# Multi-criteria analysis on Sedimentation Enhancing Strategies using a best-practice based decision support tool

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by

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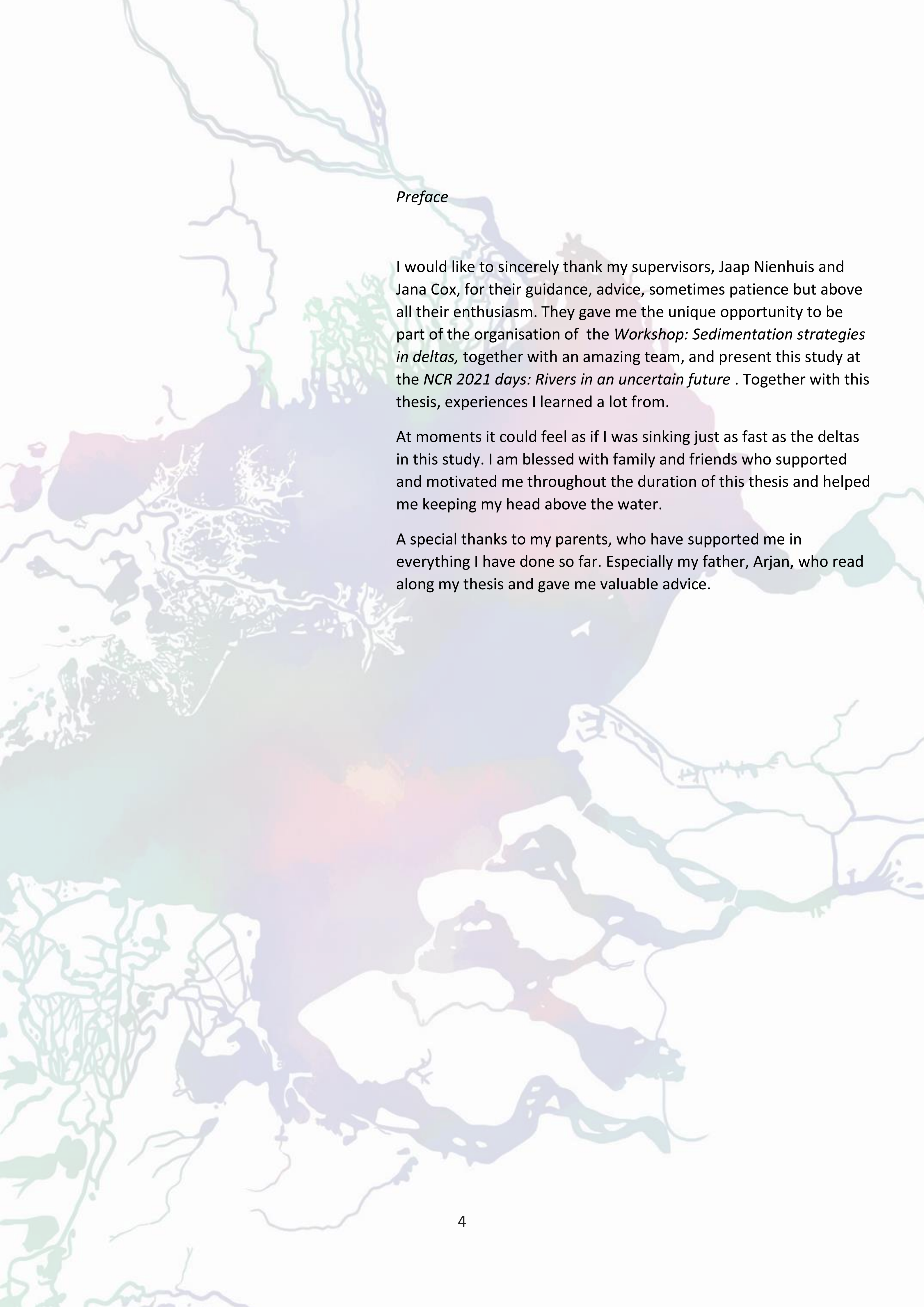

## *Preface*

I would like to sincerely thank my supervisors, Jaap Nienhuis and Jana Cox, for their guidance, advice, sometimes patience but above all their enthusiasm. They gave me the unique opportunity to be part of the organisation of the *Workshop: Sedimentation strategies in deltas,* together with an amazing team, and present this study at the *NCR 2021 days: Rivers in an uncertain future* . Together with this thesis, experiences I learned a lot from.

At moments it could feel as if I was sinking just as fast as the deltas in this study. I am blessed with family and friends who supported and motivated me throughout the duration of this thesis and helped me keeping my head above the water.

A special thanks to my parents, who have supported me in everything I have done so far. Especially my father, Arjan, who read along my thesis and gave me valuable advice.

## *Abstract*

Many deltas around the world are confronted with subsiding land and reduced sediment inflow, a problematic scenario particularly when combined with a rising sea level. To prevent drowning and to maintain the morphological functioning of the delta, sufficient sediment and an effective sediment management are crucial. Sedimentation Enhancing Strategies (SESs) concern measures that enhance natural sedimentation processes in deltas in a suitable manner.

Many SESs are designed for local use and are case specific. Best practices and guidelines that would help to use these designs in other deltas, are lacking. The main objective of this research is to determine the suitability of an existing SES as sediment management for any other delta. Therefore, I developed a decision supporting tool that scans the applicability, merits and risks of SESs. The criteria to assess the suitability were based on a literature research and an expert consultation on case-studies from the Danube, Ems-Dollard, Ganges-Brahmaputra, Mississippi and Rhine-Meuse deltas. Adding new data in future adds to the merits of the tool; the present version is a good proof of principle.

Since the relevant aspects are multidisciplinary, the tool includes a multi-criteria analysis for an automated assessment of the applicability of existing SESs for other deltas. The criteria that determine the applicability of SESs are local biophysical settings, presence of a levee or polder system, restricting budget, available outfall area and the primary interests of the decision maker that uses the tool. These interests concern environmental impact and the necessary or desired land use/type change. Not all criteria could be quantified in the multi-criteria analysis, for example the rate of stakeholder involvement/participation and acceptance.

The assessment by the tool can be considered indicative since all successful Sedimentation Enhancing Strategies require taking into account site-specific considerations. This emphasises the importance of more and improving designs, pilots and/or upscale modelling of implemented or planned SESs.

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# 1. Introduction

## 1.1 Context

Deltas are considered the major centres of population and agriculture (Syvitski et al., 2009). Many of these low-lying lands, high in ecological and economic value, are threatened by combinations of subsiding lands and reduced sediment fluxes (Dunn et al., 2019; Ericson et al., 2006). Changing (and in most cases declining) sediment fluxes influence the delta functioning of the system, but also the long-term availability of land for nature and mankind (Tessler et al., 2018). Changing land management practices and dam constructions reduce sediment supply to the river and hence the delta, while the land itself subsides due to changing tectonics, natural soil compaction or anthropogenic interference in delta such as sediment, groundwater or gas/fluid extraction. A problematic scenario for these often densely populated areas, especially when combined with a rising sea level (Ericson et al., 2006; Syvitski et al., 2009).

*Figure 1-1 Visualisation of global threats to often densely populated deltas.*

## 1.2 Problem definition

To prevent drowning and to maintain the morphological functioning of the densely populated deltas at a longer term, sufficient sediment and effective sediment management are crucial. Different deltas demand different approaches to deal with subsiding land while confronted with a rising sea level. Hence, around the world a range of Sedimentation Enhancing Strategies (SESs ) are being implemented. However, the efficiency of the SESs depends on the morphological, ecological, social, economical and governance situation of the delta and the project settings of the SES itself. Defining the proper criteria for the implementation and realization phase of the SES in a multi-disciplinary perspective is therefore crucial, especially when transferring expertise from one to another delta.

Best SES-practices as well as guidelines are lacking, highlighting the need for an instrument that compares different SESs and their applicability in different delta's in both present conditions and future scenarios. Without such an instrument, the various group interested or involved in the decision-making process, cannot benefit from insights and experiences from pilots and SESs in other delta's around the world.

## 1.3 Definition Sedimentation Enhancing Strategies

Serious strategies are required to counteract loss of delta elevation relative to sea-level and to enhance land elevation or vertical sediment accretion (Giosan et al., 2014; Paola et al., 2011). These Sedimentation Enhancing Strategies are locally implemented and case-specific. SESs included in this study are considered to enhance sedimentation in a natural and suitable manner as nature-based solutions. The strategies considered are presented in table 1-1.

*Table 1-1 Definition of the SESs included in this study.*

| The Sedimentation Enhancing Strategy | Definition |
|---|---|
| Tidal River Management | Breaches are made in the embankment/surrounding dike of the beels/polders to allow river inflow. This results in the return /restoration of tidal-flooding in the newly created floodplains and allow deposition of river sediments.[1] |
| Sediment River Diversions | Redirecting water and sediment from a main river channel by breaching a part of the levee system or by adding a flow diversion structure. The gates in the structure allows timed diverting of river flow into the adjacent wetlands.[2] |
| Wetland Restoration | Embankments are removed to reconnect the polder with the river and allowing flooding in the adjacent area. With the tides sediments enter the system and can be deposited.[3] |
| Double Dikes | Consists of two parallel levees along the river side. The primary levee closest to the river is the original levee, the second levee is created to stop overflow from the primary levee. A culvert is implemented in the primary levee to allow tidal flow into the area in between the levees, which results in the settlement of sediment.[4] |
| Project Kleine Noordwaard | A once agricultural polder is set aside to accommodate river flooding. Tidal dynamics are restored with the aim of nature development. [5] |

Not all possible strategies of increasing the sediment budget or sediment deposition have been included in this study. It is good to consider that urgency plays a large role in managing risks in decision-making as well, which might lead to strategies such as dredging, nourishments, or construction of hard structures. These are not necessarily fully ''natural'' strategies, sustainable on a longer term. Another category that is not included is the restoration of sediment supply by bypassing of sediment at dam systems, especially when grain size can be sorted to let through (Kondolf et al., 2014). And eventually, one should also take into consideration the strategy of adjusting the spatial distribution of a delta when retreat of the coastline inevitable (Ibáñez et al., 2014).

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[1] (Gain et al., 2017a),

[2] (Kolker et al., 2012; Rutherford et al., 2018)

[3] (Tudor, 2008)

[4] (Kwakernaak et al., 2015)

[5] (van der Deijl et al., 2017)

## 1.4 Research questions and objective

In this thesis I investigate SESs as applied in different deltas, guided by the following main question:

*Which criteria determine the applicability of a Sedimentation Enhancing Strategy from a multi-disciplinary approach?*

The main objective of this research is to determine the suitability for implementation and execution of SESs in a user-specific delta. I do this using a decision supporting tool that scans the applicability, merits and risks of SESs.

The aim of the decision support tool is to  provide an overview of potentially suitable SESs for decision makers that will highlight benefits and drawbacks of existing strategies, in relation to new areas of application. The potential user of the tool can be  anyone seeking a multi-disciplinary perspective on delta management and sedimentation enhancing strategies including but not limited to;  policymakers, governmental bodies, river basin managers, research institutes, river- and harbour managers, nature conservation parties, contractors, engineering firms.

In the process of answering the main research question, the following sub questions where considered:

*Table 1-2 Sub questions to the main research question included in this study.*

| # | Research subquestions |
|---|---|
| | *1. Evaluating and defining the SESs in its multi-disciplinary context* |
| 1.1 | What are the relevant Sedimentation Enhancing Strategies? |
| 1.2 | Which aspects from a morphological, ecological and policy framework are relevant for the sediment management strategies? |
| 1.3 | What is the (expected) environmental impact of the strategy applied? |
| | *2. Evaluating the SESs applied in their deltas* |
| 2.1 | What are the delta features that determine the applicability of the Sedimentation Enhancing Strategies? |
| 2.2 | What is the potential contribution of the sediment strategy to the current delta system? |
| 2.3 | What is the expected change of the delta system with sea level rise? |
| | *3. Applicability for other deltas and the design of a decision support tool* |
| 3.1 | For whom is the data on Sediment Enhancing Strategies on a global level relevant? |
| 3.2 | Which properties of sediment enhancing strategies need to be assessed, or are of relevance, for decisionmakers from different deltas? |

## 1.5 Report Structure

After the introduction in *Chapter 1*, the methods of this study are presented in *Chapter 2*. Chapter 3 provides more context on the design, implementation and execution of the Sedimentation Enhancing Strategies. The results in Chapter 4 will present and/or visualise the results from the literature research on the SES and how these results are incorporated into a decision support tool. Consequently the results of the design and performance of the tool are presented. In Chapter 5 results of the multi-criteria research and decision support tool are discussed. Chapter 6 completes this report with the final conclusions.

# 2 Methods

To arrive at a decision support tool for Sedimentation Enhancing Strategies, several steps were made. The flowchart in *figure 2-1* provides an overview of these steps. A more detailed description is presented in the sections of this chapter.

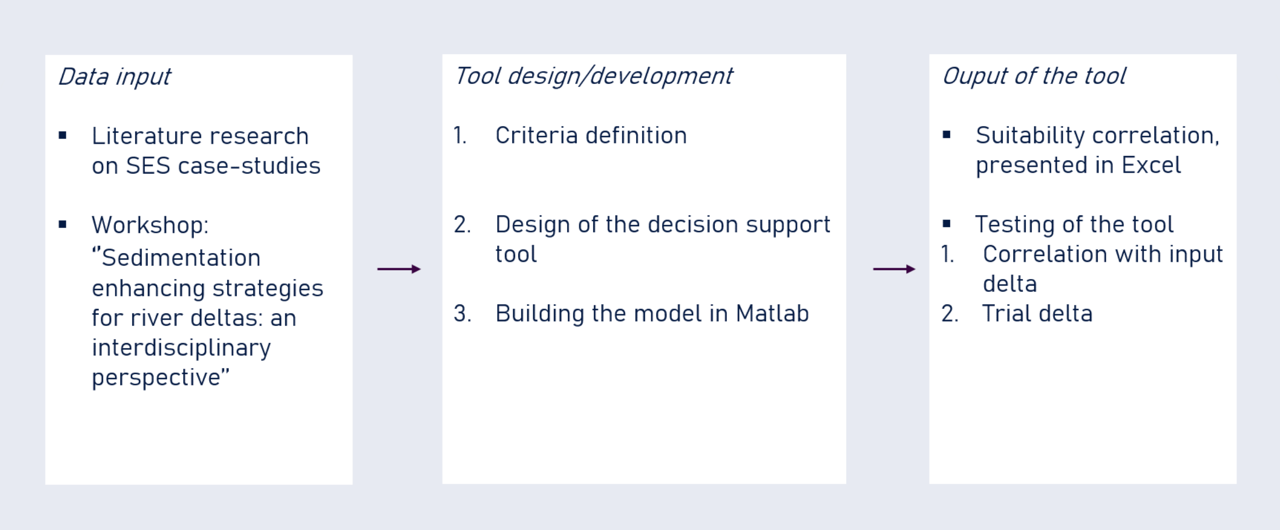

*Figure 2-1 Flowchart presenting the methods of this study.*

## 2.1 Input of the SES decision support tool

This research consists of two parts. The first part is a review of literature and data, and that enabled the second part: the development of a decision support tool.

The aim of the literature review is to gain insight on the criteria that  determine the suitability the specific SESs. The decision support tool is designed/intended for anyone seeking a multi-disciplinary perspective on SESs. Hence these criteria should cover all relevant disciplines.

Data, literature and results of  applied sediment enhancing strategies, was collected for the Danube, Ems-Dollard, Ganges Brahmaputra, Rhine-Meuse and Mississippi deltas. This diverse group of deltas and strategies provides a clear overview on all aspects relevant for applicability of these cases to other deltas, from an ecological, morphological and political point of view.

The tool includes a model of automated correlation and ranking of SESs available in literature with the input data from the user (*see Results*). The input by the user of the tool is aimed to be as minimum as possible, to facilitate an easy usage of the tool and a broad applicability amongst disciplines.  Hence the user-related input should be uniformized, general, at a non-specialist level and as brief as possible.

### 2.1.1 Data collection

In the first part of the study data concerning the case-studies for the chosen deltas was collected. Case-studies with already implemented SESs or still in the design phase were considered. The literature included, both reports (governmental or by involved parties) and scientific literature on the SESs. The SES-cases reported for the Danube, Ems-Dollard, Ganges-Brahmaputra and Mississippi delta contained sufficient data for analysis in this study.

In addition, expert consultation and outcomes of the interactive online workshop "Sedimentation Strategies for Deltas", organised by researchers at Utrecht University, are used in this study. The workshop was attended by experts, researchers, stakeholders and interested parties from different disciplines to discuss and exchange on practices and implementation aspects of sedimentation strategies from a multi-disciplinary perspective. (Nienhuis, Cox, et al., 2020)

### 2.1.2 Data analysis

After the workshop, the knowledge gained, the consultation data and the already collected data were categorised in different categories; delta characteristics, bio-physical aspects, project settings, general outcome. Definition of the categories was based on the outcomes of the workshop in consult with experts from different disciplines.(Nienhuis, Cox, et al., 2020)

*Table 2-1 Categorized parameters obtained from literature research.*

| Delta characteristics | Bio-physical aspects | Project settings | General outcome |
|---|---|---|---|
| Delta | Location implementation relative to river stream (up/mid/down -stream) | Duration of the implementation of the SMS (yr) | Mean annual sediment addition to the system (tons) |
| Coastal Country | Annual mean discharge (m3/s) | Start of strategy (yr) | Average sediment inlet discharge (m3/s) |
| Population density of coastal country per $km^2$ (in 2019) | Sediment type in the system (grain size/origin) | Frequency/timing of execution the strategy | Land raised in (mm/yr) |
| Gross Domestic Product (USD$, in 2019) | Distribution of deposited/added sediment (description) | Area implemented/outfall area /polder area (ha) | Implementation costs/ ha (USD$/ha) |
| Mean subsidence (mm/yr) | Change in depth of the river (m) | Levee system necessary for implementation strategy (Yes/No) | Amount of sediment added to the system over time-span of sediment addition to the system. (m3/yr) |
| Rate of SLR (mm/yr), RCP 4.5 Scenario | Change in width of the river (m) | Polder/beel necessary for implementation strategy (Yes/No) | Gained land type (Nature/Agriculture/ Aquaculture/Wetland/Recreation/ Residential) |
| Rate of SLR (mm/yr), RCP 8.5 Scenario | Mean tidal range at estuary (m) | Upscale modelling undertaken (Yes/No/Other) | Degree of positive environmental impact (Low/Moderate/High/Very High) |
| Levee system present (Yes/No) | Tidal regime (Micro/Meso/ Macro) | Tests and simulations undertaken (Yes/No/Other) | Degree of negative Environmental impact (Low/Moderate/High/Very High)) |
| Polder system present (Yes/No) | River/Tide/Wave dominance | SRED included (Yes/No) | Environmental impact additional remark |
| Main causes land subsidence or sediment shortage (anthropogenic causes) |  | Funding (USD$) |  |
|  |  | Implementation Costs (USD$) |  |
|  |  | Primary objective of the project |  |
|  |  | Landownership (State/Private/Other) |  |

The comprehensive database, consisting of the data gathered, was created in Microsoft Excel/ collected in an offline database. Analysis of the data resulted in the definition of the relevant criteria for the implementation/suitability/success of SESs relevant for the development of the SESs decision support tool (*see section 2.2*). Exclusion of criteria from the tool was necessary when extensive referencing was lacking or if gaps were present between data of different SESs.

