Tidal Grevelingen Project

Market consultation about a flood barrier variant with tidal power plant

Description of tidal power plant variant 2018 market consultation

Date

12 October 2018

Status

Final report 1.0

project GetijGrevelingen

Foreword

In the concept Grevelingen and Volkerak-Zoommeer Government Development Plan, in 2014 the Cabinet selected the improvement of water quality in Grevelingen as development perspective. For this purpose, tides on the lake will be reintroduced to a limited extent through a flood barrier in the Brouwersdam that connects the Grevelingen to the North Sea.

The basic principle is a tidal range of no more than 50 cm at an average median level of 0.20 m below sea level (NAP), the current middle water level. The partnership aims to find out whether the function of the flood barrier can be combined with a Tidal Power Plant. The state's prerequisite is that the project itself must be self-sustaining as public funds are intended for water quality.

On 7 March 2018, the Ministers of Infrastructure and the Environment and the Ministry of Agriculture, Nature and Food Quality announced their intention to make an additional €75 million available for the construction of a flood barrier (letter TK IenM/BSK-2018/41968). This meant the funding was in place and the Grevelingen Tidal Project has been given the go-ahead. Preparations are being made to take an MIRT 2-decision[1] in 2018. A choice will be made as to which alternative(s) within the scope of the project are to be included in the plan development phase (MIRT 3).

Whether the Tidal Power Plant alternative is included in the plan development phase depends in part on market interest. The Tidal Power Plant Steering Group has commissioned a study to assess market interest and to make all public information regarding this alternative available to the market.

The document forms the basis for the 2018 market consultation. The variant described only represents one option for a feasible business case under the conditions set out. In the plan development phase, it is up to the market to come up with its own variant within the prerequisites of aims, time and finances.

It must be emphasised that this market consultation document does not form part of the tender and that no rights may be derived from it. Insights obtained from the 2018 market consultation may be used in the decision-making process and preparation of the tender. Rijkswaterstaat reserves the right not to use or the obtained suggestions and insights whether partially or in full.

Han Weber

J.F. (Han) Weber (mr.)

Provincial Executive member, South Holland
Chairman Steering Group Tidal Power Plant Province South Holland

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1 Dutch Multi-Year Programme for Infrastructure, Spatial Planning and Transport

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Summary

Future development of the Grevelingen requires the restoration of attenuated tides to Lake Grevelingen. The Grevelingen Tidal Project[2] is currently in the process of working out the details.

Objective

The primary objective is to improve the water quality, which will turn Lake Grevelingen back into a resilient and robust ecosystem. A closable flood barrier in the Brouwersdam will be constructed for this purpose. This requires a tidal range not exceeding 50 cm. Also taken into account is an annual rise in sea level of 1 cm per year over the coming thirty years.

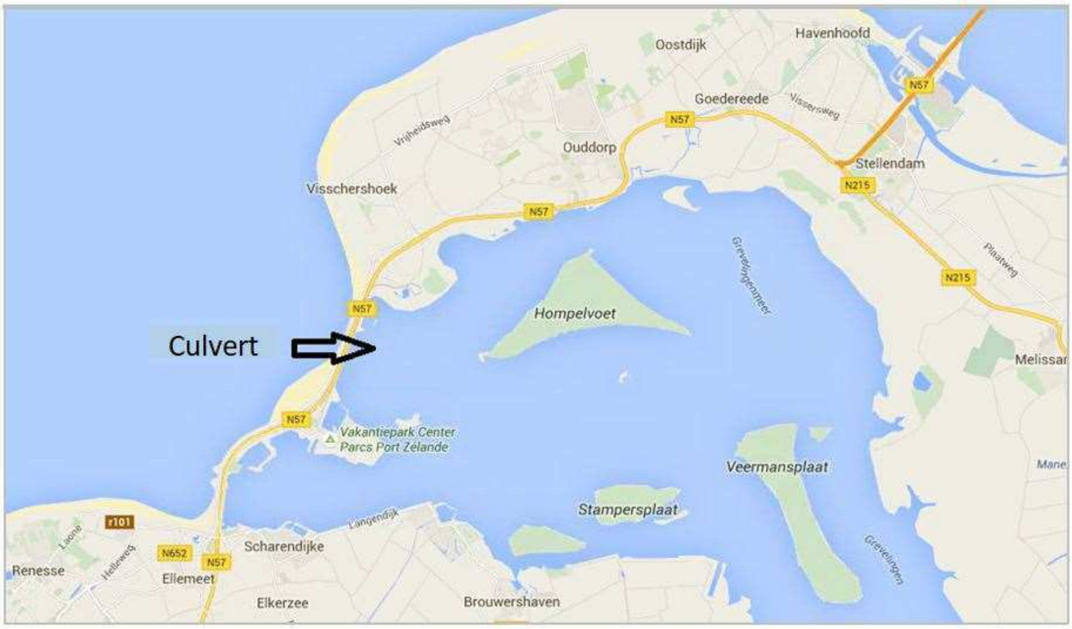

Figure 1: Planned location of the flood barrier

A secondary objective is the generation of sustainable energy from the tidal flow. The development of a tidal power plant in the flood barrier will provide opportunities for innovation and export aimed at river deltas threatened by rising sea levels.

The secondary objective is a piggy-back opportunity which can only be achieved by involving market players prepared to take a risk. Prerequisites for the construction are private funding from additional investment, the operation and maintenance of the tidal power plant and the use of marine-life-friendly tidal turbines.

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[2] The Tidal Grevelingen Project is a partnership between the provinces of South Holland and Zeeland, the municipalities of Goeree-Overflakkee and Schouwen-Duiveland, the Ministry of Infrastructure and Water Management, Rijkswaterstaat, the Ministry of Economic Affairs and Climate Policy, the Ministry of Agriculture, Nature and Food Quality and Staatsbosbeheer.

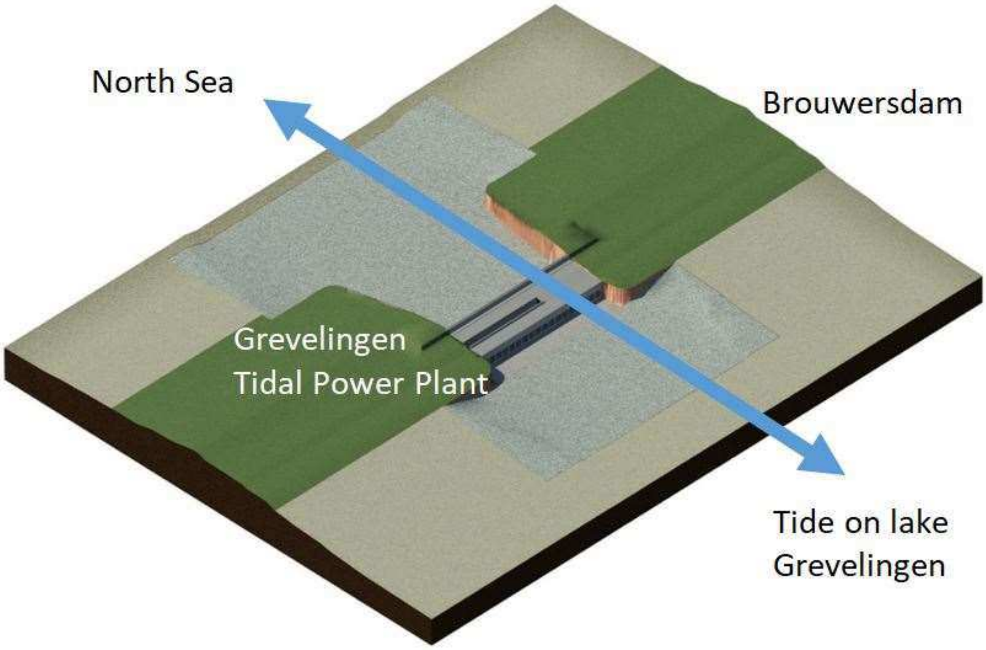

Figure 2: Impression of a flood barrier with tidal power plant

Process and status

In the plan development phase the public partners are seeking a private alliance partner, who will need to put the primary aim of the Grevelingen Tidal programme first and want to research the opportunities for power generation as a secondary priority. The public partners are organising the 2018 Market Consultation to gauge market interest.

This document will provide market players with insight into a feasible variant of a flood barrier with tidal power plant. It sets out the design and the business case for this variant. Market players are free to research, develop and install any other variant of such a tidal power plant, provided that it meets the objectives and requirements.

For the plan development phase following the MIRT 2-decision, the choice was made for a market approach in the form of an alliance with a clear division of tasks between the public and private partners. The purpose of this alliance is to work out the potential optimisations and required control measures. The duration of the plan development phase is limited to a maximum of two years. At the end of this phase, a go/no-go decision will be made (MIRT 3). In the event of a no-go, only the basic variant of the flood barrier will be constructed.

Available information

The version of the flood barrier with tidal power plant described here is based on the results from a Joint Fact-Finding process (2015) and an independent public feasibility study by EU project, Pro-Tide.

Some of the data in the Joint Fact-Finding process is confidential. The principles of the Pro-Tide variants were tested during the feasibility study, as described in the report from the precompetitive phase.

In 2016, the estimate for the flood barrier produced a cost price with a variation coefficient of 24%. Partly on the basis of this, the public Pro-Tide variant was modified. The optimisations arising from previous variants have partly been included in this business case. In addition, an opportunity and risk dossier has been drawn up.

A detailed summary of the results is available in the form of a fact sheet (Annex 4).

Conclusion

Broadly speaking, it has been concluded that the tidal power plant variant described in this document will return a profit of €8.8 million at an Internal Rate of Return (IRR) of 7.7%. This makes the business case potentially feasible given the set preconditions, circumstances, risk and opportunities and with a 30 cm rise in sea-level.

In order to achieve the project objectives in full, a consortium will be selected in the tender for the entire project, from the plan development phase up to and including construction and operation. Although a single contract, it will be split up into two phases with a clear go/no-go decision-making moment, after which it will be decided whether the contract form needs to be amended if it better suits the decision with regard to the following phase.

Continuation

The following step is to put the results of this variant into a market consultation this quarter and gauge the interest of the market players. Their reaction will be taken in to account in an MIRT 2-scope decision to be taken in early 2019. Optimisations and risk management will then be worked out in an alliance form in the plan development phase, following selection of an alliance partner. This will finally be determined during the transition between the plan development phase to the realisation phase.

1 Introduction

1.1 Background

The provinces of South Holland and Zeeland, the municipalities of Goeree-Overflakkee and Schouwen-Duiveland, the Ministry of Infrastructure and Water Management, Rijkswaterstaat, the Ministry of Economic Affairs and Climate Policy, the Ministry of Agriculture, Nature and Food Quality and Staatsbosbeheer[3] wish to improve the water quality in Lake Grevelingen. This is achievable by constructing a flood barrier in the Brouwersdam, which currently forms a barrier between Lake Grevelingen and the North Sea. A flood barrier would mean the limited reintroduction of tides to Lake Grevelingen. A tidal range no more than 50 cm around a median NAP level of -0.20 m would be enough to improve water quality. This plan is included in the concept version of the Grevelingen and Volkerak-Zoommeer Government Development Plan (2014).

Building a flood barrier in the Brouwersdam will offer opportunities for generating tidal power. The construction of a tidal power plant in the flood barrier will add a renewable energy component to the project.

In 2016 the cost of the limited reintroduction of tides to the Grevelingen was estimated to be about €139.5 million (whereby no account was taken of any rise in sea level). This consists of the costs of a flood barrier (€118 million) and for mitigating environmental and other measures (€21.5 million). The environmental measures are needed to mitigate the effects of the tides on the water barriers, shipping, recreation and wildlife in and around Lake Grevelingen, either by making them manageable or by minimising them.

The results of the cost estimate were shared in a letter to the Lower House (Lower House 2016, ref. IENM/BSK-2016/284609). The additional resources requested, which amount to €75 million were made available in the Nature and water quality package in the Rutte III Coalition Agreement (letter: TK IenM/BSK-2018/41968).
This will provide sufficient financial cover – in addition to the resources previously pledged by the state and the region – to be able to implement the development perspective from the concept Grevelingen and Volkerak-Zoommeer Government Development Plan.

In 2014, the Brouwersdam Tidal Power Plant Project Agency had already looked into the feasibility of such an integration. The results were recorded in the report of the 2015 precompetitive phase. Some of this information is in the public domain. In 2015 the project agency and the European Interreg NWE project 'Pro-Tide' worked together to develop a public reference variant and business case. The whole of this business case is in the public domain.

In 2018 the Grevelingen Tidal Project team modified the 2015 business case, based partly on the insights gained from the design of the flood barrier in 2016. The updated business cases give market players and potential investors/financiers

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[3] Henceforth in this document, the partnership will be referred to as 'public partners'.

insight into a developed example of a feasible variant. The key figures in this business case have been included in a fact sheet (Annex 4).

The Grevelingen Tidal Project is currently working towards an MIRT 2-decision – which is expected to be taken – at the start of 2019. This decision will include one or more preferable alternatives, which will be worked out in greater detail during the plan development phase. Whether the tidal power plant variant of the flood barrier is included in the project scope depends partly on market interest, as market players themselves will be expected to come up with the additional investment to fund the operation and maintenance of the tidal power plant.

To prepare for an MIRT 2-decision, the Grevelingen Tidal Project is organising a market consultation to be held in the last quarter of 2018. This market consultation will help advise the public partners about which version of flood barrier(s) can be included in the scope of the MIRT 2-decision regarding the plan development phase. The objective of the Market Consultation 2018 is to gauge the interest of the market.

1.2 Market consultation objective

In the concept Grevelingen and Volkerak-Zoommeer Government Development Plan, the Cabinet opted in 2014 for the improvement of the water quality of the Grevelingen as a development perspective. The Ministers of IenW and LNV announced on 7 March 2018 that they would make €75 million available – in addition to the previously promised funds – for the construction of a flood barrier. This means that the financing has been completed and a restart can be made with the Grevelingen Tidal project. The goal is to achieve a resilient and robust ecosystem by reintroducing the tide.

To reduce limited tide, a flood barrier in the Brouwersdam must connect the Lake Grevelingen with the North Sea again. The basic principle is a tidal range of a maximum of 50 cm with an average center position of 0.20 m below NAP (current middle level). With the ministers' decision the funding of the public goals, as formulated in the concept Government Development Plan, has been secured.

The pledge by the region is to combine the flood barrier with a tidal power plant. In addition to generating sustainable energy, this offers opportunities for innovation and export. The national government wants the energy part to be financially budget-neutral and the operating costs conditionally covered. With the market consultation, the project explores whether and how the market is interested in taking a risk-bearing part of the energy part as a chance of success.

Among other things, the public parties are currently working on a Management Agreement to secure these formal aspects. In the plan development phase, the primary aim is an optimal balance between underwater and overwater nature. Secondarily, the chance of combining sustainable energy production with fish-friendly turbines in a catching opportunity.

The Steering Committee Grevelingen Tidal Power Plant has given the order to test the interest of the market and to make all public information of this variant available to the market. This assignment will be completed by the end of 2018 and taken into account in the MIRT 2-decision.

