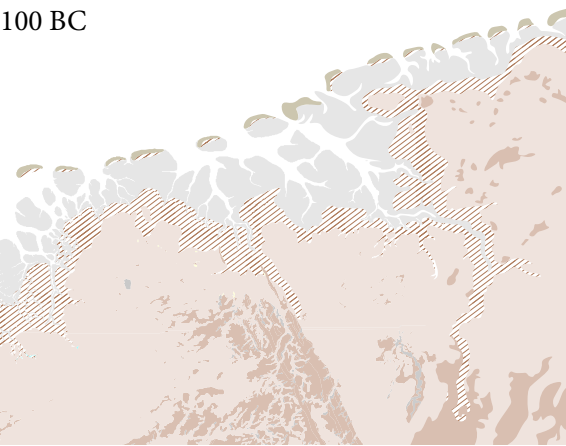
Recreation value enhancement.





Mud as Socio-Economy Booster



Church on the turp
Photo: Zhaolei Li, 2022.

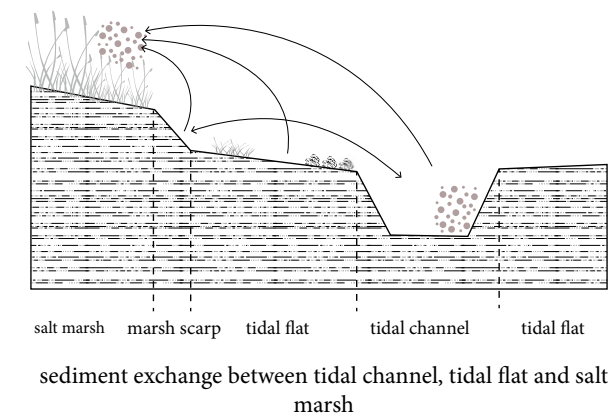
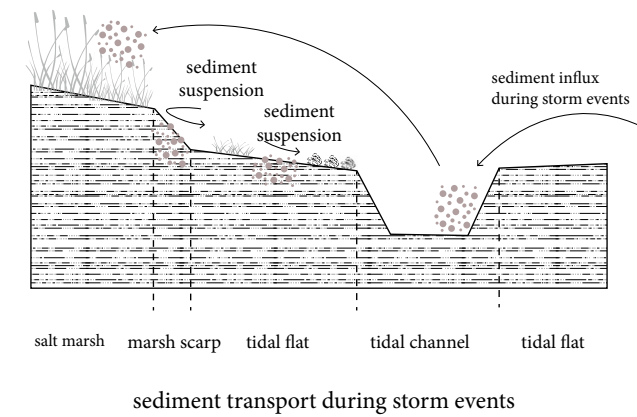
Mud as Socio-Economy Booster
Geomorphological evolution



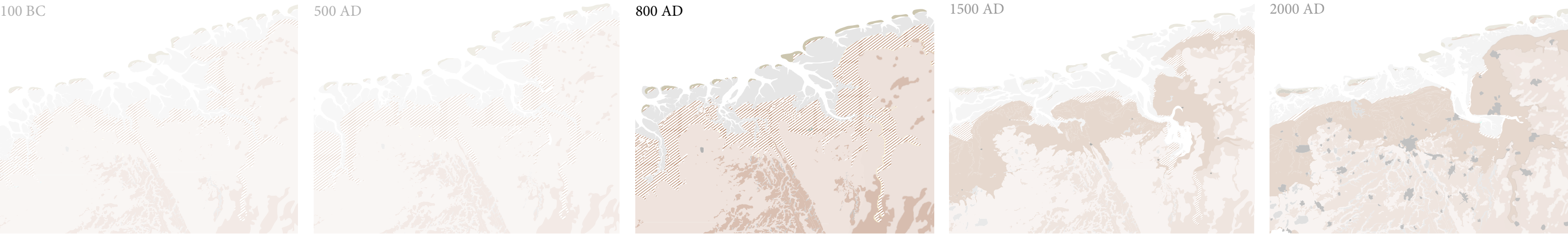
- | | | | |
|---|------------------------|---|-------------------------|
|  | Dunes and beach ridges |  | Peat |
|  | Intertidal areas |  | Pleistocene grounds |
|  | Former lakes |  | Reclamation/Diked areas |
|  | Supratidal areas |  | Urban areas |

Mud as Socio-Economy Booster

Geomorphological evolution



Mud as Socio-Economy Booster
Geomorphological evolution

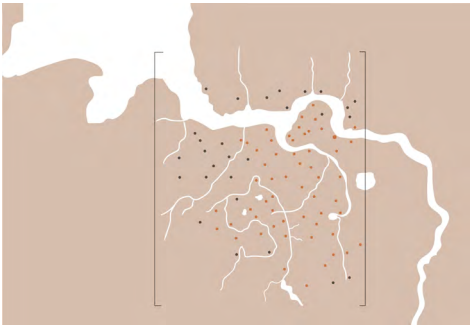


- | | | | |
|--|------------------------|--|-------------------------|
| | Dunes and beach ridges | | Peat |
| | Intertidal areas | | Pleistocene grounds |
| | Former lakes | | Reclamation/Diked areas |
| | Supratidal areas | | Urban areas |

Mud as Socio-Economy Booster

Land Reclamation

1270 AD



1550 AD



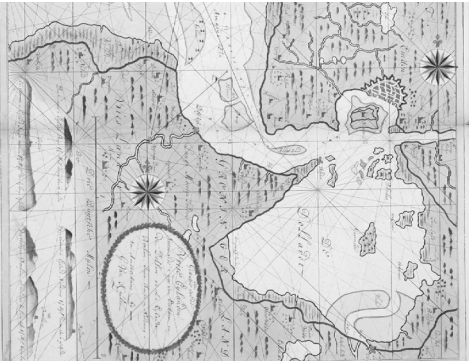
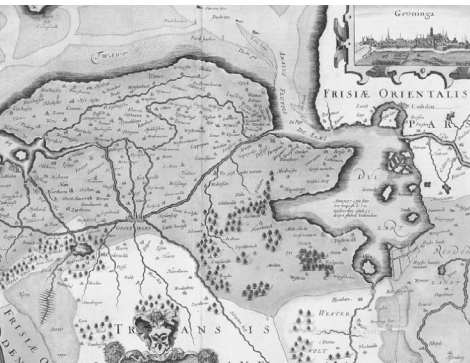
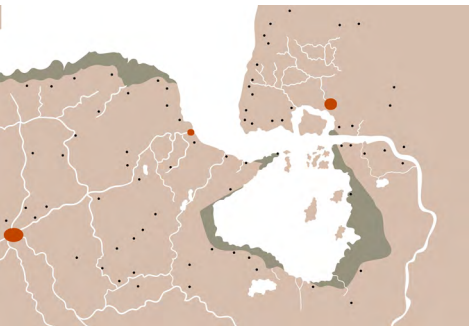
1617 AD



1650 AD

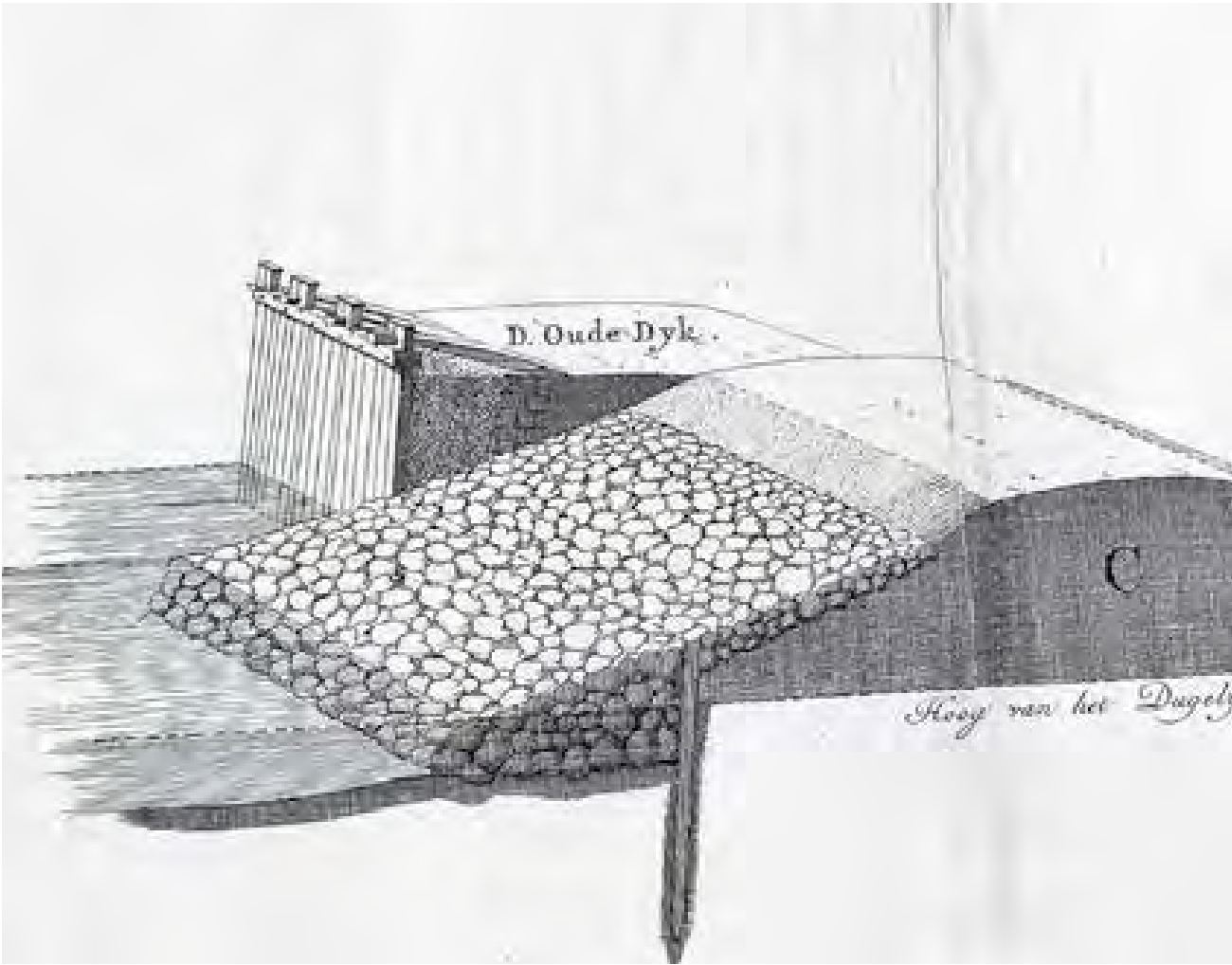










1720 AD



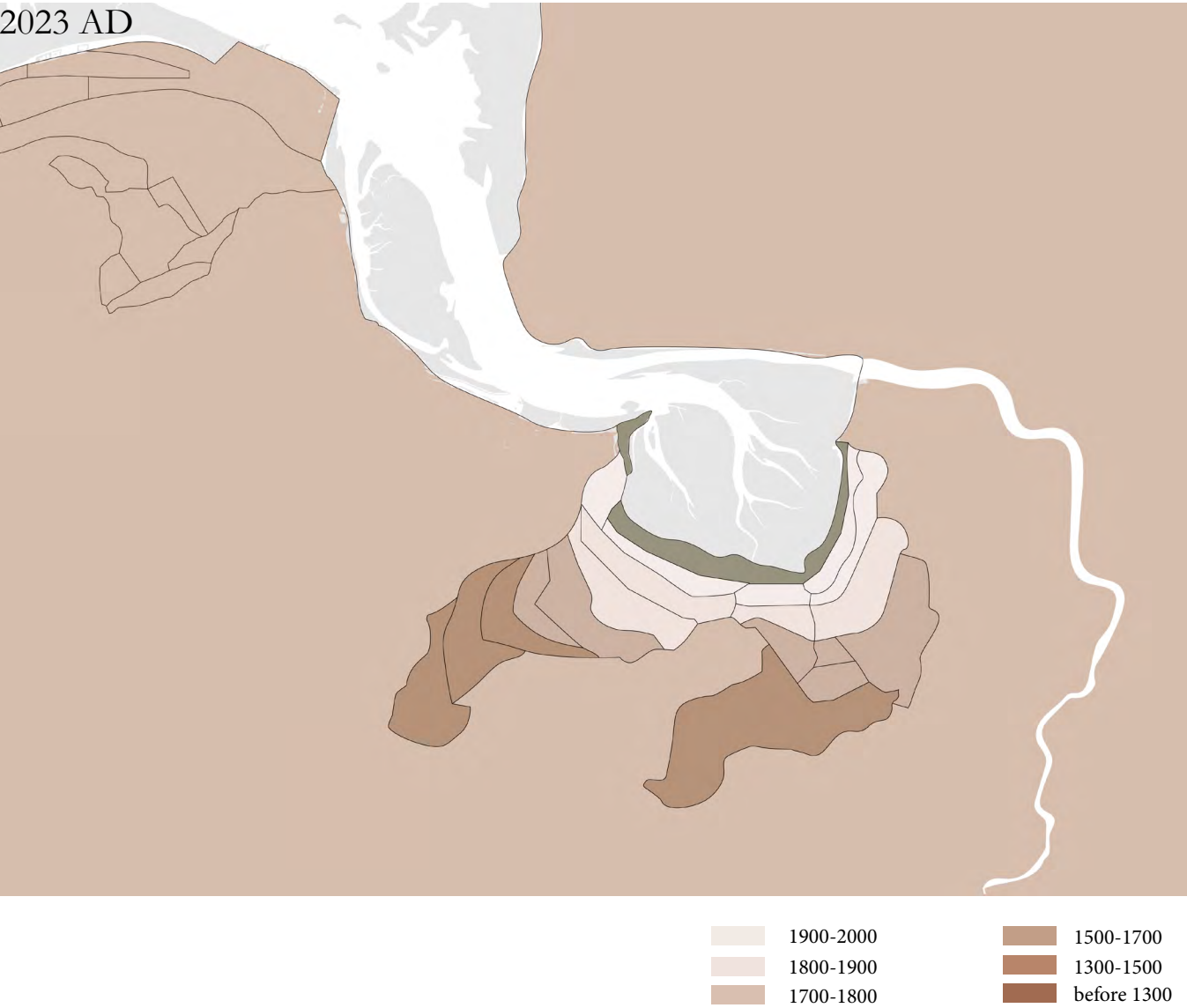
- Mainland
- Saltmarsh
- Intertidal areas
- Rivers & lakes
- Cities
- Terps

Mud as Socio-Economy Booster
Land Reclamation



- | | | | |
|---|------------------------|---|-------------------------|
|  | Dunes and beach ridges |  | Peat |
|  | Intertidal areas |  | Pleistocene grounds |
|  | Former lakes |  | Reclamation/Diked areas |
|  | Supratidal areas |  | Urban areas |

Mud as Socio-Economy Booster
Land Reclamation



Sculpture “De Wadloper ”, a mudflat runner standing waist-deep in water,
looking out over the mudflats.
Photo: Lammert Kwant

Mud as Socio-Economy Booster

Mud Imagery

As early as 2nd Century BC
Low dikes and terps, enhancing sedimenta-
tion.



Around the 10th – 11th Centu-
ry, Systematic building of lines
of dikes became the norm.



Large-scale construction
of gates and artificial
control of the river.



The end of the 19th Century
Modern shipbuilding in the
German town of Emden.

In the 20th century, settlement of larger
industrial companies such as the Nordseew-
erke shipyard and the Volkswagen factory.



Before humans started to influence the
development of the mainland coastal
zone,

With the hard labour of mud work-
ers, they slowly took back land from the
sea.

An astronaut fell on a mudflat in
the Wadden Sea and was rescued
by people using sledges.

Mudflats walking has become a
very popular tourist activity

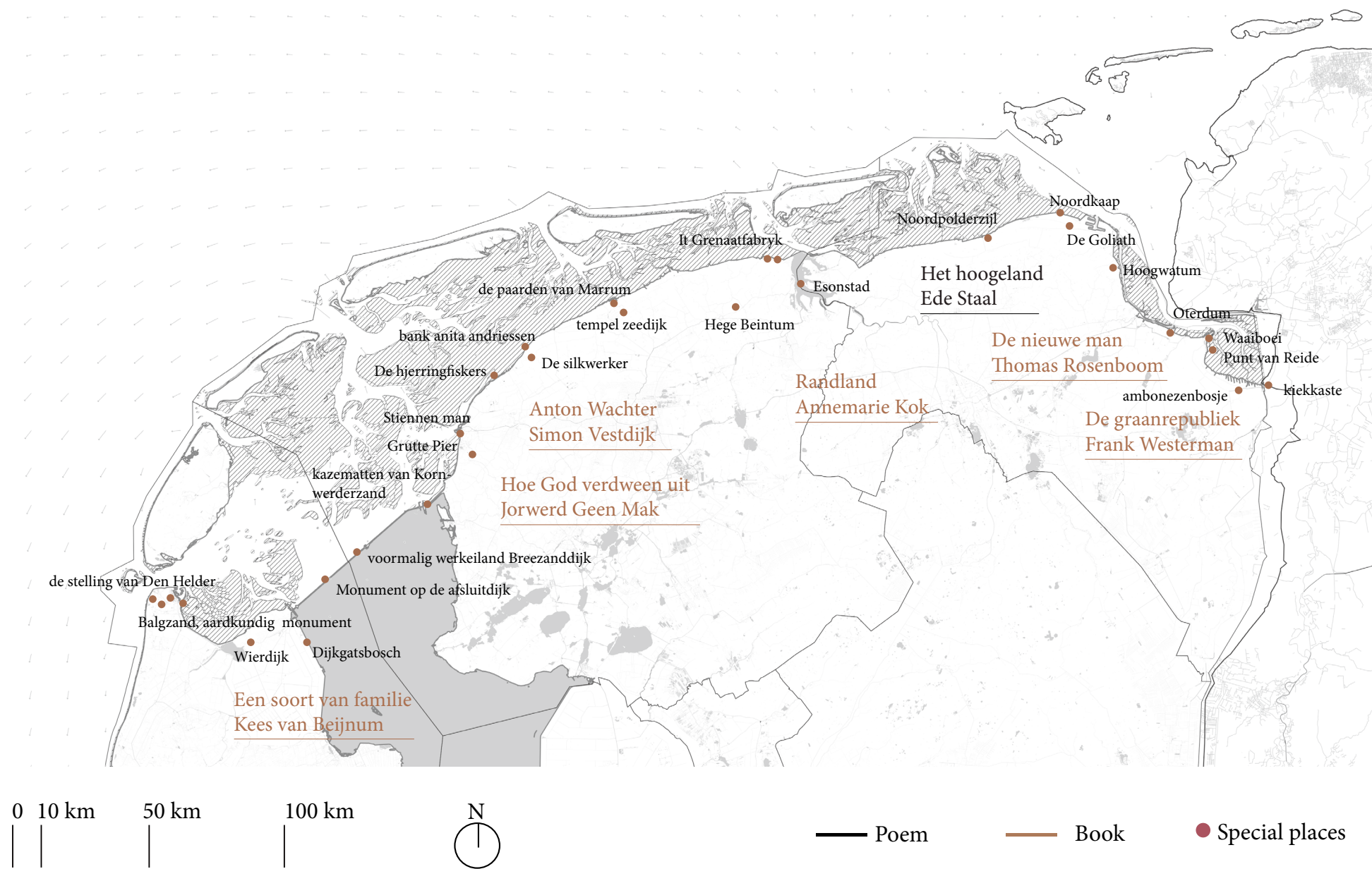
Mud as Socio-Economy Booster
Mud Imagery



Legend, Literary works and old Festivals
Data: Dutch sagas, Cor Bruijn, 1946. Atelier Fryslân, 2020. Schaapman, J., Jukema, N. Rixt, & Wagenaar, T. ,2022.

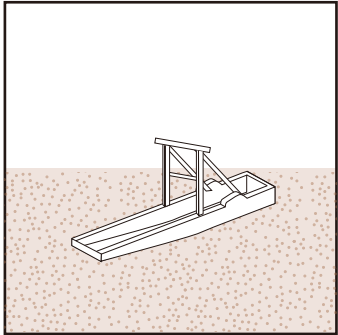
Mud as Socio-Economy Booster

Mud Imagery

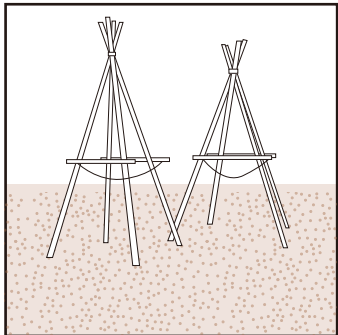


Poems, books and spaces
Data: Atelier Fryslân, 2012.