Conversion of units occurred resulting in the decided standard units in *table 2-2* , used in this study.

*Table 2-2 Quantities and units used in this study.*

| Quantity | Unit |
|---|---|
| Rate of land/sea level change | mm/yr |
| Costs/ GDP | USD$ |
| Area | ha |
| Time | yr |
| Discharge | $m^3/s$ |
| Size dimension | m |

The significance of ranking of the environmental impact, both positive and negative, is based on the environmental impact study from Coastal & Environmental Services, South Africa (CES, 2013). A description of the significance is present in *table 2-3.*

*Table 2-3 Description of significance used to define the Environmental impact. Based on Table D-2: Description of Environmental Significance Ratings from (CES, 2013).*

| Significance | Description |
|---|---|
| Low | " Acceptable impact for which mitigation is desirable but not essential. The impact by itself is insufficient even in combination with other low impacts to prevent the development being approved. These impacts will result in either positive or negative medium to short term effects on the social and/or natural environment"(CES, 2013., p. 65) |
| Moderate | " An important impact which requires mitigation. The impact is insufficient by itself to prevent the implementation of the project but which in conjunction with other impacts may prevent its implementation. These impacts will usually result in either a positive or negative medium to long-term effect on the social and/or natural environment." (CES, 2013., p. 65) |
| High | " A serious impact, if not mitigated, may prevent the implementation of the project (if it is a negative impact). These impacts would be considered by society as constituting a major and usually a long-term change to the (natural &/or social) environment and result in severe effects or beneficial effects."(CES, 2013., p. 65) |
| Very high | "A very serious impact which, if negative, may be sufficient by itself to prevent implementation of the project. The impact may result in permanent change. Very often these impacts are unmitigable and usually result in very severe effects, or very beneficial effects." (CES, 2013., p. 65) |

## 2.2 The decision support tool

The next step in the study consisted of translating the findings and relevant criteria from the literature research and analysis to the interests of the potential user of the tool. This resulted in the design of the SESs decision support tool, as *figure 2-1* shows.

### 2.2.1 Design of the SESs decision support tool

The starting point for the design of the decision support tool was to formulate a method to incorporate the criteria into the model and categorise or rank the defined SESs if possible. The tool is specifically made to be applied to any other river delta and assess if existing SES are possible or which are most suitable, taking into consideration the delta characteristics.

The relevant criteria, testing the suitability of the SES, were defined by data analysis following the literature research and data collection (*table 2-4*). Hence, outcomes of the tool are restricted to what is added and/or present in the collected data. The performance of the tool relates to the database. This marks the importance of extending and validating this database and keeping the decision support tool updated. A flowchart was made to visualise the input, output and different steps in the tool. For every criteria considered a step was included in the flowchart (*see Results*). The decision support tool is written in the Matlab® R2020b programming language (*MATLAB*, 2020).

*Table 2-4 Criteria and additional information included in the decision support tool.*

| Criteria | Additional information |
|---|---|
| Delta regime user rel. to delta regime lowest resemblance (%) | Primary objective of the project |
| Suitability of the strategy (Yes/No) | Land use type before implementation of the delta of implemented SES |
| Degree of positive environmental impact (low/moderate/high/very high) | Obtained land type after implementation of the SES of the delta of implemented SES |
| Degree of negative environmental impact (low/moderate/high/very high) | Sediment balance (RCP4.5 and RCP 8 scenario) |
| Implementation costs (USD$) per land gain per ha (mm/yr) | Remarks on process of implementation and/or execution of the SES |
|  | Main drawbacks of the implementation and execution of the SES |
|  | Main highlights of the implementation and execution of the SES |

## 2.3 Output of the tool

The output of the decision support tool aims to inform the user of the tool with quantitative and qualitative outcomes which inform the user which strategies are possible and which are most suitable for the input delta. Visualisation considers a target audience of different disciplines and so is given as an Excel file to provide a clear and categorized outcome.

Multiple tests were performed, either with data from a delta already present in the database or with data from a new delta (*see Results*). The first to verify if the model worked correctly and the second to establish whether the right correlation occurred and to determine the performance of the tool.

# 3 The Sedimentation Enhancing Strategies

A brief definition of the different Sedimentation Enhancing Strategies is included in the introduction. In the first section of this chapter more context will be provided on these globally implemented strategies (*figure 3-1*). A description of the SES, of the different case studies and  of the general outcome is included to showcase case-specific resemblances or differences. In the second section the optimization and recommendations in strategy performance/execution are presented as well as factors influencing sediment retention.

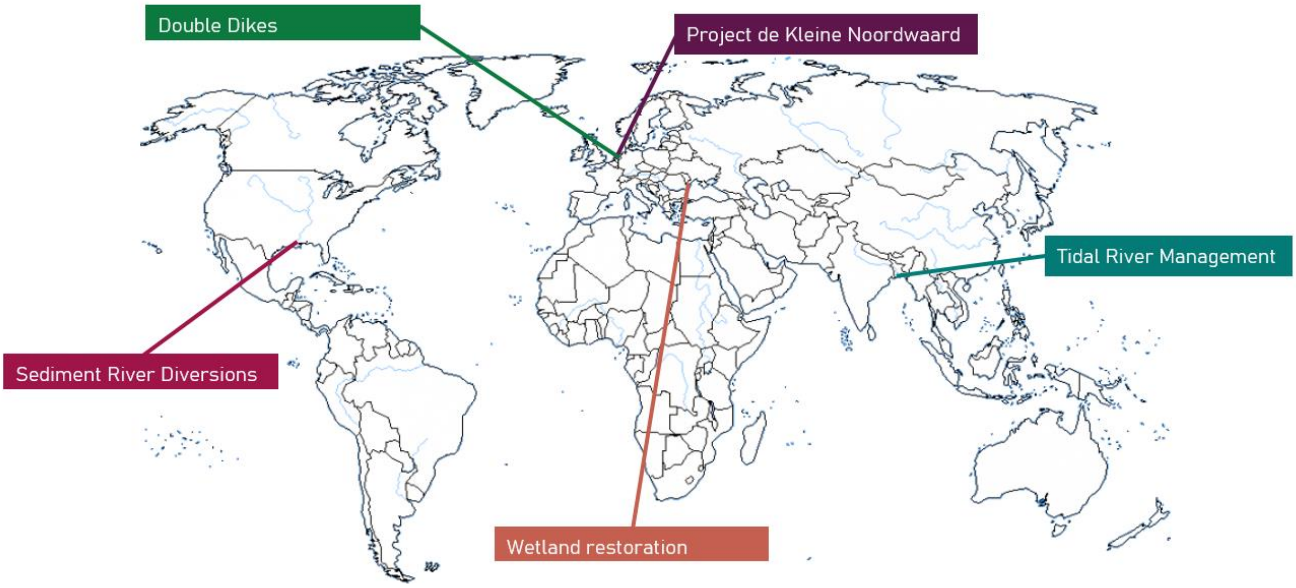

*Figure 3-1 Location of the different included SESs in this study, on a global level.*

## 3.1 The strategies in context

### 3.1.1 Tidal River Management

The West Bengal delta, part of the Ganges-Brahmaputra delta, covers a large area of floodplains. A serious threat for land and water use in this area is subsidence, in a context of ongoing urban population growth, the pressure of sea level rise and salinization issues.(Brown & Nicholls, 2015)

In the Hari River water logging , salinisation, siltation and congestion in the river bed motivated local people, and later government bodies, to implement Tidal River Management  (Hossain et al., 2015).

*Figure 3-3 Satellite image of the Ganges-Brahmaputra delta. (ESA, 2020)*

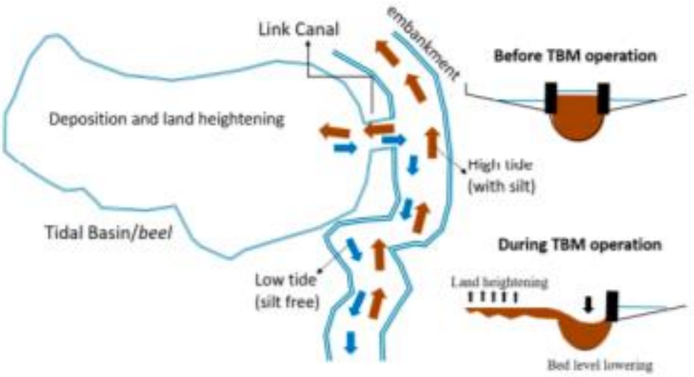

*Figure 3-2 The concept of Tidal River Management, tidal flow in the basin adjacent to the river. (Talchabhadel et al., 2018)*

### Description of the Sedimentation Enhancing Strategy

The practice of Tidal River Management (TRM) at the Hari river consists of the breaching of polders, or beels as they are locally called in the southwest delta of Bangladesh, to allow inflow of tides carrying sediment into the new basin/area. Beels are low depressions in the landscape which are surrounded by embankments, near river dykes or are located in polders. Breaches are made in the embankment/surrounding dike of the beels to allow river inflow. This results in the restoration of tidal-flooding in the newly created floodplains and allow deposition of river sediments as *figure 3-2 s*hows. The adjacent riverbed, in this case the Hari River, experiences scouring downstream of the considered beel. (van Staveren et al., 2016) .

#### *Case study description*

For this strategy three TRM beels are considered. TRM was first implemented in 1997 in *Beel Bhaina*. Local people experienced nuisance of the congesting river and its reduced navigability and considered the embanked structures/polders as the main issue and thus local people opened the beel themselves. The Bangladesh Water Development Board, seeing the success of *Beel Bhaina*, then repeated TRM in 2001 in the *Beel Pakhimara* and in 2006 in *Beel Khukshia*. The implemented TRM SES, have a lifetime of approximately 3 to 5 years. (Gain et al., 2017a)

#### *General results*

The implementation was considered a relative success for all the three beels, because the cross-section of the Hari river increased and the land in the created tidal basins elevated through increased sedimentation. Issues resulted from the uneven sediment distribution in all the beels, leading to complications with stakeholder involvement and their compensation which occurred during the implementation of TRM in both *Beel Khukshia* and *Beel Pakhimara*. (Gain et al., 2017a). TRM is also considered in other deltas and implemented in other beels in the Ganges-Brahmaputra delta (Animesh K. Gain et al., 2019; Warner et al., 2018)

### 3.1.2 Sediment river diversions

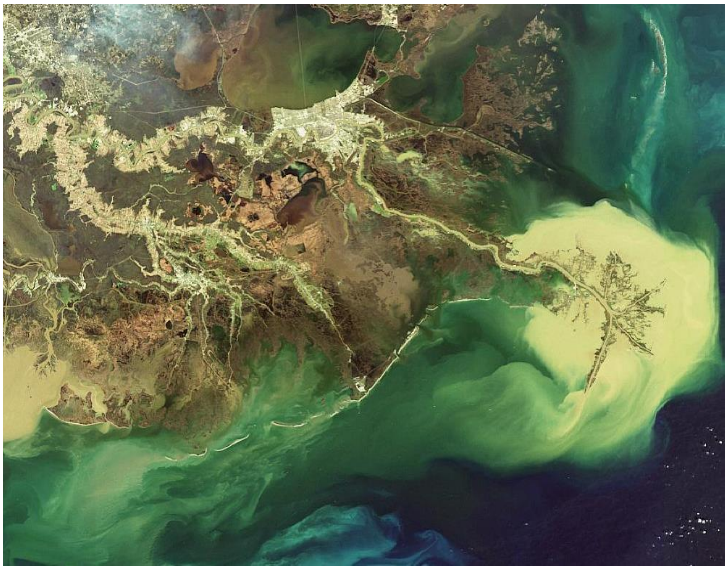

*Figure 3-4 Satellite image of the Mississippi delta. (ESA, 2007)*

Over time, the Mississippi River, *figure 3-4*, became separated from its delta plains due to the embanking of the river (Khalil et al., 2018). Together with subsidence by oil and gas mining, flood control measurements, navigation structures and a rising sea level create a serious threat to the stability of the delta area and its elevation. (Paola et al., 2011) In the Coastal Mississippi area extensive plans are made by the Coastal Protection and Restoration Authority (CPRA) to reduce the major land loss it endures and restore the local wetland ecosystem. These plans include the construction of river diversions (CPRA, 2014).

### *Description of the Sedimentation Enhancing strategy*

Sediment river diversion involves redirecting water and sediment from a main river channel by breaching a part of the levee system or by adding a flow diversion structure (Kolker et al., 2012). An example of a diversion structure is presented in *figure 3-5*. These gates can be controlled to mimic the natural flooding of the land behind the levees. River water transports sediment and nutrients to the newly created wetlands. When river water moves from a constricted flow, through the gates, into the wider wetland, flow velocities are reduced which facilitates sedimentation. (Peyronnin et al., 2017)

*Figure 3-5 Concept of Sediment River Diversions. (Coastal Protection and Restoration Authority of the State of Louisiana, 2017)*

### *Case study description*

The *West Bay diversion* is a relatively small diversion without a gated structure. The main goal for this project was to rebuild and maintain 3978 hectares of marsh area by enhancing the natural process of delta growth (Allison & Meselhe, 2010). The *Mid-Barataria bay* and *Mid-Breton* projects are upscaled versions of the West Bay diversions which are planned for 2023 and 2024 respectively (CPRA, 2019) Both are structured sediment diversions intended to divert river water and sediment into the adjacent wetlands. The main advantage is that both diversions can be timed, to ensure the highest sedimentation efforts, and they have a long lifespan of approximately 50 years (Li et al., 2021). This together with their relative high implementation costs, put them in great contrast with for example the relatively cheap and short-term SES Tidal River Management (Scott, 2019).

### *General results*

The *West Bay diversion* succeeded in enhancing sedimentation. Shoaling occurred in a shipping anchorage more downstream the river diversion due to the decreased local river discharge, negatively affecting the local navigability (Kolker et al., 2012; Sharp et al., 2013). For the *Mid-Breton* and *Mid-Barataria bay* diversions modelling work has been performed to investigate the effect on the local environment and optimize the operations (de Mutsert et al., 2017; Holston, 2021; Ou et al., 2020).

### 3.1.3 Wetland restoration

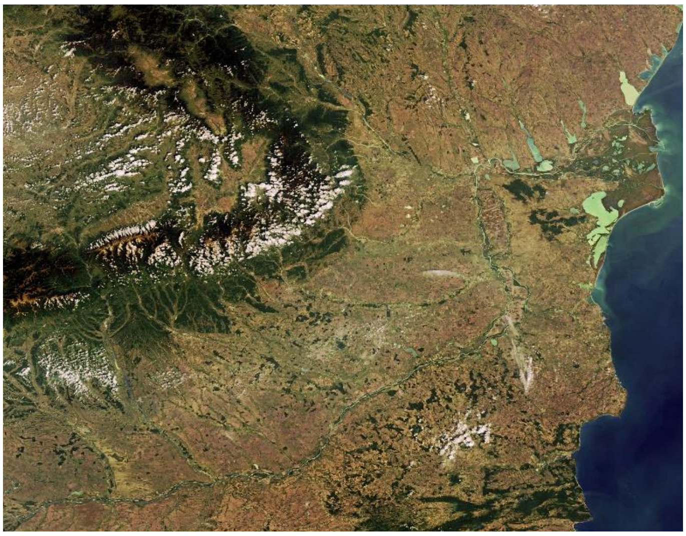

Figure 3-6 Satellite image of the Danube delta. (ESA, 2004)

Although the Danube delta deals with relatively low subsidence, the delta still struggles with a negative sediment budget. Human interventions, like the construction of dams, led to a decrease in the sediment supply to the coastal areas (Dan et al., 2009). To ensure that local sediment is retained for potential future scenarios when , management of the sediment input is crucial (Day et al., 2019).

#### Description of the Sedimentation Enhancing strategy

Wetland restoration, in the case of the Danube delta, is very similar to TRM. Embankments were removed to reconnect the polder with the river and allowing flooding in the adjacent area (Nijland et al., 2001). With the tides sediments enter the system and can be deposited. This increased sedimentation is accompanied by nutrient enrichment, this allows vegetation to establish. Increased vegetation enhances the effect of vertical accretion and elevation change. (Elsey-Quirk et al., 2019)

#### *Case study description*

The *Babina* and *Cernovca* islands, as can be seen in *figure 1-6,* are two abandoned agricultural polders. As part of a pilot program the embankments of the polders were removed and reconnection with the Danube River occurred. This was accomplished by the cooperation between WWF, Danube Delta National Institute and the Danube Delta Biosphere Reserve Administration in 1993. (Petrescu, n.d.) The aim of the project was to restore the hydrological state of the system, allowing tidal movements to occur, and restore the ecological functioning of the newly created wetland (T. Hein et al., 2016)

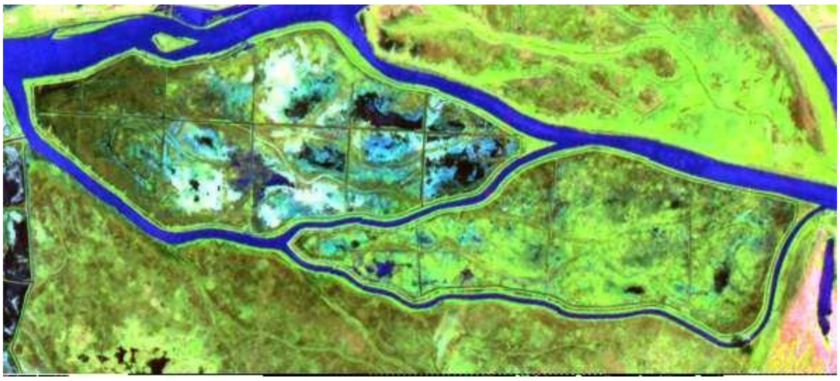

Figure 3-7 Satellite image of the Babina (left) and Cernovca (right) polder. (Tudor, 2005)

#### *General results*

The removal of the embankments resulted in increased sedimentation in the abandoned polders (T. Hein et al., 2016). Restoring the wetland ecosystem and corresponding services, was considered a good alternative for unprofitable polders (Nijland et al., 2001). Local communities have the opportunity to profit from this land change, by the change in ecosystem services. The land change resulted in an increased fish population, nutrient retention, increased cultural values and opportunities for recreation and tourism. (Petrescu, 2010; Tudor, 2008) Both sediment and nutrients are filtered and retained in the system (T. Hein et al., 2016). New habitats were created and attracted fish, bird and other species (Tudor, 2008). Issues arose from stake holder participation, when dealing with public landownership (Nijland et al., 2001).