1.3 Status and decision-making process

The Tidal Grevelingen programme is currently in the final stage of MIRT 2-orientation phase. Within this context, a number of variants are being explored in accordance with the MIRT rules framework[4]. After the decision-making process the plan development phase will start and the taking of the MIRT 3 decision will be followed by the realisation phase.

The results of the market orientation will be used to test whether any market players really are interested in bearing the risk of developing and realising a tidal power plant. This is, after all, a precondition for a possible tender, whereby a flood barrier and the tidal power plant would be developed and realised as an integral part of the project.

Not all stated amounts and principles for this sample case of the tidal power plant variant bear the “decision” status. The decision on them will be taken in early 2019 during the transition (MIRT 2-decision) from the orientation phase to the plan development phase. The stated amounts and principles are therefore still subject to change.

1.4 Process of realisation and quality

The tidal power plant variant presented in this document is a choice out of several options. It serves as an example of a feasible variant but it does not exclude alternative variants. In working out this variant, a distinction has been made between the civil section (the tidal flood barrier at Lake Grevelingen) and the private section (the tidal power plant). The civil part will be publically funded. The market will be called upon to fund the private section.

The example presented in this document is based on the results of the flood barrier calculations and the business case from the 2015 Pro-Tide variant. The 2018 variant takes into account a 30 cm rise in sea level.

A hydro-energetic model was used to determine the potential amount of tidal energy, based on the objectives and the current assumptions (Annex 3). Then a design for the tidal power plant was made. Based on the design the quantities were determined and set out in a cost model. This model kept the civil and private sections recognisably separate.

The costs and the financial returns are input for the financial-economic model (business case). The process of realisation is illustrated schematically in figure 3.

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[4] https://www.google.nl/search?hl=nl&q=mirt+spelregelkader

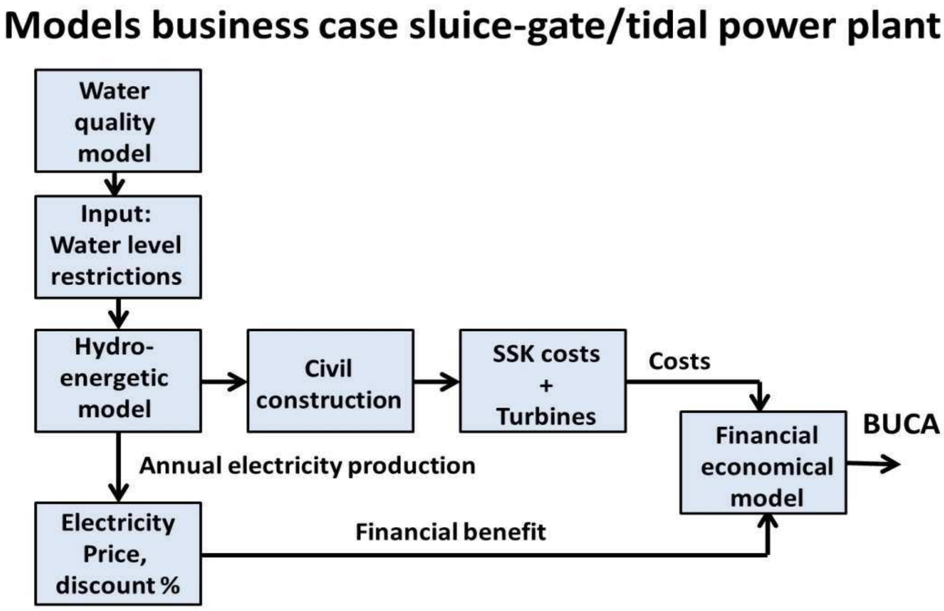


figure 3: Process of realisation (BUCA = business case)

The business case and underlying dossiers have been broadly tested by various internal and external experts, in line with a level of quality appropriate to an MIRT orientation phase. This will form the basis of an MIRT 2-decision.

Table 1: Summary of business case testing and underlying dossiers

Aspect	***Part***	***Testing body/bodies***
Water quality and level management	Tide	Deltares
Hydro-energetic model	Through-flow and power generation	Deltares Entry
Technology and design	Water safety, stability and discharge coefficient	Horvat en Partners Rijkswaterstaat Cubiqsquare Deltares
2015 Risk and Sensitivity analysis	Cost drivers	Horvat en Partners
Costs and risks	Risk dossier	Rijkswaterstaat Horvat en Partners Entry (energy part)
Business case and financial parameters	Feasibility and financial viability	Province Zuid-Holland Rijkswaterstaat Entry
Testing of variants in market approach	Market approach to tidal power plant	Rijkswaterstaat CRS Consultancy Allen&Overy

1.5 Guide

This document provides an extensive, detailed description of the tidal power plant variant of the flood barrier. Together with the 2018 Market Consultation Procedure report, this document forms the basis for gauging interest among market players.

This introduction sets out the ambitions, goals and functionalities. Chapter 2 addresses the aspects of underwater and surface wildlife, the Water Framework Directive (WFD; Dutch: KWR) and Natura 2000 (N2000). Here too, the relationship with the principles for the design is set out. Chapter 3 deals with the sample design and explains the mitigating measures in broad terms. Chapter 4 outlines the costs of the flood barrier and the additional cost of the tidal power plant. Chapter 5 describes the business case of the tidal power plant variant, based on the design principles and the costs set out in the preceding chapters. The object-specific risks and opportunities are set out in Chapter 6. Further explanation of the market approach is included in Chapter 7.

In the annexes you will find a list of abbreviations used (Annex 1) and a list of reference publications referred to in this report (Annex 2). Annex 3 sets out the principles and considerations for the ambitions relating to Lake Grevelingen and Annex 4 is a fact sheet showing the key results.

The Grevelingen Tidal Project team has been wary about making information available. Only information required to answer the main question in the market consultation has been selected. By doing so, the team aims to limit the workload for the market players at this stage.

2 Wildlife and Water Quality Ambitions

The Grevelingen Tidal project is preparing a decision about the project scope. This chapter describes the steps taken so far, how the involvement of the market is seen and which timeline is foreseen.

2.1 Main objective

The main objective of the project is the restoration of a resilient and robust ecosystem in Lake Grevelingen. This can be achieved by sustainably improving the water quality of Lake Grevelingen. To do so, it is necessary to reintroduce tides to a limited extent. This will lay the foundation for a futureproof Grevelingen, where first-rate wildlife is closely linked with a powerful economy.

This objective fits in with the ambition for the programme-based approach to the ecology of large bodies of water and is included in the letter from the Ministers of Infrastructure and the Environment and the Ministry of Agriculture, Nature and Food Quality to the Lower House (IenM/BSK-2018/41968). On 8 March, both ministers ratified this in a meeting at the Brouwersdam by making an additional €75 million available. This means the funding for a flood barrier has been agreed. By so doing, the ministers have indicated their intention to take the first significant step towards realising the ambition for the large bodies of water.

2.2 Programme-based approach to the ecology of large bodies of water (Dutch: PAEGW)

By implementing the Grevelingen Tidal programme, the state is fulfilling the legal obligations arising from Natura 2000 and the Water Framework Directive. By clarifying the relationship between ecological water quality, integrated wildlife-related obligations and spatial dynamics in the Grevelingen, it must be possible to set priorities and choose a strategy for the final implementation at the end of the plan development phase.

Strategies

Two strategies are central to making the wildlife (above and below water) in the Grevelingen more robust.

1. Restoring connections

   The most significant strategy is the restoration of the connections between the estuaries and the adjacent areas, not least to absorb climatic effects. There are various ways of establishing connections. By connecting Lake Grevelingen with the surrounding bodies of water by flood barriers, the tides will, to a limited extent, return to it. Tides are key to reintroducing dynamics as a basis for a healthy food chain. The nutrients and oxygenation in the Grevelingen would then provide a favourable starting point for a resilient ecosystem with scope for the development of wildlife values under the influence of tides (estuary area). The banks of the basins and the islands provide the opportunity for developing a littoral zone.

With an ingeniously attenuated tide, the tidal dynamics (vertical flow) can break through the stratification. This will help restore order to the oxygenation of the lake. The tidal dynamic can also help restore the habitats, which would easily allow a slight sand hunger to be absorbed.

There would also be sufficient flow and refreshment (horizontal flow) for ecological recovery of seabed life. In addition, attenuated tides will postpone the moment at which the discussion needs to be held about the long-term viability of the Delta Works as a consequence of the anticipated rise in sea levels.

The original situation - an estuary with the corresponding high flow rates - will be partially restored. As the connections will be ‘limited’, the slight sand hunger that currently exists in the Grevelingen is expected to be increased to a limited extent. It would be wise to pay attention to this when developing the connections.

2. Developing and restoring habitats

The active restoration and development of habitats will help create robust wildlife. This will help in habitats where restoration is no longer viable using natural processes alone. Sometimes, it can be done in addition to other measures and sometimes as the only option to do something about restoration. The measures could bring about typical estuary wildlife in the transition area between salt to freshwater, such as new littoral zones, brackish water zones and shallow water zones.

New bird islands and additional shorelines (in conjunction with intensive management) could be effective and essential to the improvement of breeding grounds. This would reinforce what is already happening in the Grevelingen.

Just as in the Oosterschelde, sand suppletion will be required to preserve the mudflats and sandflats in the long term. One the one hand, this is due to sand hunger and on the other hand it is to allow flats and islands to grow in future as the sea level rises when the level of the Grevelingen is adapted accordingly.

2.3 Status of the principles for wildlife and water quality

The latest insights (September 2018) into the objectives for wildlife and water quality and the possible effects of limited tides on these are described in Annex 4 covering principles and considerations. These are guiding principles for the design of the various variants. In essence, it concerns the right balance between the required tidal action on the one hand and the adverse effects of restored tides on the other. The required tidal range, expressed as the number of cm of tide required for a resilient system with good water quality, is measurable by reducing the lack of oxygen near the seabed and underwater wildlife. In the event of adverse effects, the issue is making sure the consequences on the coastal wildlife in the transition zone between low and high tide remain manageable. The legal obligations arising from the Natura 2000 Directive must be taken into account. The increase in the size of littoral zones will be beneficial as it will serve as a foraging site for waders and coastal breeding birds, provided that any negative effects on the existing Natura 2000 values are mitigated and/or compensated.

This means that during the plan development phase, a balanced consideration of the objectives, the setting of the tidal range and the period in which a particular tidal range is maintained will be sought in coordination with the stakeholders. The ecological objectives are the main priority with the wishes relating to the generation of renewable power taking second place.

Summary of Ecological Aims of the Grevelingen Water System

- Promote WFD conservation objectives by increasing the resilience of the system by reintroducing attenuated tides.
- Improve the habitat and diversity of species.
- Promote better prospects for salty habitat types, waders (benefit from littoral zone), seals, etc.
- Prevent adverse consequences for higher-lying ‘freshwater' habitat types and plants such as dune valley vegetation and the Red List species lady’s tresses (*Spiranthes spiralis*) and green-winged orchid (*Anacamptis morio*).
- Prevent adverse consequences for Natura 2000 habitat types and plants that depend on fresh groundwater and are partly affected by salt water as a result of tides (wet dune valleys and fen orchid (*Liparis loeselii*)).
- Preventing adverse consequences for salt marshes and salty grasslands close to the water because this habitat type cannot withstand daily flooding. Higher up, the introduction of tides will improve the quality of the habitat type because in the autonomous situation gradual desalination takes place. In the short term, the effect is negative. For the long term (after 2035) we cannot currently predict whether tides will result in greater, smaller or similar areas of salt marshlands and saline grasslands compared to the autonomous situation. This depends on local elevation and the extent of desalination in the autonomous situation, and it will require further investigation in a subsequent phase.
- Prevent adverse effects for coastal breeding birds whose breeding sites will be flooded by the tide and therefore disappear if additional measures are not taken.

3 Sample design

This chapter deals with the design aspects of the tidal power plant variant derived from the objectives and principles set out in chapter 1 and Annex 4. The dimensioning of the tidal power plant is based on the results of the hydro-energetic model. The working out of the details is based on normative design aspects from the Grevelingen water system, the characteristics of Lake Grevelingen and the functions and requirements of the tidal power plant.

3.1 Introduction

The design concerns a flood barrier in the Brouwersdam combined with turbines for the generation of sustainable power. The design is both the starting point for the market consultation and an example in a variant investigation running up to an MIRT 2-decision. The design will be fine-tuned in the plan development phase. Market players are of course free to come up with any other variant that meets the preconditions and fits within the target budget for a flood barrier and the corresponding mitigating measures.

The dimensioning will be based on the results of the hydro-energetic model. As such the design will provide insight into the numbers and amounts, such as how many cubic metres of concrete will be used. This data was used for the cost estimate set out in chapter 4.

The following table shows the key input and output parameters for the hydro-energetic model. These parameters form part of the delivery specification information that the data exchange between the different models specify (e.g. hydro-energetic model, design (Building Information Model), business case and standard system for estimates [Dutch: SSK-kostenraming]). The delivery specification information was drawn up for internal use only.

Table 2: Input and output parameters for the hydro-energetic model

Input for the hydro-energetic model		
Average tidal range (Grevelingen)	40	cm
Average level (Grevelingen)	-20	cm NAP
Maximum water level (Grevelingen)	+5	cm NAP
Permissible overshoot (Grevelingen)	1	%
Minimum level at Grevelingen	-45	cm NAP
Permissible undershoot (Grevelingen)	10	%
Sea level rise	+ 30	cm
North Sea Tide	Brouwershavense gat08[5]	Datafile
Design of the tidal power plant	Prismatic, parallel ducts measuring 8 x 8 m^2, discharge coefficient 1.1	-

[5] Brouwershavense gat08 is a Rijkswaterstaat monitoring site that records water levels. It is on the North Sea side of the Brouwersdam, slightly to the west of the Brouwers Sluice.

Output for the hydro-energetic model *(is input for the design)*		
Number of ducts	18	-
Number of ducts with turbines	11	-
Power generated	60	GWh
Max. supplied power	25	MW

The following calculations and steps have been performed for the design of the flood barrier:

- Identify the desired functions and requirements
- Calculate the discharge coefficient for two flow directions
- Calculate the storage basin and flood barrier profile requirement
- Work out design drawings for flood barrier (RWS 2018)
- Calculate seabed protection
- Calculate most important mitigating measures
- Determine quantities via construction phases

The above steps and calculations refer to documents. They have not been included in the reference list, partly because they concern confidential business information (cost indicators) and partly to limit the size of the dossier at this stage.