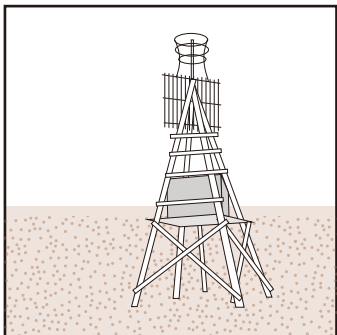
Mud as Socio-Economy Booster
Mud Recreation



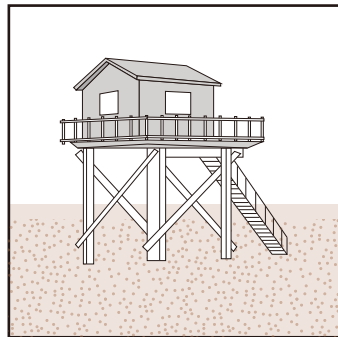
Mud Sled



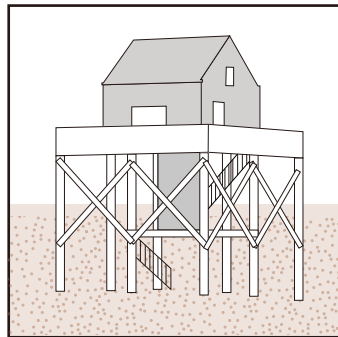
Wad stool (Wadstoel)



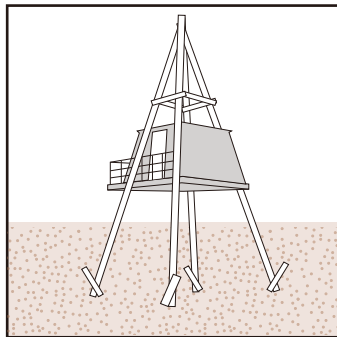
Cape with Shelter



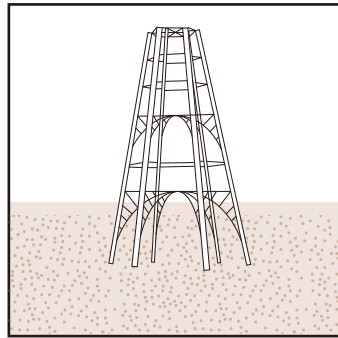
Drowning Shelter



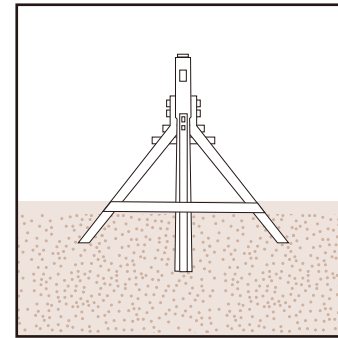
Bird Watching House



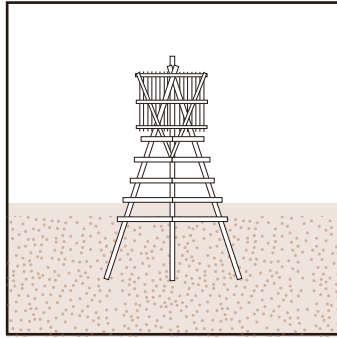
Drowning Shelter



Emden Kaap van Rottumeroog



Boundary Post

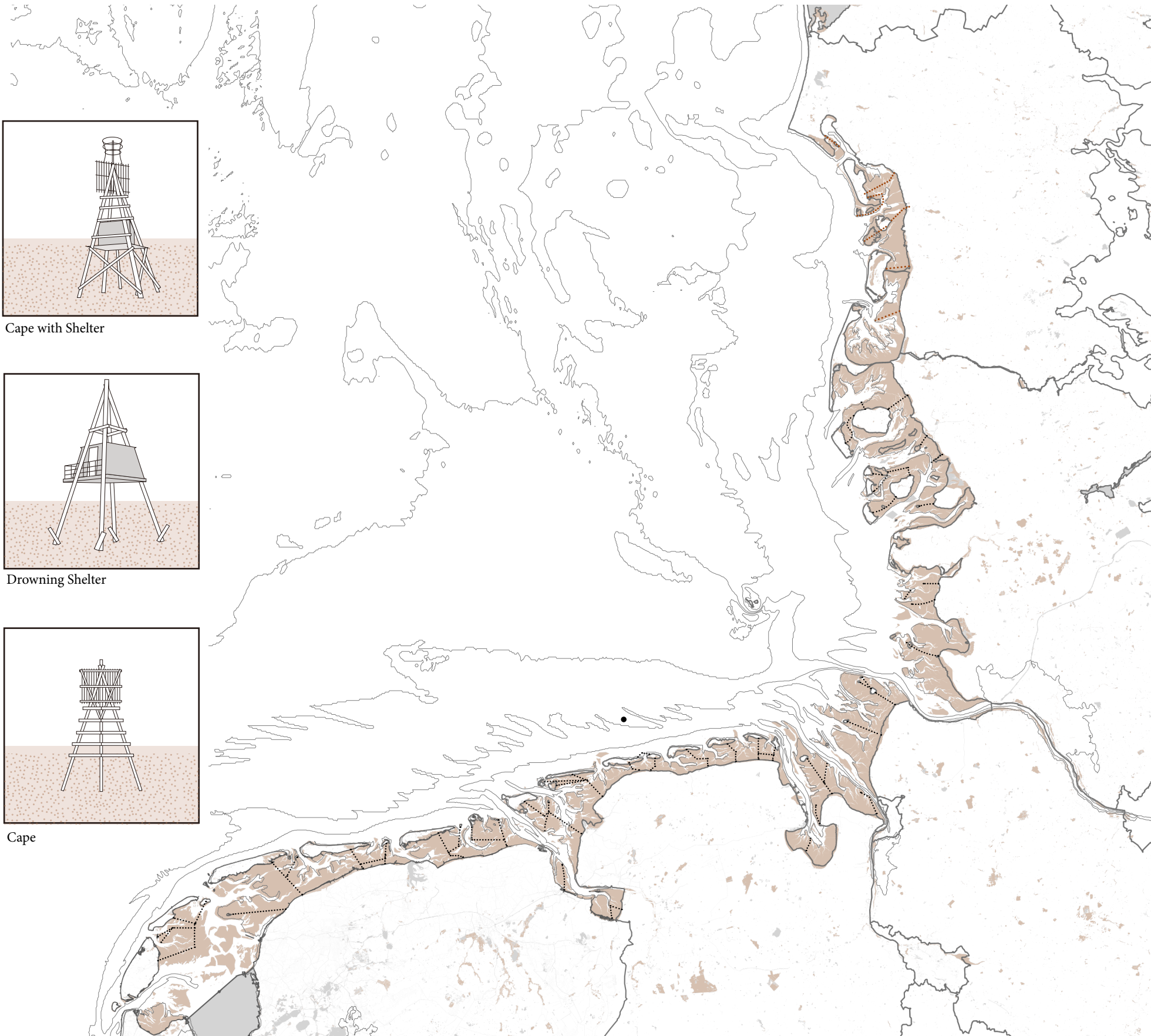


Cape

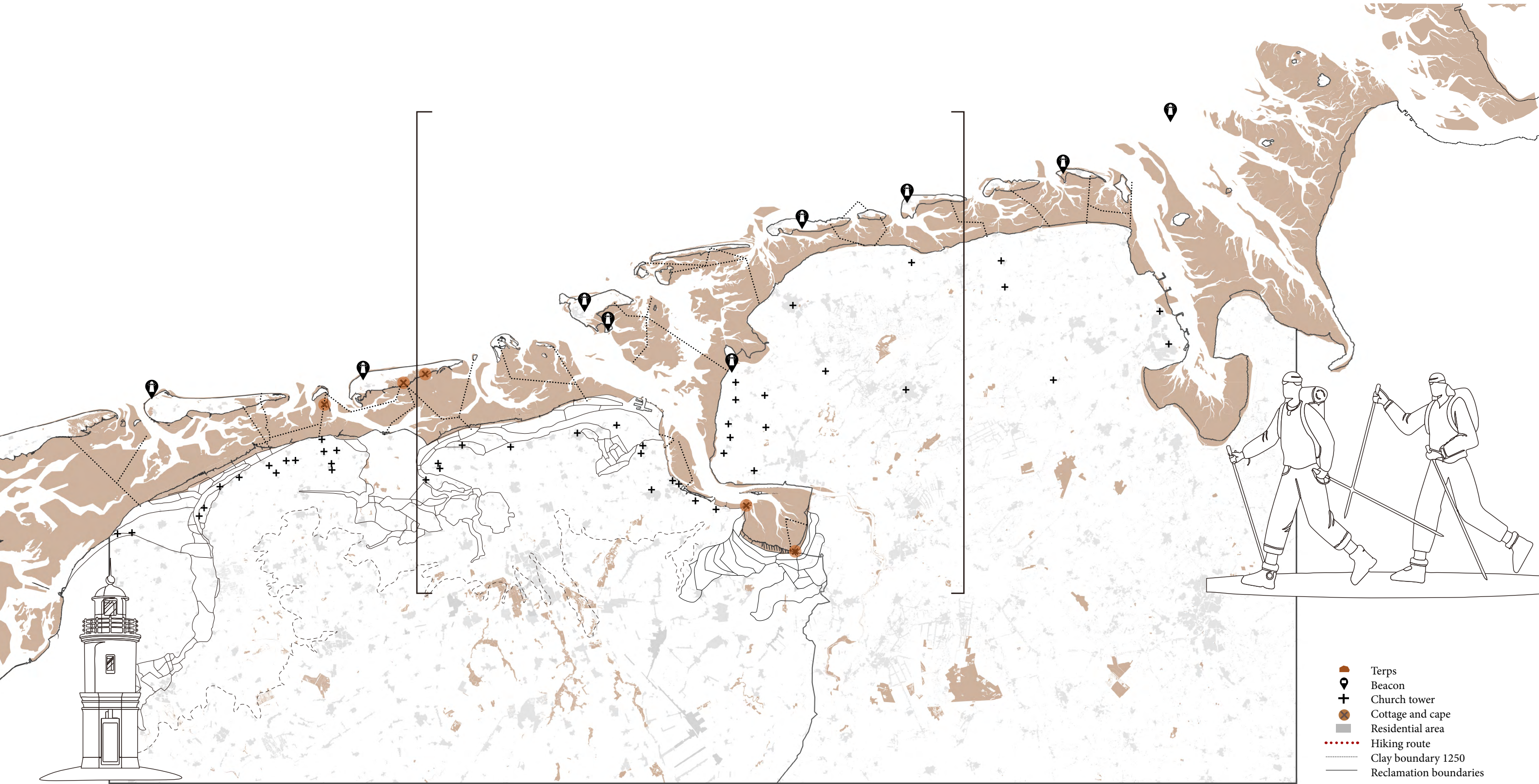
0 10km 20km 50km



..... Hiking route



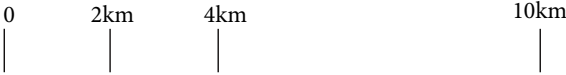
Mud as Socio-Economy Booster
Mud Recreation



0 5 km 10 km 30 km



Mud as Socio-Economy Booster
The Journey of Culture

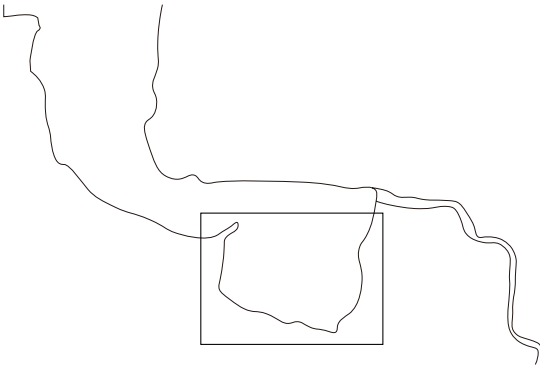


- | | | |
|----------------------|----------------------|-----------|
| Existing terps | The cultural journey | Mudflat |
| Historical buildings | Monastery sites | Saltmarsh |
| Disappeared terps | Monuments | Grassland |
| | Transport | Farmland |

Mud as Socio-Economy Booster
The Journey of Culture



Mud as Socio-Economy Booster
The Journey of Culture



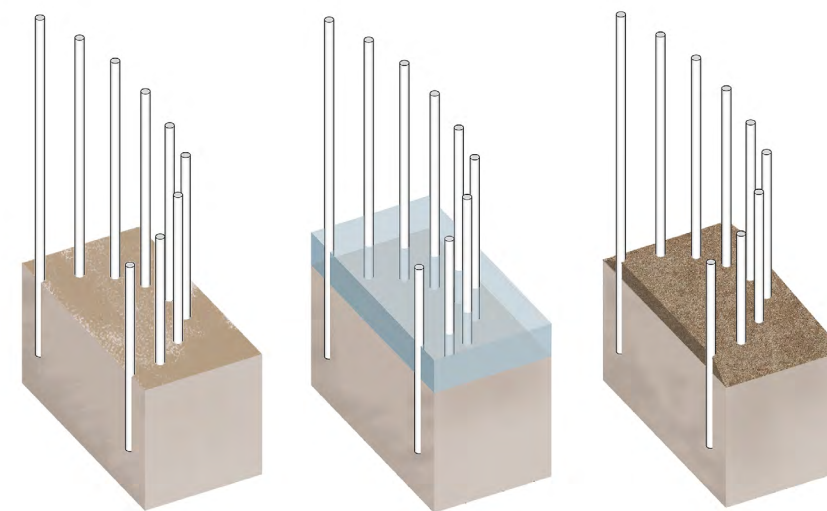
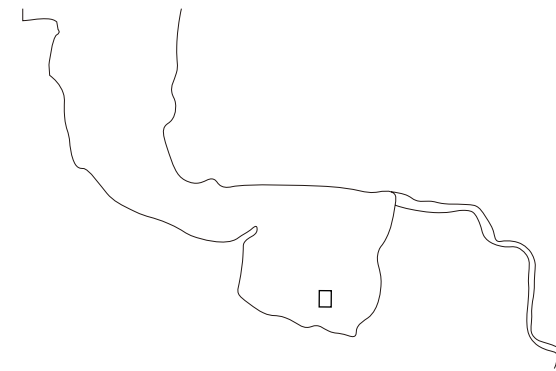
Spontaneous land art in Venetian lagoon.
Photo: Dennis Dracup, 2010



Public participation in the Mud Gallery
Photo: Zoe, Alanna, Dani, 2021

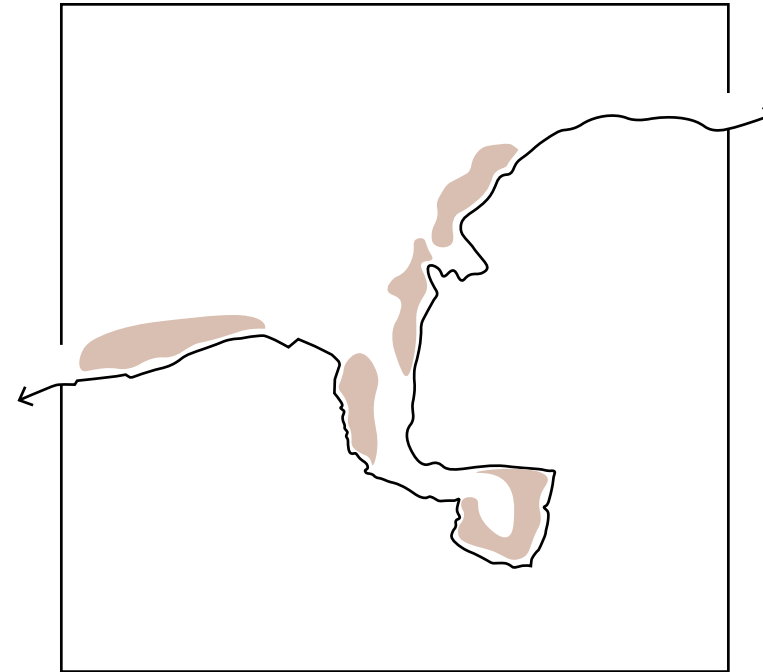


Mud as Socio-Economy Booster
The Journey of Culture



“Many a skipper who sails the Dollard in calm weather has clearly seen houses and towers at the bottom of the sea, and others have heard on a quiet evening that in the depth still ringing bells.”

5min



Mud as Ecology Enhancement

Mud aggregation to reduce river turbidity
and create shallows as mussel bed, bird mound.

Reconnection of old rivers.

Phytoremediation of mud.

Mud as Ecology Enhancement
Species Status



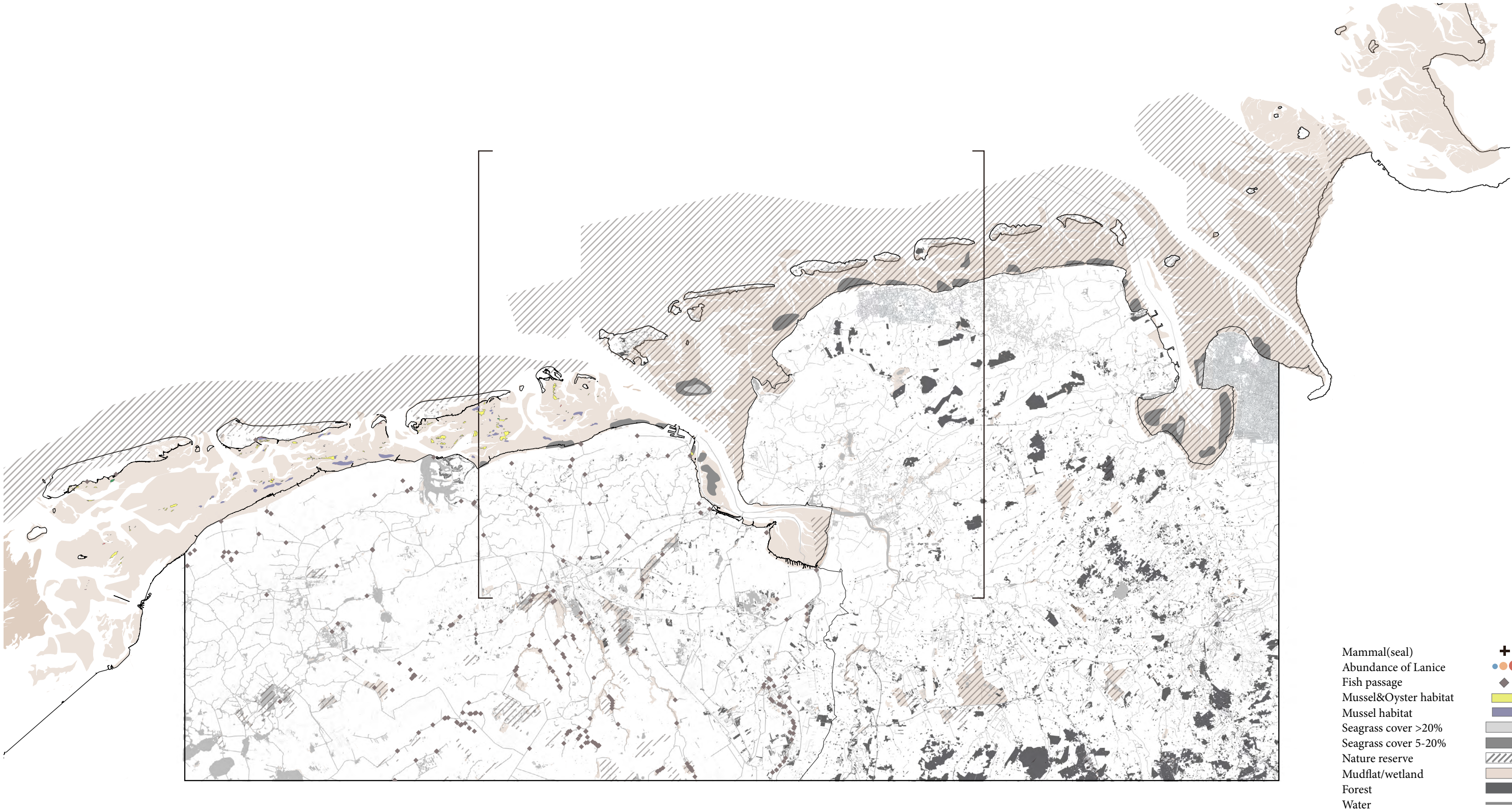
Barnacle Geese (*Branta leucopsis*),
Margaretenkoog
Photo: Peter Prokosch, 2012

Mud as Ecology Enhancement
Species Status



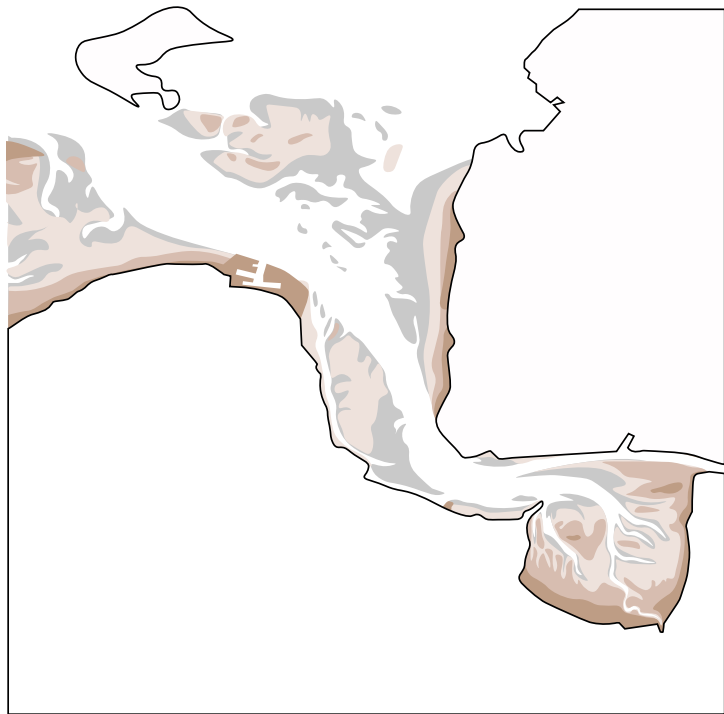
The Punt van Reide is important for birds and seals to breed
Photo: sealsanctuary.sealifetrust.org, 2019

Mud as Ecology Enhancement
Species Status



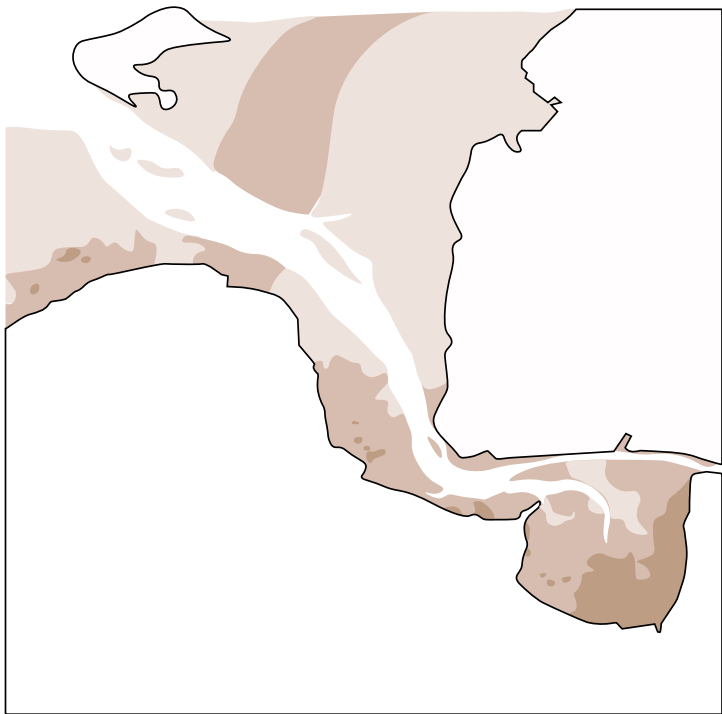
Mud as Ecology Enhancement
Mud Ecology

Dry time of tidal flats



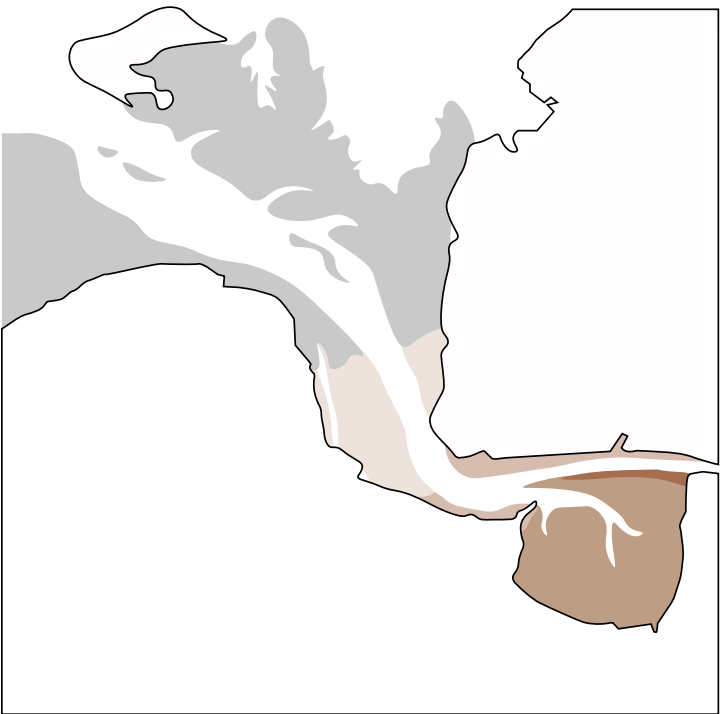
- 1-25 More often wet
- 26-50
- 51-75
- 76-100 Long dry