### 3.1.4 Double Dykes

*Figure 3-8 Satellite image of the Eems-Dollard estuarium. (NASA, 2000)*

The Ems-Dollard delta is located at the border of the Netherlands and Germany (*figure 3-8*). The delta consists of mostly tidal flats and marsh. (Marijnissen et al., 2020)

Challenges the Ems Estuary faces are subsidence and the lack in natural sediments sinks. This results in poor ecological conditions due to the siltation of the river water and the salinization of the adjacent areas. The pilot project Double Dikes is designed to counteract these challenges, by allowing the silt originated from the river water to settle and thereby increasing water quality and vertical accretion. (Bosch Slabbers, 2020; van Maren et al., 2020)

#### *Description of the Sedimentation Enhancing strategy and Case-study*

As part of the Eems-Dollard 2050 plan, the pilot project *Double Dykes/ Parallel defences* is implemented. The project consists of two parallel levees along the river side. (*Project Dubbele Dijk - Programma Eems Dollard 2050*, 2020). The primary levee closest to the river is the original levee, the second levee is created to stop overflow from the primary levee. A culvert is implemented in the primary levee to allow tidal flow into the area in between the levees, which results in the settlement of sediment. (*Double dike along the Eems*, n.d.; van Loon-Steensma & Schelfhout, 2020) The area between the levees is divided into two sections as *figure 1-8* shows. One allows sediment to settle and the other is intended for crustacean and shellfish farming and/or saline or salt-tolerant agriculture.(Eems-Dollard 2050, 2020a)

*Figure 3-9 Image of the Double Dikes project. Two sections can be recognised; the sedimentation zone (right) and the experiment/agriculture zone (left). (Eems-Dollard 2050, 2020a)*

#### *General results*

The project *Double Dikes* started in 2018 and continues until 2022. The results of monitoring so far indicated increased sedimentation (Eems-Dollard 2050, 2020a). The Double Dikes project creates a zone suitable to experiment with saline cultivation, or the opportunity for saline or salt-tolerant agriculture which could be of economic interest (Kwakernaak et al., 2015).

### 3.1.5 Project de Kleine Noordwaard

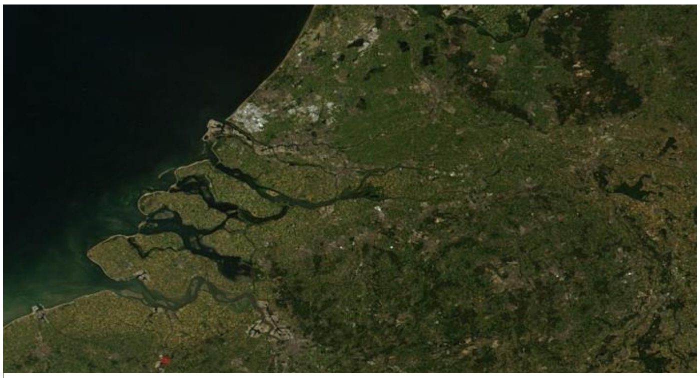

*Figure 3-10 Satellite image of the Rhine-Meuse delta. (Schmaltz, 2006)*

In the Netherlands, 9 million people are living in areas below sea level and 70% of the gross domestic product is being earned in these areas. (Mulder et al., 2011). The rising sea level and negative sediment budget, due to anthropogenic interventions in the Rhine-Meuse delta, cause a problematic scenario in the coastal regions of the delta (J. R. Cox et al., 2021).

#### *Description of the Sedimentation Enhancing strategy and Case-study*

The Room for the River project was initiated to implement spatial security measures which will accommodate excess water and increase flood safety (Schut et al., 2010). The depoldering of the Noordwaard was one of the projects initiated through Room for the River. In the Noordwaard, a once agricultural polder was set aside to accommodate river flooding. Tidal dynamics were restored with the aim of nature development (van Staveren et al., 2014). When compared to TRM and the Double Dikes SESs, mainly fresh water is diverted into the depoldered area.

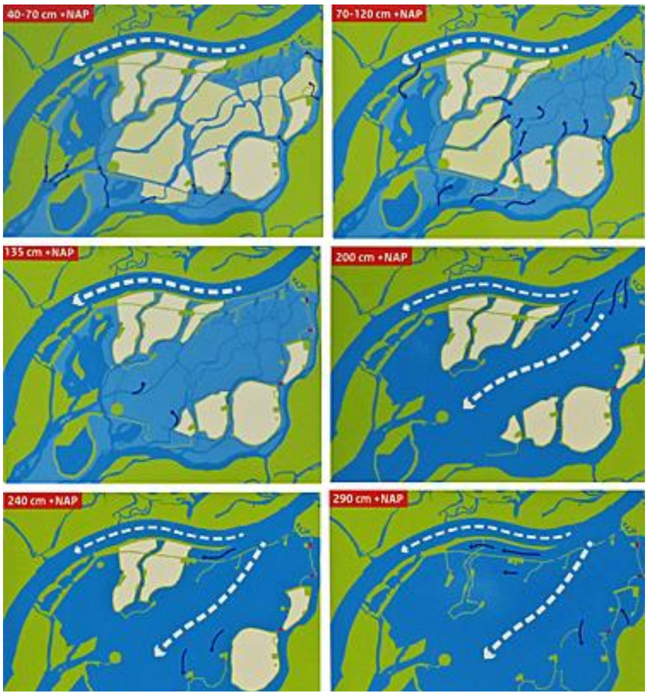

*Figure 3-11 Visualized concept of de-poldering. With the flood water can inundate the once poldered area, and eventually sediment can settle. (Room for the river programme completes its largest depoldering project Noordwaard, the Netherlands | Dutch Water Sector. (n.d.))*

#### *General results*

*Project kleine Noordwaard* resulted in sedimentation in the once poldered area although this was not the intention of the project. The Zuiderklip polder, adjacent to the Noordwaard polder experienced a negative sediment budget. Sufficient inflow of the river into the wetland and creating sufficiently large residence time of water within the polder areas for sediment settling are crucial (van der Deijl et al., 2019). During the process of implementation conflicts occurred with the local stakeholders, the main cause was the uncertainty of flood management plans. (Edelenbos et al., 2013)

## 3.2 Optimization opportunities in SES performance/execution

Opportunities to optimize the efficiency and/or suitability of Sedimentation Enhancing Strategies, can be of interest for those considering implementing a SES. These ‘’tweaks’’ show the potential to be of importance for a range of different SES from a multi-disciplinary point of view as *section 3.2.1.* presents. *Section 3.2.2.* presents local factors affecting sediment retention.

### *Placement and timing of the embankment cut*

Efficiency of the Tidal River Management depends, among other things, on the timing and placement of the embankment cut, the size of the embankment cut and the amount of embankment cuts/inlets present in the delta system (Islam et al., 2020).

TRM results in scouring of the river downstream from the tidal basin, which in turn decreases river discharge, culminating in a decrease in the suspended sediment concentration downstream of the embankment cuts. Therefore, careful consideration on the placement of multiple embankment cuts is relevant (Jakariya, 2016). Suggested methods of applying TRM is to implement it rotation wise in the river system, starting with the beels more downstream and shifting consequently to beels upstream (Khadim et al., 2013; Talchabhadel et al., 2020). This to avoid high levels of siltation after the *TRM* operation is closed (Masud et al., 2019).

When TRM is compared with sediment river diversions, the same issue arises concerning the extraction of river water and sediment. River diversions reduce the local discharge resulting in downstream channel aggradation (Meselhe et al., 2016a). The sand capture efficiency of the diversion depends, among other things, on the relative water discharge of the diverted flow through the diversion versus the discharge of the river, placement of the diversion cut/intake on lateral bars, the invert elevation and the placement of the cut/intake and the local curvature of the river (Alomari et al., 2020; Meselhe et al., 2016b).

To capture sediments from the bedload of the river more efficiently, research and or modelling of the sediment concentration profiles of the bedload of the river can be of importance. A shallow diversion intake/cut, in the embankment, might not be able to capture the high sand concentrations situated low in the water column. (Dean et al., 2013)

### *Timing of controlled SES*

The timing of the diversion, on a seasonal scale, determines the discharge and consequently how much water can enter newly created wetlands/outfall areas. For the Mississippi river diversion, a threshold discharge of 17,000 $m^3/s$ is considered to operate the river diversion to maximize the sediment supply (CPRA, 2014). At this threshold and during high flow season (December-June) the potential sand resuspension increases and results in higher sand loads in the water column. This makes hydrograph analysis essential when increasing the sand capture and land build in the outfall area of the diversion (Allison & Meselhe, 2010; Gaweesh Ahmed & Meselhe Ehab, 2016; Rosen & Xu, 2014).

Striving for the highest sediment capture through timed diverting of river water and sediments could negatively impact vegetation, water quality, fish and other species (Peyronnin et al., 2017). Timing the diversion during winter season will decrease the risk of damaging the local ecosystem as most of the system is in dormant state during winter season (Peyronnin et al., 2016). Sediment diversions have the potential to create new wetland habitats. An increased duration of flooding, will test the resilience of the system and habitats to coop with flooding. Considering having shorter times of inundation, when executed during growing season, would decrease the amount of stress the ecosystem and species present experience (Peyronnin et al., 2017).

Taking into consideration the local stakeholders and their needs (in terms of growing season, tourism etc.) can increase the acceptability of implementing and executing a SESs. The inclusion of gates in TRM, allowing timed water inflow, could be an improved TRM version. If TRM could be executed during Monsoon period, crops can grow during the dry periods and salinity concentrations would be kept as low as possible (Islam et al., 2020).At the same time minimizing the duration of flooding and consequently maximizing the time available for aqua and agriculture are the main interests of local farmers (Gain et al., 2017b). This indicating the potential importance of timing a SES.

*Outfall size of the SES*

The size of the diversion determines the amount of sediment gained by the system. As for sediment river diversions, a large diversion would result in more land gain over a short period. The land gain area is substantially larger, greater than the sum of the two volumes of the smaller diversions, for large (inlet discharge > 1420 cubic meters per second) river diversions (Allison & Meselhe, 2010).

The side-effects of operating on a large scale on the system are the over-freshening, leading to algal blooms, and replacement of fish species (de Mutsert et al., 2017). Performing the diversion more infrequently, over short periods but on a large scale could be a solution to still offset the land loss and minimize the ecosystem costs (Day et al., 2016; Rutherford et al., 2018).

Other SESs, like depoldering, TRM and wetland restoration, are restricted to the size of the embanked area or dikes would have to be removed/broken down. No upscaling or modelling of the relatively recent implemented pilot project Double Dikes has taken place but we hypotheses it will be similar as the dikes need to be moved/expanded to allow for upscaling. Implementing multiple SESs in one delta could be of interest. But as implemented SESs have an effect on the connected river system ranging from changed navigability, local shoaling to the redistribution of species, performing sufficient research is crucial (de Mutsert et al., 2017; Jakariya, 2016; Rutherford et al., 2018).

*Sediment redistribution*

For deposited sediments (sand) to accumulate even distribution of sediment across the outfall area is necessary. In the beels alongside the Hari river, where TRM is applied, the main objective is to convert the flooded tidal basin to land suitable for agricultural use. Maintenance of TRM consists of keeping the channel connected to the tidal basin and redistribution of the sediment to prevent accumulation only near the embankment cut (Gain et al., 2017a). Compartmentalization and channelization of and in the tidal basin created, could help for the redistribution of the sediment. (Talchabhadel et al., 2018)

These potential scenarios/improvements for Sedimentation Enhancing Strategies can lead to optimized executing of the SES on a multidisciplinary level. This emphasises the importance of improving designs, executing more tests and/or upscale modelling of implemented or planned SESs as well as good quality data before the implementation phase .

### 3.2.1 Sediment retention

Once implemented local factors affect the actual nett success of the SES, or the actual amount of added and retained sediment. Although a SES might be able to keep up with the rising sea level, factors like the local flood regime can change spatial sedimentation and effectiveness of the SES.

*Vegetation*

Coastal wetlands enhance sediment accumulation and are therefore potential flood protection strategies. Vegetation in salt marshes decelerates local currents, caused by tides, through exerting friction. This allows sediment to settle and accumulate (Bouma et al., 2005; Marijnissen et al., 2020). During high intensity events, like storms, roots can prevent erosion damage and accompanied sediment loss through binding the marsh bed. (Marijnissen et al., 2020) This binding also reduces the resuspension of sediments (Braskerud, 2001). SESs that include planting and/or developing vegetation are likely to be more effective. Luckily the establishment of vegetation is often included as part of the aim when implementing a SES (*see section 3.1*).

The inclusion of Sedimentation Retention Enhancing devices can also increase the efficiency of sediment trapping of the system. Examples are the additions of earthen dikes or vegetated islands in the area exposed to flooding or sandbars in the river channel (McQueen et al., 2020; Meselhe et al., 2012)

#### *Climatology/seasonality*

Climate factors can influence local sediment suspension and deposition. In the Mississippi delta cold fronts can be coupled to resuspension of sediments in wetlands. Timing the sediment diversion prior to the passage of a cold front maximization of sediment suspension and eventually deposition can be achieved (Peyronnin et al., 2016). Closing the diversion would be suggested after the passing of the front allowing better drainage and consolidation to increase soil strength. (Snedden et al. 2007).

Resuspension also depends on the amount of fetch present in the system. When strong winds can build up, tidal movements of the sediment can even be overruled as happens in the Noordwaard. The case of the Noorwaard, efficiency of trapping sediments decreased with increasing wind strengths (van der Deijl et al., 2017).

Considering the uncertainty in sediment deliverance and in the ability of the system to retain the sediment is important. These aspects are often controlled by the local climate. With a changing climate, and accompanying consequences often not yet to be foreseen, even of more important to keep in mind when implementing a SES.

# 4 Results

In *section 4.1 Data collection Sedimentation Enhancing Strategies*, the results of the literature research is presented. *Section 4.2 Sedimentation Enhancing Strategy decision support tool* contains the design and structure of the SES decision support tool. The final *section 4.3 Testing the SES decision support tool* shows the results of testing the SES decision support tool.

## 4.1 Data collection Sedimentation Enhancing Strategies

In the following subsections, for every category used in the tool (*see Methods),* the result of the of data collection is addressed or visualised.

### 4.1.1 Delta characteristics

In *Appendix A.I* the results of the data gathering on delta characteristics for all the SESs and the accompanying case-studies are listed. The data on the deltas was relatively easy to find and/or obtain compared to strategy or case-specific data. If sea level rise for the RCP 4.5 or 8.5 scenario was not present or could be found, the Global Mean Sea Level Rise[6] is included for either one of the scenarios.

*Table 4-1 Parameters from the results of the literature research, delta characteristics.*

| Parameters – Delta characteristics | | | | |
|---|---|---|---|---|
| Delta | Population density of coastal country per km$^2$ (in 2019) | Mean subsidence (mm/yr) | Rate of SLR (mm/yr), RCP 8.5 Scenario | Polder system present (Yes/No) |
| Coastal Country | Gross Domestic Product (USD$, in 2019) | Rate of SLR (mm/yr), RCP 4.5 Scenario | Levee system present (Yes/No) | Main causes land subsidence or sediment shortage (anthropogenic causes) |

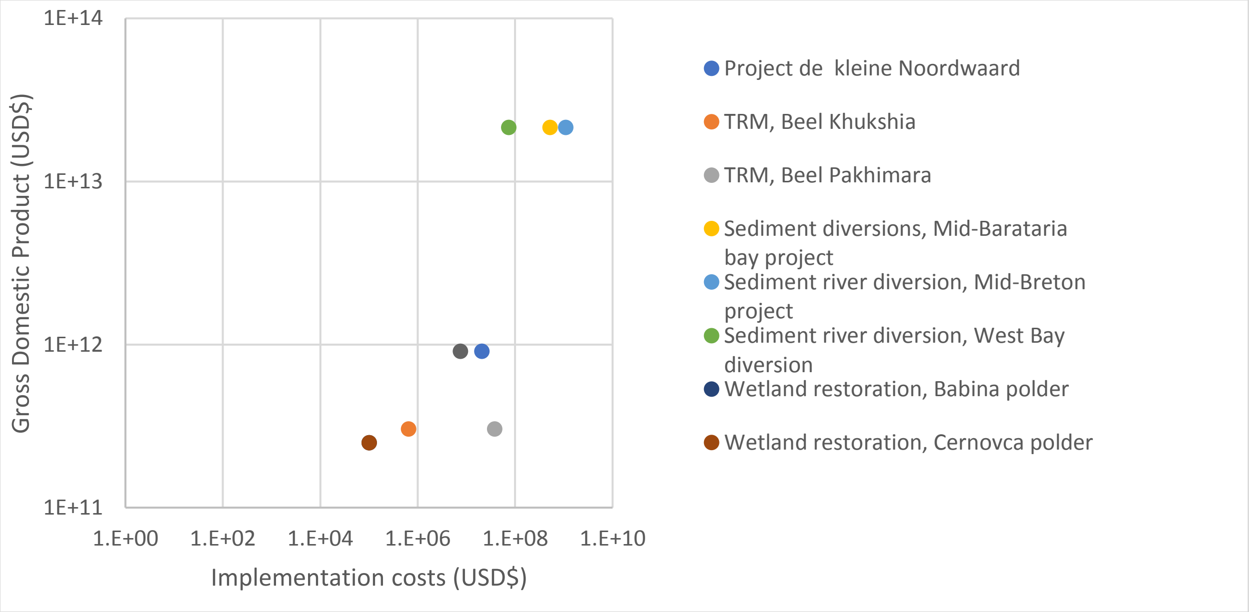

*Figure 4-1 Gross Domestic Product (USD$) against Implementation costs (USD$).* [7]

The Gross Domestic Product can be defined as the yearly sum of all monetary values of services and goods in a country (Callen, 2008). *Figure 4-1* shows a generic increase of implementation costs for

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[6] (Davis et al., 2018)

[7] GDP of 2019

SESs with increasing value of the GDP of countries. The correlation indicates that the GPD seems an appropriate scaling factor for a first-guess of implementation costs

The key factors from the delta characteristics category, influencing the suitability of a SES, are the presence of either a polder system or levee system and the economic ability of countries to implement certain strategies.