Grevelingen Water System

The figure below illustrates the boundaries of the Grevelingen water system:

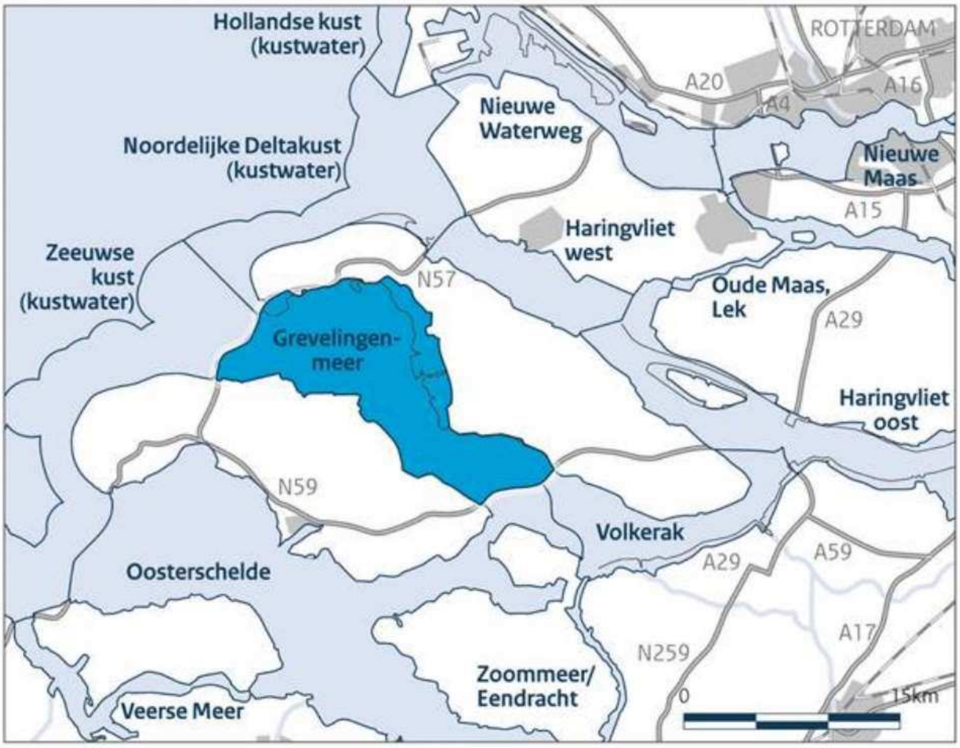


Figure 4: Grevelingen Water System boundaries

The tables below illustrate the key aspects and specific dimensions of Lake Grevelingen.

Table 3: Description of the plan area

Description of the area	***Saltwater lake***
Boundaries	The lake is enclosed by Goeree-Overflakkee, Schouwen-Duiveland, the Brouwersdam and the Grevelingendam
Delta works	Construction of Grevelingendam in 1965 (damming the river system) followed by the Brouwersdam in 1971 (damming of the North Sea)
Consequences of damming	From original estuary zone (transition zone between sea and river, characterised by daily tidal action) through damming to initially a freshwater lake which then became a permanent saltwater lake after commissioning of the Brouwers Sluice in 1978.
Sluices	Grevelingen Sluice (shipping), Brouwers Sluice (discharge sluice), Flakkee Discharge Sluice (opening permanently in 2019)
Discharge	Through the Brouwers Sluice into the North Sea and through the Flakkee Lock Gate connection into the Oosterschelde
Tides/flow	No tides, a target level of 0.20m-NAP is retained
Salt content	The aim is at least 16g Cl/l (flow through)
Landscape	Lake Grevelingen is a varied nature reserve, characterised by calm and space. The picture is one of hamlets, holiday villages and stretches of dry land along delta dams and erstwhile sea dikes. In the lake itself, there are three large flats flanked by a dozen smaller islands
Cables/pipelines	In the eastern part, two high-voltage power cables and a gas flood barrier cross the area
Manager	Rijkswaterstaat (Water Management) Forestry Commission (wildlife and recreation areas)
Management	Wildlife management: grazing (on all mudflats and various sandflats), mowing (Hompelvoet and occasionally on other flats), do nothing, restricted opening Rijkswaterstaat Service Zeeland, Northern district manages water level, ports, waterways, water defences/structures etc.
Adjacent water systems	Krammer-Volkerak, Oosterschelde, North Sea

Table 4: Specific dimensions of Lake Grevelingen

Total surface area	***14,000 ha***
Surface area of marshes	3,120 ha
Greatest depth	48 m
Average depth	5.4 m

Summary of tidal power plant

At the centre is the flood barrier in the Brouwersdam in which a tidal power plant has been built. The following is a summarised description of its origins, the choice of location, the measurements and its operation. This anticipates the reasoning behind the design.Herkomst ontwerp

Origins of the design

The basic principle is a tidal range of no more than 50 cm. To determine this tidal range, historic water levels on the North Sea have been entered into a simulation model. In this design, the tidal power plant variant from the 2015 Pro-Tide study was selected as starting point. This version incorporates the design experience of the 2016 flood barrier and takes account of the sea level rise.

Choice of location

The Brouwersdam consists of a northern and southern part on both sides of the Kabbelaarsbank. In view of a number of impediments in the southern and central part of the Brouwersdam, a flood barrier is being built in the northern part of the dam.

Figure 5: Site of the tidal power plant in the Brouwersdam Measurements and operation

Input is the water level on the North Sea ("Brouwershavensegat 08") on a 10-minute basis. Using a flow coefficient of 1.1 in the flood barrier (Deltares 2018) and tidal turbines (Meijnen 2015) the resulting change in water level on Lake Grevelingen is calculated, assuming the lake has a constant surface area of 110 km^2 (storage basin model).

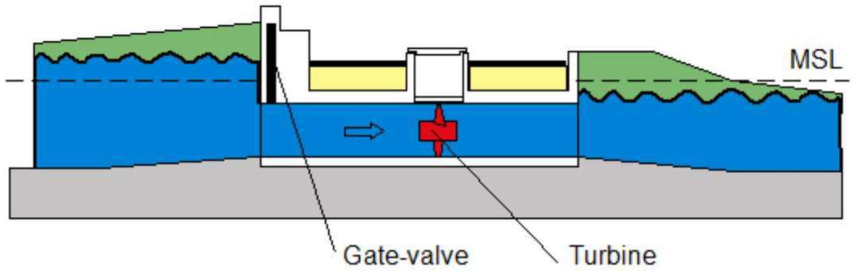


Figure 6: Schematic cross-section of the tidal power plant

The required size of the tidal power plant is determined by the situation with a 30 cm rise in sea level. After all, the water level of the North Sea is very skewed compared to the water level in Lake Grevelingen. Outflow into the sea in particular will require a large flood barrier. The calculation shows 18 ducts (1,152 m^2), 11 of which will be fitted with turbines that will generate electricity as the tide rises. As the tide goes out, the turbines will turn freely (without producing electricity), the blades will be in the vane position or lifted clear of the water. The level in the lake will be achieved by a combination of sluice gate setting and controlling the resistance of the turbines. As the tide comes in, a number of ducts can be closed as needed.

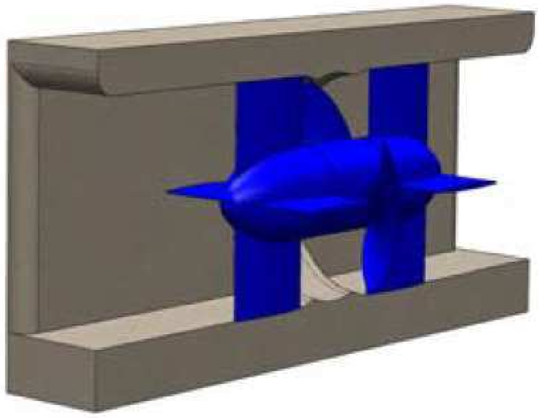


Figure 7: Example of turbine in rectangular flood barrier

Figure 7 shows a turbine in a rectangular flood barrier (also known as 'ducted'). The turbine is enclosed in a ring that when placed in a rectangular duct causes the water to flow along the turbine to prevent any loss through leakage.

In the period when the sea level rise of 30 cm is exceeded, a modest modification (supply of electricity) will allow the power plant to be used as a pump plant, so that the water level requirements can be met for a longer period (beyond 2050). This will result in a more climate-robust flood barrier, which will serve the interests of agriculture, Natura 2000, fisheries, recreation and ports.

Functions and requirements

The objectives and the principles (Annex 4) and wishes that stem from them have been translated into functional specifications that will result in the design of the flood barrier and the mitigating measures. A tidal power plant in the Brouwersdam will have to perform the following key functions:

- Protect the hinterland against high water
- Manage saltwater
- Provide enough water
- Provide clean and healthy water
  - Offer water of a basic quality
  - Offer free passage to fauna
  - Offer (restored) habitat
- Accommodate shipping
- Operational functions
  - Facilitate wildlife
  - Facilitate recreation
  - Offer water to fishing industry and anglers
  - Offer cultural history and landscape value
  - Handle road traffic
- Safeguard economic potential

Due to the impact of the flood barrier on the environment, mitigating measures are required. These have now been broadly decided and will be worked out in greater detail in the plan development phase.

The required size of the flood barrier/tidal power plant depends on the demands in respect of the water level variation on Lake Grevelingen. The basic principles (see Annex 3) will form the basis. A decision on the water level has not yet been taken.

It should also be noted that the demands in respect of the water level management apply during normal operation of the flood barrier/tidal power plant. They will not apply under conditions such as extraordinary water-level setting measures, extreme weather conditions and maintenance of the flood barrier/tidal power plant.

3.2 Principle of design and operation of the tidal power plant

The most important considerations regarding the design are:

- A flood barrier in the Brouwersdam has been shown to be the most effective measure for improving the water quality in Lake Grevelingen. This was shown in the 2011 MIRT Exploration.
- An attenuated tide of approx. 50 cm is considered to be sufficient to improve the water quality to the required level (Deltares 2011).
- The design variant put forward by Pro-Tide/IV Infra in 2015 was chosen. This variant consists of a flood barrier featuring parallel ducts with internal dimensions of 8 x 8 m. The ducts can be closed off by vertical rising sluice gates on the seaward side and can be fitted with large turbines to generate renewable power. The number of parallel ducts is to be determined by the water-level requirements using a hydro-energetic calculation.

Whether or not it is fitted with a tidal power plant, a flood barrier in the Brouwersdam will have to produce an attenuated tide in Lake Grevelingen. This means that at every high tide on the North Sea, an amount of water, equal to the (average) surface area of Lake Grevelingen multiplied by the required tidal height (50 cm) must be allowed to pass through. However, this also means that virtually the same amount of water must be discharged every time the tide goes out. This means approximately 55 million m^3 having to pass back and forth through the flood barrier twice a day.

The height difference between the North Sea and Lake Grevelingen will cause the water to flow in and out. As soon as the water level on the North Sea is higher than that in Grevelingen, water can be let through the flood barrier. The level of Lake Grevelingen will then rise. Once the North Sea tide turns, the sea level will drop and reach a point where it is lower than the raised level of Lake Grevelingen, allowing water to flow back out through the flood barrier.

As the average water level in the Grevelingen is lower than it is on the North Sea (average 0.20 m below NAP) the drop when the water is let in is greater than it is during outflow. Therefore, a smaller flood barrier would be required to let water in than would be needed to let the same volume of water flow out. This is known as the 'skew' of the flood barrier operation. As such the outflow is what determines the required flood barrier size, although this size needs to be restricted when water is flowing into the lake. If this were not done, so much water would flow in that it could not be discharged in time.

There are three ways of restricting the flood barrier size when letting water flow into the lake at high tide:

- Some of the ducts are fully closed off, for example by vertical rising sluice gates, so that water can only flow in through the remaining open ducts, while all the ducts are opened during outflow. These vertical rising sluice gates are necessary anyway to comply with water safety requirements. In the event of extreme weather conditions (e.g. storms) it must be possible to shut off the flood barrier entirely, as is the case with the Oosterschelde storm surge barrier.
- All ducts can be partially closed so water can flow in under the half/partially closed vertical rising sluice gates. As water is let in, the flood barrier openings are therefore 'pinched', whereas during outflow the sluice gates are fully opened.
- Instead of pinching the ducts with sluice gates as water is let in, the size of the flood barrier can be restricted by the introduction of the inhibiting operation of tidal turbines. The turbines take the energy from the water flowing in through the flood barrier so that the remaining flow energy is used to allow exactly the same volume of water to flow in as the volume that has to flow back out again

Although the sluice gates can virtually only be set as the tide turns, the turbines can be continually adjusted according to the amount of inhibiting action required in the flood barrier. This makes the tidal control more flexible and less dependent on forecasting. As such, the tidal power plant offers a significant added value in terms of accurate water-level management.

Although sea level rise is a fact, we cannot yet be sure how fast it will be. As far as this subject is concerned, looking beyond a rise of up to 30 cm is of no use because the climate scenarios will diverge even more in future. It is for this reason that the choice was made to take a 30 cm rise in sea level into account. The rate at which this rise takes place, or how many years it takes for the sea level to rise by 30 cm has not been established here. It may be assumed that this will be the case in 30 years' time; in other words, a rise of 1 cm per year.

3.3 Hydro-energetic modelling

The hydro-energetic model of the flood barrier/tidal power plant under discussion here is based on the model developed in the EU Pro-Tide project (Van Berkel 2015). The model calculates the flow through the flood barrier/tidal power plant and power generation based on the resistance coefficient and the North Sea and Lake Grevelingen water-levels snapshot.

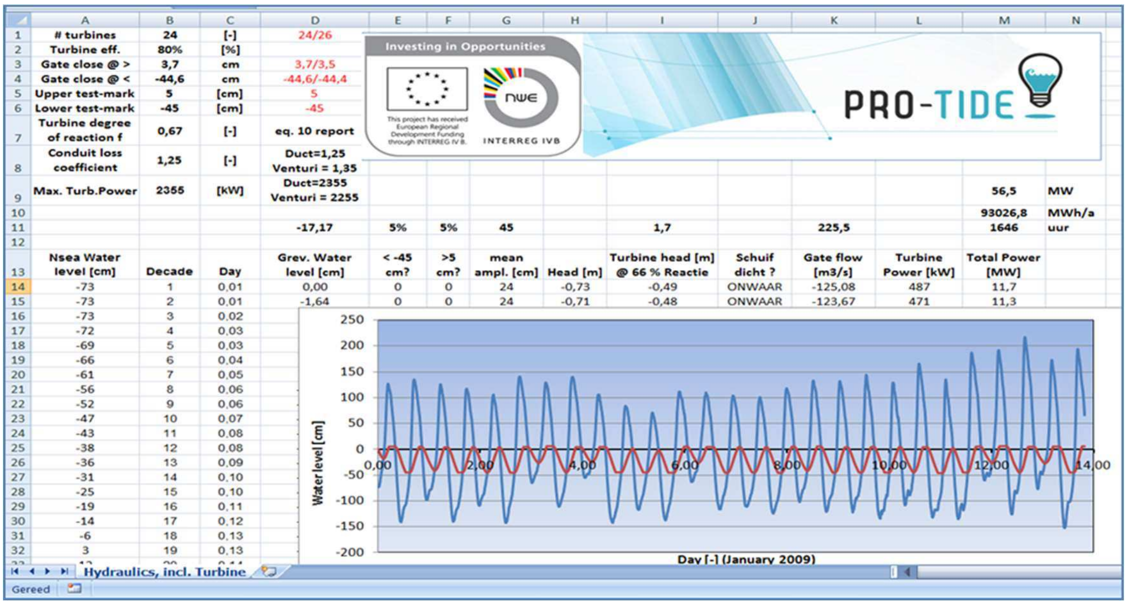


Figure 8: Screenshot of the hydro-energetic model (Microsoft Excel)

At the heart of the hydro-energetic calculation of the flood barrier/tidal power plant is the calculation of the speed water flows through the ducts, which is dependent on the water levels in the North Sea and on Lake Grevelingen (Berkel 2015, referring to Meijnen 2015). For further details on the hydro-energetic model, please refer to RWS 2018, Background document, business case for Brouwersdam Flood barrier/Tidal power plant.