Sediment size



- Fine sand
- Very fine sand-silt
- Silt

Salinity



- 27-35 Marine
- 22-26
- 17-21
- 12-16
- 0-11 Brackish

Mud as Ecology Enhancement
Dredging and Dumping



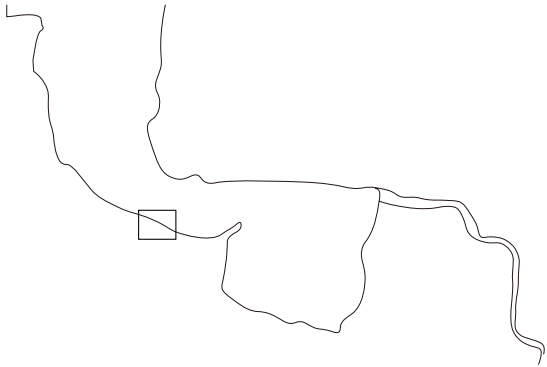
The Kleirijperij site of Delfzijl just after deposition
Photo: Luca Sittoni, 2019

Mud as Ecology Enhancement
Dredging and Dumping



Dredging and dumping of silt are major interventions in the
Ems-Dollard
Photo: Christiaan van Velzen, 2018

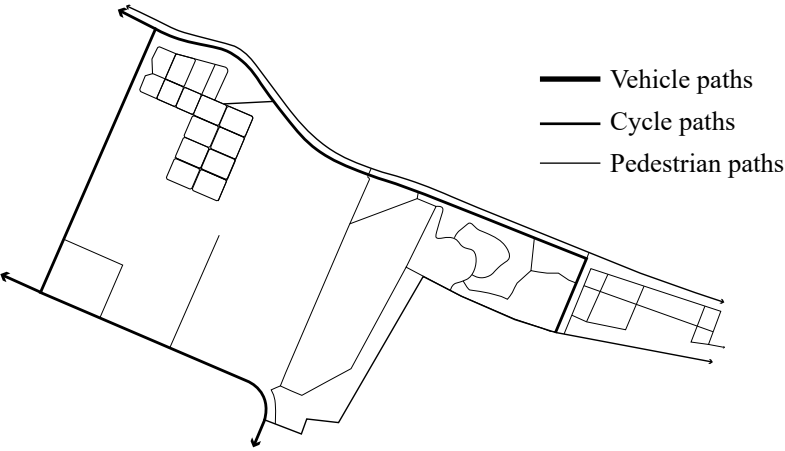
Mud as Ecology Enhancement & Socio-Economy Booster
Dumping Park



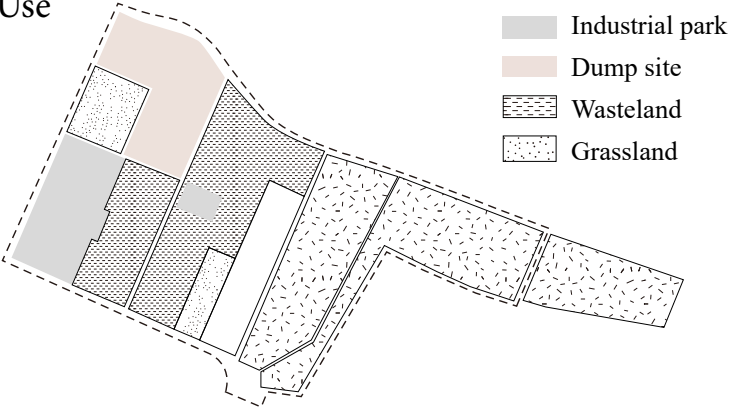
Green Corridor



Connection



Land Use



Mud as Ecology Enhancement & Socio-Economy Booster

Dumping Park

Phytoremediation Species



Alpine Pennycress
(Thlaspi caerulescens)



Common Sunflower
(Helianthus annuus)



White Lupin
(Lupinus albus)



Indian Mustard
(Brassica juncea)



Fescue Grass
(Festuca arundinacea)

Phytoremediation and Biomass Species



Hemp
(Cannabis sativa)



Reed
(Phragmites australis)



Switchgrass
(Panicum virgatum)



Willow
(Salix spp.)



Poplar
(Populus spp.)



Bulrush
(Typha orientalis)



Purple willow
(Salix purpurea)

Biomass Species



Maize
(Zea mays)



Sugar beet
(Beta vulgaris)



Rapeseed
(Brassica napus)



Elephant Grass
(Pennisetum purpureum)



Miscanthus
(Miscanthus spp.)



Silvergrass
(Miscanthus sinensis)

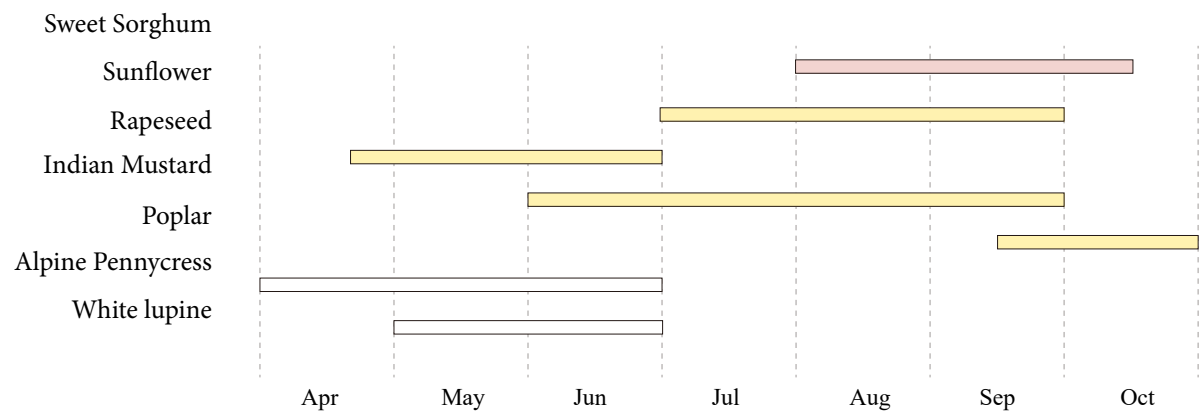


Giant Reed
(Arundo donax)

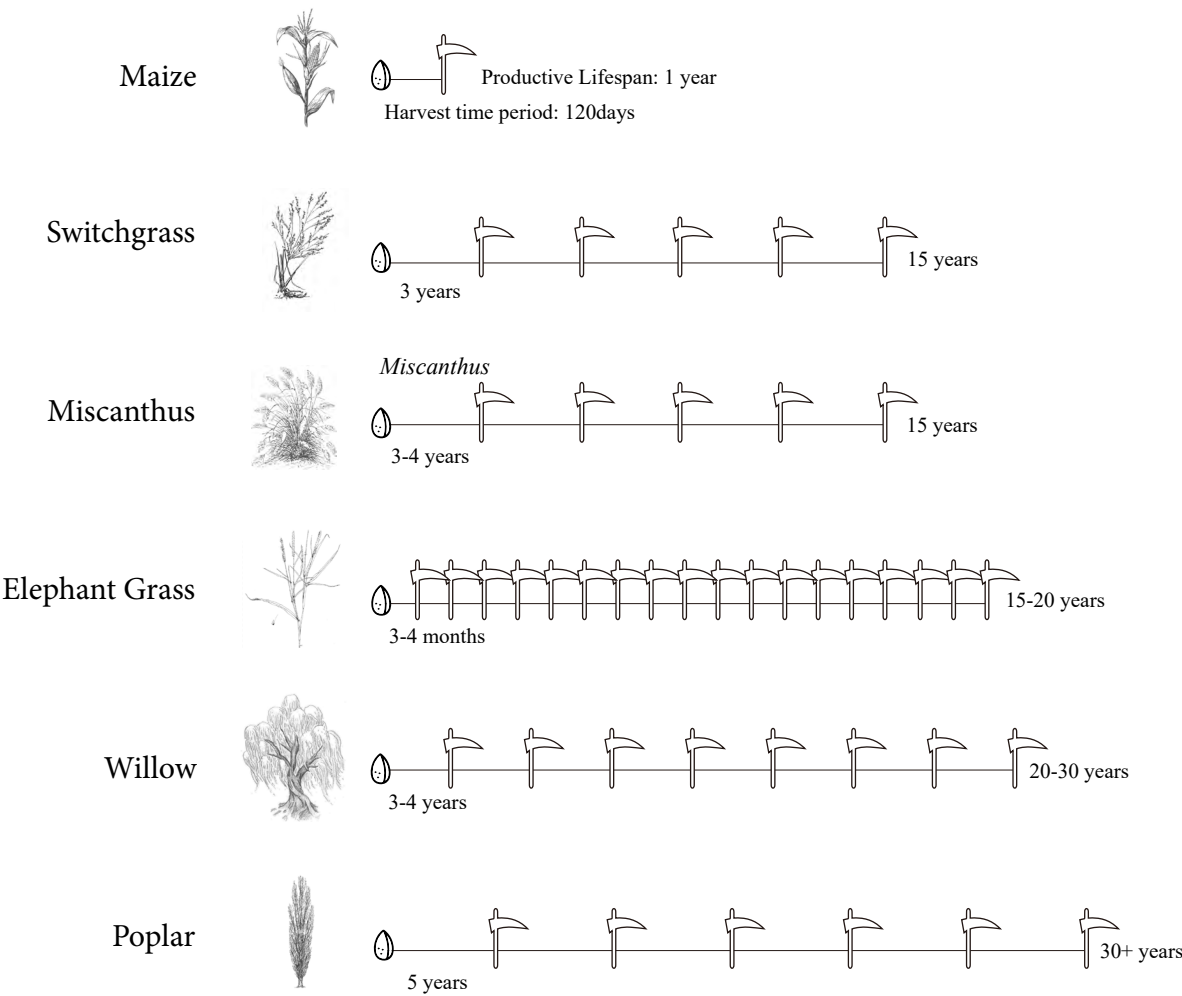


Sweet Sorghum
(Sorghum bicolor)

Mud as Ecology Enhancement & Socio-Economy Booster
Dumping Park

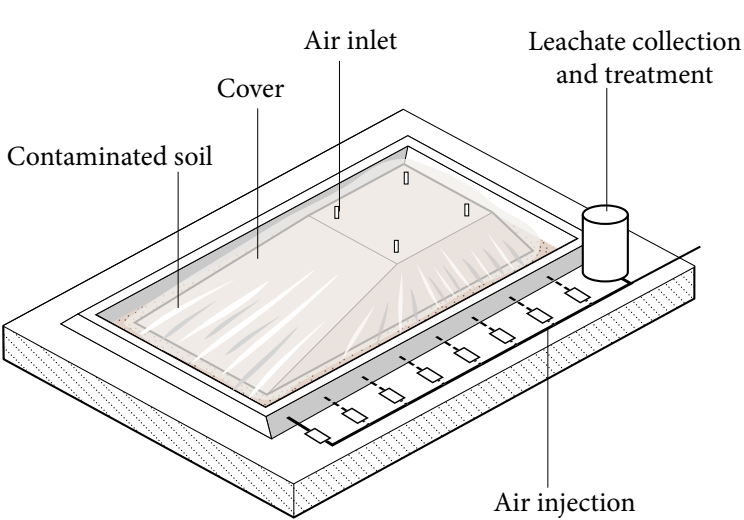


Flowering period & flower colour

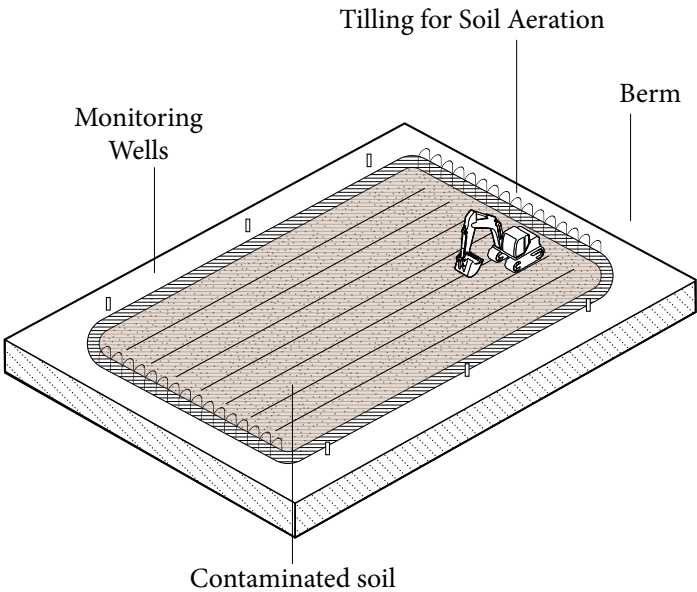


Productive Lifespan & Harvest period

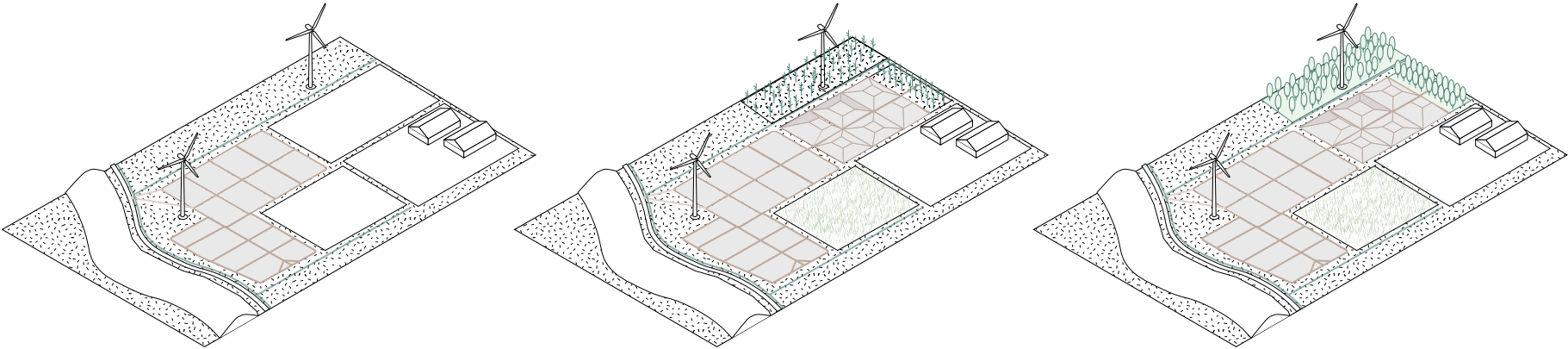
Mud as Ecology Enhancement & Socio-Economy Booster
Dumping Park



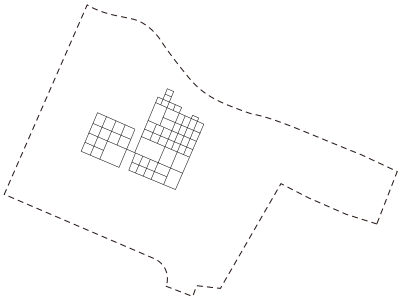
Biopile



Land Farming



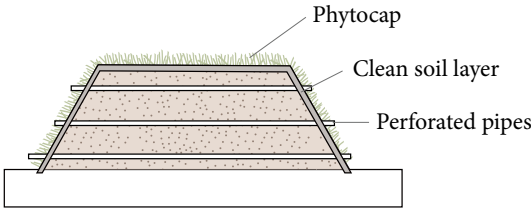
Mud as Ecology Enhancement & Socio-Economy Booster
Dumping Park



Willow
(Salix spp.)

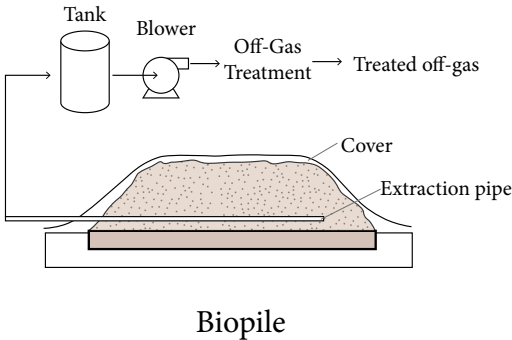
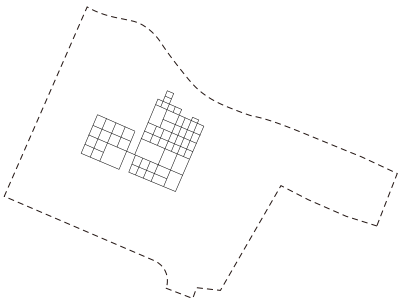
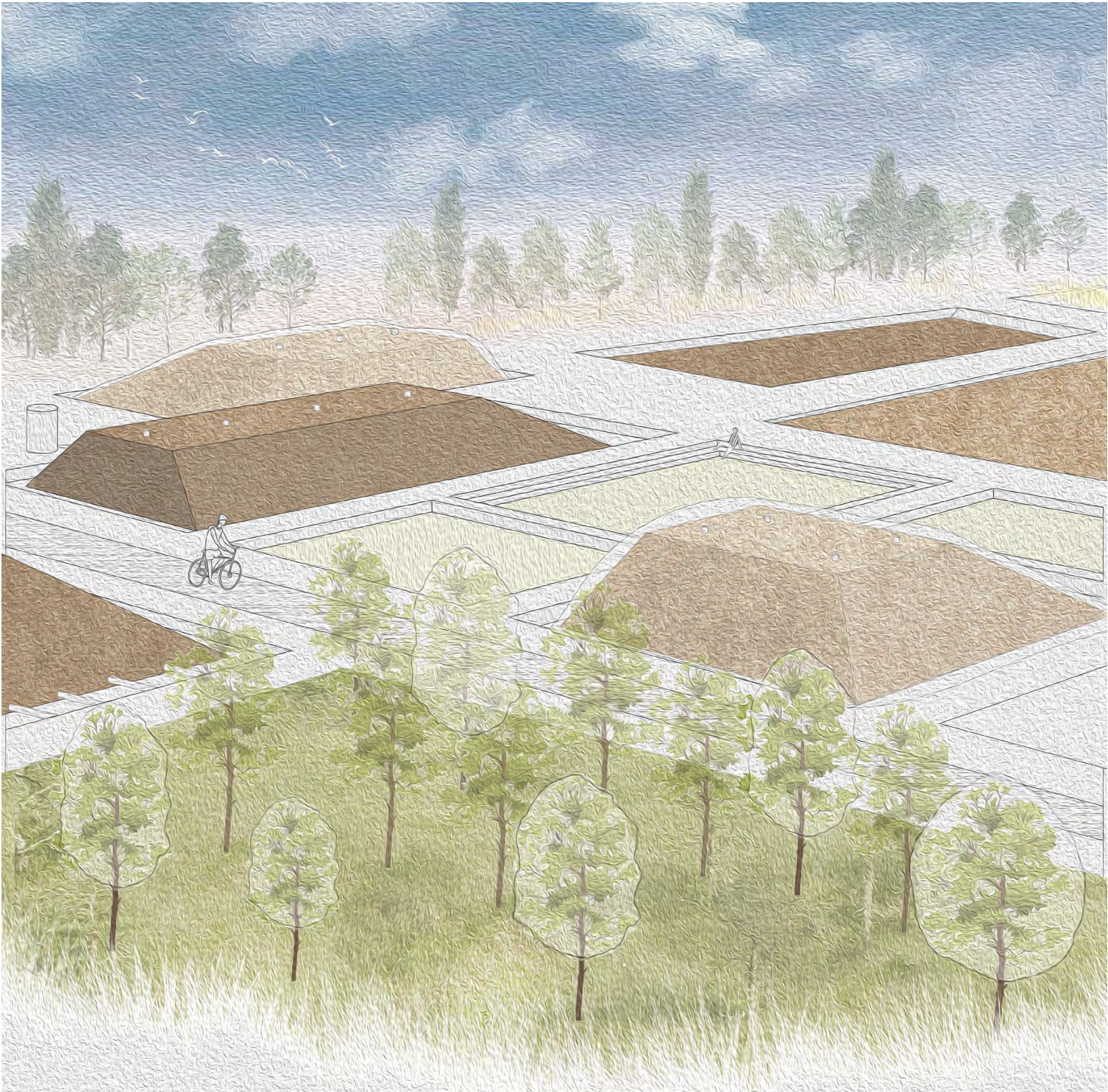
Poplar
(Populus spp.)