### 4.1.2 Biophysical aspects

*Appendix A.II* shows the data collected for the different case-studies for the biophysical aspects. The sediment type added to the local system could for all the SESs in general addressed as from fluvial origin. Data on changes in river width and depth were not available for all SESs. It only was present if issues developed (f.i. shoaling in navigation routes) after implementing the SES.

*Table 4-2 Parameters from the results of the literature research, biophysical aspects.*

| Parameters – Biophysical Aspects | | | | |
|---|---|---|---|---|
| Location implementation relative to river stream (up/mid/down -stream) | Annual mean discharge (m3/s) | Distribution of deposited/added sediment (description) | Change in width of the river (m) | Tidal regime (Micro/Meso/ Macro) |
| River/Tide/Wave dominance | Sediment type added to the system (grain size/origin) | Change in depth of the river (m) | Mean tidal range at estuary (m) | |

Sediment is transported in and out of an estuary by the river, tide and current/wave systems and both anthropogenic and aeolian transport. This interplay defines the morphological functioning of the delta and forms the local landscape (Dyer, 1995). In the SES case-studies the local biophysical aspects determine the success of the strategies. Tidal movements is one of these aspects, it is a crucial factor for many SESs as it directly influences the nett local sediment transport into the area of interest. Local biophysical settings determine the suitability of a SES.

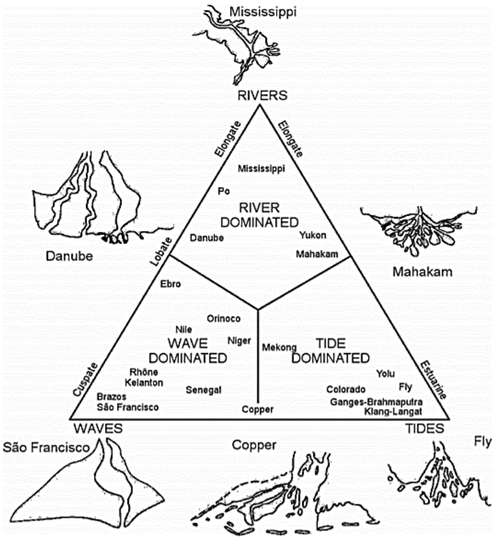

*Figure 4-2 Classification of river deltas, after (Galloway, 1975), according to morphological dominance of delta plains (Witek & Czechowski, 2014).*

Addressing the potential importance of wave, river and tide forcing on the morphology of a delta was done by Galloway (Galloway, 1975) as *figure 4-2* shows. The forcing's can be expressed as relative sediment fluxes Qwave, Qtide and Qriver (kg/s). The study of Nienhuis et al. (2020) indicates and presents the opportunity to predict large-scale delta morphology depending on the relative contribution of Qtide, Qriver and Qwave to the river delta (Nienhuis, Ashton, et al., 2020).

In figure 4-3 a ternary diagram including the ratios of the relative sediment fluxes originated from deltas of the SESs is present. Note that this does not show a homogeneous distribution of SESs. The strategies, in general, either cluster at the relative river dominated point or the tide dominated point of the ternary diagram. One may question why SESs in intermediate deltas' are lacking.

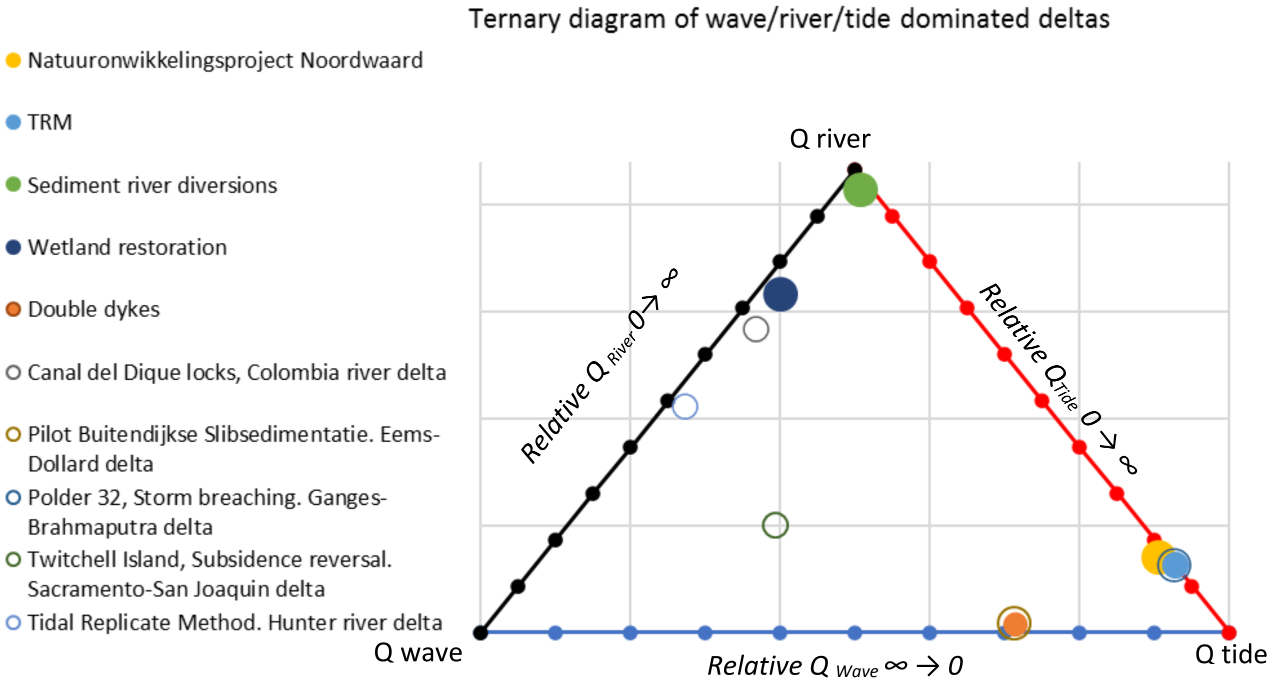

*Figure 4-3 Ternary diagram for the relative River/Wave/Tide dominance expressed in sediment flux (kg/s) for the different delta's (Nienhuis, Ashton, et al., 2020) in which sedimentation enhancing strategies are planned/designed/implemented..[8]*

### 4.1.3 Project settings

If reports of SESs were available the data on the project settings was relatively easy to obtain/find. This does not hold however, for the funding's and implementation costs. Landownership was really case-specific and consequently harder to find. For all the SESs either a levee system or polder/beel was necessary making these embankments of importance. The execution of upscale modelling, test and/or simulations happened for all SESs apart from TRM and wetland restoration and the sediment river diversion *West Bay* case-study .

*Table 4-3 Parameters from the results of the literature research, project settings.*

| Parameters – Project settings | | | |
|---|---|---|---|
| Duration of the implementation of the SMS (yr) | Area implemented/outfall area /polder area (ha) | Upscale modelling undertaken (Yes/No/Other) | Implementation Costs (USD$) |
| Start of strategy (yr) | Levee system necessary for implementation strategy (Yes/No) | Tests and simulations undertaken (Yes/No/Other) | Primary objective of the project |
| Frequency/timing of execution the strategy | Polder/beel necessary for implementation strategy (Yes/No) | Land use before implementation of SES (description) | Landownership (State/Private/Other) |

Land use before the implementation of the SES consists of aqua- or agriculture practices, nature or degrading wetlands. The SESs TRM and Double Dikes intended to create land for aqua- or agriculture practices, the other SESs solely aimed for flood safety and/or nature development. In *Appendix A.III* the data on the project settings is present.

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[8] The filled circles represent the strategies included in the literature research of this study. The solely outlined circles represent sedimentation enhancing strategies which originate from consultation data, these are included to give more perspective.

### 4.1.4 General outcome

The data of the general outcome is present in *Appendix A.IV,* the parameters in *table 4-4.* The assessment of the environmental impact was performed by experts resulting from the *Sedimentation enhancing strategies for river deltas: an interdisciplinary perspective* workshop (*see Methods*), making the data relatively easy to obtain (Nienhuis, Cox, et al., 2020). Not all SESs included in this study are at their final stage or are not implemented yet. This limits data concerning the general outcome of the SESs .

*Table 4-4 Parameters from the results of the literature research, general outcome.*

| Parameters – General outcome | | |
|---|---|---|
| Mean annual sediment addition to the system (tons) | Implementation costs/ ha (USD$/ha) | Degree of positive environmental impact (Low/Moderate/High/Very High) |
| Land raised in (mm/yr) | Gained land type (Nature/Agriculture/ Aquaculture/Wetland/Recreation/ Residential) | Degree of negative Environmental impact (Low/Moderate/High/Very High)) |

Quantities or rates of sediment added to the systems are relatively hard to find. Often, there are no clear boundaries to within sediment deposits or even sedimentation occurs, making the measurements of sediment added to this dynamic system more difficult to measure. The majority, of the SESs obtained the ‘’Nature’’ land type.

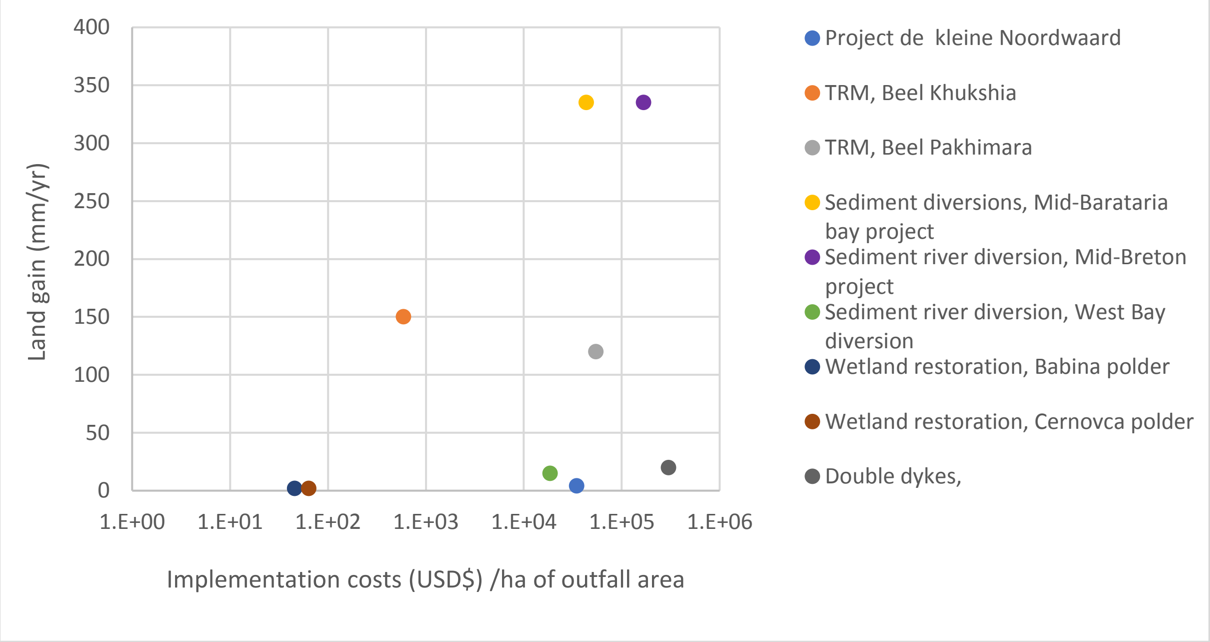

*Figure 4-4 Land gain of the strategy (mm/yr) versus the implementation costs (USD$) per hectare of outfall area.*

In figure 4-4 the land gain (mm/yr) is plotted against the Implementation costs (USD$) /ha of outfall area. In general with increasing implementation costs the land gain rate increases, apart from Double Dikes, West Bay diversion and project de Kleine Noordwaard. The Mid-Barataria and Mid-Breton sediment river diversions scored both high in implementation costs and land gain.

## 4.2 The Sedimentation Enhancing Strategy decision support tool

I've developed a decision support tool to further investigate the applicability of SESs in different environments. In this section the decision support tool is presented. The script of the tool is present as text in *Appendix D*.

### 4.2.1 User of the tool

The decision support tool is designed/intended for anyone seeking a multi-disciplinary perspective on delta management and sedimentation enhancing strategies, including but not limited to: policymakers, governmental bodies, river basin managers, research institutes, river- and harbour managers, nature conservation parties, engineering firms.

### 4.2.2 Aim of the tool

As users of the tool might differ, so do the objectives and interests in using the tool. The tool showcases all strategies, even when considered ''not suitable'' as the main aim of the tool is to inform the user of the tool on potential drawbacks, highlights and possibilities.

The tool is specifically made to be applied to any other river delta and assess if existing SES are possible or which are most suitable, taking into consideration the delta characteristics.

### 4.2.3 The different steps in the model

The flowchart in *figure 4-5* shows the structure of the SES decision support tool. Further in this section we will walk through the structure of the tool for every step.

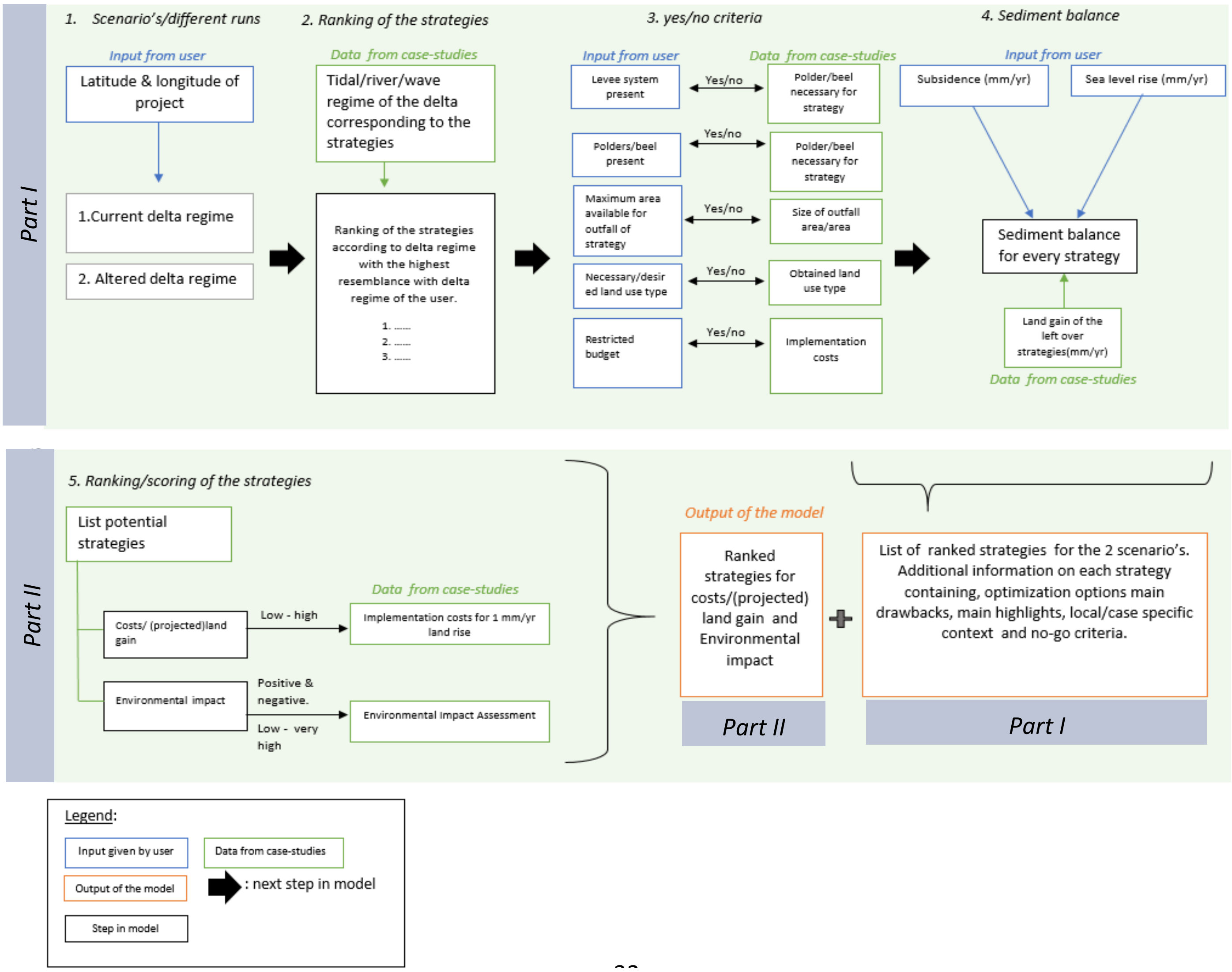

*Figure 4-5 Flowchart of structure of the SES decision support tool.*

The tool can be divided into two parts (*figure 4-5*). The first part consist of two runs, a quantitative ranking of the SESs with input from the user of the tool. The second part does not use input of the user and consists of qualitative ranking.

## *Part I*

### Step 1. Scenario's/different runs

The first step in the tool consists of the two runs. One for the current delta regime, considering the ratio in sediment fluxes (*see section 4.1.2.*), and one for an altered delta regime of interest. This allows the user to consider a scenario in which the wave/tide/river dominance has shifted/changed into another regime of dominance or a future equilibrium state. Required input to be specified from the user consists of the relative sediment fluxes for the two delta regimes. Potentially the tool could be linked to the Global Delta App, in Google Earth Engine (Nienhuis, Ashton, et al., 2020). Only the coordinates of the desired location would be necessary/asked from the user, increasing the usability of the tool.

### Step 2. Ranking of the strategies

With the obtained input from step 1, a quantitative ranking takes place. The SESs included in the tool are ranked from relative low to high resemblance (%) with the delta regime of the user relative to the delta regime of the SES showing the lowest resemblance (*based on figure 4-3 in section 4.1.2.*). The ranking occurs for the two runs, including the two regimes (current and altered) in the tool.

### Step 3. Yes/No criteria

Based on the literature research, see *section 4.1.1 & 4.1.3.*, certain no-go criteria are included in the tool. These criteria obstruct or prevent the suitability of a SES in the delta of the user. Included criteria are:

- Desired/necessary land type (Not important/Agricultural/Aquaculture/Nature/Recreation/Residential/Wetland)
- Levee/polder system present (Yes/No)
- Restricted budget (USD$)
- Maximum available outfall area for the SES (ha)

The input from the user consists of the preferred or restricting quantitative or qualitative data. The tool performs a correlation with this input data and the data from the SESs. The suitability is then presented as a separate column before the already ranked SESs. An example '' Not suitable, implementation costs exceed budget.''