In the model, regulating the maximum water level is effected with sluice gates (closed off if water reaches an extreme level). This is a simplification of what actually happens, where (it is anticipated) the water level will be regulated using the resistance of the turbines, possibly in combination with opening/closing of vertical rising sluice gates as the tide turns. It is also assumed that it will not be possible to set these sluice gates when the tide is not turning but that a continuously variable response (resistance) can be set instantaneously to fine-tune the operation. This type of adaptive fine-tuning has not been included in the calculation model.

Depending upon...
1. number of ducts in the flood barrier/tidal power plant,
2. optional: number of ducts fitted with turbines,
3. response rate (resistance) of the turbine,
4. setting the maximum and minimum water level for closing the sluice gates,

... the hydro-energetic model shows the...
1. average tidal range on Lake Grevelingen,
2. average water level of Lake Grevelingen,
3. the minimum and maximum water levels (including deficits or surpluses),
4. average tidal flow,
5. Annual power generation.

In the 2015 version and the version used in 2018 the model was checked for consistency and accuracy by Deltares and approved for the purposes of this study (Kleissen 2015, Kleissen 2018).

Dimensioning the tidal power plant

Input is the water level on the North Sea (monitoring site: 'Brouwershavensegat 08') at 10-minute intervals. Using a flow coefficient of 1.1 in the flood barrier (Deltares 2018) and tidal turbines (Meijnen 2015) the resulting change in water level on Lake Grevelingen is calculated, assuming the lake has a constant surface area of 110km^2 (storage basin model).

The required size of the tidal power plant is determined by the situation with a 30 cm rise in sea level. After all, the water level of the North Sea is very skewed compared to the water level in Lake Grevelingen. Outflow into the sea in particular will require a large flood barrier. The calculation shows 18 ducts (1152 m^2), 11 of which will be fitted with turbines that will generate electricity as the tide rises. As the tide ebbs, the turbines will turn freely (without producing electricity), the blades will be in the vane position or lifted clear of the water.

In the number of ducts, account has been taken of the design agreements such that:

- the required number of ducts is rounded down to the nearest 0.2. If the remainder is more than 0.2, then the total number of ducts is rounded up. This was chosen to prevent significant additional costs in the form of an extra duct as soon as the calculated number of ducts came out at just above a whole value,
- the existing Brouwers Sluice counts as one and its operation is considered to be the equivalent of one 8 x 8 m duct. The calculated requirement minus one duct is therefore the number of ducts in the new structure.

If the flood barrier containing 18 ducts is realised at the start of the project (at a 0 cm sea level rise), then this would be a case of over-dimensioning. At the start, the large flood barrier can be used to serve several purposes.
1. Make use of the maximum tidal range of 50 cm (N.B. in practice, a 50 cm tidal range amounts to an average of just 40 cm due to having to eliminate the effect of higher water levels on the North Sea, e.g. Spring Tide, wind etc.) in order to optimise the oxygen content and therefore the water quality.

2. Generate tidal power as the tide comes in and goes out, with:
    a. turbines installed in all ducts (some of which are gradually removed as the sea level rises), or
    b. starting out with just 11 turbines.

This study does not look into which of the variants offers the best implementation strategy for operating the flood barrier at 0 cm to 30 cm sea level rise. This optimisation will be included in the subsequent plan development phase. The business case in this report is based on the possible tidal power plant in a worst case scenario of a 30 cm increase in the sea level. It is seen as a worst case scenario because at high tide the water flows in too easily (which means the flow needs to be pinched) whereas when the tide is going out it will not be able to flow out quickly enough.

One option is that the installed turbines can be operated as or be replaced by pumps. This means the attenuated tides and the median water level in the Grevelingen would remain possible even after a sea level rise of 30 cm.

In summary:

1. In order to comply with the basic principles (incl. a 30 cm sea level rise) 18 ducts are needed in the flood barrier (average annual tidal range of 40 cm).
2. This 18-duct flood barrier can included 11 turbines that only generate power as the tide is coming in.
    This tidal power plant:
    a. will require – at the given sea level – a structure of the same size as a flood barrier,
    b. will convert hydraulic energy into electricity – it would otherwise be dissipated by positioning vertical rising sluice gates (i.e. converting the energy into heat).
    c. will require additional investment in turbines rather than a larger structure.
3. The tidal power plant is dimensioned according to a 30 cm sea level rise. Prior to the period of sea level rise and with a view to a future sea level rise, the budgeted flood barrier can:
    a. be set up as a resource which would initially achieve a greater tidal range, resulting in a quicker and more effective improvement of the water quality in the Grevelingen, or
    b. be used alternatively as a bi-directional tidal power plant.

    Both versions are optional and not worked out in greater detail in this study.
4. In the period when the sea level rise of 30 cm is exceeded, a modest modification (supply of electricity) will allow the power plant to be used as a pump plant, so that the water level requirements can be met for a longer period (beyond 2050?). This will result in a more climate-robust flood barrier, which will serve the interests of agriculture, Natura 2000, fisheries, recreation and ports. This added value would need to be fine-tuned in an MKBA (Social Cost-Benefit Analysis).

Principles used in sample design

The following principles were used in the sample design:

- Structure to be built on dry site (using a construction pit) due to the expected higher costs of building under water (as with caissons).
- Single sluice gates will meet water safety standards, provided they close of the duct under their own weight if the drive were to fail. It is for this reason that vertical rising sluice gates have been chosen.
- Intelligent control of the sluice gates is needed, by using them to shut off (or pinch, i.e. partly close) the ducts, to meet the required variation of water level in Lake Grevelingen. The installed turbines could also have the secondary function of helping to manage the required water level.
- Twin operating and control systems will avoid the issue of two adjacent vertical rising sluice gates failing to close, enabling the seabed protection to be carried out with less effort.
- In emergencies a vertical sluice gate can be lowered under its own weight as the tide turns. The operation of the vertical rising sluice gates, in particular the failure probability analysis, still needs to be worked out in greater detail.
- Seabed protection measures will have to keep erosion pits away from the structure under regular operational conditions and in the event of one sluice gate failing to close at normative high water levels.
- The seabed protection in a tidal power plant is the same as it is in a flood barrier without turbines.
- No groynes are considered necessary on the seaward side.
- It must be possible to carry out dry inspection of the ducts.
- The length of the ducts is based on the profile of the current traffic measures at 45 m nominal width with an additional 4 m for the sluice-control room.

The main features of the design

The design consists of 18 concrete ducts each measuring 49 m and having internal dimensions of 8x8 m. If a tidal power plant is built, a turbine ‘box’ measuring 8x8x8 m can be placed in 11 of the 18 ducts. These boxes can be lowered through an opening and positioned in the middle of each duct.

The depth of the ducts is based on the correlation between the underpressure resulting from the high discharge coefficient and the prevention of air entrapment and cavitation.

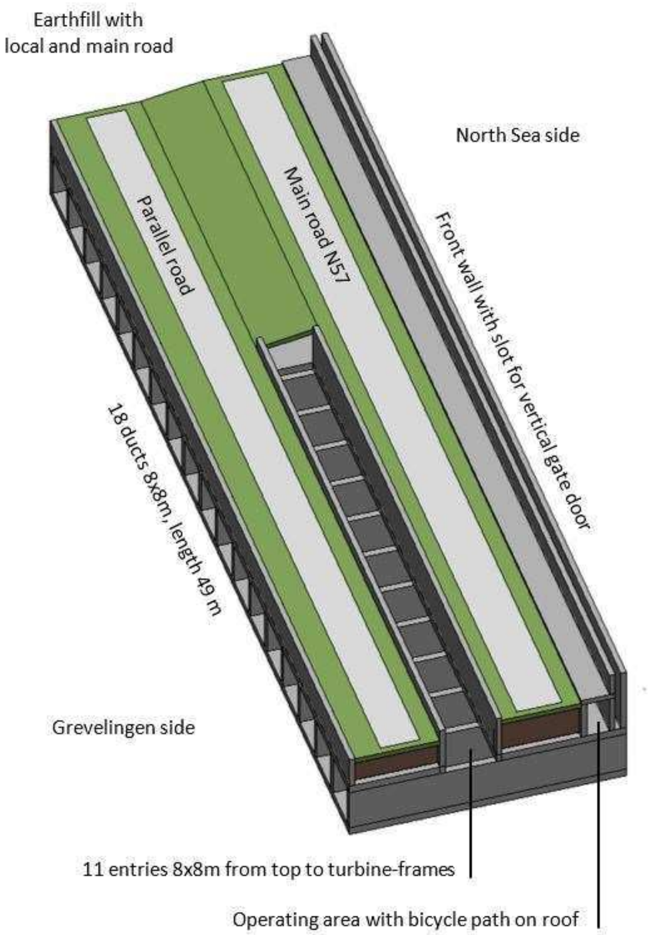


Figure 9: The structure of a flood barrier with tidal power plant in the location filled in with soil.

The location in the Brouwersdam

The choice of location for the flood barrier along the length of the dam was based on two criteria:

1. the available space in the Brouwersdam and
2. there is sufficient depth in Lake Grevelingen to enable the water to be exchanged as much as possible over the whole lake.

With regard to the cross section, the choice was influenced by

1. the presence of the N57 trunk road and the service road with tram rails and
2. the requirement that the horizontal alignment of the finished situation must not deviate from the current situation.

This has resulted in the funnel walls having an asymmetrical shape. An incidental advantage of this asymmetry is that the new structure will be sheltered by the crest of the Brouwersdam.

Heavy steel sheet piling has been chosen to bridge the height difference and to guide the tidal water flowing in and out. These will be placed against the ducts both on the North Sea side and the Lake Grevelingen side. These 'funnels' will guide the flow through a gradual narrowing into the structure and then with a gradual widening out of it again. This will create the proper discharge coefficient.

The effect will be boosted by making the (future) seabed gradually slope towards the bottom of the ducts.

Seabed protection is needed between the steel sheet piling (funnels) and further out towards the open water on both sides. The ducts on the seaward side can be closed off with vertical steel rising sluice gates.

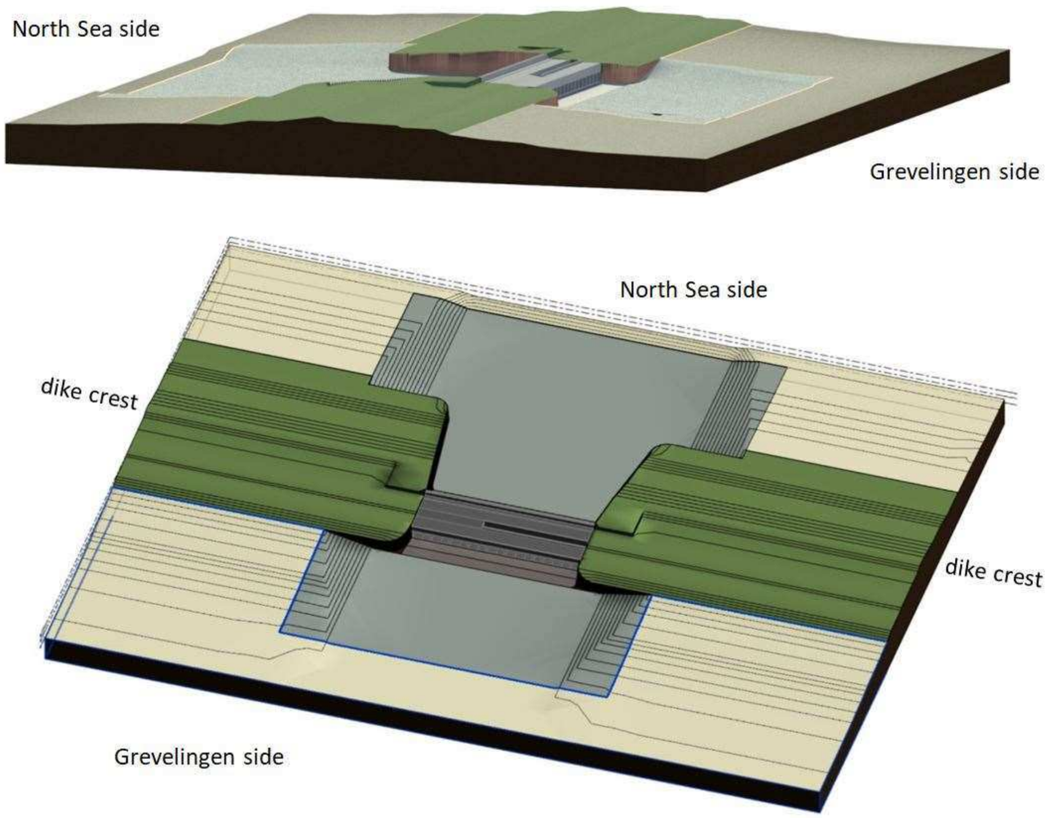


Figure 10: Location in the Brouwersdam.

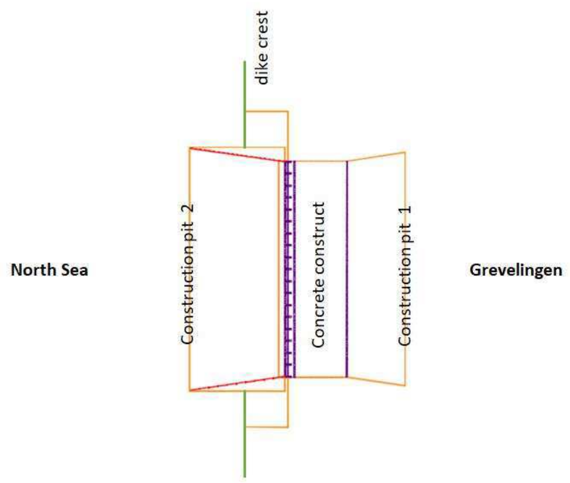
3.4 Construction method

Once preparatory work has been completed, the first step will be to create a temporary diversion. The main road and the service road will be diverted along appropriate asphalt curves onto earthworks built against the banks of the Grevelingen. In this phase, the cycle path will continue to run straight on along the crest and the recreation road on the seaward side will not yet be interrupted.

The existing road around the concrete structure of the flood barrier will be dug up. The ground level will be lowered by 2 to 4 m so shorter sheet piling can be used. On the Grevelingen side an anchored sheet piling wall will be erected to make ‘construction pit 1’. Inside this another 15 m layer of soil will be dug out. The end sheet piling will serve as formwork and later as a wing wall (funnel on Grevelingen side). Between the dike crest and construction pit 1 there is space for a temporary ‘site road’ along the structure. On the deep floor on the Grevelingen side, there is space left over for cranes, storage and dewatering.