Bulrush
(Typha orientalis)

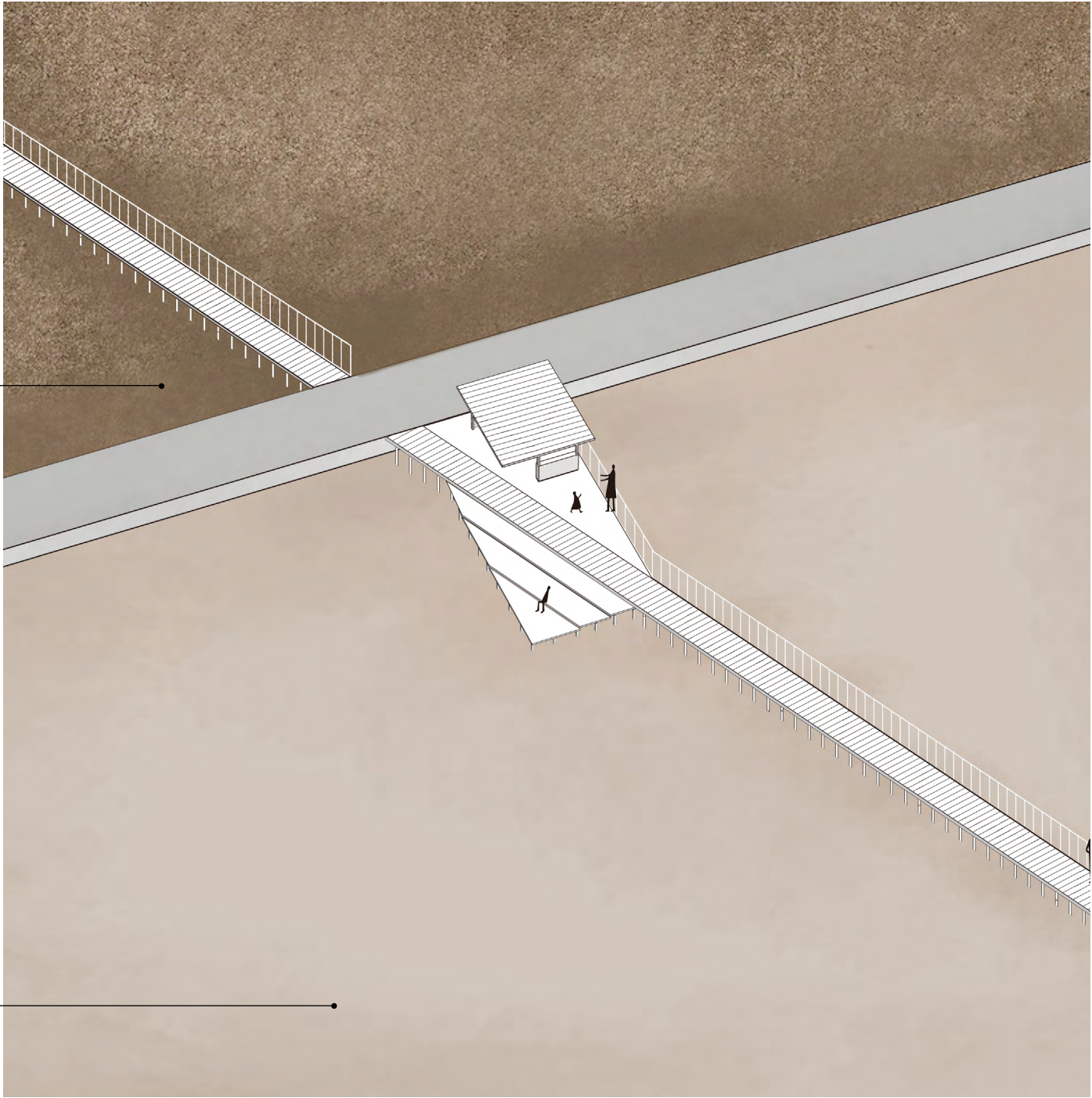
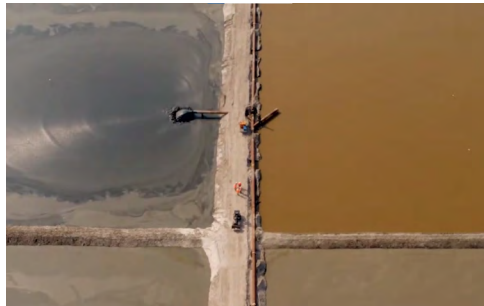
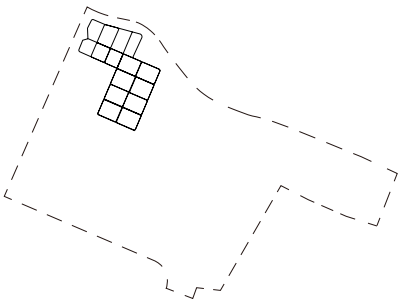


Biopile

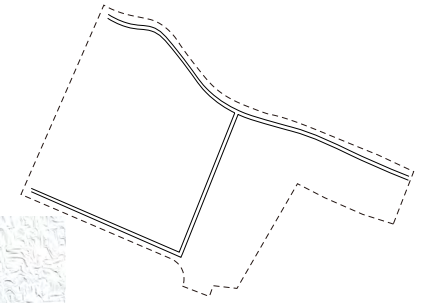
Mud as Ecology Enhancement & Socio-Economy Booster
Dumping Park



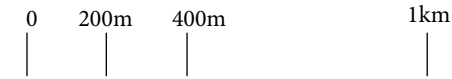
Mud as Ecology Enhancement & Socio-Economy Booster
Dumping Park



Mud as Ecology Enhancement & Socio-Economy Booster
Dumping Park



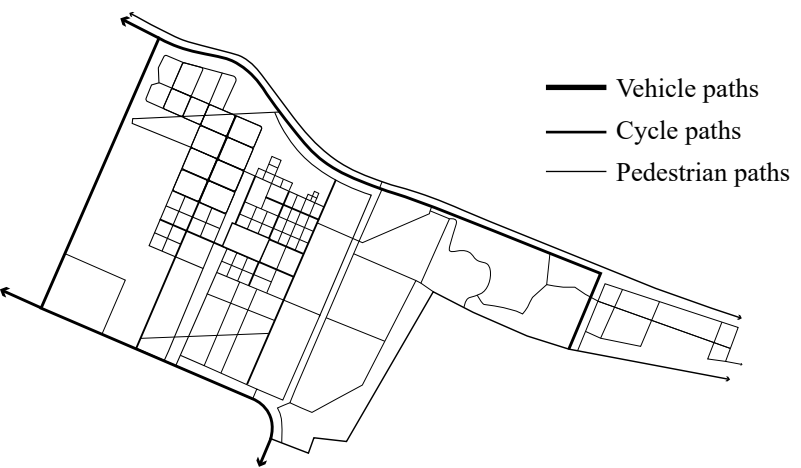
Mud as Ecology Enhancement & Socio-Economy Booster
Dumping Park



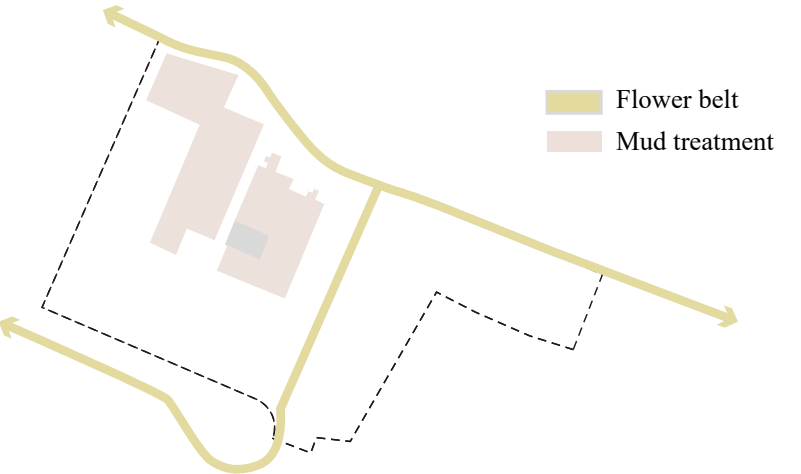
Green Corridor



Connection



Experience



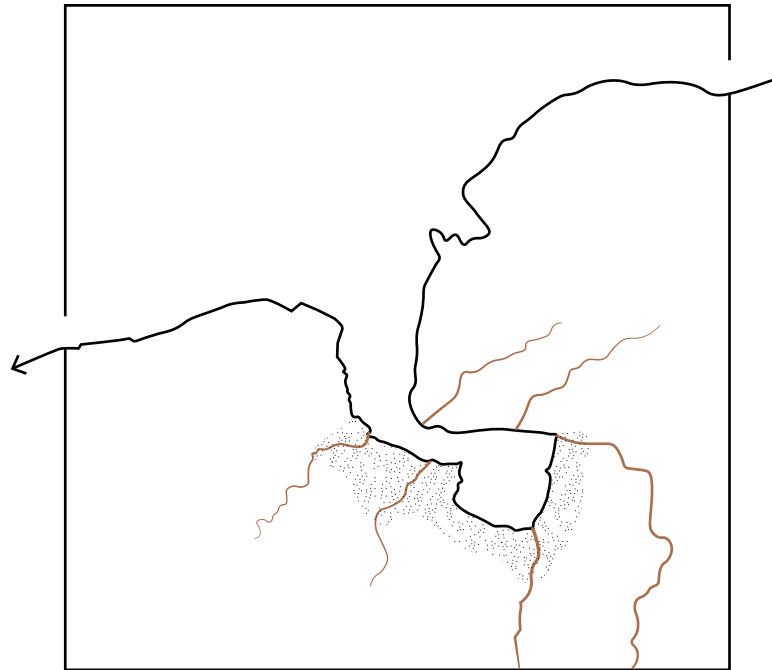
Mud as Ecology Enhancement & Socio-Economy Booster
The Journey of Energy



0 200m 500m 1km



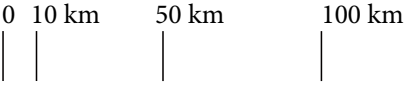
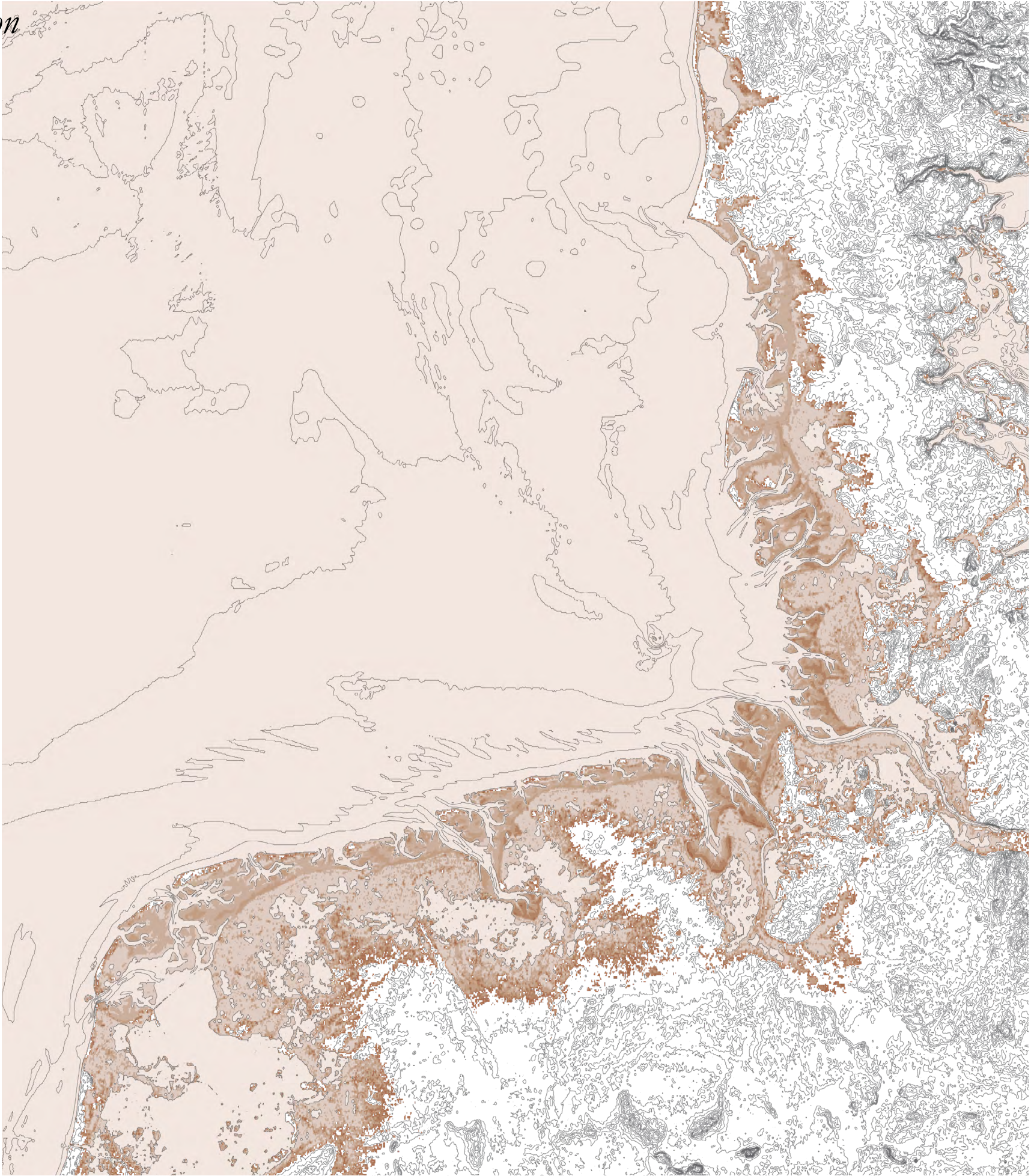
- Existing terps
- Solar panels
- Biomass park
- Recreation node
- Transport



Mud as Climate Adaptation

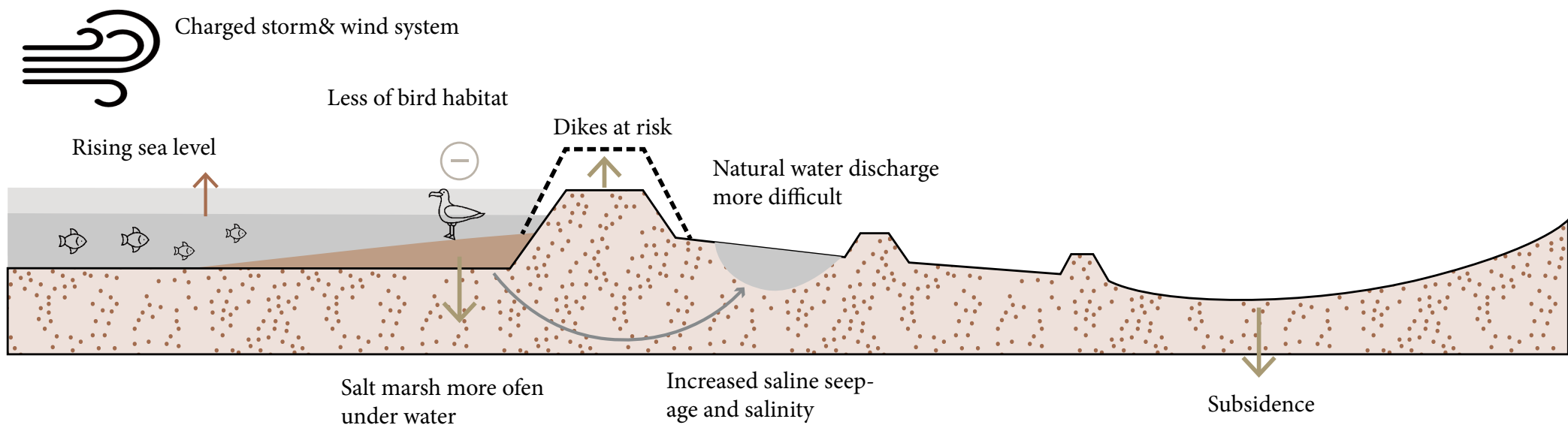
Mud as subsidence compensation.
Mud as material to create double dike
Multi-layers of flood defence & buffer.

Mud as Climate Adaptation
Sea Level Rise

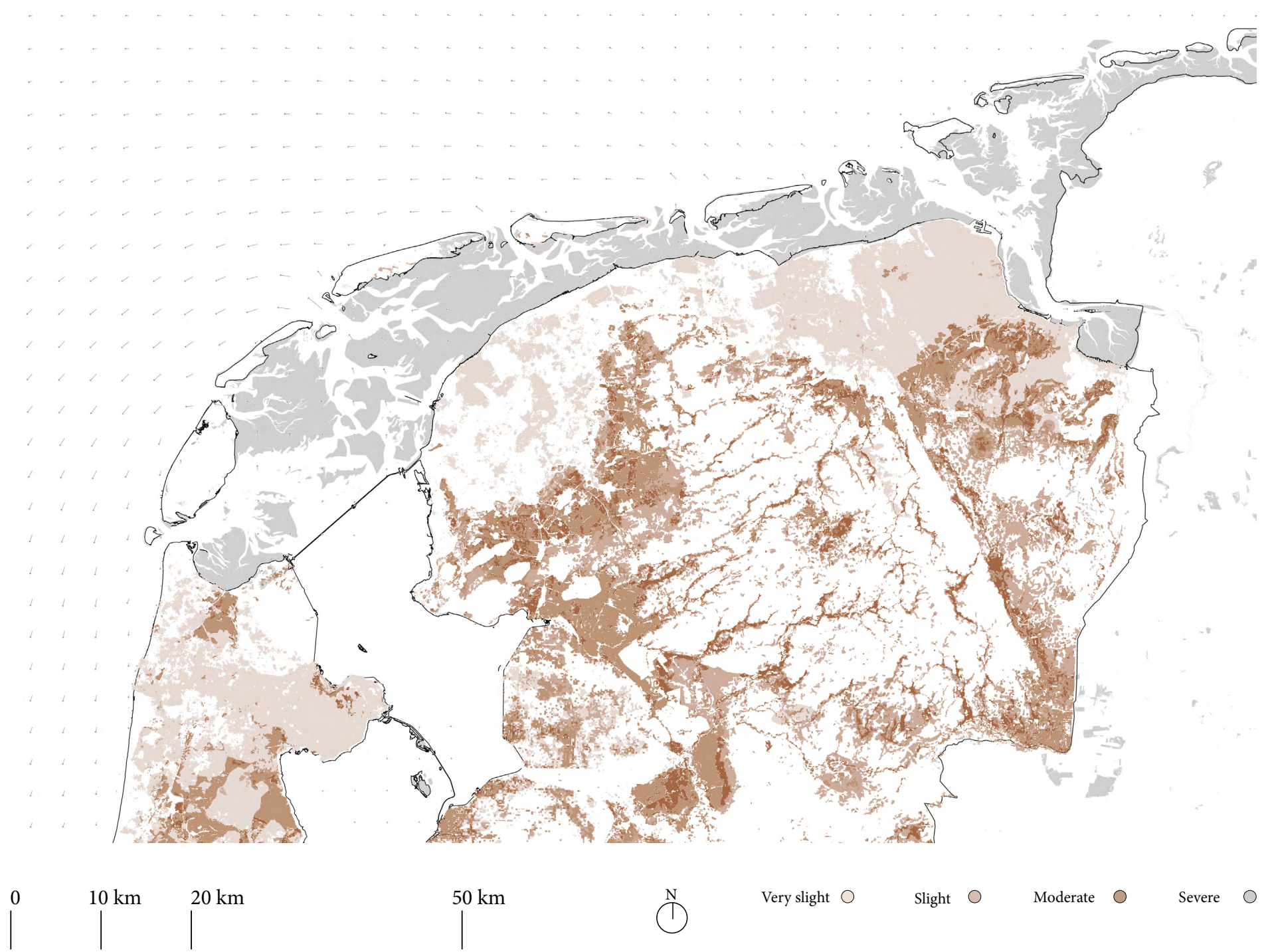


- Height of sea level rise-0m
- Height of sea level rise-1m
- Height of sea level rise-2m
- Height of sea level rise-3m
- Height of sea level rise-4m
- Height of sea level rise-5m

Mud as Climate Adaptation
Sea Level Rise



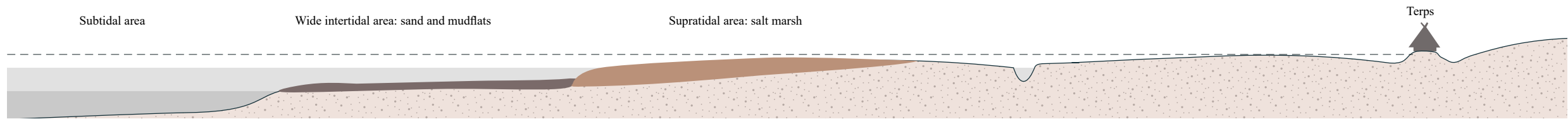
Mud as Climate Adaptation
Soil Subsidence



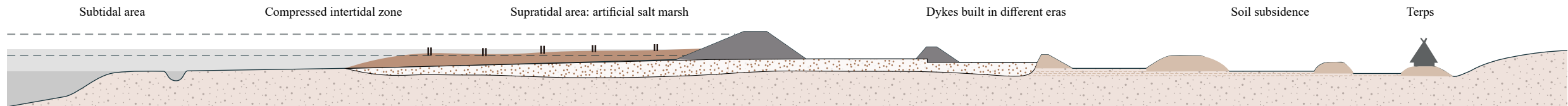
Forecasting land subsidence until 2100.
Data: www.arcgis.com/apps/mapviewer/, [Klimaateffecatlas](#)

Mud as Climate Adaptation
Soil Subsidence

The past



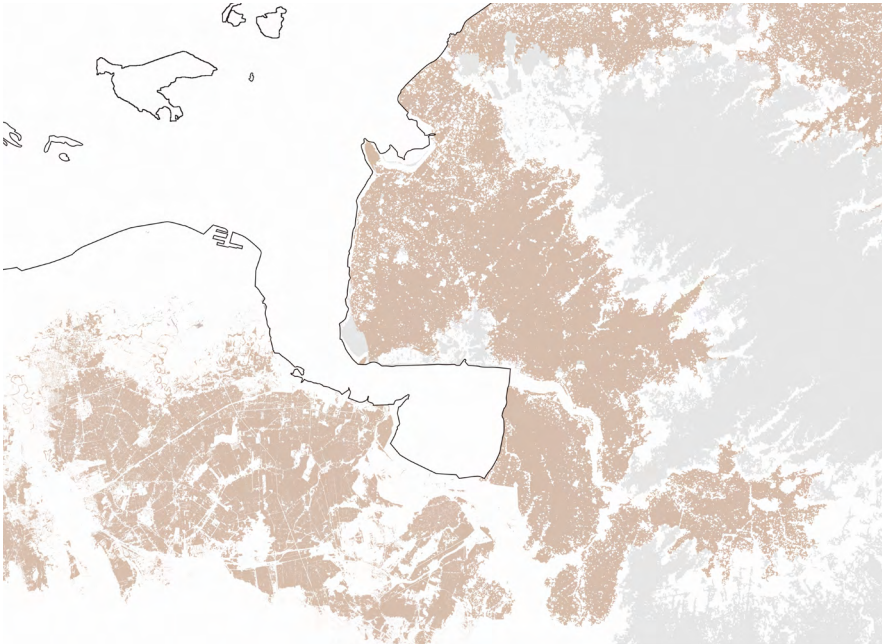
The present



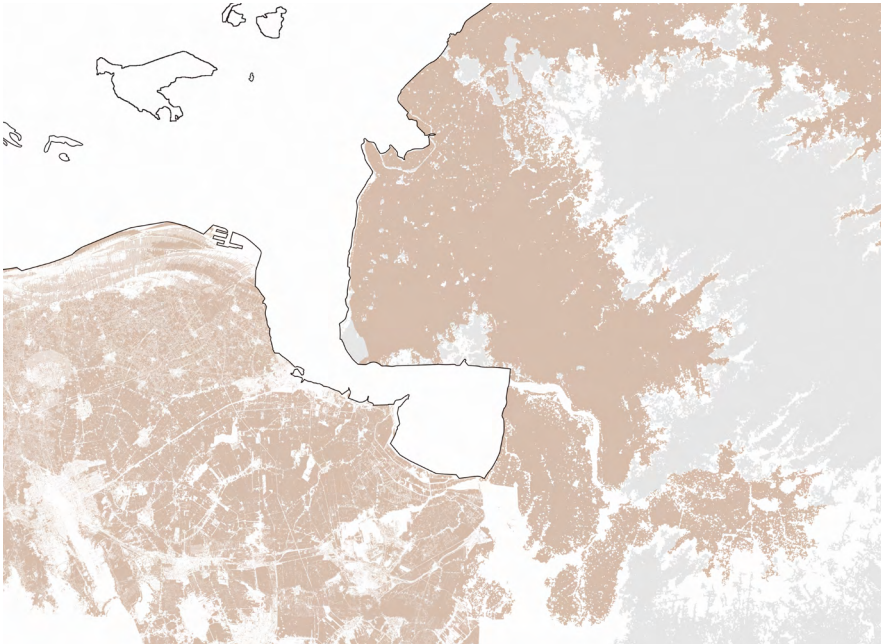
Evolution of the sections.