### Step 4. Sediment balance

The sediment balances consist of the land gain by the SES (mm/yr) minus the projected sea level rise (mm/yr) and subsidence (mm/yr). This is calculated for the delta in which the strategy is implemented and for the delta of the user of the tool. The sea level rise is considered for both the RCP4.5 and RCP8.5 scenario. Asked input from the user consists of the subsidence in the coastal area, and the sea level rise for the different scenario's, if not available Global Mean Sea Level Rise (mm/yr) could be used.

## *Part II*

### Step 5. Ranking/scoring of the strategies

In part II the SESs are ranked two times. Ranking occurs on environmental impact from low/moderate/high to very high, for both a positive and negative environmental impact. Another ranking of the SESs occurs on implementation costs per land gain from low to high (USD$/ha for 1 mm/yr).

### 4.2.4 Additional data

Not all relevant data could be translated into quantifiable or qualitative criteria. This was the case for the primary objective of the implementation of the SES, land use type before and after implementation of the SES, remarks on process of implementation and/or execution of the SES, main drawbacks of the implementation and execution of the SES and main highlights of the implementation and execution of the SES. Together with a short description of SES and the delta of implementation they are included as an informative note in the tool, which is in line with the informative character of the tool.

The main highlights and drawbacks are not present in the tables including the different parameters used for criteria definition (*see Methods*), but can be found in *Appendix C.* It provides a generic summary on the SES from a multi-disciplinary perspective if data availability allowed it. From the highlights the most common outcome, apart from increased vertical sediment accretion, is the positive contribution to the local ecosystem in maintaining or gaining a certain land type. A drawbacks more common among the SESs was issues originated from stakeholder involvement/participation.

### 4.2.5 Output of the tool

The output of the tool is presented in an Excel file. The Excel file consists of three sheets. The first sheet contains Part I of the tool for the current delta regime, the second sheet Part I of the tool for the altered delta regime and the third sheet contains Part II of the tool. The decision of presenting the output in Excel, was to offer the user a clear overview of the SESs and accompanying data and information. The decision to include ''not-suitable'' SESs in the output of the tool is based on that they still can be of importance from an informative point of view.

## 4.3 Testing the SES Decision Support Tool

### 4.3.1 Test on a delta originated from the database

As an affirmation that the decision support tool actually performed the right correlation, a delta originated from the database of the tool was used as input delta. This concerned the Ganges-Brahmaputra delta, leading to the result of Tidal River Management being the most suitable SES. This in accordance with the actual implemented SES; Tidal River Management.

### 4.3.2 Application to deltas

*Figure 4-6 Satellite image of the Ebro delta ('Ebro Delta', 2021)*

To test the tool and display the results of the tool, a test performance was done for the Ebro Delta. Due to construction of dams, the Ebro delta suffers from a fluvial sediment shortage (Rodriguez-Lloveras et al., 2020; Rovira & Ibàñez, 2007). The combination with a rising sea level and an eroding current system, makes this a delta in need for a solution and of interest as our trial delta (Ericson et al., 2006). In *Table 4-5* the input data for the tool are visible. If the data is depended on the objective of the user, a random input is chosen.

*Table 4-5 Input from the user in the SES Decision Support Tool.*

| *Delta* | *Qriv / Qwave* | *Qriv / Qtide* | *Qwave / Qtide* | *Leveesystem present in system (Yes/No)* | *Polders present in system (Yes/No)* | *Maximum area available for outfall of strategy (ha)* | *Restricted budget (USD$)* | *Desired/necessary landtype (Not important/Agricultural/Aquaculture/Nature/Recreation/Residential/Wetland)* | *Subsidence of the delta (mm/yr)* | *Sea level rise (mm/yr), RCP 4.5 Scenario* | *Sea level rise (mm/yr), RCP 8.5 Scenario* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ebro | 1.1E-1 | 1.4E+1 | 1.3E+2 | Yes | Yes | 300 | 1.00E+07 | Not important | 2.5 | 6.5 | 8.9 |
| Altered delta regime | 1.1E-1 | 1.4E+1 | 1.3E+2 | Yes | Yes | 500 | 1.00E+13 | Not important | 2.5 | 6.5 | 8.9 |

The results are presented in *Appendix B. I to III.* For the delta in the current regime is the considered suitable the Sedimentation Enhancing Strategy Double Dikes, mainly due to the available outfall area. The relative resemblance with the Ebro delta regime was 0.5 %.

In the ''higher urgency'' scenario, with an increased budget and outfall area, the West Bay river diversion appeared suitable with a relative resemblance of 0.2 % with the Ebro delta regime.

# 5 Discussion

The discussion is divided in three sections. In the first section the outcome of the multi-criteria analysis is discussed. In the second and third section the decision support tool is discussed.

## 5.1 A multi-criteria approach

*Chapter 3* provides context on the different Sedimentation Enhancing Strategies. Between the SESs and their case-studies specific resemblances and/or differences were present from the implementation phase to the final outcome as well as highlights and drawbacks (see also Appendix C). Making the definition of criteria suitable for all the SESs of importance.

To provide a multi-criteria analysis, different disciplines need to be represented. This study is intended to include as many disciplines as possible. An underrepresentation of socio-economic, legal and governance perspective is present in this study. Probable explanations are the lack in data-availability or the ability to translate different disciplines in criteria or relevant remarks. This does not disprove their relevance.

### 5.1.1 Delta characteristics

The presence of a levee or a polder system is, for the SESs in this study necessary, for implementing the SES. The breaching of an embankment allows sediment to enter and eventually deposit.

A potential limiting factor is the economic ability to implement SESs. Linking the Gross Domestic Product to the economic abilities of a delta is a way of expressing this ability, but the financing process of SESs might be more complicated. The GDP is used as a rough indicator. Deltas with a high value of Gross Domestic Product might initially be better to financially support the implementation of a SES, as high expenses of structures or maintenance can be covered (Tessler et al., 2015). *Figure 4-1* confirms this trend.

### 5.1.2 Biophysical aspects

Factors controlling the suitability of the SESs are the relative fluxes transporting local sediments. If no sediment is transported to the specific location, or maintained under the right circumstances, the implementation of a SES is irrelevant for enhancing sedimentation. In *figure 4-3* the SESs either cluster at tide or river dominance, allowing to categorize them in either tide or river flow depended. This suggesting the dependence of a SES on a local flow regime.

Data on the change in river width and depth only occurred to be present if issues arose with the river flow after implementation of the SES. It can be an indicator for changed navigability and therefore of importance.

### 5.1.3 Project settings

Factors such as the costs or outfall area of a strategy for the implementation restrict the suitability when not in line with the abilities of the implementing party. Issues with landownership is of less importance not of less relevance, based on the SESs included, as it only hindered and not stopped the implementation process. An example of this hinder is when local owners of the land experience issues with compensation (Gain et al., 2017a).

Sand is necessary to build land. Accumulated sand provides a stable substrate on which eventually vegetation can establish. The established vegetation will then be able to trap the sediment consisting of finer grain sizes (Gaweesh Ahmed & Meselhe Ehab, 2016). Fluvial deposits consist mainly of clay and silts, making maximizing the sediment retention efficiency a of great concern as the majority of the SESs focus on sediments originated from the fluvial system (Blum & Roberts, 2012). Especially when the desired land type after implementation of the SES is for example agriculture or residential area, capturing sand is importance. When the main objective for implementing a SES can differ, the factors influencing the suitability or applicability of a SES differ with it. Land use/type change of the SESs need to align with the necessary/desired land use/type.

### 5.1.4 General outcome

Apart from the Double Dikes, West Bay diversion and project de Kleine Noordwaard SESs, with increasing land gain the implementation costs per hectare would increase. The West Bay diversion and project de kleine Noorwaard both did not necessary had the objective of gaining land. The Mid-Barataria and Mid-Breton sediment river diversions appeared to be high in implementation costs and land gain due the inclusion of a structured gate. Their high rates of land gain can be assigned to their large outfall area, the ability to divert large amounts of river waters and sediment and/or timing the diverting when large amounts of sediment loads are present in the river water (*see section 3.2*).

A positive environmental impact is a key factor for the suitability of a SES, when it is in line with the primary objective. Wetland restoration and project de kleine Noorwaard for example were implemented for nature development. The SESs scored relatively high in environmental impact in general. Negative impact often occurred during the construction phase or was considered if the changed land type changed local quantity of habitats and/or species.

## 5.2 Potential use of the decision support tool

### 5.2.1 The model in general

This study is intended to think, and potentially help others, think about Sedimentation Enhancing Strategies in the broadest sense or from a global level. Taking into consideration various technical, physical, ecological, and governmental aspects. These aspects are based on practical experiences that have been gained from existing and planned sedimentation projects globally.

That said, all successful sedimentation strategies require that site-specific considerations are taken into account. The framework given does not eliminate those needs, it seen as a tool that can be helpful during the brainstorming phase of a delta management plan.

### 5.2.2 Testing the tool

The potential user of the tool can be anyone seeking a multi-disciplinary perspective on delta management and sedimentation enhancing strategies including but not limited to; policymakers, governmental bodies, river basin managers, research institutes, river- and harbour managers, nature conservation parties, contractors, engineering firms. To affirm that the decision support tool is in line with the abilities to use and interest of use of the decision support, testing with the potential users, mentioned above is of relevant. This to find potential errors in the tool, increase the ease of use and to see if works in practice.

### 5.2.3 Reliability of the model.

To give a certain global conclusion you can add details to a certain extent due to local/case-specific differences, this is why the amount of parameters used is limited. The possibility of a certain SES not being suitable, due to a criteria not included, is present although the outcome of the tool considers it suitable.

Criteria can be added to the model when enough data is available. Note that the extent of research/modelling and reporting of different strategies varies for the SESs found in literature. This highlights the importance of using the tool as an informative instrument and not a guideline towards the perfect SES for implementation. The most suitable SESs could not have been included in the tool yet.

## 5.3 Potential uncertainties in data/outcome

### 5.3.1 Limitations due to data availability

In this study, research was done on different implemented and/or planned SESs. For the more recent implemented strategies, more data/literature is present compared to ''older'' strategies. Monitoring, upscale modelling or research has not been executed yet or not in the same extent as older SESs. This limits the data analysis. Also when monitoring of the SES has just started, drawbacks, highlights, environmental impact or the sustainability of the outcome might not be present yet. Hence conclusions do not always reflect developments on a longer term. The difficulty in finding the relevant data consisted mainly of local reports being the only source. Which is where this study can be of importance.

Certain data which were too case-specific were excluded from collected data, due to data gaps between different SES. This happened for the desired inlet discharge (m3/s), inlet channel width (m) inlet channel depth (m), inlet discharge threshold/minimum (m3 /s) and River discharge threshold (m3 /s). These can potentially be of importance for local SES implementation.

### 5.3.2 Quality and accuracy

In general an increase of data input in models results in a more accurate outcome, in the case of the decision support tool, this implies more data available to correlate with. However the asked input from the user is at minimum, to give it better access and make it more user friendly for a larger and varying audience.

The decision support tool offers the option to include future scenario's .The first ranking occurs on the resemblance in tidal regime of the input delta and the delta in which the SES is implemented. The model provides the option to change the delta regime to shift towards a regime with a different dominance (Wave/Tide/River). This to consider potential future scenario's. The dominance is based on the ratio of the three sediment fluxes. The option considered is present as an indication, as the morphological functioning of a delta in general but also with the interplay of the potential implementation of a SES too complex to predict change of the system.

Note that changes in sediment fluxes through anthropogenic interference can't always be predicted beforehand. The same applies for the included sediment balance. This balance consists in the model solely of negative subsidence and sea level rise and positive land gain of the SES. But factors like, anthropogenic interfering in the system, cannot always be foreseen beforehand.

### 5.3.3 Caveats of the model

The tool is based on the current offer of implemented/planned SESs considered suitable for this study (*see section 1.1.2*). It is a model that needs constant updates and critical reviewing as new strategies are tested planned or implemented. This also applies on data availability on SES. Not all criteria relevant are present (yet) in the tool, examples are maintenance(costs) and the changed navigability of the, probable, adjacent rivers.

Not all criteria of relevance could be quantified. An important factor is stakeholder involvement/participation. Issues arising from stakeholder involvement/participations occurred at implementation/planning of several SESs as the drawback of the SES as the table in *Appendix C* shows. For the SES to be responsive and sustainable more attention is necessary to the coordination and facilitation of multi-level learning including all stakeholders. An example of this would be the SES case-study of *beel Bhaina* where local stakeholders were aware of the consequences of not taking action. Together with the Bangladesh Water Development Board (BWDB) they successfully implemented TRM at the local beel compared to other beels at the Hari river. In other beels the implementation and maintenance of TRM hampered and was slowed down due to lack involvement of local stakeholder participation/involvement. (Gain et al., 2017a)

# 6 Conclusions

## 6.1 Conclusions

Sedimentation Enhancing Strategies can successfully enhance vertical accretion to keep up with sea level rise or maintain a certain elevation. The rate depends on the local circumstances. Hence, the local biophysical setting determines the primary ability of a complex delta system to allow tidal and/or river flow driven sedimentation. This determines whether a SES can enhance sedimentation successfully. The breaching of either a polder embankment or levee system is necessary to allow tidal flow or diverting river flow to enter the area of interest.

Restricting criteria from the project phase of a SES are restricting budget, available outfall area and duration of the strategy. The objectives and scope of the implementing party can determine the suitability and/or applicability of a SES. This applies for alignment of the land type/use change after implementation of a SES, with the land type/use desired or necessary from the primary objective of the implementing party. But also for the environmental impact, positive and negative, of the Sedimentation Enhancing Strategy on the local system.

To determine if the SES could be applicable and potentially be successful in other deltas, the relevant criteria and information is translated into a SES decision support tool. Outcomes of the tool are derived from data and criteria, which emphasises using the tool as an informative instrument.

Not all criteria found in best practices could be quantified, but are nevertheless relevant for the successful implementation and execution of the SESs. This concerns stakeholder involvement/participation. If criteria were too case-specific they were not included since this has no relevance on a global level. This results in a selected set of site-specific characteristics with global applicability. Nevertheless, in every successful Sedimentation Enhancing Strategies site-specific considerations play a central role.

## 6.2 Recommendations

Data availability played a crucial role in providing a multi-disciplinary perspective as well as providing quantitative and qualitative analysis on Sedimentation Enhancing Strategies. This emphasises the importance of continued data collection, research, testing and modelling in this relatively new field of enhanced sedimentations strategies. Not only on current implemented SES, but especially with the aim of transferring successful SESs to other deltas.

The SES decision support tool could be one of the first steps in this transfer, but recommended is testing of the tool among the divers group of decisionmakers the decision support tool is intended for. Constant updating and further development of the tool would be necessary to provide the user with relevant up-to-date insights.

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# Appendix A. I Delta characteristics

| *Delta characteristics* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SES | Sediment management strategy/ project | Delta system | Country (Coast) | Population density of coastal country /km2 (2019) | Gross Domestic Product(2019) (USD$) | Mean subsidence (mm/yr) | Rate of SLR (mm/yr), RCP 4.5 Scenario | Rate of SLR (mm/yr), RCP 8.5 Scenario | River/Tide/Wave dominance | Levee system present (Yes/No) | Main causes land subsidence or sediment loss (anthropogenic influence) |
| Depoldering | Project de kleine Noordwaard | Rhine-Meuse | NL | 507[9] | 9.071E+11[10] | 6.0[11] | 6.3[12] | 9.3[12] | | Yes | Soil compaction (gas/oil mining), peat oxidation, dams retaining sediment, negative sediment budget, due to anthropogenic interventions [13] |
| Tidal River Management | TRM, Beel Bhaina | Ganges-Brahamaputra | BD | 1116[9] | 3.026E+11[10] | 5.6[14] | 6.5[15] | 9.0[15] | Tide[16] | Yes | Isostatic adjustment (Himalaya), groundwater abstraction and/or drainage, soil compaction, embankments reducing sedimentation.[17] |
| | TRM, Beel Khukshia | Ganges-Brahamaputra | BD | 1116[9] | 3.026E+11[10] | 5.6[14] | 6.5[15] | 9.0[15] | Tide[16] | Yes | Isostatic adjustment (Himalaya), groundwater abstraction and/or drainage, soil compaction, embankments reducing sedimentation[17] |
| | TRM, Beel Pakhimara | Ganges-Brahamaputra | BD | 1116[9] | 3.026E+11[10] | 5.6 | 6.5[15] | 9.0[15] | Tide[16] | Yes | Isostatic adjustment (Himalaya), groundwater abstraction and/or drainage, soil compaction, embankments reducing sedimentation.[17] |
| Sediment Diversions | Sediment river diversions, Mid-Barataria bay project | Mississippi | USA | 25[18] | 2.143E+13[10] | 7.5[19] | 6.5[15] | 9.0[15] | River[20] | Yes | Reduced sediment fluxes from the Mississippi river due to separation of the delta plain from the river by levees, subsidence, oil and gas winning, local flood control levees, navigation infrastructures, soil compaction and geological settings. [20] |
| | Sediment river diversions, Mid-Breton project | Mississippi | USA | 25[18] | 2.143E+13[10] | 7.5[19] | 6.5[15] | 9.0[15] | River[20] | Yes | Reduced sediment fluxes from the Mississippi river due to separation of the delta plain from the river by levees, subsidence, oil and gas winning, local flood control levees, navigation infrastructures, soil compaction and geological settings. [20] |
| | Sediment river diversion, Mississippi, West Bay diversion | Mississippi | USA | 25[18] | 2.143E+13[10] | 7.5[19] | 6.5[15] | 9.0[15] | River[20] | Yes | Reduced sediment fluxes from the Mississippi river due to separation of the delta plain from the river by levees, subsidence, oil and gas winning, local flood control levees, navigation infrastructures, soil compaction and geological settings. [20] |
| Wetland restoration | Wetland restoration, Babina polder | Danube | RO | 75[21] | 2.5E+11[10] | 1.5[22] | 6.5[15] | 9.0[15] | River/Wave [23] | Yes[24] | Minimal impact of subsidence.[25] |
| | Wetland restoration, Cernovca polder | Danube | RO | 75[21] | 2.5E+11[10] | 1.5[22] | 6.5[15] | 9.0[15] | River/Wave[23] | Yes[24] | Minimal impact of subsidence.[25] |

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[9] (Worldometer, 2019)

[10] (The World Bank, n.d.)