On this dewatered deep floor, even deeper seepage screens will be placed, the structure and the seabed-protecting concrete slab will be built on the Grevelingen side. At this point soil will be placed over part of the roof of the flood barrier. This will serve as a weight to stop the ducts floating if one or more of them have to be closed at both ends and to create a replacement site road over the structure.

On the North Sea side, the structure's front wall reaches the height of the dike crest. Lowering the sluice gates means a replacement barrier can already be created. This will be supplemented by additional sheet piling at the height of the crest allowing the front wall of the replacement barrier outside the structure to connect with the continuous dike crest. This sheet piling will also serve as a seepage screen on the vertical sides of the structure. There will now be sufficient time and working space on the structure to install and set up the mechanical components of the vertical rising sluice gates and turbines, if applicable.

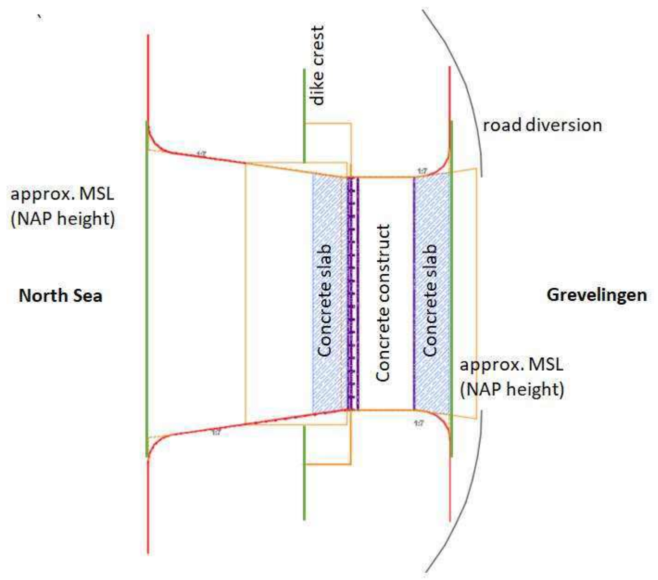


Now that a replacement barrier has been built, 'construction pit 2' can be built adjacent to construction pit 1 on the dike crest. Its purpose is to clear away the caissons and foundations beneath the dike crest. To do this the ground level will first be lowered by 4 to 9 me to limit the length of the sheet piling. Construction pit 2 forms a semi-circle that connects to the structure. In this phase, the cycle path on the crest will be temporarily closed and the recreation road on the seaward side interrupted.

Figure 11: Pit construction method

When building construction pit 2 we will try to connect with the existing caissons and the quarry-run stone foundation below them as tightly as possible. If necessary, the remaining gaps and the inside of the caissons will be generously injected with cement through holes drilled into the outer side of the construction pit. Afterwards, 15 m layer of soil will be dug out of construction pit 2 as well. The dividing sheet piling wall can be removed from construction pit 1 so the deep floor in construction pit 2 connects with the structure. The two construction pits can still be dewatered separately thanks to the closed vertical rising sluice gates.

From the dewatered deep floor, the caissons far outside the future sheet piling are disassembled and the quarry-run stone foundations below them removed for re-use. The sheet piling that will form the actual wings (North Sea side funnel) can be driven as far into the now cleared floor as possible. Due to the great retaining height of the crest, this will be a combination wall using tubular piles. The seabed-protecting concrete slab on the North Sea side can be laid against this. A 25 m strip of concrete slabs is built of rubble filled with colloidal concrete which can be laid on both sides in construction pits 1 and 2, in still dry conditions.



Four wing walls will form a funnel on both sides of the structure. They have to bring the incoming and outgoing tidal waters together gradually and let them calmly flow out. There is only limited length available for this purpose on the Grevelingen side, but on the North Sea side the wing walls will extend quite far out, at a ratio of 1:7. The sheet piling will be driven down until their tops are level with the water line at around NAP level.

Figure 12: Construction method for wing walls

Dry earthwork is limited to around NAP water levels. On the Grevelingen side it will scarcely be necessary to work with a crane. On the North Sea side, the construction pit can be deepened between the wing walls. The soil that is removed can be used to fill the excavations outside the construction pits.

The main road and the service road can be restored and run in a straight line over the structure. On top of the structure the whole ground surface can be asphalted for use as an area to erect maintenance cranes. Outside the structure, additional lanes can be laid between the main road and the service road, for example if needed for maintenance. The cycle path will be brought down from the crest (and back again) over the strip where the roof covers of the structure's control rooms are located. Alongside the service road space will be left for the narrow gauge track. Unless other requirements/principles are agreed, the recreation road on the seaward side will be permanently interrupted.

After the surplus sheet piling has been removed from the construction pits, the current channels on each side can be dredged out. On the Grevelingen side, this will mainly involve clearing the diversion and the foreshore. On the North Sea side, the old current channel has silted up. This will have to be dredged out again. Afterwards there will be a flat seabed on both sides and space will be created for eddies outside the wing wall funnels.

The wet groundwork will be carried out to the depth of the bottom of the rubble that is to be deposited. This rubble will reach around 150 m beyond the funnels and also protect the slopes from the eddies along the sheet piling walls. Ballast stone will be thrown onto a fascine and covered in rubble, jointly forming a layer of about 1 m thick. Wherever necessary, colloidal concrete will be poured into the rubble. This will create a floor 13.0 m below NAP. The incoming and outgoing tidal flows will be guided over the floor of the structure along slightly inclined concrete slabs to 11.15 m below NAP. Past the ends of the deposited rubble, erosion pits will form, taking shape until the flow and the sand bed are in equilibrium.

The finishing work includes making the connections in the soil and dike facings, traffic measures and facilities for installing two reserve vertical rising sluice gates.

3.5 Result of sample design

The hydro-energetic model of a flood barrier with tidal power plant has resulted in 18 ducts being required, 11 of which will be fitted with turbines (Berkel 2018). Details of the design results are included in the reference RWS 2018, GCBD Background document reference drawings v2e Sept 2018. This file consists of the following components:

- Quantities and most relevant design calculations
- 9 Auto CAD drawings
- 16 Revit rendered sketches
- Operational steps for the ground work

A summary of the most important quantities needed for the realisation of the work is presented in the table below.

Table 5: Summary of necessary volumes per section of work

Part	Post	Numbers	Unit
Excavation	Dry excavation	820,000	m^3
	Wet excavation	900,000	m^3
	External addition	110,000	m^3
	Addition from depot	130,000	m^3
Concrete	Bedding	1,700	m^3
	Reinforced concrete	51,000	m^3
	Total formwork	28,000	m^2
Mechanical	vertical rising sluice gates net 8 x 8m 18 items	900	ton
	Ditto spare/divisible 2 items	100	ton
	Turbine generators 11 items	p.m.	
	Connections, cables, software	p.m.	
Sheet piling	Installation	2,000	m
	Installation <25m	31,000	m^2
	Installation <40m	11,500	m^2
	Any re-use	13,000	m^2
Other	Permeable surfacing/underlayers	11,000	m^3
	Laying asphalt (NB m^3)	5,700	m^3
	Asphalt/bituminous drainage	9,400	m^3
	Laying rubble (NB m^3)	99,000	m^3
	Colloidal/injection mortar net	18,000	m^3
	Unknown, contaminated approx.	3,000	m^3

3.6 Mitigating Measures

In 2014, the Brouwersdam Tidal Power Plant project organisers asked Horvat & Partners to conduct a survey of the scale of the mitigating measures. The objective of this survey was to obtain an insight, with further support, into the expected mitigating measures (scope and costs).

A summary of the volumes needed for the realisation of the mitigating measures is presented in the table below. The figures are indicative, because the detailing regarding the mitigating measures has yet to be finalised. For the time being, they have been assessed as requirements from the environment, to be included if necessary. The cost of the requirements is not yet covered financially and will have to be borne by the stakeholders themselves. They therefore do not represent a risk for the private party in relation to the tidal power plant.

Table 6: Draft result for mitigating measures in volumes.

Mitigating: requirement	**Volume**	**Unit**
Main jetties	7,811	m
Side jetties	468	m
Non-contaminated dredging	131,517	m^3
Contaminated dredging	38,337	m^3
Dike facing WHD	10	km
Dike facing WZS	2	km
Grids	15	km
Modification of ferry slips	12	st
Other: desire		
Habitat dune valleys	21	km
Modification of bird islands	114,000	m^3
Arable farming, zero monitoring	400,000	€
Bankside recreation, Cycle paths SBB	15	km
Port Zelande sheet piling	3,500	m

4 Costs

In the following cost overviews, a distinction is made between the civil engineering work for the tidal recovery (the flood barrier) and part of the energy production (the tidal power plant). This is based on the intention that the costs and risks of the civil engineering section, including the mitigating measures, will be borne by a public contribution and the energy production section by a private market party.

Unless stated otherwise, the amounts shown are ‘all-in’ – i.e. inclusive of all costs, surcharges, risk reserves, VAT, etc. The amounts are rounded off to 1 million euros.

4.1 Costs of the civil engineering section for the flood barrier

The costs for the civil-engineering section are largely based on the national costs prices database (LBK) of Rijkswaterstaat, partly corrected for current market conformity.

The costs were determined with a probabilistic Standard Cost Estimation System (SSK), based on internal Rijkswaterstaat cost estimate. These are confidential business data and have therefore not been added. The following tables provide a summary of the amount and distribution of investment costs.

Table 7: Civil engineering costs (flood barrier) of Brouwersdam (price reference year 2017)

Description	Numbers	Unit
Investment costs	130	mln €
Variation coefficient	+ and - 23	%
Risk reserve for foreseen costs	15	%

Table 8: Composition of the investment costs (price reference year 2017)

Investment costs, civil engineering section	***Numbers***	***Unit***
Clearance and demolition work:	4.4	mln €
Asphalt and roadside objects:	2.3	mln €
Excavation:	1.8	mln €
Dam excavation:	15.6	mln €
Threshold:	0.4	mln €
Concrete:	10.7	mln €
Formwork:	7.3	mln €
Reinforcing rods:	10.9	mln €
Gates and hydraulics:	35.8	mln €
Operation and steering:	10.5	mln €
Sheet piling:	16.6	mln €
Maintenance doors:	2.0	mln €
Soil and bank protection:	8.4	mln €
Additional works:	3.2	mln €
Total, rounded off	130	mln €

Savings are possible by shortening the duct length. This is calculated at €0.33 million per running meter of narrowing. The annual service life costs for the civil engineering section (flood barrier) amount to 1.2% of the investment costs.

4.2 Additional and lower costs of the civil engineering section for the tidal power plant

Additional costs are associated with the design of the flood barrier as a tidal power plant. This involves additional costs for the construction of the machine room (concrete), for example. On the other hand, there is a possibility that savings can be made on costs for the vertical rising sluice gates through the application of turbines for fine-tuning (water level management), because these need not then be suitable for fine-tuning. The table below provides an overview of these additional and (potential) lower costs.

Table 9: Additional and lower civil engineering costs for tidal power plant (price reference year 2016)

Description	***Numbers***	***Unit***
Additional costs (concrete for machine room)	4.4	mln €
(Potential) lower costs for fine-tuning turbines	2,3	mln €
Additional costs (civil engineering)	130	mln €

This table shows that the additional costs and the reduction in costs are approximately equal to each other.

4.3 Mitigating measures

The overview below presents the costs of mitigating measures, as identified in 2016.

Table 10: Costs of mitigating measures (price reference year 2016)

Mitigating measure	Numbers	Unit
Adjustments for operational functions	Approx. 10	mln €
Dredging work	Approx. 2	mln €
Modifications of surrounding area	Approx. 1	mln €
Modifications of dikes	Approx. 3	mln €
Engineering + other costs	Approx. 2	mln €
VAT	Approx. 4	mln €
Total, rounded off	Approx. 22	mln €

The scope used for this calculation is:

- exclusive of costs for beach maintenance
- exclusive of costs of reserving space for two dual carriageways
- inclusive of all mitigating measures required by law.

A bandwidth of 50% applies for the calculation. Determining factors for this uncertainty are:

- Administrative decisions on the scope
- Participation of stakeholders in the development of the plan
- Outcomes of negotiations with stakeholders
- Potential (design) optimisations during the development of the plan
- Possibilities for re-use of materials from one project in another
- Outcomes of formal procedures during the development of the plan
- Contracting results.

With major scope expansions, the costs can mount up substantially, to above 50%. The principle chosen here is that the costs and risks are covered by public funds.

No service life costs have been estimated for the mitigating measures, because the principle is that, as in the current situation, the region will bear the management and maintenance costs. However, the changes in relation to the current situation are limited.

4.4 Costs of the technical installation of the tidal power plant

The costs of construction, installation and operation and maintenance of the tidal turbines are based on information from the Pro-Tide EU project, according to a statement by Pentair-Fairbanks-Nijhuis: see (Meijnen 2015) and (Berkel 2015).

Nijhuis has a great deal of experience in the development and construction of low static head axial propeller pumps and turbines. On this basis, a calculation model was developed and calibrated in order to be able to determine budget costs with the aid of design parameters. These costs are divided into costs for the steel work (depending on the mass of the steel elements), the costs for the power installation and other project costs. The total costs per delivered turbine diminish as the number of deliveries rises (design/engineering, model test, project management). No profit margin is included in the cost price calculation, as this varies per supplier, project, scale of delivery, etc. These costs are deemed to be included in the calculations by the private partner.

The cost price is shown in Table 11, assuming production in China (with a 33% cost reduction in relation to production in Europe) and with a sub-division into:

- Hardware: electro-mechanical turbine construction (steel work, including generator, frequency transformer and required regulators)
- Project costs: design, engineering, project management, model tests, quality control
- Installation: installation and commissioning
- Maintenance: average annual maintenance costs over the service life
- Prices are exclusive of VAT.

Table 11: Turbine costs, exclusive of VAT, with production in China (Meijnen 2015).

Number of turbines	**Hardware** *k€ per turbine*	**Production costs** *k€ per turbine*	**Installation** *k€ per turbine*	**Total** *k€ per turbine*	**Total investment** *M€ per MW*	**Maintenance**k *€ per turbine per year*
1	4,295	800	100	5,195	2,21	130
4	3,866	429	97	4,392	1,86	117
10	3,708	284	94	4,086	1,73	112
20	3,628	208	91	3,927	1,67	110
40	3,572	152	89	3,813	1,62	108
60	3,547	127	86	3,760	1,60	107

The manufacturer assigns an indicative accuracy to this budget statement of ±10%. If the flood barrier is executed as a tidal power plant, extra costs will be incurred for the connection to the electricity grid. According to a statement by Stedin in 2014, these costs amount to:

Table 12: Costs of connection to electricity grid (price reference year 2014)

Costs of connection, incl. VAT *(Stedin 2014-06-26)*	**Numbers**	**Unit**
< 10 MW	2.44	mln €
10 - 12.5 MW	3.93	mln €
12.5 - 25 MW	5.84	mln €
25 - 50 MW	21.40	mln €

The installed capacity of the 11 turbines is maximised at 25 MW, so that a sum of €5.8 million applies for the connection costs.

4.5 Integral costs for the tidal power plant (energy section)

The integral costs of investment in the tidal power plant are summarised in the table below.