Mud as Climate Adaptation
Scenarios 1: “What If” Remove All the Dikes

2023



2050

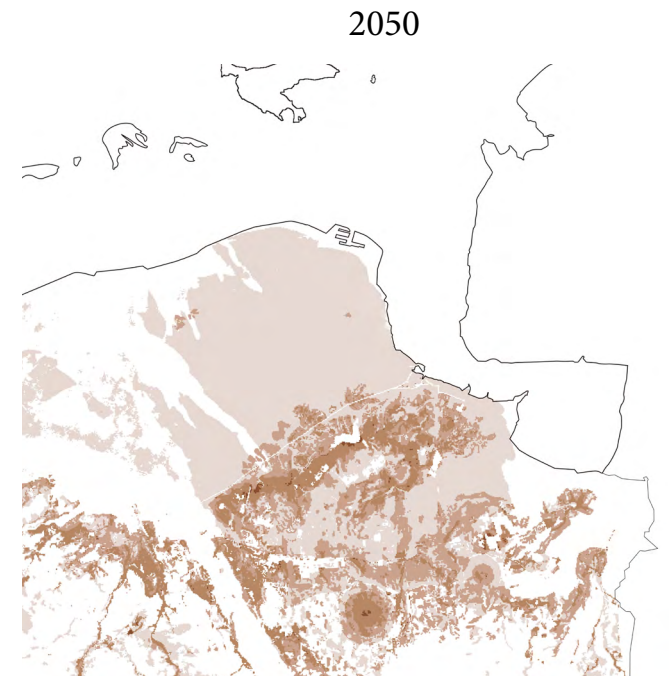


2100

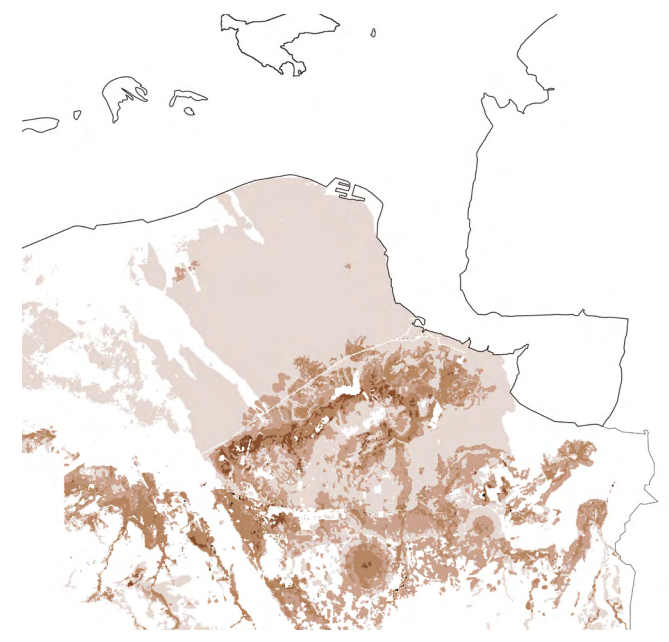


Flooded areas
Safe areas

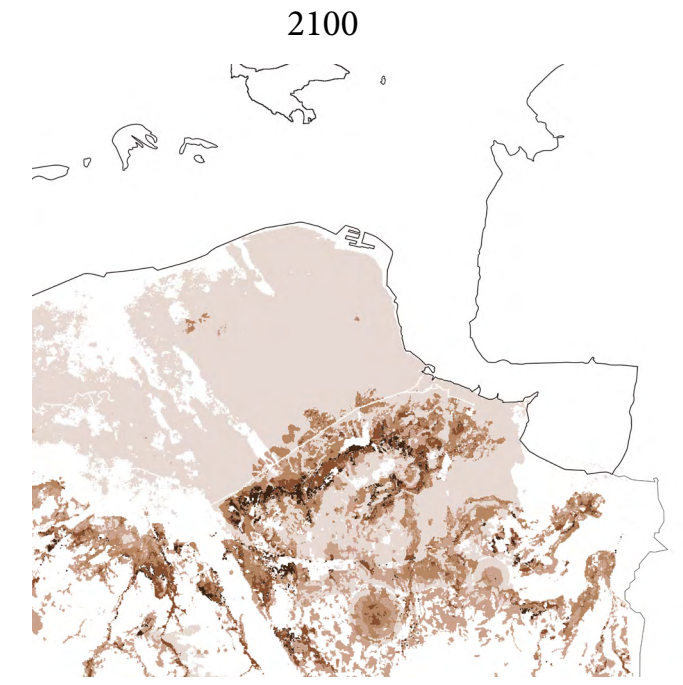
Mud as Climate Adaptation
Scenarios 2: “What If” Keep All the Dikes



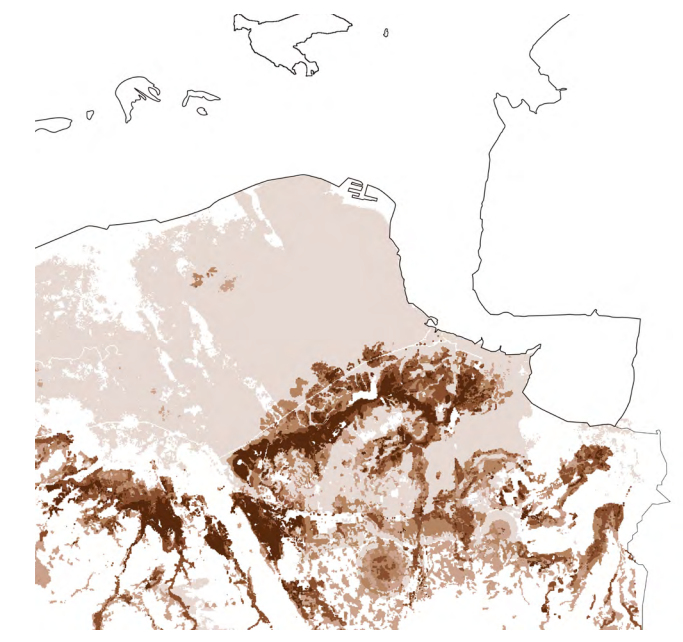
Estimated Minimum Subsidence



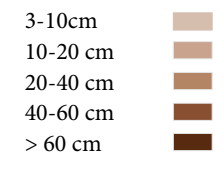
Estimated Maximum Subsidence



Estimated Minimum Subsidence

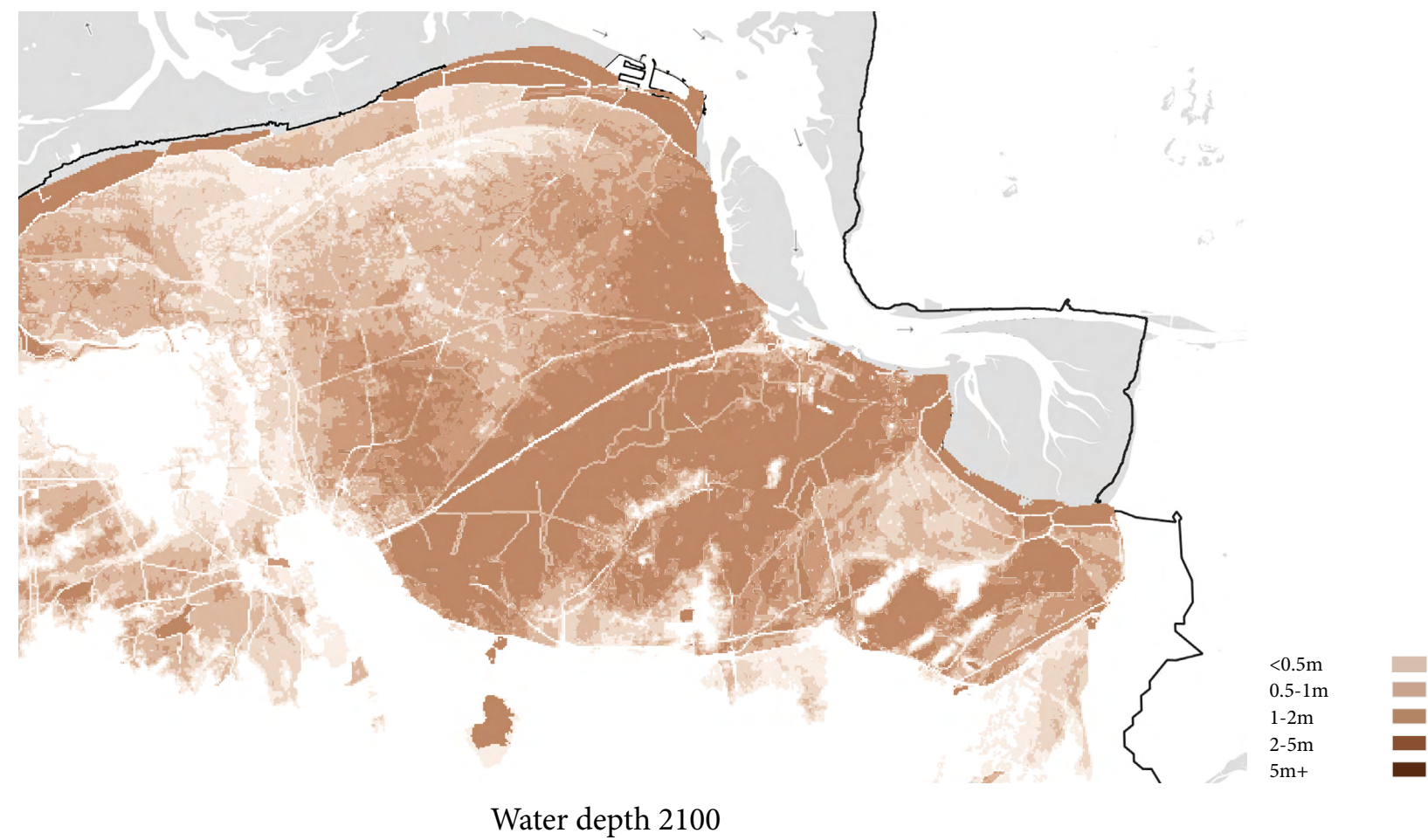


Estimated Maximum Subsidence



Mud as Climate Adaptation

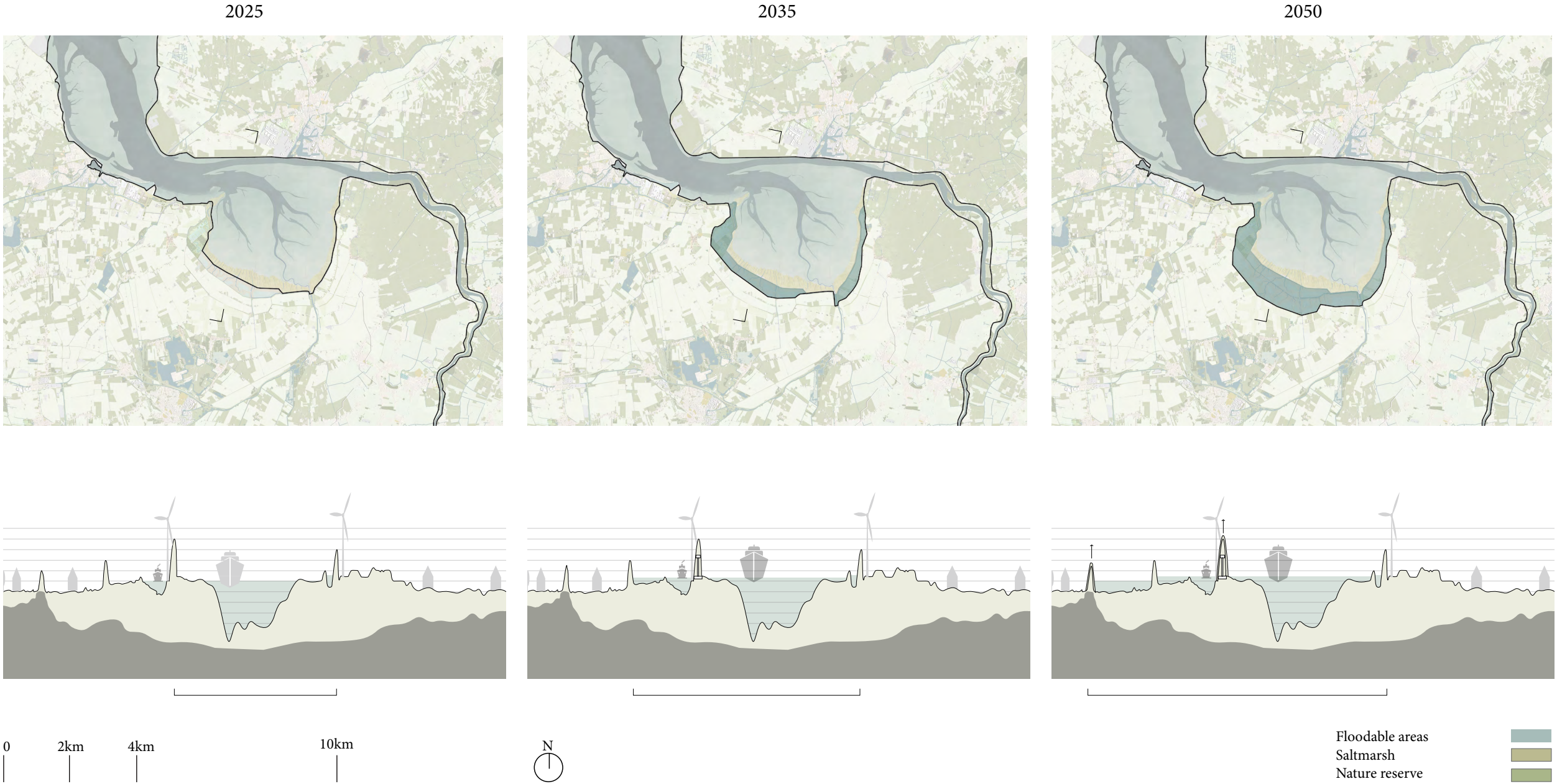
Scenarios 3: “What If” the Dike Is Breached With Soil Subsides



What If : the dike is breached with the soil subsides

Soil Subsidence Prediction
Data: Esri Netherlands Content

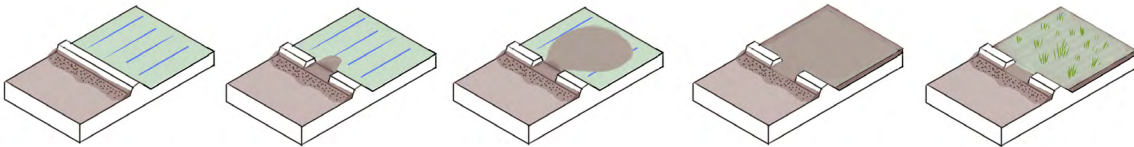
Mud as Climate Adaptation
Vision



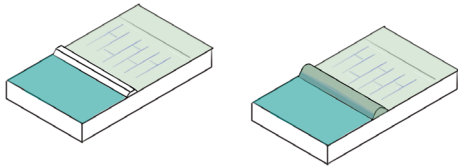
Expected Extent and Process of Inundation
Data: Google Earth 2023; Pdok.nl.

Mud as Climate Adaptation
Reopening the Dike

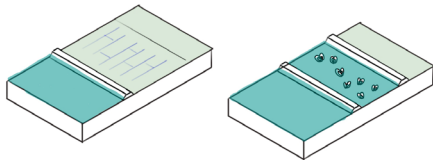
Subsidence Mitigation



Dike Reinforcement & Renovation



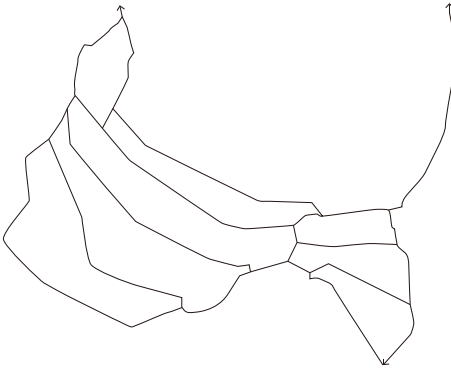
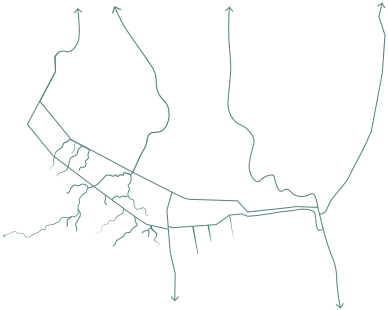
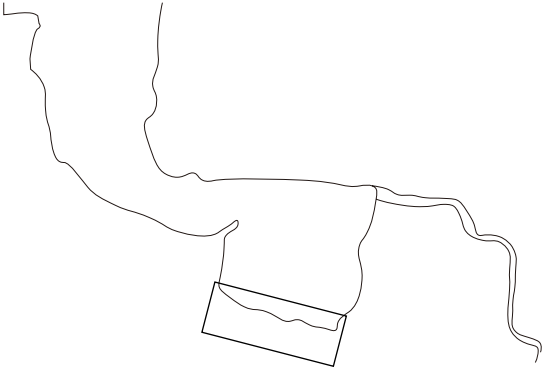
Double Dike & Aquaculture



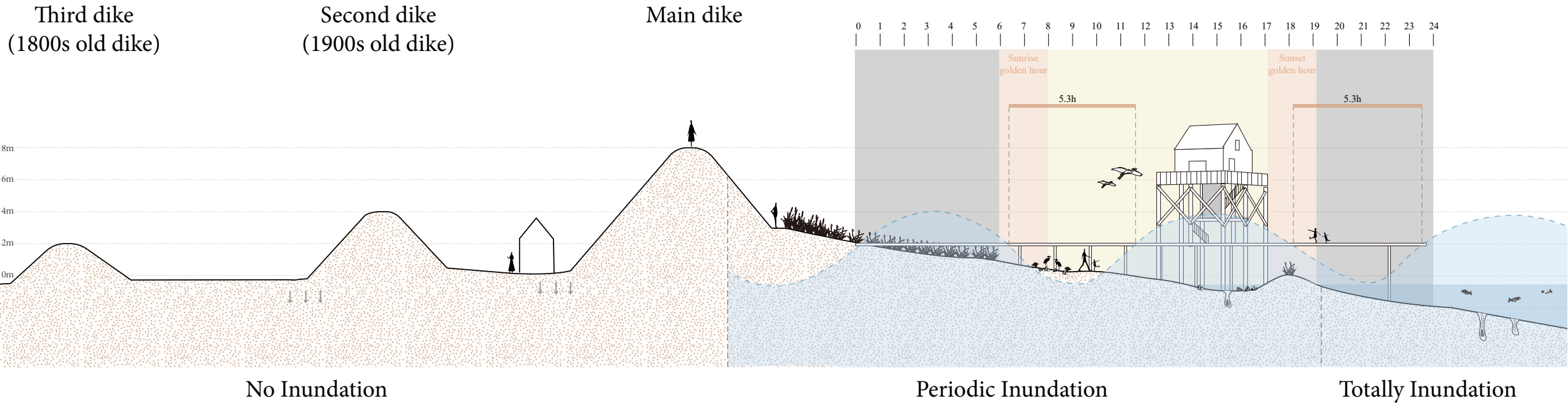
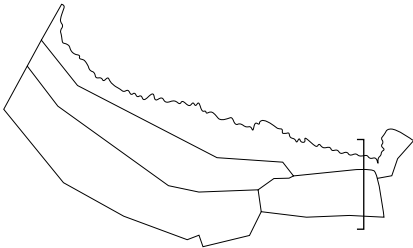
Mud as Climate Adaptation
Reopening the Dike



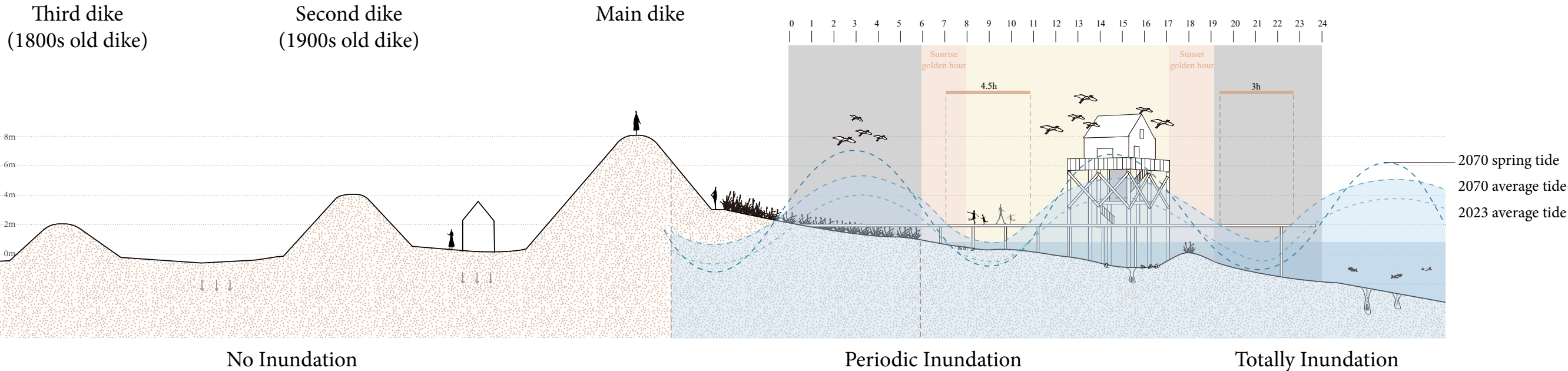
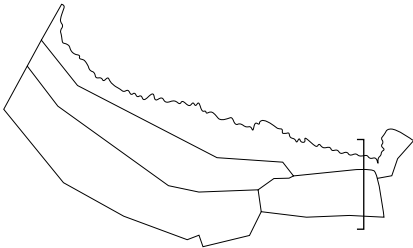
0 500m 1km 2km



Mud as Climate Adaptation
Reopening the Dike

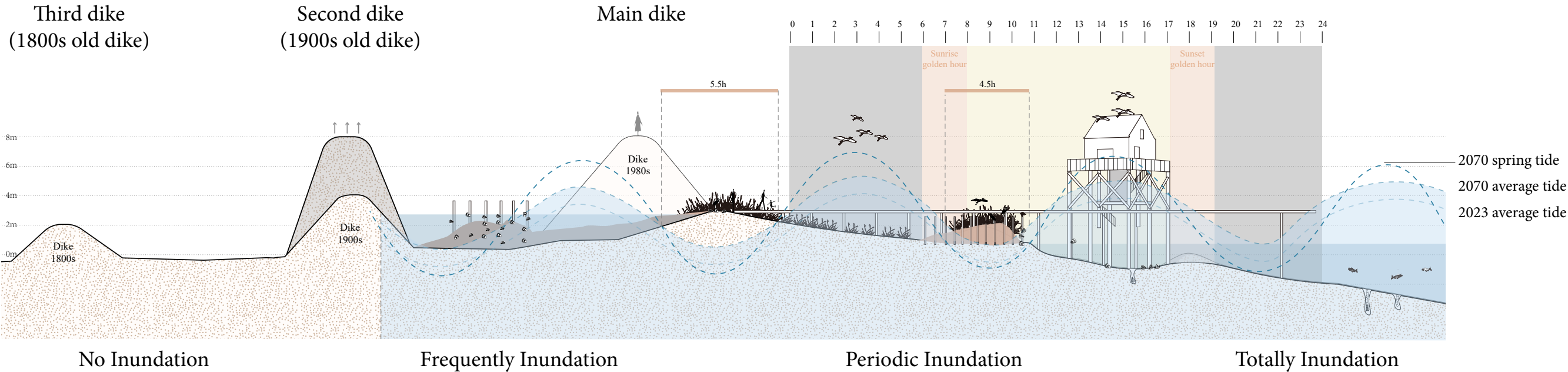
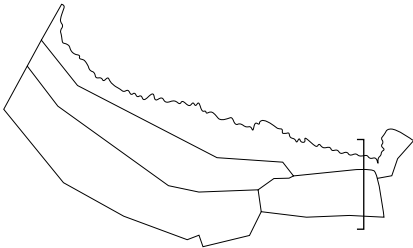