[11] (Caro Cuenca et al., 2010)

[12] (van der Spek, 2018)

[13] (T. J. S. Cox et al., 2019)

[14] (Gain et al., 2017b)

[15] GMSLR (Davis et al., 2018)

[16] (Goodbred & Saito, 2012)

[17] (Brown & Nicholls, 2015)

[18] (knoema, n.d.)

[19] Average soil compaction & tectonics.(Törnqvist et al., 2008)

[20] (Khalil et al., 2018)

[21] (Antonescu & Bell, 2015)

[22] (Vespremeanu-Stroe & Preoteasa, 2015)

[23] (Anthony, 2015)

[24] (Rovira & Ibàñez, 2007)

[25] (Bucx et al., 2014)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Double dykes | Double dykes | Ems-Dollard | NL/DE | 507[9] | 9.071E+11[10] | 2.6[26] | 6.5[15] | 9.0[15] | Wave/Tide[27] | Yes | Gas extractions, subsidence and the lack in natural sediment sinks[28] |

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[26] (Marijnissen et al., 2020)

[27] (H. Hein et al., 2011)

[28] (van Maren et al., 2020)

# Appendix A.II Biophysical aspects

| *Biophysical aspects* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SES | Sediment management strategy/ project | Location implementation relative to river stream (up/mid/down -stream) | Annual mean discharge (m3/s) | Sediment type added to the system | Distribution of sediment deposition | Change in depth of the river (m) | Mean tidal range at estuary (m) | Tidal regime | Change in width of the river (m) |
| Depoldering | Project de kleine Noordwaard | Down-stream | 270[29], 2300[30] | Fluvial | | | 3.7[31] | Meso-tidal[32] | |
| Tidal River Management | TRM, Beel Bhaina | Downstream Hari River | 263[33] | Fluvial | Uneven sedimentation resulted in drainage congestion in certain parts of the beel.[35] | ±11[35] | >4 [34] | Macro-tidal[34] | 2-3 x wider[35] |
| | TRM, Beel Khukshia | Upstream Hari river | 263[33] | Fluvial | Primary problems of waterlogging were only solved near the cut in the embankment. Aquaculture practices hindered even sediment distribution. [35] | ±11[35] | >4 [34] | Macro-tidal[34] | 2-3 x wider[35] |
| | TRM, Beel Pakhimara | Downstream Hari river | 263[33] | Fluvial | | ±11[35] | >4 [34] | Macro-tidal[34] | 2-3 x wider[35] |
| Sediment Diversions | Sediment river diversions, Mid-Barataria bay project | | 8877[36] | Fluvial. Upstream mainly gravel and sands (coarse to finer grain size), downstream silts, finer sands and clay.[37] | | | 0.35[38] | Microtidal [39] | |
| | Sediment river diversions, Mid-Breton project | | 8877[36] | | | | 0.35[38] | Microtidal[39] | |
| | Sediment river diversion, Mississippi, West Bay diversion | Downstream | 8877[36] | | Retention of the sediments occurred at the nearshore zone. Highest deposition occurred at the most seaward part of the outfall area of the SES. [40] | Upstream channel, slight decrease in river depth. More downstream at location Venice increase in depth.[41] | 0.35[38] | Microtidal[39] | |

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[29] Meuse (Ward et al., 2008)

[30] Rhine (de Jong & de Jong, 2002)

[31] (Wang et al., 2019)

[32] (Berg et al., 2007)

[33] Hari River (Khadim et al., 2013)

[34] (Bricheno et al., 2016)

[35] (Gain et al., 2017b)

[36] (Day et al., 2016)

[37] (Khalil et al., 2018)

[38] (Levin, 1993)

[39] (Mcbride et al., 2007)

[40] (Kolker et al., 2012)

[41] (Allison & Meselhe, 2010)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wetland restoration | Wetland restoration, Babina polder | Most downstream part of the fluvial delta[43] | ±6550[42] | Fluvial | Main accumulation of the sediments occurs at the middle of the once poldered area, during flood. [43] | | 0.5 to 1[44] | Microtidal[44] | |
| | Wetland restoration, Cernovca polder | Most downstream part of the fluvial delta[43] | ±6550[42] | Fluvial | | | 0.5 to 1[44] | Microtidal[44] | |
| Double dykes | Double dykes | Downstream | 80-110[45] | Fluvial | | | 2.3[46] | Macro-tidal[46] | |

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[42] (Pekarova et al., 2019)

[43] (Overmars, 2007)

[44] (Besset et al., 2017)

[45] (Deltares, 2011)

[46] (Talke et al., 2009)

# Appendix A. III Project settings

| *Project settings* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SES | Sediment management strategy/ project | Duration of the implementation of the SMS (yr) | Start of strategy | Frequency/timing of the strategy | Area implemented/polder area ha (km2) | Levee system necessary for implementation strategy | Polder/beel necessary for implementation strategy | Land use before implementation of the SES (description) | Tests/ simulations/upscale modelling were undertaken | Landownership | Implementation Costs (USD$) | Primary objective of the project |
| Depoldering | Project de kleine Noordwaard | Ongoing[47] | 2008[47] | Once implemented, tidal flooding[47] | 6.00E+02[48] | No[48] | Yes[48] | Polder land/agriculture[48] | Hydrological and flow routing modelling[48] | private (75% agriculture), municipality/state[48] | 2.07E+07 | Nature development and flood protection[48] |
| Tidal River Management | TRM, Beel Bhaina | 4[35] | 1997[35] | Once implemented, tidal flooding [35] | 6.00E+02[35] | No[48] | Yes[35] | Agriculture and small scale shrimp farming[35] | No[48] | Private[35] | | Improved water drainage of polders, increasing width and depth of the Hari river[35] |
| | TRM, Beel Khukshia | 6[35] | 2006[35] | Once implemented, tidal flooding [35] | 1.10E+03[35] | No[48] | Yes[35] | Large scale shrimp farming and rice cultivation [35] | No[48] | Private[35] | 6.48E+05[48] | Improved water drainage of polders, increasing width and depth of the Hari river[35]river |
| | TRM, Beel Pakhimara | Ongoing[35] | 2015[35] | Once implemented, tidal flooding [35] | 7.00E+02[35] | No[48] | Yes[35] | Shrimp farming[35] | No[48] | Private[35] | 3.80E+07[48] | Improved water drainage of polders, increasing width and depth of the Hari river[35]river |
| Sediment Diversions | Sediment river diversions, Mid-Barataria bay project | 50[49] | 2023[49] | Timed.[50] | 1.20E+04[51] | Yes[48] | No[48] | Degrading wetlands[48] | Numerical modelling and field data collection both on the river side and in the receiving basin.[48] | Mix of state and private.[48] | 5.17E+08[51,48] | Sustaining and creating new land. for ecosystem services and infrastructure protection.[48] |

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[47] (van der Deijl et al., 2017)

[48] (J. R. Cox et al., 2020)

[49] (CPRA, 2019)

[50] (Rutherford et al., 2018)

[51] (Scott, 2019)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Sediment river diversions, Mid-Breton project | 50[49] | 2024[50] | Timed[50] | 6.48E+03[51] | Yes[48] | No[48] | Degrading wetlands[48] |  | Mix of state and private.[48] | 1.08E+09[51,48] | Sustaining and creating new land. for ecosystem services and infrastructure protection[48] |
|  | Sediment river diversion, West Bay diversion | 20[49] | 2003[50] | Once[52] | 3.98E+03[52] | Yes[48] | No[48] | Degrading wetlands[48] | Field data collection and monitoring[48] | Mix of state and private.[48] | 7.32E+07[48] | Returning a subsided open water bay to its previous state of vegetated wetland.[48] |
| Wetland restoration | Wetland restoration, Babina polder | Ongoing[53] | 1994[53] | Once[53] | 2.20E+03[53] | No[48] | Yes[48] | Abandoned agricultural polder[53] | Pilot project[48] | During the restoration of the wetlands, the polders became public property.[54] | 1.00E+05[55] | Nature development[56] |
|  | Wetland restoration, Cernovca polder | Ongoing[53] | 1996[53] | Once[53] | 1.58E+03[53] | No[48] | Yes[48] | Abandoned agricultural polder[53] | Pilot project[48] | During the restoration of the wetlands, the polders became public property.[54] | 1.00E+05[55] | Nature development[56] |
| Double | Double dykes | 4[57] | 2018[58] | Once[57] | 2.50E+01[57] | Yes[48] | No[48] | Nature area[58] | Pilot project, modelling was undertaken[57] | State owned[48] | 7.50E+06[48] | Nature, agriculture & flood safety[58] |

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[52] (Allison & Meselhe, 2010)

[53] (WWF, 2010)

[54] (Nijland et al., 2001)

[55] (The World Bank, 2005)

[56] (Tudor, 2008)

[57] (Eems-Dollard 2050, 2020a)

[58] (Eems-Dollard 2050, 2020b)

# Appendix A.IV General Outcome

| | *Sedimentation Enhancing Strategy* | *General outcome of the SES* | | | | |
|---|---|---|---|---|---|---|
| SES | Sediment management strategy/ project | Land raised in (mm/yr) | Implementation costs/ hectare (USD$/ha)[59] | Gained land type (Nature)[60] | Degree of positive impact (Low/Moderate/High/Very High) [60] | Degree of negative impact (Low/Moderate/High/Very High))[60] |
| Depoldering | Project de kleine Noordwaard | 4.15E+00[61] | 3.45E+04 | Nature/Wetland | High | Low |
| Tidal River Management | TRM, Beel Bhaina | 2.50E+02[62] | 0.00E+00 | Agriculture | Moderate | Low |
| | TRM, Beel Khukshia | 1.50E+02 | 5.89E+02 | Agriculture | Moderate | Low |
| | TRM, Beel Pakhimara | 1.20E+02 | 5.42E+04 | Agriculture | Moderate | Low |
| Sediment Diversions | Sediment diversions, Mid-Barataria bay project | 3.35E+02[48] | 4.31E+04 | Nature/Wetland | High | Low |
| | Sediment diversions, Mid-Breton project | 3.35E+02[48] | 1.67E+05 | Nature/Wetland | High | Low |
| | Sediment diversion, West Bay diversion | 1.50E+01[48] | 1.84E+04 | | High | Low |
| Wetland restoration | Wetland restoration, Babina polder | 1.96E+00[63] | 4.55E+01 | Nature | High | Low |
| | Wetland restoration, Cernovca polder | 1.96E+00 | 6.33E+01 | Nature | High | Low |
| Double dykes | Double dykes | 2.00E+01[64] | 3.00E+05 | Nature/Agriculture/Aquaculture | Very high | Low |

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[59] Calculated from *Appendix A.III*
[60] (J. R. Cox et al., 2020)
[61] (van der Deijl et al., 2017)
[62] (Gain et al., 2017b)
[63] (Nijland et al., 2001)
[64] (Eems-Dollard 2050, 2020a)

# Appendix B.I Trial results; Ebro delta. Sheet 1

| SedimentManagementStrategy_Project | Suitability of the strategy | DeltaSystem | Country_Coast_ | Delta regime user rel. to delta regime lowest | ShortDescriptionOfSES | PrimaryObjectiveOfTheProject | LandUseTypeBeforeImplementationOfTheSES | Obtained land type | Remarks | MainDrawbacks | MainHighlights | Delta of strategy, RCP 4.5, Land | Delta of strategy, RCP 8.5, | Delta of user, RCP 4.5,Land | Delta of user, RCP 8.5, |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Tidal Replicate Method, Hunter River* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as | Hunter river | AU | 0.03 | Tidal replication/wetland restoration | Nature | | Nature | Project planned by; University (of New South | | | | | | |
| *Canal del Dique locks, Colombia River* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget. | Colombia River | CO | 0.03 | River Sediment Diversions | Flood protection and ecological restoration (integral solution optimized for the requirements of flood safety, navigation, agriculture and the environment) | | Nature | Project funded and planned by; Fondo Adaptación Colombia + ANI (National Infrastructure Authority), Degree of Non-govermental, local stakeholder engagement; Extensive, 1279 stakeholder meetings: consulting/advising | | | | | 11.04 | 8.60 |
| *Twitchell Island,San Joaquin-Sacramento Delta* | Not suitable, as implementation costs exceed budget. | San Joaquin-Sacramento Delta | USA | 0.03 | Subsidence reversal | Land raising/counteracting subsidence | | NatureRecreation | Project funded and planned by; Regional (state) government & US Geological Survey (NGO) in conjunction with researchers/universities, Gained land type; Peat and natural wetlands (ecological), also flood storage area and recently rice farming. Degree of Non-govermental, local stakeholder engagement;Unclear, seems to mostly only be government & research institutes - though for further projects stakeholder engagement is occurring | | | | | 31.04 | 28.60 |
| *Sediment diversions, Mississippi, Mid-Barataria bay project* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget. | Mississippi | USA | 0.03 | Sediment river diversion consist of a channel in a river embankment which lets river water -- and the silt and sand that is suspended in the water -- flow into a nearby estuary, to enhance river sediment delivery (both mud and sand) and/or increasing sediment retention in the receiving basin. The opening/channel can be controlled | Sustaining and creating new land. for ecosystem services and infrastructure protection | Degrading werlands | Nature | | > Oil spill projected expenditures of 133 million USD$. > Decrease in salinity due to fresh water diverted into the area may negatively impact | | | | | |
| *Sediment diversions, Mississippi, Mid-Breton project* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget. | Mississippi | USA | 0.03 | Sediment river diversion consist of a channel in a river embankment which lets river water -- and the silt and sand that is suspended in the water -- flow into a nearby estuary, to enhance river | Sustaining and creating new land. for ecosystem services and infrastructure protection | Degrading werlands | NatureWetland | | > Decrease in salinity due to fresh water diverted into the area may | | | | | |
| *Sediment diversion, Mississippi, West Bay diversion* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with obtained land type. | Mississippi | USA | 0.03 | A ''natural'' sediment river diversion exist of a cut in the leveesystem which directs the river flow to wetlands. The flow is contrained by the width and depth of the diversion. | returning a subsided open water bay to its previous state of vegetated wetland | Degrading werlands | NatureWetland | > resembles a natural crevasse splay (Allison et al., 2010) > Hurricane Katrina induced major changes in the area by erasing the initial | > local shoaling near anchorage area. (Allison et al., 2010) > might | | -0.46 | -3.02 | 6.04 | 3.60 |
| *Double dykes, Ems-Dollard,Eemshaven- Delfzijl* | Suitable | Ems-Dollard | NL/DE | 0.03 | Double dykes | Nature, agriculture & flood safety | Nature area | Wetland | | | | 10.94 | 8.38 | 11.04 | 8.60 |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Chosen alternative: willow groynes* | Not suitable, as necessary land type does not match with obtained land type. | Ems-Dollard Estuary | NL | 0.03 | Creating low energy conditions to facilitate sedimentation | Reduce turbidity by sediment extraction, Nature, Growing with SLR, KNowledge gathering | | NatureAgricultureWetland | Project funded and planned by; Rijkswaterstaat & Ministry LNV. Degree of Non-govermental, local stakeholder engagement; | | | | | 11.04 | 8.60 |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 2: lagoon excavation* | Not suitable, as necessary land type does not match with obtained land type. | Ems-Dollard Estuary | NL | 0.03 | Creating lagoon in existing salt marshes as sediment basin | Reduce turbidity by sediment extraction, Nature, Growing with SLR, KNowledge gathering | | NatureAgricultureAquaculture | Project funded and planned by; Rijkswaterstaat & Ministry LNV. Degree of Non-govermental, local stakeholder engagement; | | | | | 31.04 | 28.60 |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 3: salt marsh rejuvination* | Not suitable, as necessary land type does not match with obtained land type. | Ems-Dollard Estuary | NL | 0.03 | Rejuvinate marshes (lower them) to allow for new sedimentation | Reduce turbidity by sediment extraction, Nature, Growing with SLR, KNowledge gathering | | Wetland | Project funded and planned by; Rijkswaterstaat & Ministry LNV. Degree of Non-govermental, local stakeholder | | | | | -3.96 | -6.40 |
| *Natuuronwikkelingsproject Noordwaard / kleine Noordwaard* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget. | Rhine-Meuse | NL | 0.03 | Reconnection of the poldered area to the river stream. Which results in an inlet for sediments and water. | 1st: Nature development , 2nd : Room for the River/ flood protection | Polderland agriculture | Wetland | * Aim of the project was Not to increase sedimentation in the system, however | | | -8.19 | -11.12 | -4.81 | -7.25 |
| *Wetland restoration, Danube, Babina polder* | Not suitable, as outfall area of the strategy does not fit the available area. | Danube | RO | 0.03 | Wetland restoration, to | Regain key natural processes, enhance habitats quality to sustain rich biodiversity and generate natural resources for the local | Abandoned agricultural polder | Wetland | > The Babina island was embanked, but never taken into full agricultural functioning. | > The main factor slowing down or hamper the | >ecological restoration was | -6.01 | -8.57 | -7.01 | -9.45 |
| *Wetland restoration, Danube, Cernovca polder* | Not suitable, as outfall area of the strategy does not fit the available area. | Danube | RO | 0.03 | Wetland restoration | Regain key natural processes, enhance habitats quality to sustain rich biodiversity and generate natural resources for the local | Abandoned agricultural polder | NatureWetland | > The Cernovca island was embanked, but never taken into full agricultural functioning. | > The main factor slowing down or hamper the | >ecological restoration was | -6.01 | -8.57 | -7.01 | -9.45 |
| *TRM, Bangladesh; Beel Bhaina* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with obtained land type. | Ganges-Brahamaputra | BD | 100.00 | Restoration of tidal flowing by partial removal of embankments (or polders). Scouring of the adjacent river bed occurs and depostion of sediments takes place within the beels (polders). (van Staveren et al., 2016). | Improved water drainage of polders, increasing capacity of peripheral river | Agriculture and small scale shrimp farming | Agriculture | Waterlogging was solved in most parts of the beel.<br>However, uneven sedimentation created drainage | | | 237.94 | 235.38 | 241.04 | 238.60 |
| *TRM, Bangladesh; Beel Khukshia* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with obtained land type. | Ganges-Brahamaputra | BD | 100.00 | Restoration of tidal flowing by partial removal of embankments (or polders). Scouring of the adjacent river bed occurs and depostion of sediments takes place within the beels (polders). (van Staveren et al., 2016) | Improved water drainage of polders, increasing capacity of peripheral river | Large scale shrimp farming and rice cultivation | Agriculture | Waterlogging was solved only near the embankment cut-point. Other areas remain waterlogged. | | | 137.94 | 135.38 | 141.04 | 138.60 |
| *TRM, Bangladesh; Beel Pakhimara* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with | Ganges-Brahamaputra | BD | 100.00 | Restoration of tidal flowing by partial removal of embankments (or polders). Scouring of the adjacent river bed occurs and depostion of | Improved water drainage of polders, increasing capacity of peripheral river | Shrimp farming | Agriculture | | | | | | | |
| *Polder 32, Bangladesh* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with | Ganges-Brahmaputra- | BD | 100.00 | Storm breach | Not TRM, but storm-nduced equivalent of TRM with larger spatial scale | | Agriculture | Not a planned project.. Degree of Non-govermental, local stakeholder engagement; | | | | | 171.04 | 168.60 |