Table 13: Investment costs for the tidal power plant (price reference year 2015)

Description	Numbers	Unit
Net additional civil engineering costs for tidal power plant	0.3	mln €
Turbine costs, including hardware, project costs and installation	54.4	mln €
Once-only connection costs	5.8	mln €
Object-specific risk reserve (6%)	3.7	mln €
Supra-object risk reserve (4%)	2.6	mln €
Total	66.8	mln €

In addition to the investment costs, there will be annual costs for maintenance and operation and for capacity connection. The annual costs of operation and maintenance of the energy section (excluding the civil engineering part) are estimated at 2.5% of the investment costs. In addition, there will be annual connection costs (capital levy) of €0.3 million per year. The annual costs (including the costs of operation and maintenance) are summarised in Table 14.

Table 14: Annual costs for the tidal power plant (price reference year 2017)

Description	Numbers	Unit
Operation and maintenance of the turbines and technical installation (2.5% of the investment)	1.7	mln €
Annual costs for E-connection.	0.3	mln €
Total	2.0	mln €

The total investment costs and annual costs are shown in the financial and economic considerations of the business case. This is described in Chapter 5.

5 Business case for tidal power plant

5.1 Introduction

The financial and economic business case contributes towards the assessment of whether a tidal power plant is also a financially feasible variant from a private perspective. We refer to a feasible business case if the investment and the annual costs are recovered through the annual revenues and a sufficient return is realised for the capital providers. A conservative approach is used, which means that assumptions regarding different costs and returns are estimated cautiously.

Although the flood barrier and the tidal power plant must be executed as an inter-related project, there is a difference in the economic ratio between the investment decision for the flood barrier and that for the tidal power plant. Only with the tidal power plant will there be an investment by the private sector that can be recovered through sales of electricity. The flood barrier will be publicly funded. This has consequences for the structure of the business case. Because the question from the market is whether the tidal power plant can be financed by market parties, the business case of the tidal power plant is presented independently.

The financial feasibility of the business case is expressed in a cash flow statement and is summarised with four key figures: the Internal Rate of Return (IRR), the Net Present Value (NPV) with the selection of a justified discount rate, the Payback Period (PP) and the Levelized Costs Of Energy (LCoE).

This is an initial survey that will be developed in more depth in a later phase. Many costs are combined at a higher scale level and will need to be sharpened and specified in a later phase. The financing strategy with the accompanying ratios must also be developed in that stage. The main parameters of the (financial) business case are explained below(RWS-PZH 2018).

The data on the energy production follow from the hydro-energetic model that is explained in Chapter 3.

5.2 Assumptions for Parameters

The parameters/principles are made transparent in the tables below. An explanation of a number of important parameters follows in the subsequent paragraphs.

Table 15: General parameters

Parameter	***Assumption***	***Unit***
Corporation tax (VPB)	21	%
VAT	21	%
Indexation of electricity prices	0	%
Indexation of costs	0	%

Table 16: Investment parameters

Parameter	Assumption	Unit
Start of construction year	2023	
construction period	1	year
Project horizon (assumption)	30	years
Residual value	0	mln €
VAT	No	
Risk reserve	10	%

Table 17: Financing parameters

Parameter	Assumption	Unit
Share of borrowed capital	70	%
Share of equity	30	%
Interest on borrowed capital	3	%
Required return on equity	13	%
VPB	21	%
Discount rate (weighted average cost of capital, WACC)	5.56	%

Table 18: Cost parameters

Parameter	Assumption	Unit
Depreciation period	30	year
Depreciation method	Linear	
Maintenance costs, as a percentage of the investment	2.5	%
Annual connection costs (fixed charges and measurement costs)	11,000	€ per MW

Table 19: Revenue parameters

Parameter	Assumption	Unit
Start of operations	2024	
Market price of electricity 2024	49	€ per MWh
Indexation of electricity prices	0	%
Guarantees of Origin	2	€ per MWh
Stimulation of Renewable Energy Production subsidy (SDE+)		
SDE+ basic amount	130	€ per MWh
SDE+ correction amount	49	€ per MWh
SDE+ maximum number of full load hours	2,800	
SDE+ term	15	year
Subsidies: ▪ Demonstration of Energy Innovation subsidy (DEI) ▪ EU innovation funds	 4 2	 mln € mln €
Energy production	60	GWh
Full load hours, approx.	2,400	
VAT on revenue	No	

5.3 Key figures used

NPV (Dutch: NCW)

Due to uncertainty and inflation, the valuation of future cash flows is increasingly lowered. A discount rate is used to calculate the ‘present value’ of cash flows. The NPV is determined by deducting the investment from the discounted future returns. If this is positive, a project is in principle financially attractive.

IRR

The IRR is the discount rate at which the NPV is precisely zero. If the IRR exceeds the WACC of a project, the project is financially attractive.

WACC

The discount rate used is an average of the returns required on both equity and borrowed capital, also known as the Weighted Average Cost of Capital (WACC).

PP (Dutch: terugverdientijd)

The PP shows the number of years in which an investment is recovered. On this basis, projects can be compared, with the PP forming an important element for the investment decision.

LCoE

The LCoE is a ratio that is calculated by dividing the NPV of all costs (investment costs and operational costs) by the total energy produced. This ratio can help in the assessment of how much it costs to generate energy with the relevant energy sources in comparison with other sources of energy.

Support for business case parameters

The support for the used parameters is as shown below:

- WACC: A ratio of 20% equity to 80% borrowed capital is often used. For higher-risk projects, a ratio of 30/70 is also used (PBL[6]). In view of the business case period used (30 years) and the innovativeness of the project, a ratio of 30/70 is used in this case. The required return on equity is 13%. The rate of interest on borrowed capital is 3%. Taking account of the effect of the corporation tax (VPB), which is lower as a result of deductible interest expense, a WACC of 5.56% results.
- Term: 30 years: The technical service life of the civil engineering structure is 100 years. The technical service life of the turbines is 50 years (Source: Pro-tide 2015). Because the lengths of these periods mean a high degree of uncertainty (energy revenues) and are significantly higher than for other installations for renewable production, an economic service life of 30 years is used for the calculation here. In addition, no residual value is taken into account.
- Investment period: 1 year. The construction of the civil engineering structure will take several years to complete. However, because this is a public work, the settlement will take place over the term of the construction. One year is assumed for the acquisition and installation of the turbines, followed by 30 years of energy revenues. The investment period for the tidal power plant is therefore relatively short.
- In the calculation, a VPB rate of 21% is used. In 2018, the rate is still 25%. The government coalition accord[7] states that the rate will be reduced to 21% in three stages from 2021. Because the tidal power plant will not supply energy until after this period, the lowest rate is used in the calculation.
- Investment costs are shown exclusive of VAT. This concerns an activity in the enterprise sphere (production and sale of energy), in which VAT on investments is deductible.

Specification of costs and revenues

The investment costs consist of the following elements:

- Extra costs for the civil construction work to enable a tidal power plant (Source: SSK Rijkswaterstaat, business confidential information which is not included). See Chapter 4 for more information.
- Acquisition and installation of the turbines.
  The costs of the turbines are included in accordance with the statement of the Nijhuis Pompen company in Winterswijk (Meijnen 2015). See Chapter 4 for more information.
- Net connection, once only
  Stedin uses different rates, depending on the capacity installed. The installed capacity of the tidal power plant is maximised at 25.0 MW. The connection

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6 http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2018-conceptadvies-basisbedragen-algemeen-sde-plus-

7 https://www.rijksoverheid.nl/documenten/publicaties/2017/10/10/regeerakkoord-2017-vertrouwen-in-de-toekomst

costs then amount to €4.8 million. The actual rate will differ somewhat from this and must be specified at a later stage.

- Uncertainty margin 10%
  The above investment costs include an uncertainty margin of 10%. This seems narrow. With civil engineering works, it is not unusual to work with margins of 20%. The reason for this lower margin is that the civil engineering component (extra costs for civil construction) is limited. This only concerns the turbines themselves and Stedin's connection costs. There are fewer factors here that influence the ultimate amount of the investment. For this reason, a relatively narrow uncertainty margin is used.

The income (revenue) consists of the following:

- Energy production in MWh
  The energy production is calculated by the Pro-Tide hydro-energetic model. See Chapter 3 for an explanation.
- Price of grey energy
  The electricity price is based on the analysis of PBL for the proposal of the main points of the climate accord.[8] Although there is always great uncertainty about movements in energy prices, the expectation is that the price of electricity will rise in the coming years. In the period in which the tidal power plant will be producing energy, the electricity price is expected to lie just below €50 per MWh. In the model, we assume a price of €49 per MWh. There is also the possibility of extra revenues through the sale of Guarantees of Origin (GVO). In the model, we therefore work with a price of €51 per MWh. This price is stable in the model during the term. In the PBL analysis, the electricity price relates to the period after 2030. For this period, the electricity price may be lower. Through the operation of the SDE+ scheme, however, this lower price would be offset by a higher SDE+ contribution.
- Stimulation of Renewable Energy (SDE+) (Source: RVO[9])
  Renewable power generation by means of hydropower is stimulated by the SDE+ scheme. In the model, we assume that the basic amount for hydropower (static head of less than 50 cm) will remain unchanged in the coming years. This concerns the fixed SDE+ contribution for hydropower. A basic amount of €130 per MWh and a correction amount of €49 per MWh gives an SDE+ contribution of €81 per MWh.
- Contributions of DEI subsidies of €4 million and of EU innovation funds subsidies of €2 million.

8 http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2018-analyse-van-het-voorstel-voor-hoofdlijnen-van-het-klimaatakkoord-3380.pdf

9 https://www.rvo.nl/sites/default/files/2018/02/Brochure%20SDE%20voorjaar%202018.pdf

Table 20: Annual revenue of tidal power plant

Annual electricity production		
Energy generated	60,000	MWh per year
Structure of annual revenue		
Sale price of electricity	3,060,000	€ per MWh
SDE+ contribution	5,860,000	€ per MWh
Annual revenue	**7,920,000**	**€**

The components of the operational costs are calculated as follows:

- Maintenance of Turbines (Source: Pro-tide)
  Maintenance of the turbines (Meijnen 2015) amounts to €135,520 per turbine per year. This is consistent with about 2.5% of the investment costs.
- Annual connection costs, based on statement of RVO[10].
  The annual connection costs (fixed charge and measurement costs) amount to €11,000 per installed MW.

5.4 Result of business case

Further calculation applying the principles explained above, including a discount rate of 5.56%, results in a positive NPV of €8.8 million and an IRR of 7.7% (RWS-PZH 2018). Consequently, the financial outcomes of this survey appear to be favourable. The investment costs are recovered, with net cash flows, in 10 years. Although this is longer in comparison with investments in solar and wind power, this is also a means of production with a longer service life. After all, after these 10 years, energy will be generated for a further 20 years. In order to compare the tidal power plant with other renewable energy production, the LCoE of the tidal power plant can be calculated. This amounts to €90.7 per MWh. The LCoE of wind on land, for example, ranges between €70 and €90 per MWh. The costs of generating one MWh with the tidal power plant are therefore relatively high. This does not mean that a tidal power plant is also less financially attractive. The difference in costs is compensated by a higher SDE+ contribution for hydropower than for wind and solar power.

[10] https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/windenergie-op-land/financien/kosten-en-baten

6 Risks and opportunities

6.1 Introduction

The risks & opportunities dossier is the product of various meetings with several different companies and organisations, including the engineering firms Sweco, Horvat&Partners and Cubicsquare, South Holland provincial authority and Rijkswaterstaat.

The risks described in this dossier form part of the total risk reserve, as included in the cost estimate.

The total risk reserve in the cost estimates is higher than the amount adopted from the risk dossier, because the cost estimate also includes percentages for risks that are not named. The unnamed risk reserve is also known as 'unforeseen unforeseen'.

The risks from the risk dossier are quantified in the cost estimate according to the 'probability x consequence' principle. Together with the reserve for unnamed risks and bandwidths for cost items, the risks are calculated according to probability with the aid of a Monte Carlo simulation. This calculation produces the variation coefficient (bandwidth), but also the following top risk contribution table.

Table 21: Risks (weighted by risk contribution)

Risk	Object and caus	Contribution
Some gates do not meet the reliability standards	object: flood barrier cause: volume	18.6%
Turbines	object: energy cause: price	10.4%
New standards for water safety are more stringent than the current requirements	object: supra-object risks cause: volume	10.4%
Turbines	object: energy cause: volume	9.7%
Supply and installation of hydraulic operating mechanism (vertical rising sluice gate)	object: flood barrier cause: price	4.8%
Supply and installation of hydraulic operating mechanism (vertical rising sluice gate)	object: flood barrier cause: volume	4.1%
Unnamed supra-object risk investment costs	object: supra-object risks cause: volume	3.8%
The channels laid will partially silt up again	object: flood barrier cause: volume	3.4%
Other		34.8%
Total		100%

Some of the above risks are public risks and are therefore not included in the private risk (see also 6.2 and 6.3). The variation coefficients and the total risk reserves are presented in Chapter 4, Costs.

In 2016, a report was delivered on the system risks, advising that 15 to 20% be included for unforeseen costs in this phase of the survey. The risk reserve intended to cover unforeseen costs is currently 13% and is therefore lower than was recommended in 2016. It is noted here that more has been investigated since then, as a result of which greater certainty has arisen on the foreseen costs and a lower percentage for the risk reserve appears to be justified.

The most important risks, the operating mechanism and the turbines, merit extra attention in the next project phase.

6.2 Risks and opportunities of flood barrier

The following risks are included for the sake of completeness. They are public object-specific risks and opportunities. They do not, therefore, apply for the tidal power plant.

Table 22: Public object-specific risks and opportunities

Object-specific risks and opportunities	
Clearance and demolition work	Occurrence of unanticipated environmental technical or technical damage and/or an archaeological discovery.
	The demolition of the compression chambers will take more time than expected
	The costs of removing concrete rubble will be higher than expected (e.g. as a result of an excessive chloride content).
	The filling material in the compression chambers is partly environmentally contaminating.
	Part of the asphalt released from roads contains tar.
Excavation site and temporary facilities	Leaks occur in the construction pit.
	Storm damage through high waves.
	Bottom of the excavation site splits as a result of water pressures below the asphalt layer of the existing soil protection.
Excavation	Channels laid partially silt up again.
Flood barrier	There is a risk of outflow, because doors do not shut completely.
	Without reinforcement of the foundations, the flood barrier structure is not sufficiently stable.
	The seepage pressure beneath the connecting concrete base plates (= soil protection) is too high (this risk has been marked down in connection with cut-off walls).
	A thinner deck and floor can be laid (including prefab. N.B.: Note too high upper soil load)

	Flooding as a result of the failure risk of the system, software etc. (regular conditions) resulting in excessively high water level on the Grevelingen.
	Single gates no longer meet reliability standards (risk of failure).
	Waves pounding the gates (Deltares) require additional strength.
	Limitation of possibility for air suction (Deltares).
	Vibration (vibration shocks) with half-closed gates.
	More expensive gates are necessary in connection with fine-tuning outside turn (heavier rolls in mounting, heavier mechanisms, etc.) Opportunity for tidal power plant in connection with fine-tuning by turbines.
Soil and bank protection	The soil must be decontaminated regularly (sea side) during the laying of the soil protection, due to silting.
	Rock filling will be undermined by earth removal pit.
	Relieve pressure on soil protection by laying this deeper, which will reduce the load on the soil protection.
	Functional use of (part of) the existing soil protection (asphalt along 120 metres on the North Sea side of the dam) as part of new soil protection to be laid. (Opportunity)
Additional works	No named risks.