Mud as Climate Adaptation
Reopening the Dike



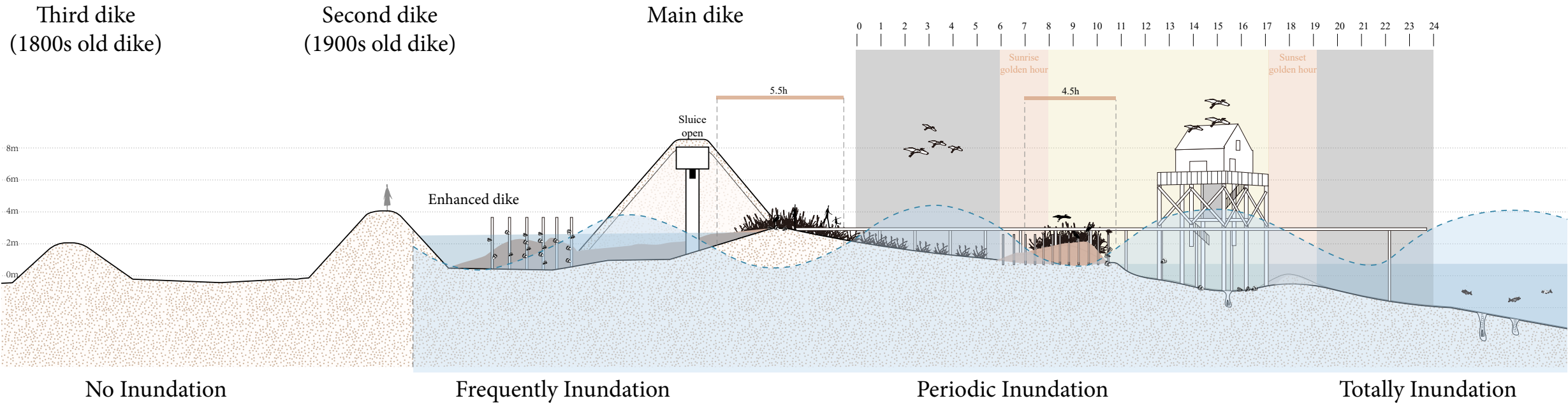
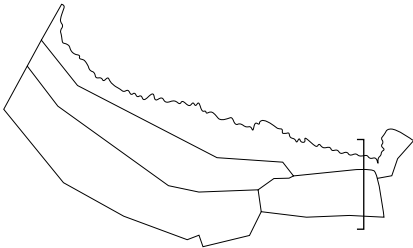
2050 (Without Intervention)

Mud as Climate Adaptation
Reopening the Dike



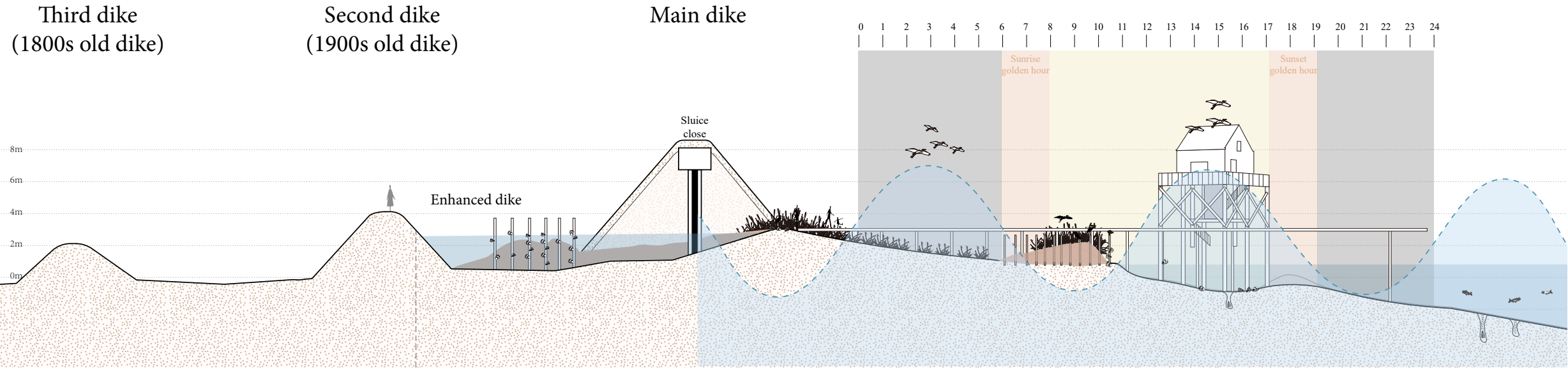
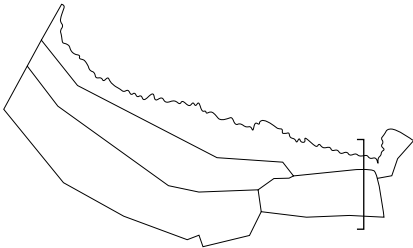
Possible Intervention

Mud as Climate Adaptation
Reopening the Dike



After Design
2035 Everage Tide Level

Mud as Climate Adaptation
Reopening the Dike



No Inundation

Frequently Inundation

Periodic Inundation

Totally Inundation



Small invertebrates



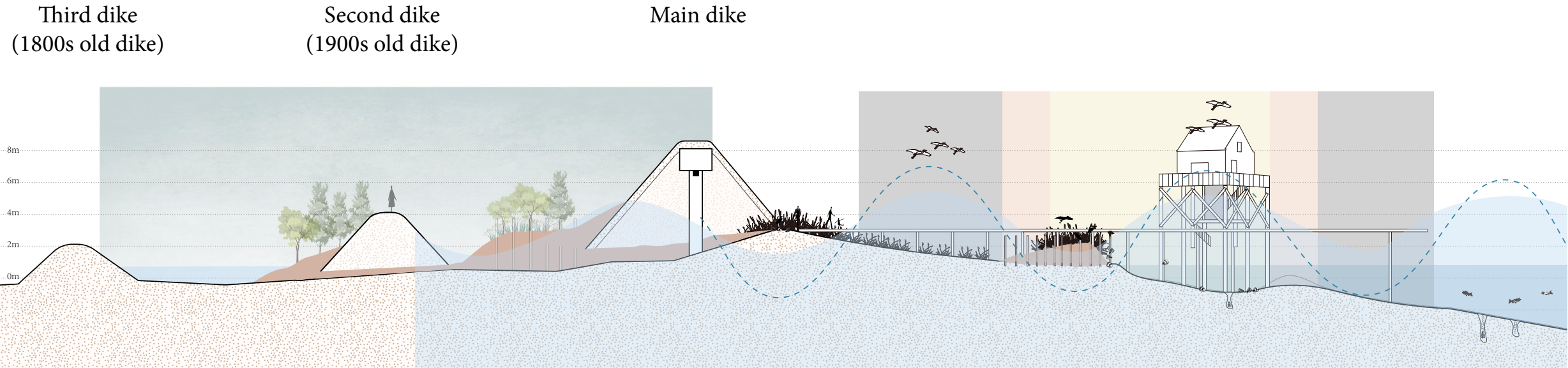
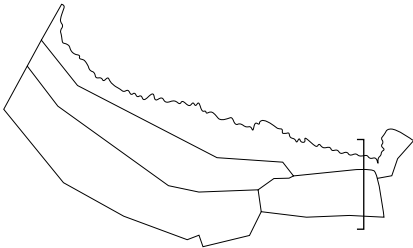
Black Rider
Tringa erythropus



Redshank
Tringa totanus

After Design
2035 Spring Tide Level

Mud as Climate Adaptation
Reopening the Dike



No Inundation

Frequently Inundation

Periodic Inundation

Totally Inundation

- 

Black Rider
Tringa erythropus
- 

Redshank
Tringa totanus
- 

Pintail (*Anas acutrostralegus*)
- 

Oystercatcher
Haematopus ostralegus
- 

Greenleg Rider
Tringa nebularia
- 

Curlew
Numenius arquata
- 

Knot
Calidris canutus
- 

Shelduck
Tadorna tadorna
- 

Teal
Anas crecca

After Design
2050

Mud as Climate Adaptation
Reopening the Dike

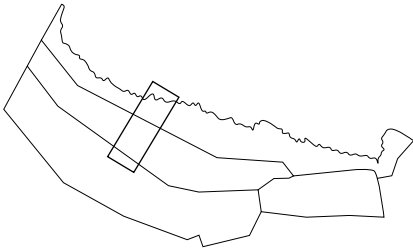


0 500m 1km 2km

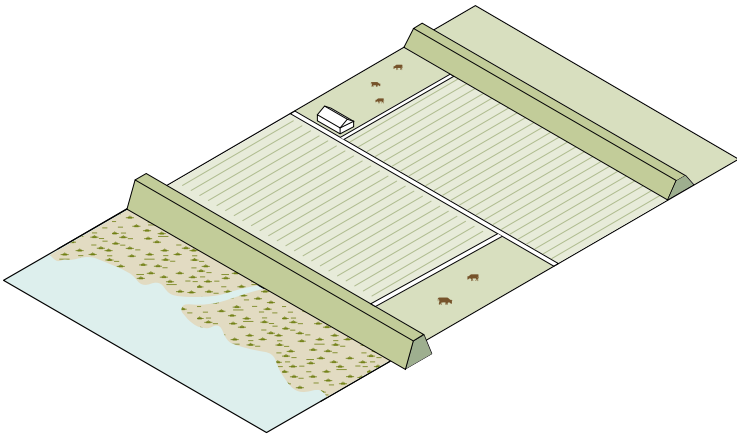


- | | | | |
|------------------|--|-----------|--|
| Dikes | | Saltmarsh | |
| Mudflats hiking | | Farmland | |
| Sedimentary area | | Grassland | |

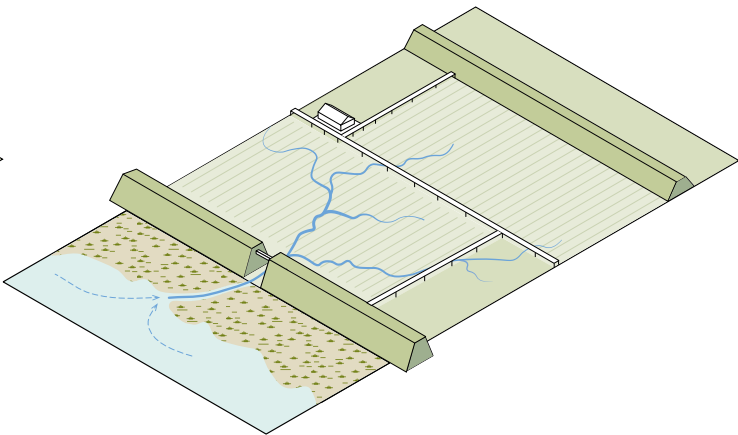
Mud as Climate Adaptation
Reopening the Dike



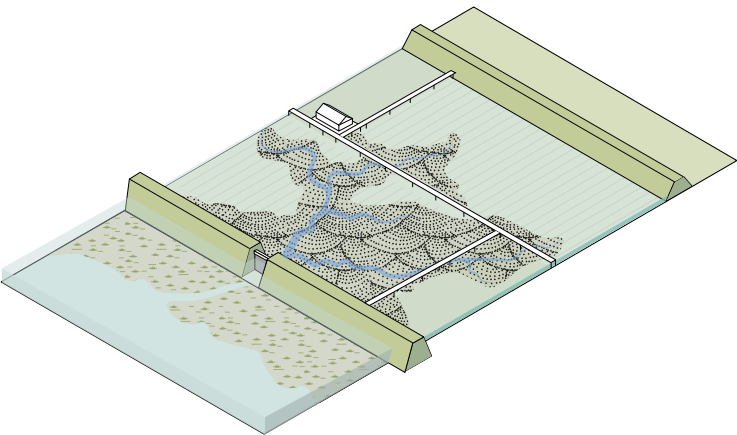
2023



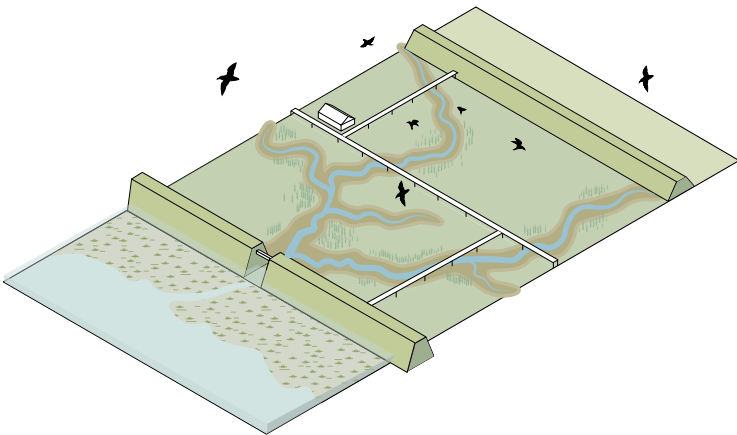
2025



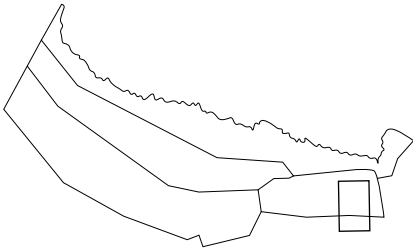
2035



2050



Mud as Climate Adaptation
Reopening the Dike



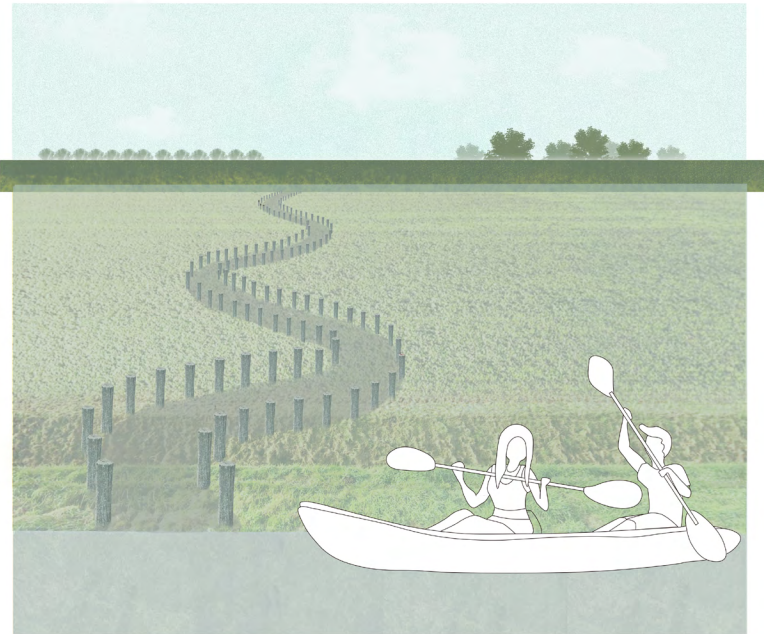
2023



2025



2035

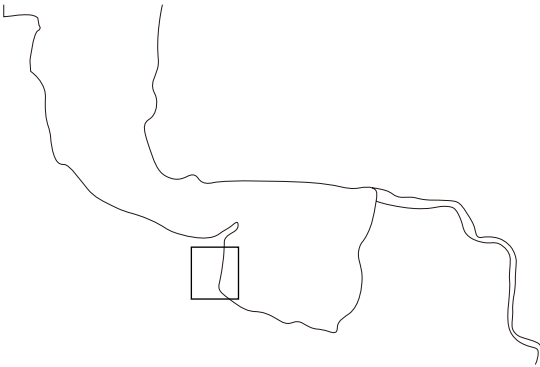


*“I remember the days when you would find
chamomile or daisies on the side of the road.
You can hardly see it anymore.”*

Mud as Climate Adaptation & Ecology Enhancement
Aquaculture

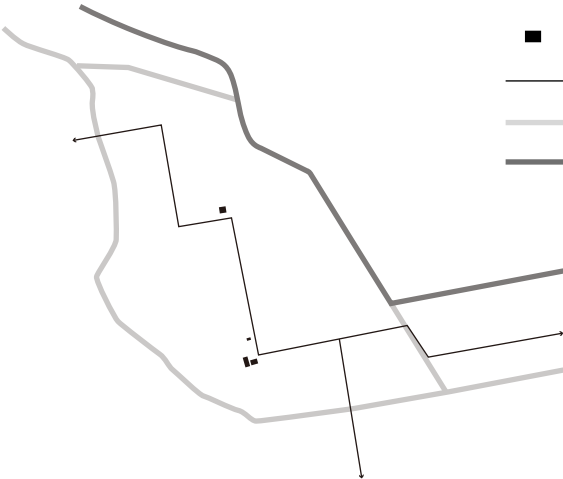


0 200m 500m 1km



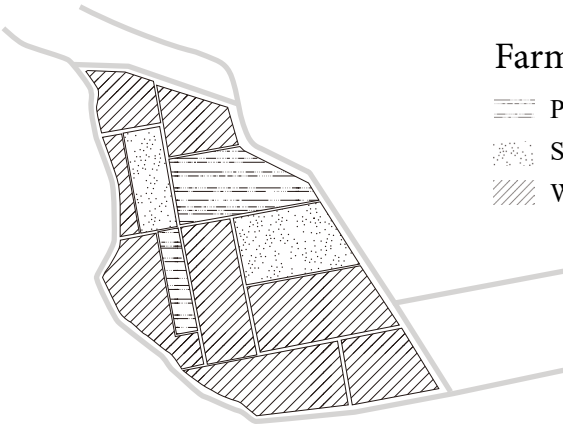
Connection

- Building
- Road
- Old dike- 4m
- Main dike- 8m



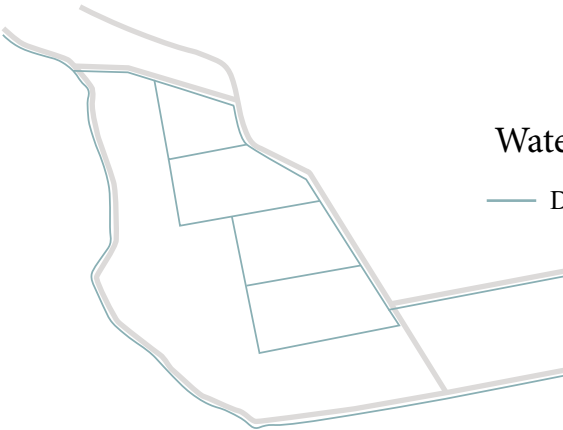
Farmland Pattern

- Potato
- Sugarbeet
- Wheat

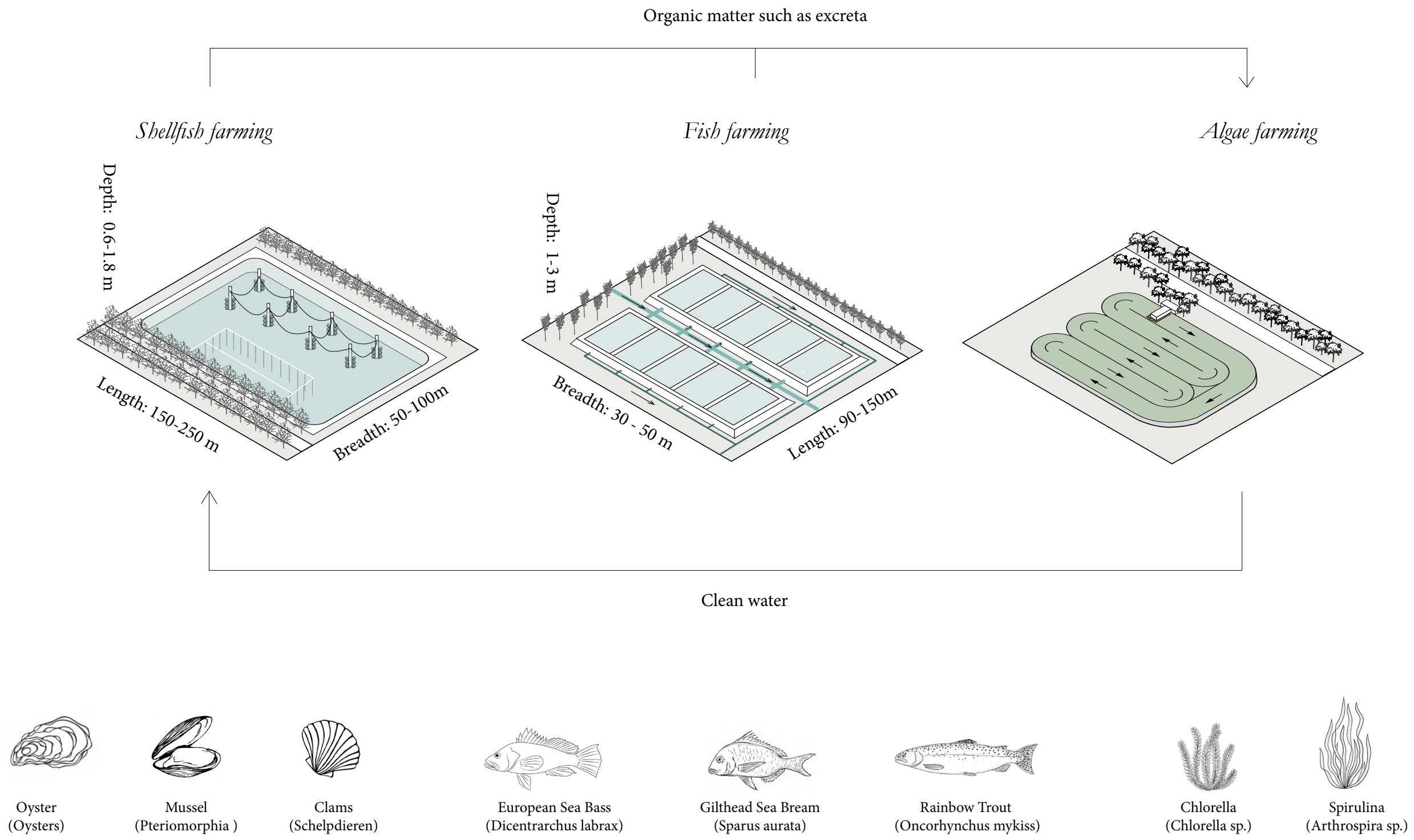
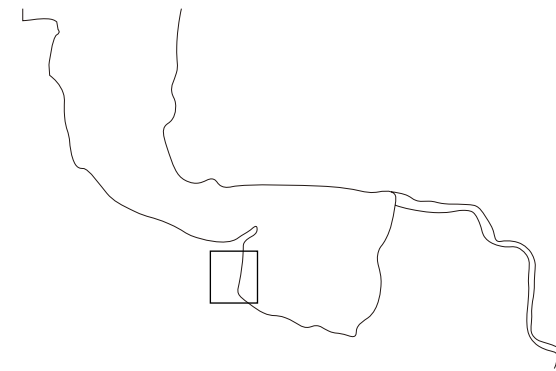