# Appendix B.II Trial results; Ebro delta. Sheet 2

| SedimentManagementStrategy_Project | Suitability of the strategy | DeltaSystem | Country _Coast_ | Delta regime user rel. to delta regime lowest resemblence (%) | ShortDescriptionOfSES | PrimaryObjectiveOfTheProject | LandUseTypeBeforeImplementation OfTheSES | Obtained land type | Remarks | MainDrawbacks | MainHighlights | Delta of strategy, RCP 4.5, Land gain - sub.- slr (mm/yr) | Delta of strategy, RCP 8.5, Land gain - sub. - slr (mm/yr) | Delta of user, RCP 4.5,Land gain - sub. - slr (mm/yr) | Delta of user, RCP 8.5, Land gain - sub. - slr (mm/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Wetland restoration, Danube, Babina polder* | Not suitable, as outfall area of the strategy does not fit the available area. | Danube | RO | 0.2659 | Wetland restoration, to | Regain key natural processes, enhance habitats quality to sustain rich biodiversity and generate natural resources for the local communities | Abandoned agricultural polder | Nature | > The Babina island was embanked, but never taken into full agricultural functioning. | > The main factor slowing down or hamper the implementation of the strategy in the Danube delta originated | >ecological restoration was very succesful, nutrients and suspended material are now filtered and retained more efficiently in the bio-accumulative horizon of the polder. > bird species | -6.01 | -8.57 | -7.01 | -9.45 |
| *Wetland restoration, Danube, Cernovca polder* | Not suitable, as outfall area of the strategy does not fit the available area. | Danube | RO | 0.2659 | Wetland restoration | Regain key natural processes, enhance habitats quality to sustain rich biodiversity and generate natural resources for the local communities | Abandoned agricultural polder | Nature | > The Cernovca island was embanked, but never taken into full agricultural functioning. | > The main factor slowing down or hamper the implementation of the strategy in the Danube delta originated legal and institutional framework as well as | >ecological restoration was very succesful, Nutrients and suspended material are Now filtered and retained more efficiently in the bio-accumulative horizon of the polder. | -6.01 | -8.57 | -7.01 | -9.45 |
| *Tidal Replicate Method, Hunter River* | Not suitable, as implementation costs exceed budget. | Hunter river estuary, Kooragang Island | AU | 0.2696 | Tidal replication/wetland restoration | Nature | | NatureRecreation | Project planned by; University (of New South Wales). Funded by private engineering firm (NCIG). Degree of Non-govermental, local stakeholder | | | | | | |
| *Canal del Dique locks, Colombia River* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget. | Colombia River | CO | 0.2700 | River Sediment Diversions | Flood protection and ecological restoration (integral solution optimized for the requirements of flood safety, navigation, agriculture and the environment) | | Nature | Project funded and planned by; Fondo Adaptación Colombia + ANI (National Infrastructure Authority), Degree of Non-govermental, local | | | | | 11.04 | 8.60 |
| *Sediment diversions, Mississippi, Mid-Barataria bay project* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget. | Mississippi | USA | 0.2731 | Sediment river diversion consist of a channel in a river embankment which lets river water -- and the silt and sand that is suspended in the water -- flow into a nearby estuary, to enhance river sediment delivery (both mud and sand) and/or increasing sediment retention in the receiving basin. The | Sustaining and creating new land. for ecosystem services and infrastructure protection | Degrading werlands | NatureWetland | | > Oil spill projected expenditures of 133 million USD$. > Decrease in salinity due | | | | | |
| *Sediment diversions, Mississippi, Mid-Breton project* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget. | Mississippi | USA | 0.2731 | Sediment river diversion consist of a channel in a river embankment which lets river water -- and the silt and sand that is suspended in the water -- flow into a nearby estuary, to enhance river sediment delivery (both mud and sand) and/or increasing sediment retention in the receiving basin. The opening/channel can be controlled | Sustaining and creating new land. for ecosystem services and infrastructure protection | Degrading werlands | NatureWetland | | > Decrease in salinity due to fresh water diverted into the area may negatively impact the dolphin stocks in the area and thus could present issues under the Marine Mammal Protection Act (MMPA) | | | | | |
| *Sediment diversion, Mississippi, West Bay diversion* | Suitable | Mississippi | USA | 0.2731 | A ''natural'' sediment river diversion exist of a cut in the leveesystem which directs the river flow to wetlands. The flow is contrained by the width and depth of the diversion. | returning a subsided open water bay to its previous state of vegetated wetland | Degrading werlands | Wetland | > resembles a natural crevasse splay (Allison et al., 2010) > Hurricane Katrina induced major changes in the area by erasing the initial depositional record, the bedded deposits were replaced by deposits from the floods (Andrus 2007) > The conveyance channel initially constructed pointed upstream. As the channel evolved over time, the orientation shifted towards a downstream direction. diversion size, outlet design, and location are important factors the design of diversions. (Day et al., 2014) | > local shoaling near anchorage area. (Allison et al., 2010) > might induce shoaling in the navigation channel (CWPPRA; Factsheet) | | -0.46 | -3.02 | 6.04 | 3.60 |
| *Twitchell Island,San Joaquin-Sacramento Delta* | Suitable | San Joaquin-Sacramento Delta | USA | 0.2738 | Subsidence reversal | Land raising/counteracting subsidence | | NatureAgricultureWetland | Project funded and planned by; Regional (state) government & US Geological Survey (NGO) in conjunction with researchers/universities, Gained land type; Peat and natural wetlands (ecological), also flood storage area and recently rice farming. Degree of Non-govermental, local stakeholder engagement;Unclear, seems to mostly only be government & research institutes - though for further projects stakeholder engagement is occurring | | | | | 31.04 | 28.60 |
| *Double dykes, Ems-Dollard,Eemshaven- Delfzijl* | Suitable | Ems-Dollard | NL/DE | 0.2740 | Double dykes | Nature, agriculture & flood safety | Nature area | NatureAgricultureAquaculture | | | | 10.94 | 8.38 | 11.04 | 8.60 |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Chosen alternative: willow groynes* | Not suitable, as necessary land type does not match with obtained land type. | Ems-Dollard Estuary | NL | 0.2740 | Creating low energy conditions to facilitate sedimentation | Reduce turbidity by sediment extraction, Nature, Growing with SLR, KNowledge gathering | | Wetland | Project funded and planned by; Rijkswaterstaat & Ministry LNV. Degree of Non-govermental, local stakeholder engagement; Consulting / Advising. | | | | | 11.04 | 8.60 |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 2: lagoon excavation* | Suitable | Ems-Dollard Estuary | NL | 0.2740 | Creating lagoon in existing salt marshes as sediment basin | Reduce turbidity by sediment extraction, Nature, Growing with SLR, KNowledge gathering | | Wetland | Project funded and planned by; Rijkswaterstaat & Ministry LNV. Degree of Non-govermental, local stakeholder engagement; Consulting / Advising. Configuration of groynes matters for sedimentation. Effectiveness increases when they are attached to the land. Classic 'kwelderwerken' are even more effective, but don't create the added value for nature. Sedimentation speeds may pick up after initial spin-up, due to initial erosion after groyne placement. | | | | | 31.04 | 28.60 |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 3: salt marsh rejuvination* | Suitable | Ems-Dollard Estuary | NL | 0.2740 | Rejuvinate marshes (lower them) to allow for new sedimentation | Reduce turbidity by sediment extraction, Nature, Growing with SLR, KNowledge gathering | | Wetland | Project funded and planned by; Rijkswaterstaat & Ministry LNV. Degree of Non-govermental, local stakeholder engagement;Consulting / Advising. Configuration of groynes matters for sedimentation. Effectiveness increases when they are attached to the land. Classic 'kwelderwerken' are even more effective, but don't create the added value for nature. Sedimentation speeds may pick up after initial spin-up, due to initial erosion after groyne placement.In addition, it was found that the starting elevation matters a lot for sedimentation speeds. | | | | | -3.96 | -6.40 |
| *Natuuronwikkelingsproject Noordwaard / kleine Noordwaard* | Not suitable, as outfall area of the strategy does not fit the available area. | Rhine-Meuse | NL | 0.2740 | Reconnection of the poldered area to the river stream. Which results in an inlet for sediments and water. | 1st: Nature development , 2nd : Room for the River/ flood protection | Polderland agriculture | NatureWetland | * Aim of the project was Not to increase sedimentation in the system, however sedimentation occured. During summer lower discharges result | | | -8.19 | -11.12 | -4.81 | -7.25 |
| *TRM, Bangladesh; Beel Bhaina* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with obtained land type. | Ganges-Brahamaputra | BD | 100.0000 | Restoration of tidal flowing by partial removal of embankments (or polders). Scouring of the adjacent river bed occurs and depostion of sediments takes place within the beels (polders). (van Staveren et al., 2016). | Improved water drainage of polders, increasing capacity of peripheral river | Agriculture and small scale shrimp farming | Agriculture | Waterlogging was solved in most parts of the beel. However, uneven sedimentation created drainage congestion in the North-western part of the beel | | | 237.94 | 235.38 | 241.04 | 238.60 |
| *TRM, Bangladesh; Beel Khukshia* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with obtained land type. | Ganges-Brahamaputra | BD | 100.0000 | Restoration of tidal flowing by partial removal of embankments (or polders). Scouring of the adjacent river bed occurs and depostion of sediments takes place within the beels (polders). (van Staveren et al., 2016). | Improved water drainage of polders, increasing capacity of peripheral river | Large scale shrimp farming and rice cultivation | Agriculture | Waterlogging was solved only near the embankment cut-point. Other areas remain waterlogged. | | | 137.94 | 135.38 | 141.04 | 138.60 |
| *TRM, Bangladesh; Beel Pakhimara* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with obtained land type. | Ganges-Brahamaputra | BD | 100.0000 | Restoration of tidal flowing by partial removal of embankments (or polders). Scouring of the adjacent river bed occurs and depostion of sediments takes place within the beels (polders). (van Staveren et al., 2016). | Improved water drainage of polders, increasing capacity of peripheral river | Shrimp farming | Agriculture | | | | | | | |
| *Polder 32, Bangladesh* | Not suitable, as outfall area of the strategy does not fit the available area.Not suitable, as implementation costs exceed budget.Not suitable, as necessary land type does not match with obtained land type. | Ganges-Brahmaputra-Megna Delta | BD | 100.0000 | Storm breach | Not TRM, but storm-nduced equivalent of TRM with larger spatial scale | | Agriculture | Not a planned project.. Degree of Non-govermental, local stakeholder engagement; | | | | | 171.04 | 168.60 |

# Appendix B.III Trial results; Ebro delta. Sheet 3

| **Strategy sorted on degree of positive impact, descending** | **Degree of postive impact** | **Strategy sorted on degree of negative impact, ascending** | **Degree of negative impact** | **EnivronmentalImpactAdditionalRemark** | **Strategies sorted, ascending costs/land gain** | **Implementation costs (USD$) for 1 mm/yr land gain** |
|---|---|---|---|---|---|---|
| *Tidal Replicate Method, Hunter River* | Very high | Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 2: lagoon excavation | Moderate | | Wetland restoration, Danube, Babina polder | 51115.33665 |
| *Twitchell Island,San Joaquin-Sacramento Delta* | Very high | Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 3: salt marsh rejuvination | Moderate | | Wetland restoration, Danube, Cernovca polder | 51115.33665 |
| *Double dykes, Ems-Dollard,Eemshaven-Delfzijl* | Very high | Wetland restoration, Danube, Babina polder | Low | x | Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 2: lagoon excavation | 120000 |
| *Wetland restoration, Danube, Babina polder* | High | Wetland restoration, Danube, Cernovca polder | Low | x | Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Chosen alternative: willow groynes | 240000 |
| *Wetland restoration, Danube, Cernovca polder* | High | Tidal Replicate Method, Hunter River | Low | Surveys were undertaken to determine the tidal range optimal for the wetland vegetation in the area. Therefore very high positive impact on the vegetation, negative impact on surrounding ecosystem is limited | Double dykes, Ems-Dollard,Eemshaven- Delfzijl | 375000 |
| *Canal del Dique locks, Colombia River* | High | Canal del Dique locks, Colombia River | Low | Environmental Impact Assessment, Multi-Criteria Analysis & Cost-benefit analysis; project was designed to have a positive environmental impact and reduce flood risk, so high positive impact, low negative impact. | Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 3: salt marsh rejuvination | 960000 |
| *Sediment diversions, Mississippi, Mid-Barataria bay project* | High | Sediment diversions, Mississippi, Mid-Barataria bay project | Low | 'Predicted to have a major positive impact on land area in the receiving basin, but with significant disruptions to commercial and recreational fisheries, and some flooding increases near the diversion.'' | Twitchell Island,San Joaquin-Sacramento Delta | 1041993.3 |
| *Sediment diversions, Mississippi, Mid-Breton project* | High | Sediment diversions, Mississippi, Mid-Breton project | Low | 'Predicted to have a major positive impact on land area in the receiving basin, but with significant disruptions to commercial and recreational fisheries, and some flooding increases near the diversion.'' | Sediment diversion, Mississippi, West Bay diversion | 3386720 |
| *Sediment diversion, Mississippi, West Bay diversion* | High | Sediment diversion, Mississippi, West Bay diversion | Low | 'Has had a major positive impact on land creation in the basin. However this impact was only seen after the installation of several terraces in 2009. Prior to that deposition was entirely subaerial.'' | Natuuronwikkelingsproject Noordwaard / kleine Noordwaard | 4982839.518 |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Chosen alternative: willow groynes* | High | Twitchell Island,San Joaquin-Sacramento Delta | Low | Yes, large positive impact (creation of new habitats) - extensively monitored for water quality and chemical composition | Canal del Dique locks, Colombia River | 30000000 |
| *Natuuronwikkelingsproject Noordwaard / kleine Noordwaard* | High | Double dykes, Ems-Dollard,Eemshaven- Delfzijl | Low | x | Tidal Replicate Method, Hunter River | |
| *TRM, Bangladesh; Beel Bhaina* | Moderate | Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Chosen alternative: willow groynes | Low | Ongoing, expected positive impact = high. expected negative impact = low. | Sediment diversions, Mississippi, Mid-Barataria bay project | |
| *TRM, Bangladesh; Beel Khukshia* | Moderate | Natuuronwikkelingsproject Noordwaard / kleine Noordwaard | Low | Yes, large positive impact for nature and landscape. small negative impact on shipping/maintenance of main channel from which diversion is created. | Sediment diversions, Mississippi, Mid-Breton project | |
| *TRM, Bangladesh; Beel Pakhimara* | Moderate | TRM, Bangladesh; Beel Bhaina | Low | x | TRM, Bangladesh; Beel Bhaina | |
| *Polder 32, Bangladesh* | Moderate | TRM, Bangladesh; Beel Khukshia | Low | x | TRM, Bangladesh; Beel Khukshia | |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 2: lagoon excavation* | Low | TRM, Bangladesh; Beel Pakhimara | Low | x | TRM, Bangladesh; Beel Pakhimara | |
| *Pilot Buitendijkse Slibsedimentatie (Pilot enhanced mud sedimentation) - Alternative 3: salt marsh rejuvination* | Low | Polder 32, Bangladesh | Low | More evenly distributed siltation compared to TRM because of uncontrolled opening, resulting in deep central channel in the polder conveying water and sediments | Polder 32, Bangladesh | |

# Appendix C Main highlights and drawbacks[65]

| SES | | Main highlights | Main drawbacks |
|---|---|---|---|
| Project de kleine Noordwaard | | > Positive impact on landscape and nature.[11,13] | > Relative small negative impact on shipping/maintenance of the main channel on the location of the diversion/embankment cut.[11]<br>> As part of the Room for the river project local issues arose from residents/farmers needed to leave their residence/farmsteads in the poldered area, or risked flooding. (Warner et al., 2018)[2] |
| Tidal River Management | | > Increased navigability of the River.[8]<br>> Increased agricultural activity and financial benefit after implementation[3,8]<br>> Relatively minimum interventions of humans necessary.[12]<br>> Helped solving the congestion and water logging issues.<br>> Relatively low implementation costs.[11] | > No economic activity can occur during the operation.[8]<br>> Uneven sedimentation lead to drainage issues.[3]<br>> Conflicts occurred with local stakeholders when participation was lacking.[3]<br>>Non-transparent compensation mechanisms created conflicts.[3]<br>> Short time span of actively depositing sediments of the SES.[3] |
| Sediment Diversions | Controlled diversion | > Predicted to have a major positive impact on land area in the receiving basin.[11]<br>> Opportunity to time the diversion to increase sediment trapping efficiency and/or minimalize negative environmental impact..[1]<br>> Relative long life span of the SES. | > Decrease in salinity due to fresh water diverted into the area may negatively impact species thriving in saline waters.[7]<br>> The reduced local discharge more downstream of the diversion can induce shoaling, affecting the navigability of the river.[5]<br>> Disruptions to commercial and recreational fisheries.[11]<br>> Increase of potential flooding near the diversion. [11]<br>> Relative high implementation costs. [11] |
| | 'Natural'' diversion | > Major positive impact on land creation in the basin. [11] | > Local shoaling near anchorage area.[1]<br>> might induce shoaling in the navigation channel<br>> Additional terraces necessary for sediment deposition to occur in non-subareal areas.[11] |
| Wetland restoration | | > Successful ecological restoration, nutrients and suspended material are retained more efficiently.[4]<br>>Establishment of new habitats,[9]<br>> Increased hydrological flow and storage capacity of water. [9]<br>> Potential economic benefits through reed harvest, (eco) tourism and fisheries.[16] | > Local issues with stakeholder participation, hampering the implementation of the SES. [10]<br>> Slowing down the implementation of the SES due to the Danube delta originated legal and institutional. [10] |
| Double dykes | | > Decrease of local siltation issues and increased water quality.[14]<br>> Collected sludge can be used for reinforcing the second levee in the system.[14]<br>> Creates area to experiment with saline cultivation.[6]<br>> Potential for saline or salt-tolerant agriculture (economic interest).[6] | |