Table 23: Public supra-object risks and opportunities

Supra-object risks and opportunities
The estimate is not complete.
Surface area data not in order (actual situation differs from source data).
There are omissions in the contract to be drawn up.
Further adjustments by agreement with stakeholders.
New standards for water safety are more stringent than the current requirements.
Exchange of water between Lake Grevelingen and the North Sea diminishes as a result of sea level rise (partial opportunity in application turbines).
Delays due to failure to obtain permits in time.
Improving the drainage coefficient with a different flood barrier design. This can make a difference of 1 or 2 ducts.
Duplications in opportunities for optimisation
Unnamed supra-object risk of investment costs (%)

Risks of mitigating measures (as part of a fixed % risk reserve):

- The dikes around Lake Grevelingen prove to be more sensitive to flow slide at some points than was anticipated.
- The current inventory may not yet include all mitigating measures. This may still lead to a scope change that falls under the public contribution.

6.3 Risks and opportunities of tidal operation

The risks and opportunities for the tidal energy piggy-back opportunity are the responsibility of the private parties. An overview of this is presented in the table below.

Table 24: Private risks and opportunities of the tidal energy piggy-back opportunity

Private risks and opportunities of the tidal energy	
Investment	Keep connection costs below threshold of an installed capacity of <25 MW
	Avoiding the above risk of the need for fine-tuning by having to make lifting gates adjustable outside the turn (avoidance of risk with flood barrier).
	Avoidance of the risk of water exchange between Lake Grevelingen and the North Sea diminishes as a result of sea level rise (Horvat) (avoidance of flood barrier risk).
	Pump operation possible after 30 cm sea level rise (will require new investment amount, outside scope).
	Greater yield of turbines by increasing the static head. By opening the gates when high tide is almost at the maximum (Disadvantage: more expensive gates necessary in connection with fine-tuning outside turn (heavier rolls in mounting, heavier mechanisms, etc.).
	Extra investment subsidies turn out to be lower.
	Hydraulic resistance of inoperative turbines too great for drains: 1 extra concrete duct.
	Further safety requirements for power outage.
	Extra facilities against mortality and/or to promote fish migration.
Service life	Emergency repairs to gate and/or turbines during service life.
	Extend maintenance interval.
	Sale value with SDE+ not €130 per MWh during the first 15 years.
	Risk of early removal of 1 or more turbines due to sea level rise or insufficient tidal flow.

We have no influence on this within the project, but a (substantial) reduction in this subsidy could lead to a later reconsideration of the financial business case by a market party.

The result of the business case must also be seen in the context of the different uncertainties regarding the costs and revenues of the tidal power plant. The view of the feasibility depends partly on how potential opportunities and risks are assessed and the effect that this has on the outcomes of the business case. In order to provide a picture of the impact of the variables and assumptions included, a sensitivity analysis is included in the table below. Changes in assumptions are expressed in the outcome of the NPV here. These can be compared with the NPV of €8.8 million calculated in Chapter 5.

Table 25: Sensitivity analysis

Incident	***NVP by increase 10%***	***NVP by reduction 10%***	***Unit***
Investment costs	3.9	13.6	mln €
Energy production	16.0	1.6	mln €
Operational costs	6.9	10.5	mln €
Electricity price	10.0	7.6	mln €
Basic SDE+ amount	14.6	3.0	mln €

Other risks:

- The economic service life of the turbines is less than 30 years.
- The government does not reduce the rate of corporation tax after all.
- Turbines cannot be used for water level management, as a result of which the additional costs of the investment in the civil engineering construction will rise.

Other opportunities:

- The WACC (discount rate) used could fall (the estimates of returns on equity and borrowed capital are high).
- The tidal power plant qualifies for extra stimulation measures, such as green financing.
- Optimisation of VPB settlement.

7 Market approach

7.1 Introduction

In 2015, a strategic procurement plan was drawn up for the Grevelingen Tidal Project in which a number of choices for the market approach to the tidal power plant were surveyed and determined. The strategic procurement plan formed the basis for the outline market approach described here.

The notion that the realisation of a tidal power plant is still at the stage of a potentially feasible business case is important for the type of market approach here. In the plan development phase, it will be necessary to determine whether a tidal power plant of a certain size is actually feasible. It is precisely this uncertainty which means that the market approach for the Grevelingen Tidal Project will have to be designed in a different manner from what is presently customary for projects of this scale.

Leading principles for the market approach for the Grevelingen Tidal Project include:

- Early deployment of the knowledge and expertise of private companies in order to make maximum use of their knowledge and creativity. This will contribute towards optimal smart and innovative solutions for a future-proof Grevelingen, with a resilient and robust eco-system and generation of renewable energy.
- Coordination of public-law procedures (ProjectMER and permits) and joint development of the plan in a public-private partnership. The spatial planning procedures and the design process (for a technically and financially feasible design) are interwoven in order to realise an integrated cost-efficient and feasible design.
- Rapid assurance about costs so that an early positive business case can be developed for the tidal energy component.
- An efficient and effective process, resulting in a shorter lead time for the entire project and limited transaction costs. The duration of the plan development phase is limited to a maximum of two years.
- A phased approach to obtain a stable scope and the possibility of funding the entire scope (flood barrier including a tidal power plant).
- Inclusion of an explicit go/no-go decision between the plan development phase and the realisation phase. In the event of a no-go, only the flood barrier will be realised. If no feasible proposal for realisation of the flood barrier/tidal power plant or the flood barrier only is achieved, there will be an exit, with the plan development costs reimbursed and the design becoming the property of the State.

Scope of Grevelingen tidal power plant

The parts of the scope for a flood barrier with a tidal power plant are:

- The development of the plan for an integrated scope for the flood barrier with a tidal power plant.
- Drawing up an integrated design, optimised for a resilient and robust eco-system, in the interests of a future-proof Grevelingen.
- The design of mitigating and compensatory measures.

- The realisation of the integrated scope for a flood barrier with a tidal power plant.
- Maintenance of the flood barrier.
- Maintenance and operation of the tidal power plant.
- The financing of the energy component, the tidal power plant, including the (permit and) subsidy applications.

The construction of a tidal power plant and its operation require different expertise from that needed to execute the water quality measures:

- Water quality measures (the flood barrier): deployment of the competency fields of civil engineering, mechanical engineering, installation engineering, ecology and morphology.
- Utilities infrastructure (de tidal power plant): delivery and installation of turbines, installation work, connection to the electricity grid and their operation.

The expectation is that a multi-disciplinary private consortium will be able to provide the necessary additional expertise in the execution of this component. Such a consortium may consist of the following private parties and fields of knowledge:

- hydraulic engineers; specifically with knowledge and experience of technical aspects of hydraulic engineering and water system knowledge and models
- turbine builders; various turbine technologies such as Bulb and free flow
- engineering firms; specifically with experience relating to/ambitions regarding turbines and ecology and morphology
- research institutes; specifically with experience relating to/ambitions concerning sustainability
- energy operators; specifically with experience relating to/ambitions concerning sustainable energy production
- private financiers; specifically with experience of funding energy projects

The principle of the procurement strategy is that a great deal of interaction between public and private parties will be necessary for the realisation of the project objectives. This calls for collaboration in the form of an alliance.
The challenge is to be able to cost and finance the scope for the realisation and operation. The design solutions to be developed must fit within the spatial planning and public law framework. These solutions must be coordinated with stakeholders and parties concerned and must be tested for costing and financing.

7.2 Risks

In the final choice of the market approach, the following risks must be taken into account. This can take place in the chosen process, the contract form(s) and the tendering procedure.

The risks are:

1. the absence of financing for the tidal power plant at present. The search for financing for the tidal power plant is an important objective of the alliance. On bidding for this contract, the candidate private parties must have a positive image of the commercial feasibility.
2. The inter-relationship of the tidal power plant and the flood barrier make an integrated design necessary, with the accompanying allocation of responsibilities.

3. Insufficient or no interest from the private sector in an early market approach due to the unusual combination of water and energy challenges, as a result of which the contract may have an excessively high risk profile.
4. Insufficient or no interest from the private sector in an early market approach because the scope is not yet fully determined.
5. As yet, there is no single market. The combined scope of the water and energy challenge calls for new, as yet unusual partnerships in the market.
6. The business case for the tidal power plant is not completed and there are no attractive fall-back options for private alliance partners.
7. Undermining of the scope in the plan development phase through 'opportunistic' behaviour by an alliance partner. Low-risk revenue will take precedence.
8. The knowledge and expertise of alliances is limited on the part of the client and on the part of the private party.
9. A combined contract proves not to be feasible after all in the tendering stage.
10. A decision on the award of different subsidy components is not reached in time.
11. The permits necessary for the energy component are not obtained in time.

The challenge is to reduce these uncertainties during the preparation and development of the plan. An appropriate process for preparation and development of the plan must be designed for that purpose. The final risk spread must be included in the proposal for realisation/operation that is submitted after the development of the plan.

7.3 Proposed market approach

The public organisations believe that a tidal power plant can only be made feasible on condition of:

- an integrated design of the water and energy task
- optimised for a resilient and robust eco-system
- and supported by a compiled business case.

This requires a consortium of different private parties to come on board at an early stage. Otherwise, an optimised and combined design will not be possible. That condition makes it necessary for the public partners and the private consortium to first develop the Grevelingen tidal power plant plan in more detail together. On that basis, it can be determined whether there is a scope that can be priced, a clear spread of risks and feasible operation. After this planning state, it is therefore necessary to include an explicit decision-making moment between the plan development phase and the final realisation phase. The objectives of this is go/no-go moment include testing whether the price for solving the water quality falls within the pre-determined performance budget and whether all necessary public law permits will be obtained. For the consortium, it offers an opportunity to carry out a last check on the feasibility of the energy operations. After checking the public-law conditions and the feasibility of the energy operations, the consortium can progress to the realisation and operation phase.

It is essential here that the private party that will later bear the realisation and operating risks was itself involved in the development of the design and the business case. The role of the private party is therefore crucial, given the intention on the basis of the procurement strategy to select a party at an early stage that will not only commit to the development of the plan as a partner or alliance partner, but also to the realisation of that plan. The private party must be able to develop an integrated plan together with the public partners and must we willing to bear the risks of its realisation and operation. The precise composition of a private consortium is still open.

Envisaged contract form

The aim is to select a contract form that takes account of this flexible and phased set-up.

A consortium will be selected in the tender for the entire project, from the plan development up to and including construction and operation. Although a single contract, it will be split up into two phases with a clear go/no-go decision-making moment:

- The first phase of the contract concerns the plan development phase and preparations for realisation.
- The second phase of the contract is a construction and operating contract. In this phase, the work could then still be split into, for example:
  - An integrated construction contract form for the Brouwersdam flood barrier, including maintenance (a Design, Build, Maintain (DBM) contract). It should be noted that the DBM contract will have more of the character of an Engineering, Build, Maintain (EBM) contract, as the design will already be produced in the first phase. The conditions for such a contract form are that a scope that can be priced and a feasible business case for the energy operations are available.
  - If necessary, an energy concession could be granted to a private party for the construction and operation of the tidal power plant. A condition for this is that consistent agreements can be reached on the coordination of the operation of the tidal power plant and the operation of the flood barrier.

  Another possibility is that a single integrated contract is chosen for the second phase for the construction and operation of the tidal power plant and the flood barrier. The contract form may still vary. One possibility could be a Design, Build, Finance, Maintain and Operate (DBFMO) contract, or an integrated concession.

7.4 Financial model and financial incentives

Financial model

The provisional distribution of the costs between the client and the envisaged private party is, in outline, as described below.

Public funding of the project objectives consists of:

- Civil and mechanical engineering work
- Mitigating and compensatory measures
- Unforeseen circumstances (higher sea level rise than expected)

The private contribution to the project objectives will consist of:

- Optimisation of public objectives and coordination with the energy objectives

- Risk-bearing investment for the energy component (realisation)
- Generation of renewable tidal energy (maintenance and operation)

The funding of the realisation will be made available in the form of a performance budget. The performance budget must:

- Be regarded as adequate by the market parties for the realisation of the project objectives, within an integrated solution for water and energy.
- Be regarded by the public parties as a reasonable, commercial price for realising the public project objectives.

In addition to the performance budget, another source of funding will be necessary specifically for the tidal power plant:

- Specific subsidies to promote renewable energy.
- Equity contribution.
- Deployment of borrowed capital.

The costing and financing of the tidal power plant is an explicit task and responsibility of the consortium. The consortium must provide for shareholders' equity or obtain a loan and apply for the subsidies. The private alliance partner will have to conduct talks with financiers and with the Ministry of Economic Affairs and Climate Policy for that purpose. Private financiers must be willing to accept a lower rate of return. In the tendering phase, a perspective on the feasibility of this participation propensity must be clear.

Financial incentives

Financial incentives in the plan development phase can be designed in different ways. An overview of incentives that are under consideration at present is presented below.

Earning the contract for the second phase

The main incentive for the private consortium is to 'earn' the contract for the second phase. Naturally, this requires a feasible plan and a positive business case.

Distribution of the surplus

If a contract price is set that is well below the performance budget, the development of the plan has been successful and a financial incentive is in order. In that case, the deployment of the surplus will be determined by agreement. The following conditions apply for this:

- the proposal complies with the set objective and conditions of the project.
- agreements on the deployment of the surplus will be reached in the realisation phase.
- the government bodies and other stakeholders will be involved in the talks on the surplus.

Guaranteed reimbursement for plan development phase

Another financial incentive is that the client always pays contractual reimbursement for the plan development phase. This applies regardless of whether or not the project goes ahead. In this phase, therefore, the contractor runs a limited risk.

For the first phase a payment mechanism could be agreed in which the reimbursement is paid as a lump sum, or that a once-only participation fee is paid at the start and the remainder is paid after the end of the plan development phase.

A payment will also be made if the contract has to be cancelled early. The alliance contract will in any event include an exit possibility for the following situation:

- if the plan development and development phases do not lead to the results formulated in advance.
- if the flood barrier cannot be realised for or within the performance budget.

In both cases, only the public partner can cancel the contract, in which case the reimbursement payable to the private consortium will be based on the actual costs incurred.

7.5 Tendering procedure

In all probability, the tendering procedure will take place in the form of a competition-oriented dialogue. This procedure makes it possible to enter into talks on the risks of the contract and how the candidates or the contracting authority will manage those risks. The tendering procedure will consist of a selection phase and a dialogue phase. The dialogue is expected to focus primarily on the collaboration method and the necessary competencies, the management of the risks, the financial aspects of the contract and (to a limited extent) the technical risks of a tidal power plant.