Water

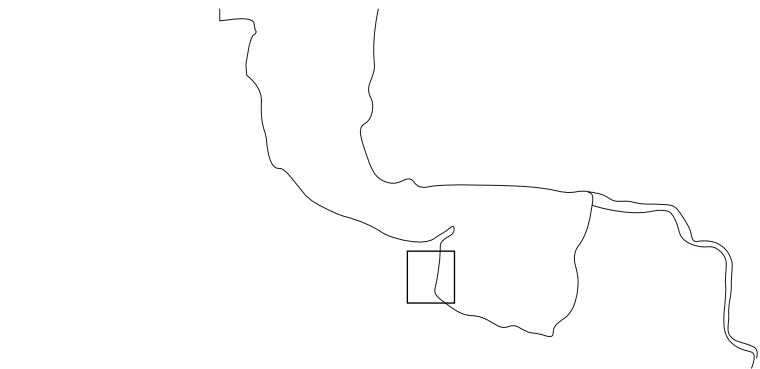
- Ditches



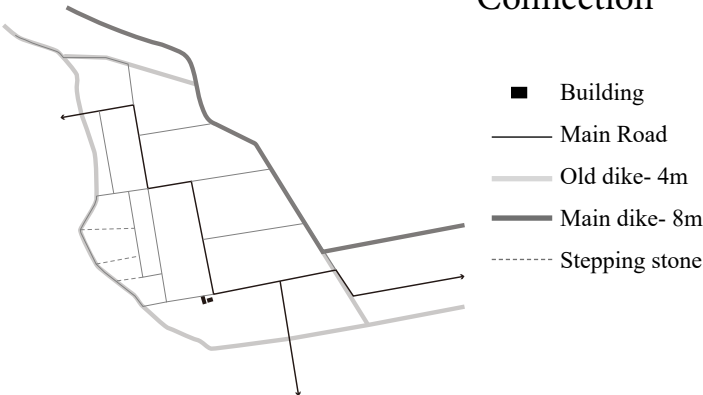
Mud as Climate Adaptation & Ecology Enhancement
Aquaculture



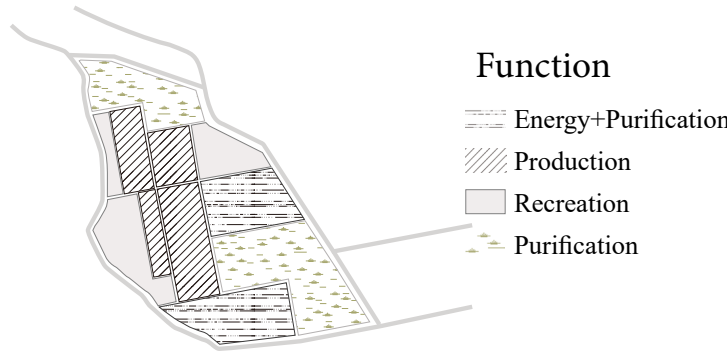
Mud as Climate Adaptation & Ecology Enhancement
Aquaculture



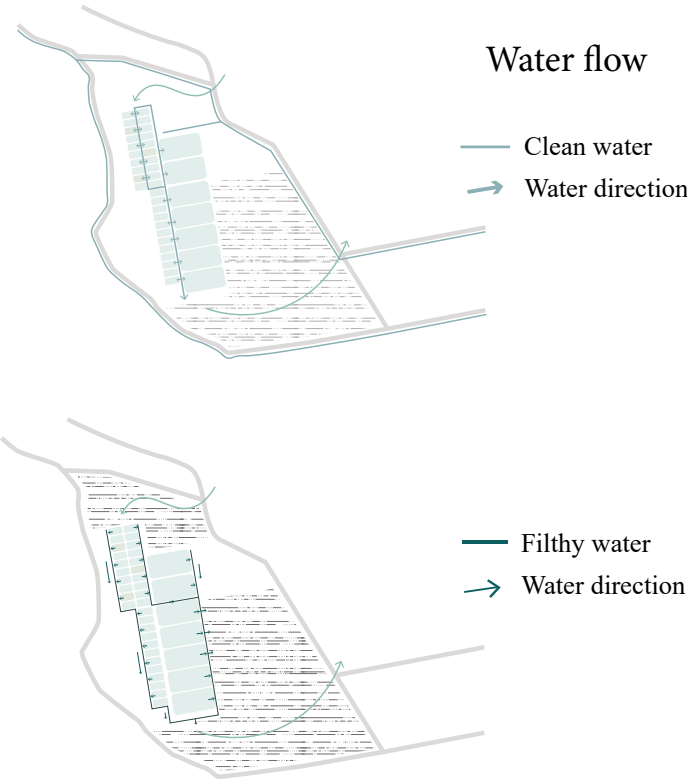
Connection



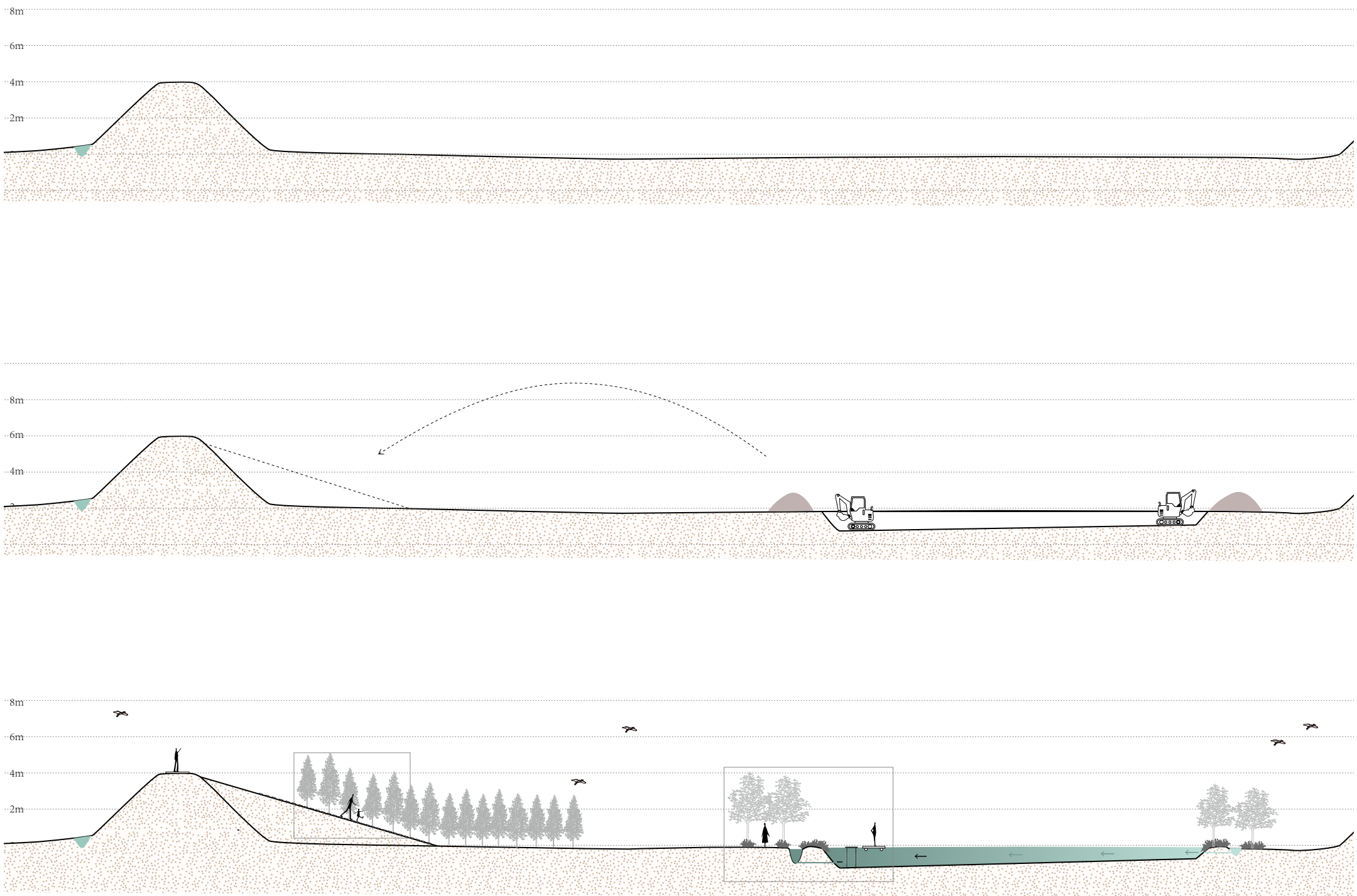
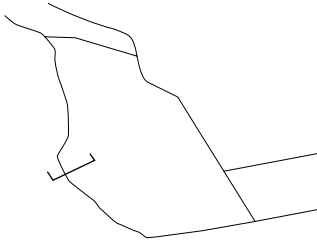
Function



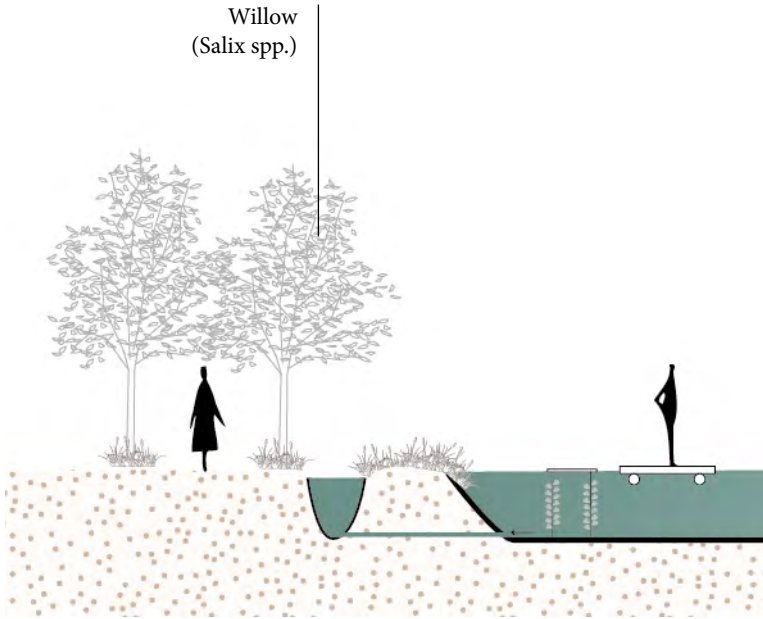
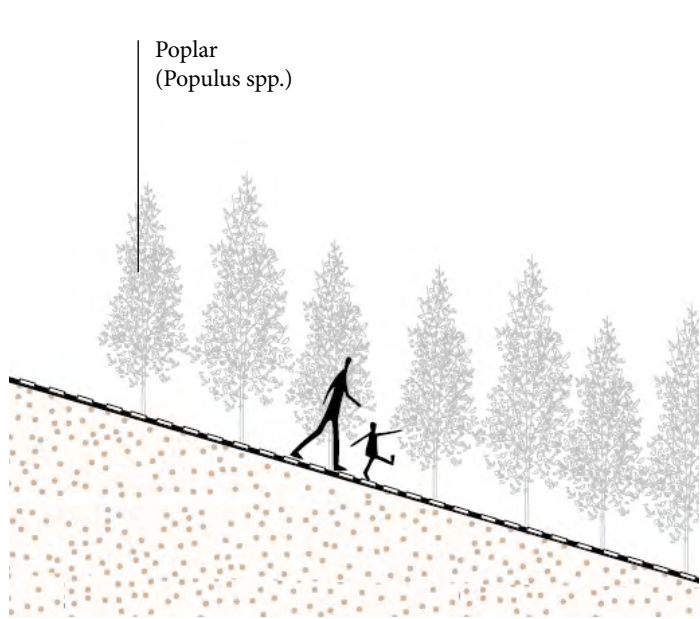
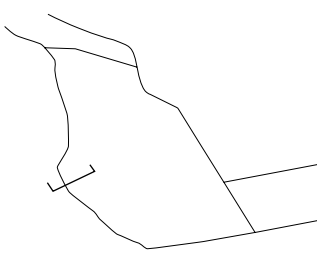
Water flow



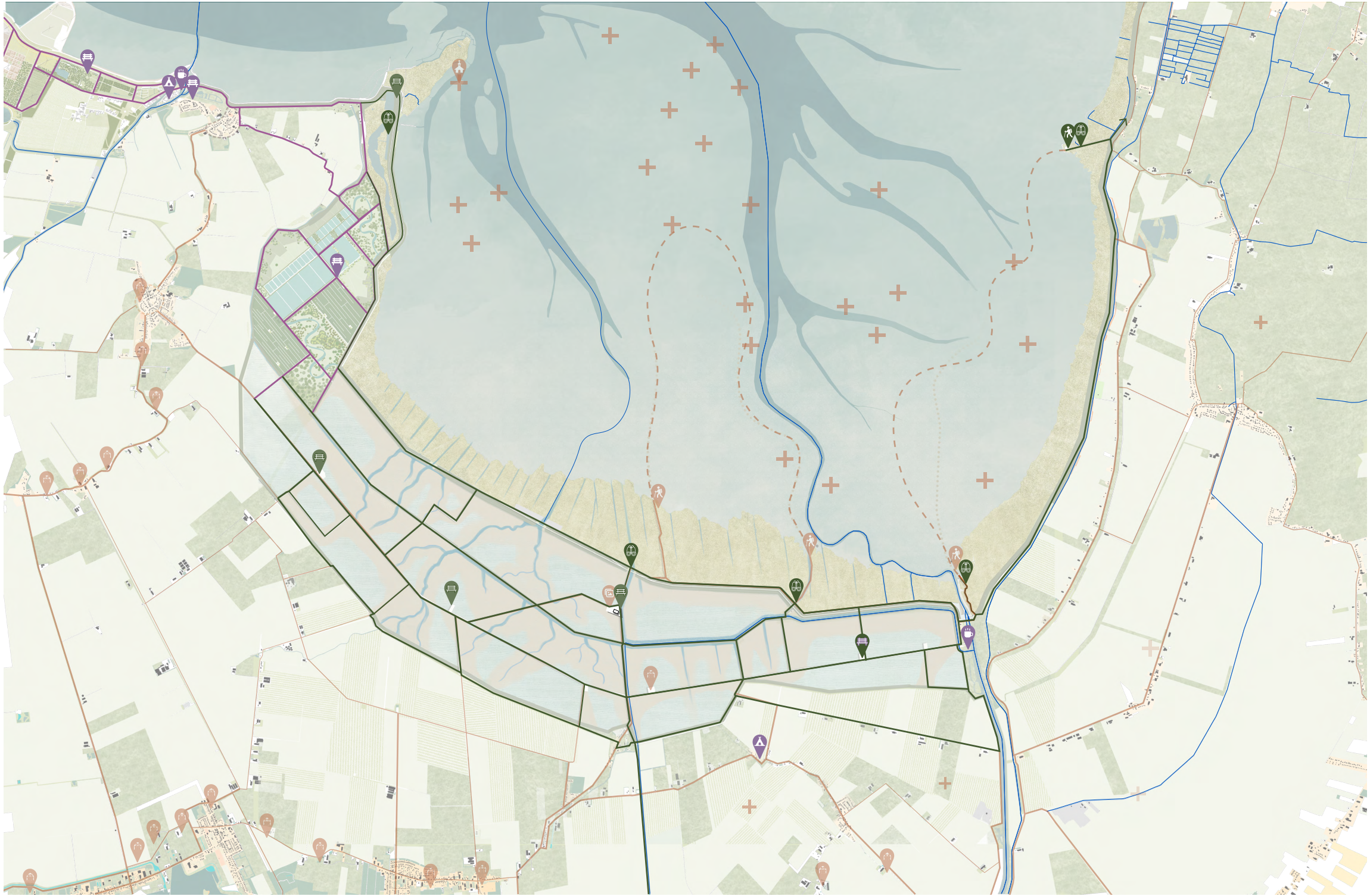
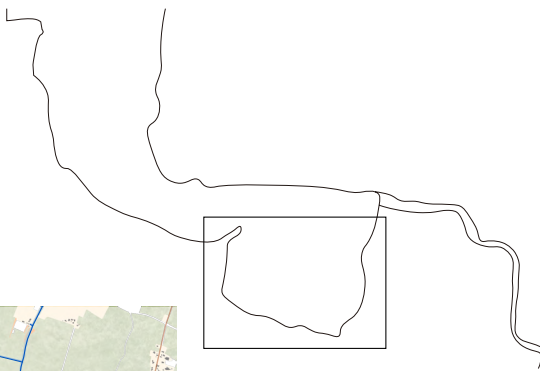
Mud as Climate Adaptation & Ecology Enhancement
Aquaculture



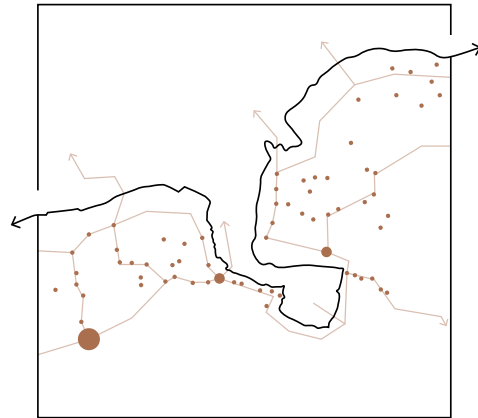
Mud as Climate Adaptation & Ecology Enhancement
Aquaculture



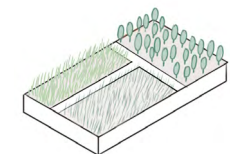
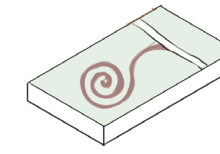
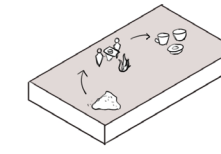
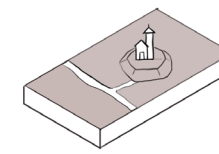
Mud as Climate Adaptation & Ecology Enhancement
The Journey of Ecology & Energy



- Culture monuments
- Recreation nodes
- Buried villages
- Old terps
- Mud hiking
- Ecology journey



Mud as Socio-economy booster

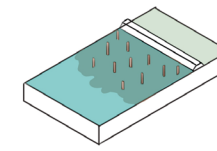


Recreation & Handicrafts

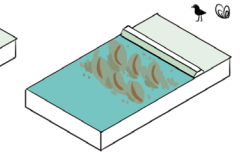
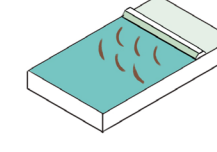
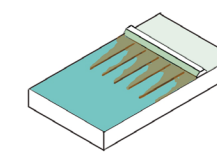
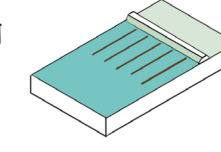
Biomass



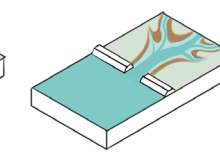
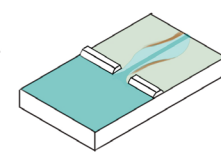
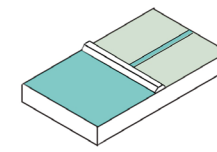
Mud as Ecology enhancement



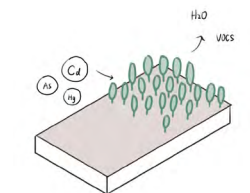
Sediment capture



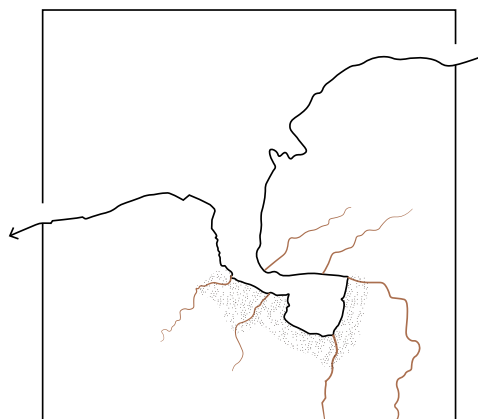
Mussel bed or bird mound



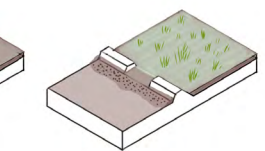
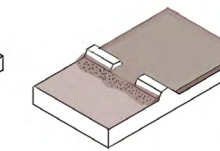
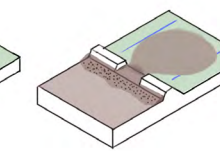
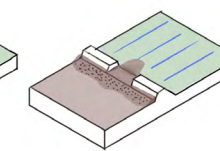
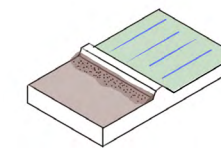
Fish passage



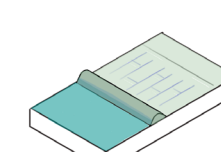
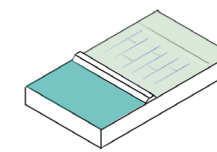
Phytoremediation



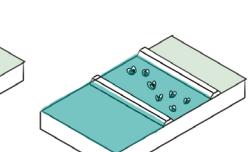
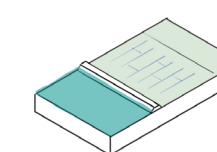
Mud as climate adaptation