---

[65] *. ([1]Allison & Meselhe, 2010; [16]Ebert et al., 2009 [2]Edelenbos et al., 2013; [3]Gain et al., 2017; [4]Hein et al., 2016; [5]Kolker et al., 2012; [6]Kwakernaak et al., 2015; [7]Lang, 2017; [8]M. M. A. Masud et al., 2020; [9]Niculescu et al., 2017; [10]Nijland et al., 2001; [11]Sedimentation Enhancing Strategies for River Deltas, 2020; [12]Talchabhadel et al., 2018; [13]van der Deijl et al., 2019;[14] van Loon-Steensma & Schelfhout, 2020; [15]Warner et al., 2018)*

# Appendix D Script of the SES decision support tool

```
---------------------------------------------------------------------------
---------------------------------------------------

%
SEDIMENTION ENHANCING STRATEGY, DECISION SUPPORT TOOl
% A concise tool to help inform people, involved in the decision-making
% process, on different sedimentation enhancing strategies. Part I consists
of 2 runs for
% the current delta regime scenario (towards river/tide/wave dominance) and
for an altered scenario's tending
% towards river/wave/tide dominance. Part II ranks different sedimentation
% enhancing strategies on environmental impact and land gain/
% implementation costs.
% E. Sieben 18-06-2021
%--------------------------------------------------------------------------
----------------------------------------------------

clc
clear all;
close all;

sed_strat    = readtable('Sedimentation Enhancing
Strategies.xlsx','ReadRowNames',true); % Data of the different sediment
strategies
%
trial_delta  = readtable('Trial_delta','ReadRowNames',true); % Input file
with data from the user of the tool
output_model = sed_strat; % Output file from the model

% ----- PART I ------

%       1. Runs for the different scenarios

for s = (1:2) %Loop for the 2 scenarios, the current/wave/river/tide
regime, the ratio's can be altered for the altered scenario sediment fluxes
(w/r/t) differ per regime.

%        2. Ranking of the strategies

% Loop running over all the strategies. Calculates distance between the
point of different ratios of sediment fluxes of
% ''input delta'' to the point of the different ratios for the delta in
% which the strategy is applied. Then the strategies are sorted to relative
% ''resemblance' with the system or shortest distances between the points.

for j = (1:(height(sed_strat)));

dis_delta(j,1) = sqrt(((trial_delta{s,1}-
(sed_strat{j,'Qrivier_Qwave___'}))^2)+((trial_delta{s,2}-
sed_strat{j,'Qrivier_Qtide___'})^2)+ ((trial_delta{s,3}-
sed_strat{j,'Qwave_Qtide___'})^2));

dis_delta(:,2) = ((dis_delta(:,1)/max(dis_delta(:,1))*100));

end

dis_deltaT = array2table(dis_delta(:,2)); % Conversion array to rable
dis_deltaT.Properties.VariableNames = {'Delta regime user rel. to delta
regime lowest resemblence (%)'};
outputmodel_a = [output_model dis_deltaT]; % Addition of the values to the
output file
```

```
outputmodel_2 = sortrows(outputmodel_a,'Delta regime user rel. to delta
regime lowest resemblence (%)'); % Sorting of values to highest resemblance
with input delta settings


%          3. Yes/no criteria

%
suitability((height(sed_strat)),5) = (0);
trial_delta_array(1,:)= table2cell(trial_delta(1,:));
outputmodel_c_array(:,1) =
table2array(outputmodel_2(:,'LeveesystemNecessaryForImplementationStrategy'
));
outputmodel_c_array(:,2) =
table2array(outputmodel_2(:,'Polder_beelNecessaryForImplementationStrategy'
));
outputmodel_c_array(:,3) =
table2cell(outputmodel_2(:,'AreaImplemented_polderAreaHa_km2_'));
outputmodel_c_array(:,4) =
table2cell(outputmodel_2(:,'ImplementationCosts_USD__'));
outputmodel_c_array(:,5) =
table2cell(outputmodel_2(:,'GainedLandType_Nature_'));
outputmodel_c_array(:,6) =
table2cell(outputmodel_2(:,'GainedLandType_Agricultural_'));
outputmodel_c_array(:,7) =
table2cell(outputmodel_2(:,'GainedLandType_Aquaculture_'));
outputmodel_c_array(:,8) =
table2cell(outputmodel_2(:,'GainedLandType_Wetland_'));
outputmodel_c_array(:,9) =
table2cell(outputmodel_2(:,'GainedLandType_Recreation_'));
outputmodel_c_array(:,10) =
table2cell(outputmodel_2(:,'GainedLandType_Residential_'));

 % Loop for the different strategies
for j = (1:(height(sed_strat)));

% Levee system present and/or necessary
  if  isequal(trial_delta_array(1,4),outputmodel_c_array(j,1));
      suitability (j,1) = 1;
  end
  if  isequal(trial_delta_array(1,4),{'Yes'});
      suitability (j,1) = 1;
  end

% Polder/beels present and/or necessary
  if  isequal(trial_delta_array(1,5),outputmodel_c_array(j,2));
      suitability(j,2) = 1;
  end
  if  isequal(trial_delta_array(1,5),{'Yes'});
      suitability (j,2) = 1;
  end

%Maximum area available for outfall of the strategy
  if trial_delta_array{1,6} >= outputmodel_c_array{j,3};
      suitability (j,3) = 1;
  end

%Restricted budget
 if trial_delta_array{1,7} >= outputmodel_c_array{j,4};
      suitability (j,4) = 1;
 end

%land type gained for every type and combination
```

```
 if isequal(trial_delta_array(1,8),outputmodel_c_array(j,5))
       suitability (j,5) = 1;
 end
 if    isequal(trial_delta_array(1,8),outputmodel_c_array(j,6))
       suitability (j,5) = 1;
 end
 if isequal(trial_delta_array(1,8),outputmodel_c_array(j,7))
       suitability (j,5) = 1;
 end
 if isequal(trial_delta_array(1,8),outputmodel_c_array(j,8))
       suitability (j,5) = 1;
 end
 if  isequal(trial_delta_array(1,8),outputmodel_c_array(j,9))
       suitability (j,5) = 1;
 end
 if    isequal(trial_delta_array(1,8),outputmodel_c_array(j,10))
     suitability (j,5) = 1;
 end

 if isequal(trial_delta_array(1,8),{'Not important'});
      suitability(j,5) = 1;
 end

end

suitabilityT = array2table(suitability);

land_types(:,1) = table2cell(outputmodel_2(:,{'GainedLandType_Nature_'}));
land_types(:,2) =
table2cell(outputmodel_2(:,{'GainedLandType_Agricultural_'}));
land_types(:,3) =
table2cell(outputmodel_2(:,{'GainedLandType_Aquaculture_'}));
land_types(:,4) = table2cell(outputmodel_2(:,{'GainedLandType_Wetland_'}));
land_types(:,5) =
table2cell(outputmodel_2(:,{'GainedLandType_Recreation_'}));
land_types(:,6) =
table2cell(outputmodel_2(:,{'GainedLandType_Residential_'}));

% Combine the land types in one cell for final output
for j = (1:(height(sed_strat)))

joined_land_types{j,1} =
strcat(land_types(j,1),land_types(j,2),land_types(j,3),land_types(j,4),land
_types(j,5),land_types(j,6));
obtained_land_type = array2table(joined_land_types,
'VariableNames',{'Obtained land type'});

end

 % Changing results to right format
  for j = (1:(height(sed_strat)));

  if ( [suitabilityT{j,1}]== 0) ;
  result_3{j,1} = ('Not suitable, as no leveesystem is present.');
  else
  result_3{j,1} = [];
  end
if ( [suitabilityT{j,2}]== 0) ;
  result_3{j,2} = ('Not suitable, as no polder/beel is present.');
  else
  result_3{j,2} = [];
end
```

```
if ( [suitabilityT{j,3}]== 0) ;
  result_3{j,3} = ('Not suitable, as outfall area of the strategy does not
fit the available area.');
  else
  result_3{j,3} = [];
end

if ( [suitabilityT{j,4}]== 0) ;
  result_3{j,4} = ('Not suitable, as implementation costs exceed budget.');
  else
  result_3{j,4} = [];
end

if ( [suitabilityT{j,5}]== 0) ;
  result_3{j,5} = ('Not suitable, as necessary land type does not match
with obtained land type.');
  else
  result_3{j,5} = [];
end
  end

for j = (1:(height(sed_strat)))
    result_3{j,6} =
strcat(result_3(j,1),result_3(j,2),result_3(j,3),result_3(j,4),result_3(j,5
));

if isequal(result_3{j,6}, {[]});
   result_3{j,6} = ('Suitable');
end

end

result_3_n = array2table(result_3, 'VariableNames',{'Leveesystem'
'Polder/beel' 'Outfall area' 'Restricted budget' 'Land type' 'Suitability
of the strategy'});


outputmodel_3 = [outputmodel_2 result_3_n(:,'Suitability of the
strategy')]; % Addition of results yes/no criteria to output file


%               4. Sediment balance

Rise = table2cell(outputmodel_3(:,{'LandRaisedIn_mm_yr_'}));
Slr(:,1)  =
table2cell(outputmodel_3(:,{'RateOfSLR_mm_yr__RCP4_5Scenario'}));
Slr(:,2)  =
table2cell(outputmodel_3(:,{'RateOfSLR_mm_yr__RCP8_5Scenario'}));
Slr_user(:,1)  =
table2cell(trial_delta(:,{'SeaLevelRise_mm_yr__RCP4_5Scenario'}));
Slr_user(:,2)  =
table2cell(trial_delta(:,{'SeaLevelRise_mm_yr__RCP8_5Scenario'}));

Sub(:,1) = table2cell(outputmodel_3(:,{'MeanSubsidence_mm_yr_'} ));
Sub_user = table2cell(trial_delta(:,{'SubsidenceOfTheDelta_mm_yr_'}));

for j = (1:(height(sed_strat)));
result_4a{j,1} = Rise{j,1} - Slr{j,1} - Sub{j,1};
result_4a{j,2} = Rise{j,1} - Slr{j,2} - Sub{j,1};
result_4a{j,3} = Rise{j,1} - Slr_user{1,1} - Sub_user{1,1};
result_4a{j,4} = Rise{j,1} - Slr_user{1,2} - Sub_user{1,1};

end
```

```
result_4b = array2table(result_4a, 'VariableNames',{'Delta of strategy, RCP
4.5, Land gain - sub.- slr (mm/yr)','Delta of strategy, RCP 8.5, Land gain
- sub. - slr (mm/yr)', 'Delta of user, RCP 4.5,Land gain - sub. - slr
(mm/yr)', 'Delta of user, RCP 8.5, Land gain - sub. - slr (mm/yr)'});

outputmodel_4 = [outputmodel_3 result_4b]; % Addition of results sediment
balance to output file

%______OUTPUT PART 1____

if s == 1
    Current_regime_ = outputmodel_4;

elseif s== 2
    Altered_Scenario_  =  outputmodel_4;

end
end

for j = (1:(height(sed_strat)));

Current_regime(j,:) = [ Current_regime_(j,{'Suitability of the strategy'})
Current_regime_(j,{'SedimentManagementStrategy_Project'})
Current_regime_(j,{'DeltaSystem'}) Current_regime_(j,{'Country_Coast_'})
Current_regime_(j,{'Delta regime user rel. to delta regime lowest
resemblence (%)'})   Current_regime_(j,{'ShortDescriptionOfSES'})
Current_regime_(j,{'PrimaryObjectiveOfTheProject'})
Current_regime_(j,{'LandUseTypeBeforeImplementationOfTheSES'})
obtained_land_type(j,{'Obtained land type'}) Current_regime_(j,{'Remarks'})
Current_regime_(j,{'MainDrawbacks'}) Current_regime_(j,{'MainHighlights'})
Current_regime_(j,{ 'Delta of strategy, RCP 4.5, Land gain - sub.- slr
(mm/yr)'}) Current_regime_(j,{ 'Delta of strategy, RCP 8.5, Land gain -
sub. - slr (mm/yr)'}) Current_regime_(j,{ 'Delta of user, RCP 4.5,Land gain
- sub. - slr (mm/yr)'}) Current_regime_(j,{ 'Delta of user, RCP 8.5, Land
gain - sub. - slr (mm/yr)'})];
Altered_Scenario(j,:) = [ Altered_Scenario_(j,{'Suitability of the
strategy'}) Altered_Scenario_(j,{'SedimentManagementStrategy_Project'})
Altered_Scenario_(j,{'DeltaSystem'})
Altered_Scenario_(j,{'Country_Coast_'}) Altered_Scenario_(j,{'Delta regime
user rel. to delta regime lowest resemblence (%)'})
Altered_Scenario_(j,{'ShortDescriptionOfSES'})
Altered_Scenario_(j,{'PrimaryObjectiveOfTheProject'})
Altered_Scenario_(j,{'LandUseTypeBeforeImplementationOfTheSES'})
obtained_land_type(j,{'Obtained land type'})
Altered_Scenario_(j,{'Remarks'}) Altered_Scenario_(j,{'MainDrawbacks'})
Altered_Scenario_(j,{'MainHighlights'}) Altered_Scenario_(j,{ 'Delta of
strategy, RCP 4.5, Land gain - sub.- slr (mm/yr)'}) Altered_Scenario_(j,{
'Delta of strategy, RCP 8.5, Land gain - sub. - slr (mm/yr)'})
Altered_Scenario_(j,{ 'Delta of user, RCP 4.5,Land gain - sub. - slr
(mm/yr)'}) Altered_Scenario_(j,{ 'Delta of user, RCP 8.5, Land gain - sub.
- slr (mm/yr)'})];

end

% ----- PART II ------

%          5. Scoring/ranking the strategies

Strategies =
table2array(outputmodel_4(:,{'SedimentManagementStrategy_Project'}));

% -Environmental impact-
```

```
% Degree positive impact
for j = (1:(height(sed_strat)));

    result_5_1_p{j,1}     = outputmodel_4{j,
{'SedimentManagementStrategy_Project'}};
    result_5_1_p{j,2}     = outputmodel_4{j,
{'DegreeOfPositiveImpact_Low_Moderate_High_VeryHigh_'}};


    % Degree of positive impact

    if
isequal(outputmodel_4{j,'DegreeOfPositiveImpact_Low_Moderate_High_VeryHigh_
'},{'Very high'})
         result_5_EIA_p{j,1} = 1;

    elseif
isequal(outputmodel_4{j,'DegreeOfPositiveImpact_Low_Moderate_High_VeryHigh_
'},{'High'})
        result_5_EIA_p{j,1} = 2;

    elseif
isequal(outputmodel_4{j,'DegreeOfPositiveImpact_Low_Moderate_High_VeryHigh_
'},{'Moderate'})
         result_5_EIA_p{j,1} = 3;

    elseif
isequal(outputmodel_4{j,'DegreeOfPositiveImpact_Low_Moderate_High_VeryHigh_
'},{'Low'})
         result_5_EIA_p{j,1} = 4;
    end
end

result_5_1_p = [result_5_1_p result_5_EIA_p];
result_5_EIA_p_sorted = sortrows(result_5_1_p,3); % Sorting of the
strategies from Very high to low postive degree impact

% Degree negative impact
 for j = (1:(height(sed_strat)));

    result_5_1_n{j,1}     = outputmodel_4{j,
{'SedimentManagementStrategy_Project'}};
    result_5_1_n{j,2}     = outputmodel_4{j,
{'DegreeOfNegativeImpact_Low_Moderate_High_VeryHigh__'}};
    result_5_1_n{j,3}     = outputmodel_4{j,
{'EnivronmentalImpactAdditionalRemark'}};
    % Degree of positive impact

    if
isequal(outputmodel_4{j,'DegreeOfNegativeImpact_Low_Moderate_High_VeryHigh_
_'},{'Very high'})
         result_5_EIA_n{j,1} = 1;

    elseif
isequal(outputmodel_4{j,'DegreeOfNegativeImpact_Low_Moderate_High_VeryHigh_
_'},{'High'})
        result_5_EIA_n{j,1} = 2;

    elseif
isequal(outputmodel_4{j,'DegreeOfNegativeImpact_Low_Moderate_High_VeryHigh_
_'},{'Moderate'})
         result_5_EIA_n{j,1} = 3;
```

```
    elseif
isequal(outputmodel_4{j,'DegreeOfNegativeImpact_Low_Moderate_High_VeryHigh_
_'},{'Low'})
         result_5_EIA_n{j,1} = 4;
    end
end

result_5_1_n = [result_5_1_n result_5_EIA_n];
result_5_EIA_n_sorted = sortrows(result_5_1_n,4); % Sorting of the
strategies from Very high to low postive degree impact

result_5_EIA_x = [result_5_EIA_p_sorted result_5_EIA_n_sorted];
result_5_EIA_x(:,3) = [];
result_5_EIA_x(:,6) = [];
result_5_EIA = array2table(result_5_EIA_x, 'VariableNames',{'Strategy
sorted on degree of positive impact, descending' 'Degree of postive impact'
'Strategy sorted on degree of negative impact, ascending ' 'Degree of
negative impact' 'EnivronmentalImpactAdditionalRemark'});

% Landgain/ costs: implementation costs to increase 1 mm/year

Imp_costs = table2cell(outputmodel_4(:,{'ImplementationCosts_USD__'}));
%
 for j = (1:(height(sed_strat)));
    result_5_Costs_gain{j,2} = (Imp_costs {j,1})./(Rise{j,1});
    result_5_Costs_gain{j,1} = Strategies{j,1};
end

result_5_Costs_gain_sorted_x = sortrows(result_5_Costs_gain,2);
result_5_Costs_gain_sorted = array2table(result_5_Costs_gain_sorted_x ,
'VariableNames',{'Strategies sorted, ascending costs/land gain'
'Implementation costs (USD$) for 1 mm/yr land gain'});,

% Result of scoring and ranking

Ranked_strategies = ([result_5_EIA result_5_Costs_gain_sorted]);

% ------- FINAL OUTPUT -------------

% writetable(Final_output,F_xlsx,'Sheet',files(i).name)
filename = 'Final_output_SES.xlsx';

writetable(Current_regime,filename, 'Sheet',1 , 'Range', 'A1');
writetable(Altered_Scenario,filename, 'Sheet',2, 'Range', 'A1');
writetable(Ranked_strategies,filename, 'Sheet',3, 'Range', 'A1');
```