Subsidence mitigation



Dike reinforcement and renovation



Double dike and aquaculture

Masterplan



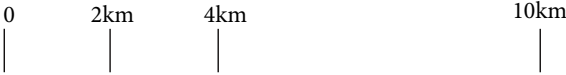
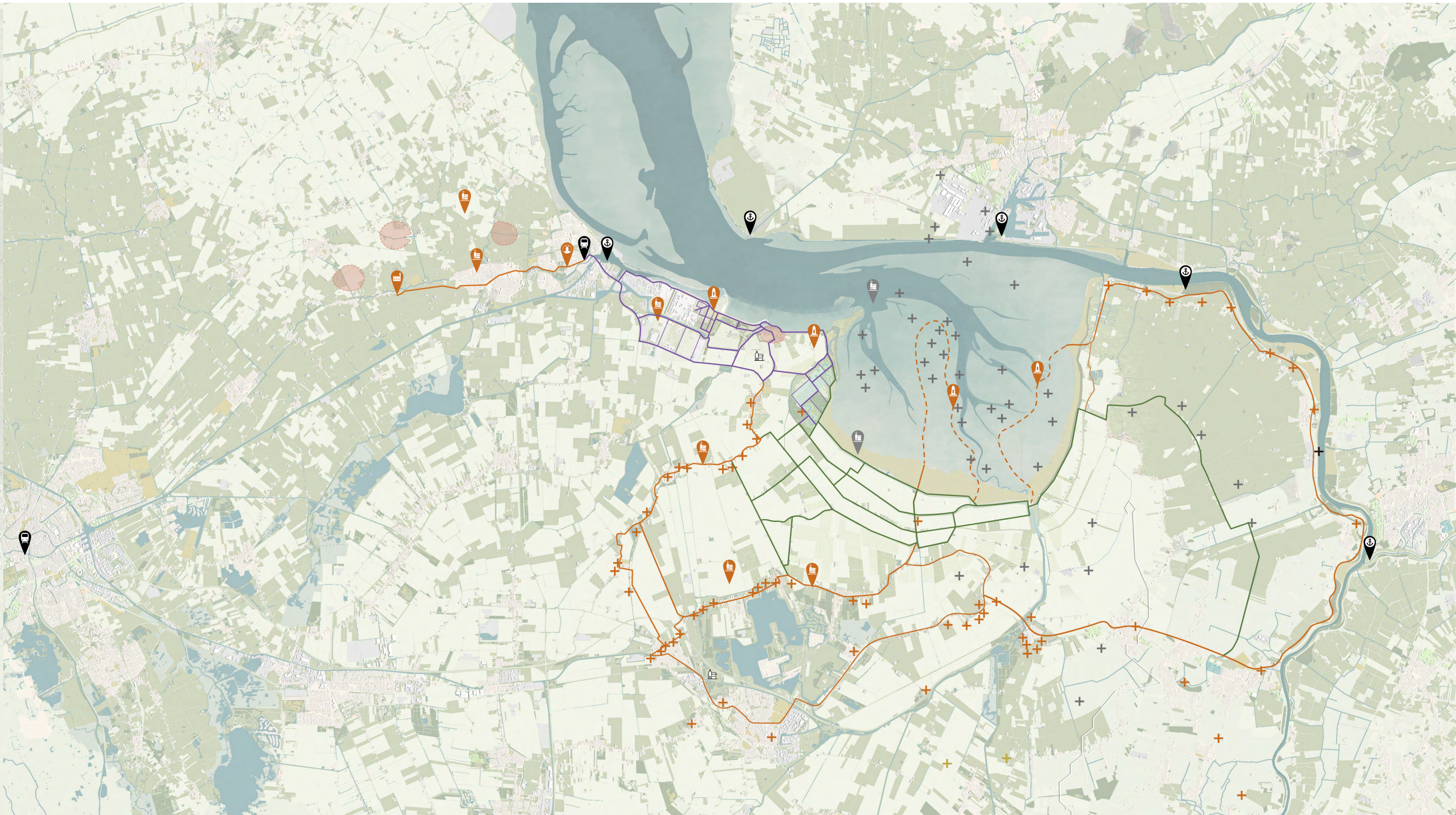
- Existing terps
- Historical buildings
- Disappeared terps

- The energy journey
- The ecological journey
- The cultural journey

- Monastery sites
- Monuments
- Transport

- Mudflat
- Saltmarsh
- Grassland
- Farmland

Masterplan 2025



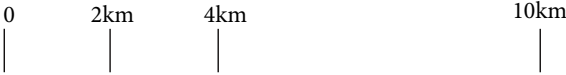
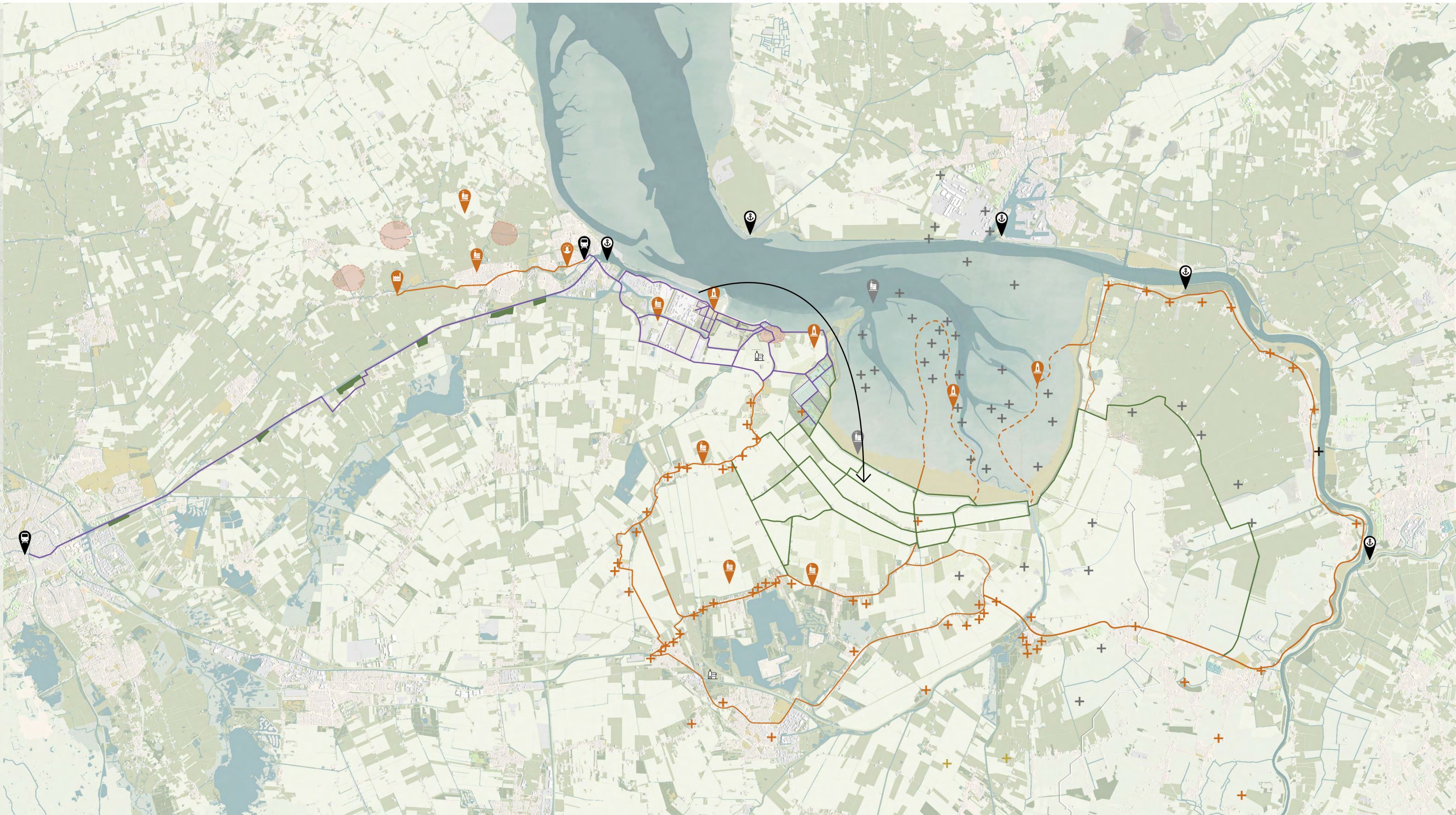
- Existing terps
- Historical buildings
- Disappeared terps

- The energy journey
- The ecological journey
- The cultural journey

- Monastery sites
- Monuments
- Transport

- Mudflat
- Saltmarsh
- Grassland
- Farmland

Masterplan 2025



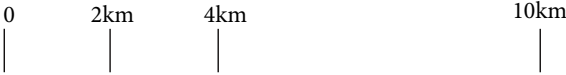
- ✚ Existing terps
- ✚ Historical buildings
- ✚ Disappeared terps

- The energy journey
- The ecological journey
- The cultural journey

- 🏰 Monastery sites
- 🏰 Monuments
- 🚂 Transport

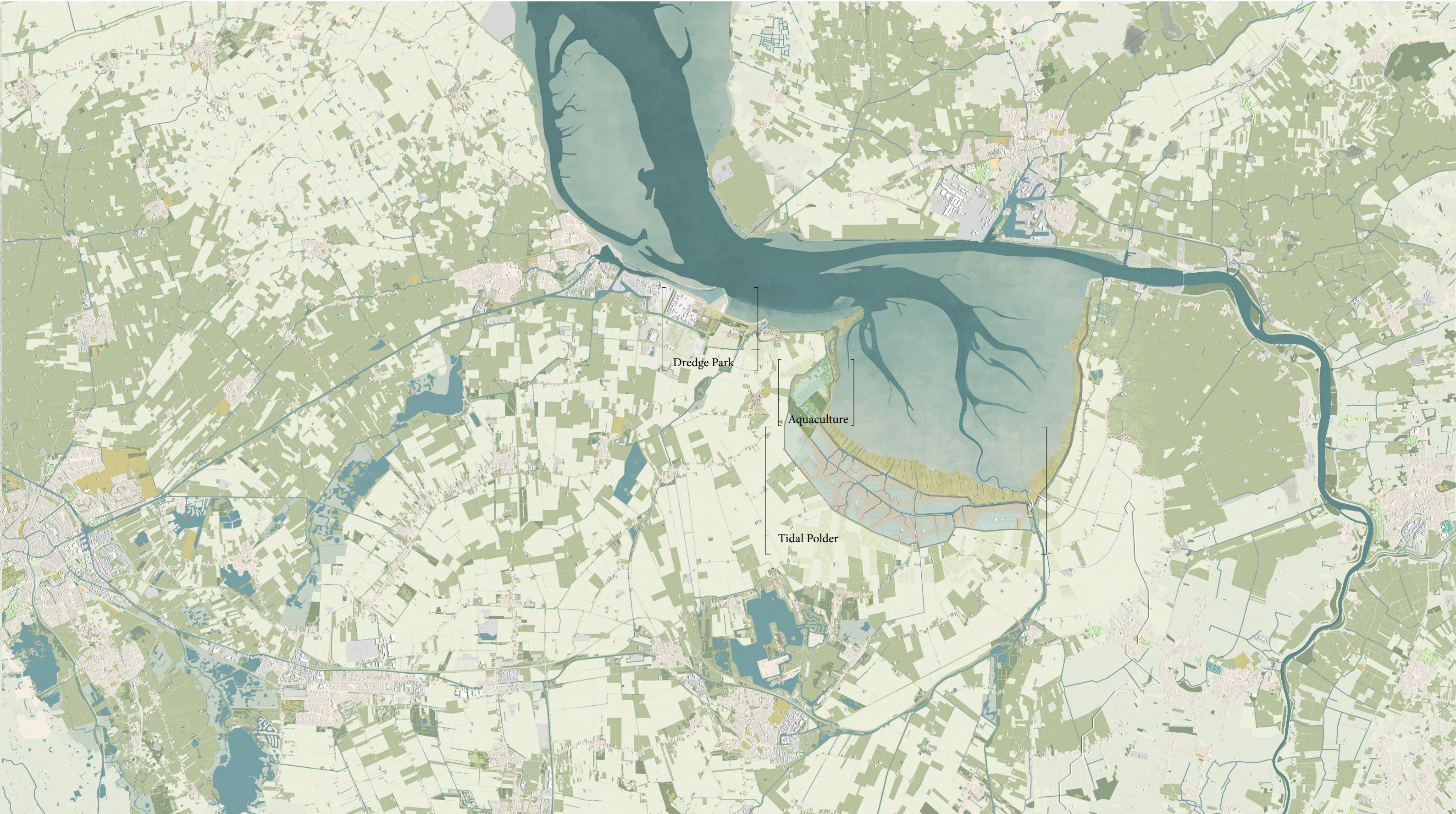
- Mudflat
- Saltmarsh
- Grassland
- Farmland

Masterplan 2035



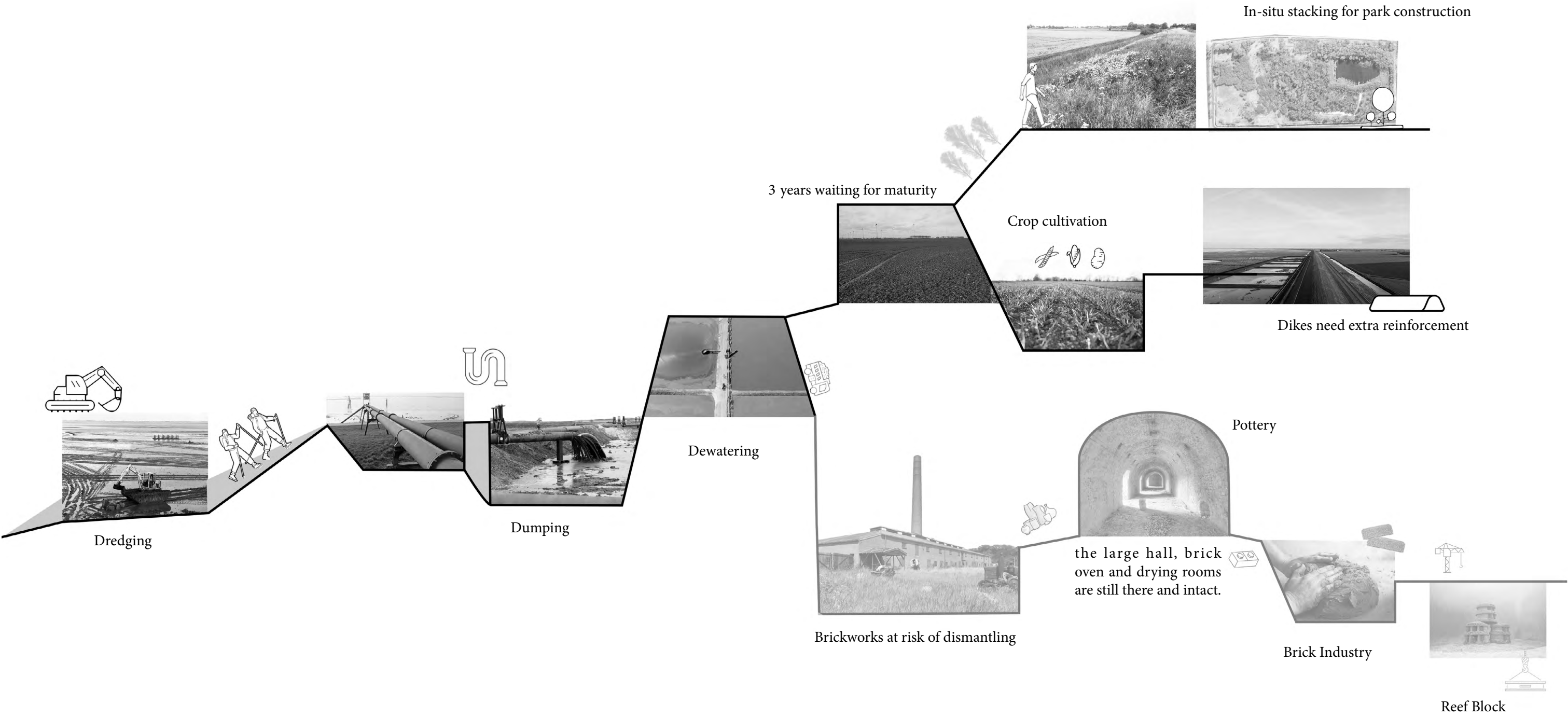
- Mudflat
- Saltmarsh
- Grassland
- Farmland

Masterplan 2050

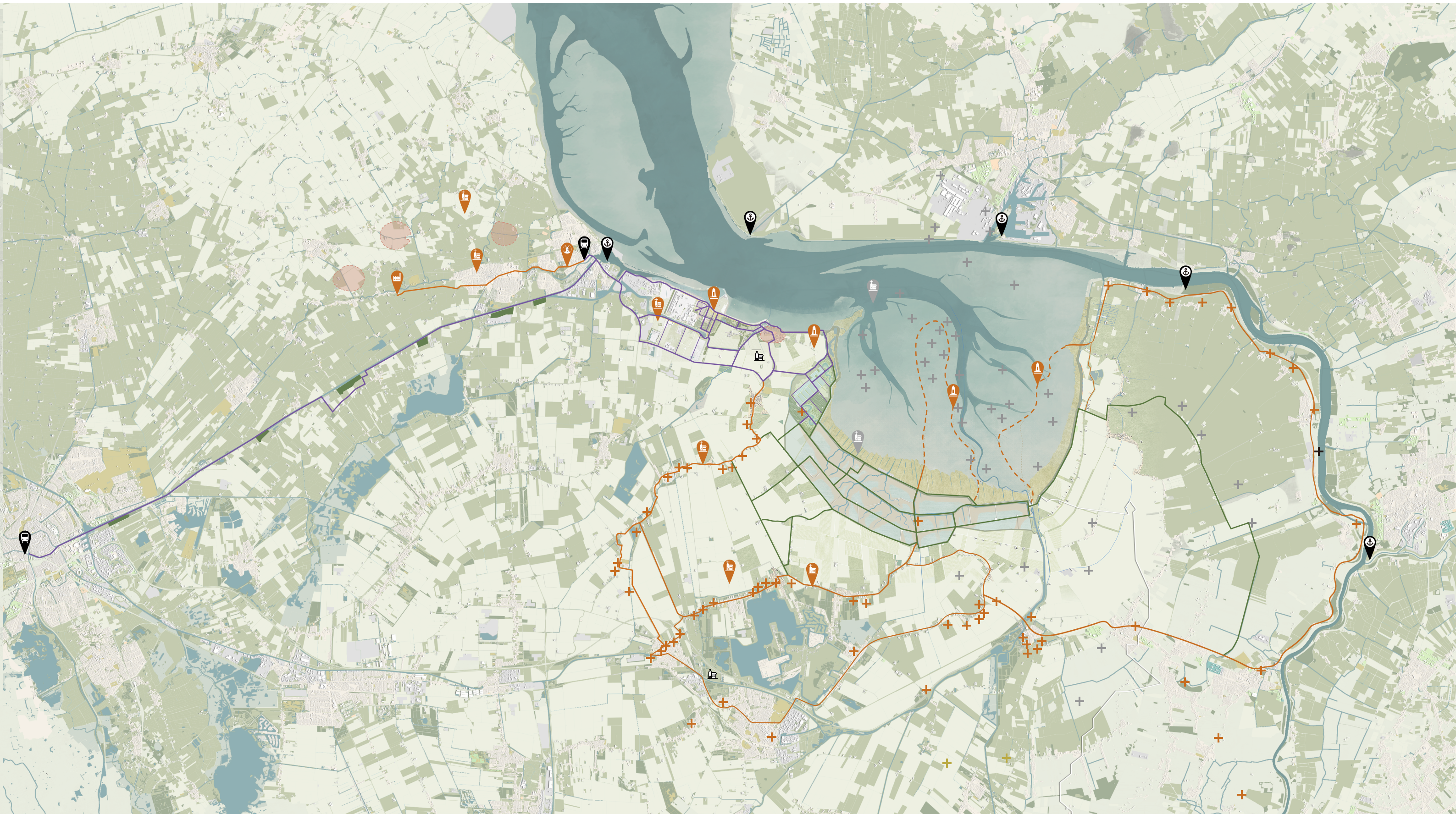


- Mudflat
- Saltmarsh
- Grassland
- Farmland

Mud Industry



Masterplan



- Existing terps
- Historical buildings
- Disappeared terps

- The energy journey
- The ecological journey
- The cultural journey

- Monastery sites
- Monuments
- Transport

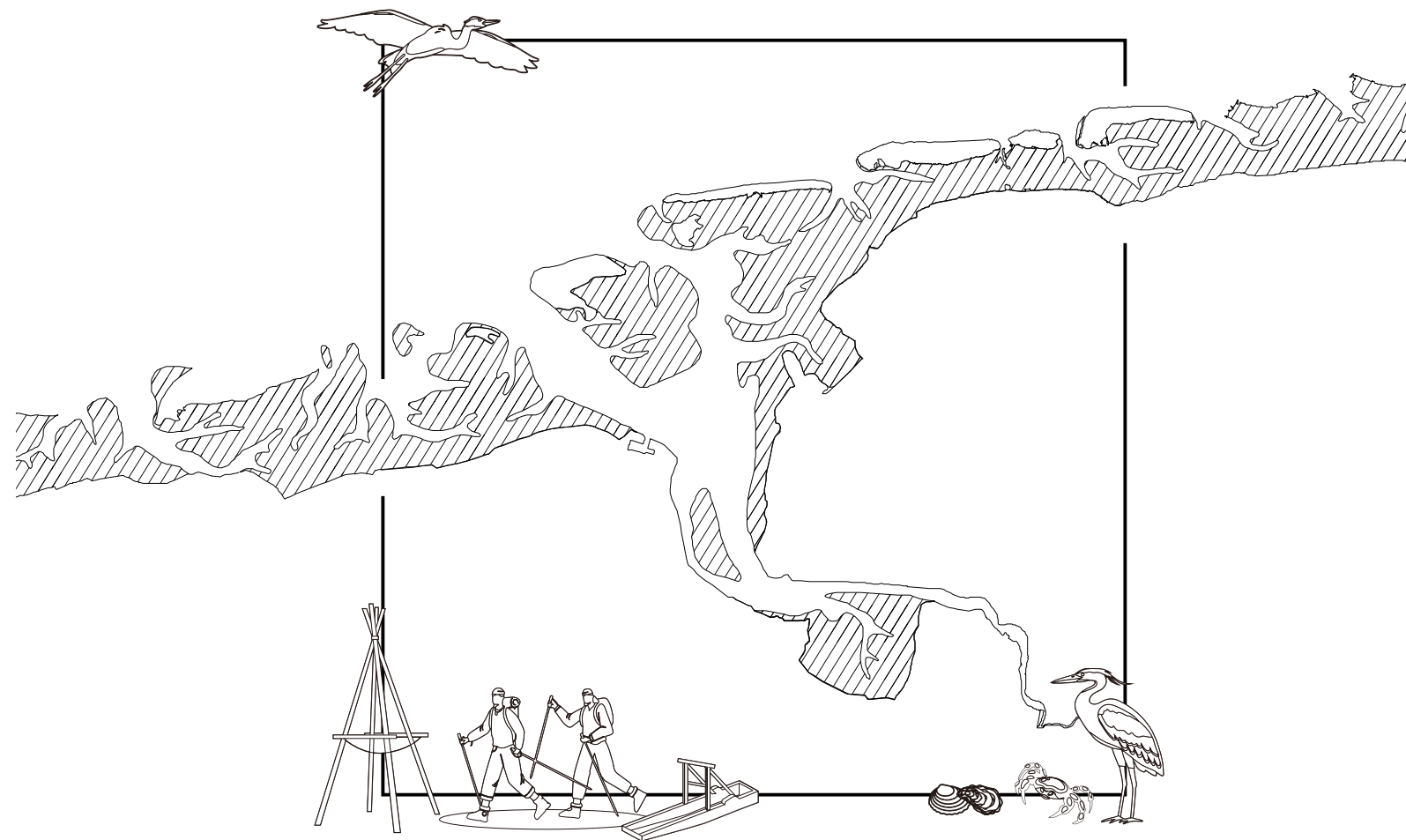
- Mudflat
- Saltmarsh
- Grassland
- Farmland



Brede Groene Dijk : A dike made of salty dredging sludge
Photo: Elcke Vels, 2022

Mudscapes

Embracing Nature, Feeling Culture in the Ems Estuary



Zhaolei Li
2023.06.29