The results of the tendering procedure could be:

- A basic management plan for an alliance, including:
  - the collaboration within the alliance
  - the accompanying processes, in outline.
- An outline financial plan, which will include:
  - the allowances used
  - pricing method
  - commercial terms
  - review of the financial commitment
  - risk management plan of the alliance.

The dialogue will be designed for adequate discussion of the risks of the project and these could also play a role in the award of the realisation and operation contract. The party that can convincingly show that it is best able to manage the risks would score well in the MEAT-BPQR assessment. Due to the early market approach, competencies for collaboration will play an important role in the ultimate choice of the consortium.

7.6 Planning

The following indicative plan is used for the planning of the Grevelingen Tidal Power Plant Project if and after an MIRT 2-decision has been taken:

Table 26: Indicative planning

Planning phase	***Indicative planning***
Preparation of the contract file and the tendering procedure	about 6 months
The tendering phase of the competition-oriented dialogue, with a dialogue in two phases	about 8 months.
The joint development of the plan (including financial feasibility and go/no-go) and MIRT 3 decision	maximum of 2 years
Realisation phase	some 2 to 3 years
Operation of the tidal power plant	30 years (term of business case).
Preparation of the contract file and the tendering procedure	about 6 months

Appendix 1 Abbreviations

BPQR	Best Price-Quality Ratio *Dutch: Beste prijs-kwaliteitverhouding(BPKV)*
DEI	Demonstration of Energy Innovation subsidy
MEAT	Most Economically Advantageous Tender *Dutch: Economisch Meest Voordelige Inschrijving (EMVI)*
LCoE	Levelized Costs of Energy
IRR	Internal Rate of Return
MER	Environmental Impact Report *Dutch: Milieu Effect Rapportage*
NPV	Net Present Value *Dutch: Netto contante waarde (NWC)*
SDE+	Renewable Energy Subsidy
SSK	Standard Cost Estimation System *Dutch: Standaard systematiek kostenraming*
VPB	Corporation Tax *Dutch: Vennootschapsbelasting*
WACC	Weighted Average Cost of Capital

Appendix 2 References

The references below are partly digitally bundled and are part of the Tidal Grevelingen dossier, Tidal Power Plant variant for the benefit of the Market Consulation 2018. The documents are mostly written in Dutch.

General

- Tweede Kamer, 2016
  https://www.google.nl/search?hl=nl&q=IENM%2FBSK-2016%2F284609
- Verslag van de precompetitieve fase 2015
  www.gcbd.nl
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  http://www.gcbd.nl/PF/pfdocumenten/default.aspx
- Ministerie I&M, Ontwerp Rijksstructuurvisie Grevelingen Volkerak Zoommeer
  http://www.zwdelta.nl/projecten/rijksstructuurvisie-grevelingen-volkerak-zoommeer/ontwerp-rijksstructuurvisie.htm
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  http://www.zwdelta.nl/projecten/rijksstructuurvisie-grevelingen-volkerak-zoommeer/ontwerp-rijksstructuurvisie.htm
- Nota duurzame leefomgeving 19 juni 2015
- Bouwrichtlijnen infrastructuur
  http://www.rws.nl/zakelijk/werken-aan-infrastructuur/bouwrichtlijnen-infrastructuur/index.aspx
- Rijkswaterstaat, Beheerplan voordelta 2015 – 2021 (2015)
  http://www.rijkswaterstaat.nl/water/projectenoverzicht/noordzee-beheerplan-voordelta/index.aspx
- Rijkswaterstaat, Ontwerpbeheerplan deltawateren (2015)
  http://www.natura2000.nl/items/ontwerp-beheerplan-deltawateren-ter-inzage.aspx

Documents

The following documents are available on Tenderned:

- Loor 2018, Bepaling afvoercoëfficiënt doorlaatmiddel Brouwersdam
- Kleissen 2015, Toetsing hydraulisch rekenmodel
- Kleissen 2018, Beoordeling Hydro-energetisch model
- Berkel 2015, Optimised TTP Brouwersdam Pro-Tide
- Berkel 2018, Hydro-energetisch model
- Berkel 2018, Hydro-energetisch achtergronddocument
- Meijnen 2015, Two Propeller Turbine Configurations
- Cubic Square 2018, Achtergronddocument ontwerptekeningen variant getijdencentrale
- Cubic Square 2018, Achtergronddocument 3D-tekeningen variant getijdencentrale

- Cubic Square 2018, Achtergronddocument ontwerp en hoeveelheden variant getijdencentrale
- RWS-PZH 2018, Getijdencentrale Brouwersdam 2018 voorbeeld rekenmodel

Appendix 3 Principles and considerations

De laatste inzichten (september 2018) zijn vastgelegd in dit document. Deze zijn af te leiden uit de doelstellingen en zijn richtinggevend voor het ontwerp van de verschillende varianten.

Dit zijn zeker nog niet de definitieve uitgangspunten. In de Planuitwerkingsfase zullen aan het document nog aanpassingen, aanscherpingen en optimalisaties plaatsvinden. Er kunnen dus geen rechten ontleend worden aan dit concept uitgangspunten document.

Part I: Principles Lake Grevelingen

Desired tide Lake Grevelingen

Maximum 50 cm tide.

Water safety

- The new flood barrier (and additional functions) must at all times comply with the current Water Act and the Statutory Testing Instruments (WTI) 2017.
- Temporary embankments during construction that take over the function of a primary embankment are also regarded as embankments within the meaning of the Water Act and must function as such at all times.
- A civil technical service life of at least 100 years applies for the new flood barrier (and additional functions). For mechanical installations, a minimum service life of 30 years applies.
- The flood barrier in the Brouwersdam must be realised (within a search area of 800 metres) north of 'Port Zélande'/ Kabelaarsbank, as shown in the following map between section line 1975 and section line 2120.
- The flood barrier in the Brouwersdam must be a maximum of 400 metres long in total.

Water quantity and Ecology:

The following future water level management will not be realised with the new flood barrier alone, but in combination with the current Brouwers lock and the Flakkee Sluice Gate. Efforts will be made to keep the existing two locks as fully open as possible.

- A tidal flow must occur on the entire Lake Grevelingen twice every 24 hours.
- The difference between high and low tide (the tidal range) should be at least 40 cm with each monthly average tidal range. It must be possible to realise this tidal range from the moment of commissioning to the moment of a sea level rise of 30 cm.
- The sea level rise is measured at the location of the Brouwershavense gat 08 (BG08)
- The level in Lake Grevelingen may not exceed NAP +0.05 m.

- In the event of the (partial) failure of the flood barrier to close under normal conditions:
  - the water level may rise by a maximum of:
    - 1 x per 10 years max. NAP + 0.1 m.
    - 1 x per 100 years max. NAP + 0.3 m.
    - 1 x per 1,000 years max. NAP + 0.5 m.
  - the flood barrier must be operating correctly again within one week.
- The level in Lake Grevelingen may:
  - not fall below NAP -0.45 m 90% of the time.
  - not fall below NAP -0.50 m 100% of the time.
- The average level around which the tidal range takes place must:
  - be a **monthly** average NAP of -0.20 m, with a permitted deviation of + or – 1 centimetre.
  - be an **annual** average of NAP -0.20 m.
- The above levels apply for both the Scharendijke location (GG1) and the Herkingen location (GG2);
  This regulation is intended to compensate the distortion caused by waves through operation of the three flood barriers.
- Extreme conditions or emergencies beyond the control of the future managers represent an exception to the above principles.
  A maximum water current of 0.3 m/s applies throughout Lake Grevelingen, with the exception of the area within the safety markings at the location of the flood barrier.
- Installation of structures and their effects on the use of Lake Grevelingen and the Voordelta must take place in compliance with the environmental legislation. Necessary compensatory measures/mitigating measures fall within the scope of this project.
- The following applies for the new flood barrier (and additional functions): Fish mortality for all fish species must not exceed 0.1% per passage.
- The above standard could be broadened slightly (eel 0.7%, all other fish species 1%) in connection with permission, stating the reasons, to derogate from the Test Framework for Hydropower Plants in Dutch National Waters. The Best Existing Technology applies pursuant to the Water Act.

Operational functions

- Existing shipping and road traffic must not be obstructed during the execution of the work and when the new flood barrier is in use. Exceptions to this may be possible with the consent of the shipping lane/traffic administrator.
- Changes to shipping lanes and navigation channels must comply with the Shipping Lanes Directive 2011 and the Inland Shipping Police Regulations.
- The current road traffic functions must be retained in the new situation.
- Existing (recreational) facilities (beaches on Lake Grevelingen, beach on the outside of the Brouwersdam, jetties, marinas, etc.) must remain free of damage, secure, accessible and functional during and after the execution of the work. If this is not reasonably possible, mitigating or compensatory measures must be taken.
- The safety of persons in all working areas must be protected at all times.

TOP REQUIREMENTS in order of importance

- Will probably be included in the assessment criteria (MEAT)
- Are not included in the public financing costs of this project.
    1. Tidal power plant - as much energy as possible
    2. Protection of beaches on North Sea side → sustainable and structural solution (e.g. longitudinal dike)
    3. Length of flood barrier → the narrower the better (Brouwersdam is a recreational Hotspot);
    4. Limited duration of construction work in relation to nuisance in the region
    5. Involve local entrepreneurs in design, construction, operation

REQUIREMENTS

- Will not be included in the assessment criteria (MEAT)
- Are not included in the public financing costs of this project.Lokale belanghebbenden betrekken bij onderdelen aanbestedingsproces, selectie van het ontwerp
    6. Involve local stakeholders in parts of tendering process, selection of the design.
    7. Social Return (The objective of social return is to ensure that a government investment also produces a social return, being the creation of permanent jobs for people with difficulty in accessing the labour market).
    8. Requirements from Regional Cooperation (not yet known).
    9. Serve sport fishing and divers better (not on the Brouwersdam itself).
    10. Lock or incline (only with unique and as yet non-existent commercial facility).

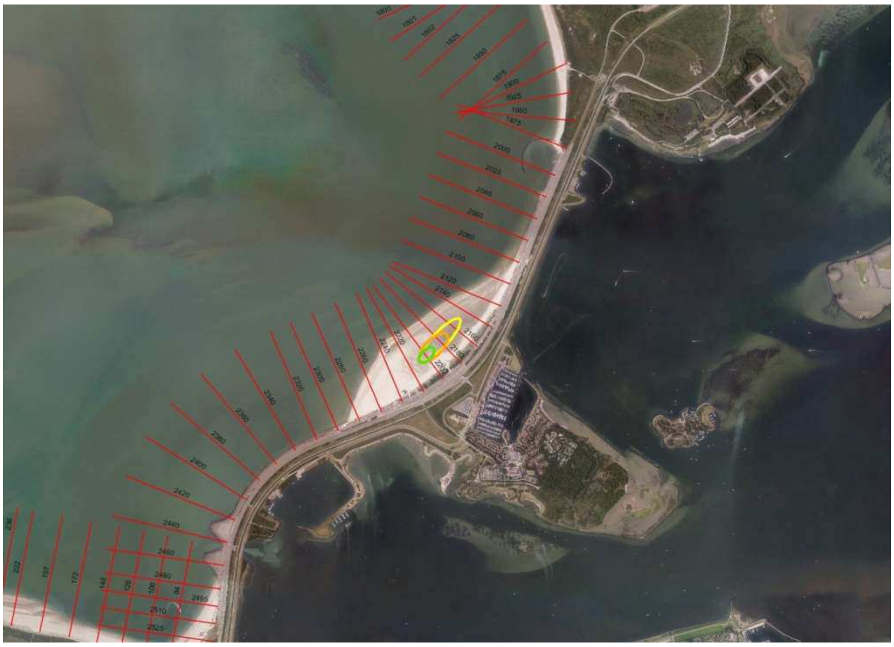


Figure 13: Provisional position of the flood barrier is in the northern part of the Brouwersdam between rai 2040 and rai 2100.

Part II: Considerations regarding basic assumptions

Water level management

Re-establishing an almost constant tidal movement of 50 cm on Lake Grevelingen represents a sustainable solution to the water quality problems (oxygenation).

With a tidal range of 50 cm, the dynamics are sufficient to maintain the desired water quality and allow life on the seabed to recover fully.

The Grevelingen and Volkerak-Zoommeer Government Development Plan assumes a maximum tidal range of 50 cm around an average mid-position water level of NAP -20 cm. Some flexibility is required when working with the market to find optimisations during the plan development phase, and this may ultimately lead to reconsideration.

During the previous market consultation, the reconsideration of the tidal range was in fact discussed. This can either be decreased to reduce costs or increased to produce higher revenues:

- Cheaper solutions are possible based upon a smaller flood barrier, and thus a smaller tidal range (± 30 cm), in combination with additional measures.
- Positive results (BuCa) have been achieved for a flood barrier and tidal power plant from an average tidal range of 40 cm. Greater revenues can be achieved by permitting a larger tidal range. For example, the energy generated increases by ± 10 GWh/y for every 5 cm increase in tidal range.

The above was the reason for the inclusion of a minimum average tidal range of 30 cm and a maximum average tidal range of 50 cm around the current mid-position water level in the basic principles for water level management, so that the creativity of the marketplace can be optimally exploited at as low a cost as possible.

A range of less than 30 cm is undesirable because of the dynamics needed for mixing the existing oxygen concentrations. Conversely, a range of more than 50 cm is undesirable because of the effect this would have on the other types of use, such as nature and recreational navigation. This would also take up too much physical space because the Brouwersdam is a designated recreational hotspot for active leisure activities.

Water safety

The future retaining structures in the Brouwersdam will affect the water level of Lake Grevelingen and the dimensioning of seabed protection (whether a retaining structure is open or closed under normative circumstances on the North Sea, this will give rise to a different load than that which occurs under day-to-day circumstances).

Reliability of closing

As the Structures Guide states, the probability of the permissible volume of water flowing in from outside being exceeded is important when assessing the reliability of closing. As long as this water can be safely stored in Lake Grevelingen, there is no problem. However, when the amount of inflowing water becomes so great that there is a danger of flood defences overflowing and/or failing this is surplus water caused by the failure of the structure.

This highlights an important aspect of this project, namely the acceptable water level on Lake Grevelingen. The requirement regarding water quality is formulated as a water level below NAP +0.05m 99% of the time, excluding extreme situations or calamities. These extreme situations, and their definition, are important for the analysis, and in the search for an optimal reference design. A water level must be specified for these extreme situations, for example for a 1/10, 1/100 and/or 1/1000 situation.

Furthermore, the Structures Guide states that the average probability per year of the permissible volume of water flowing in from outside via the open structure being exceeded must be smaller by a factor of 10 than the standard frequency.

The reliability is dependent upon many aspects, for example the operating system (automatic, manual, or both), signalling level, restoration time, etc.

Dimensioning of seabed protection

The failure of the closing procedure during a close request will lead to high flow rates and result in severe loads on the seabed protection. Damage to the seabed protection can lead to the structure being undermined and subsequently failing. The Structures Guide states that if the closing reliability has a higher probability of occurrence than 0.01*standard, the seabed protection must be dimensioned to take into account the fact that the structure is not closed in normative circumstances.

Two approaches have been outlined for this eventuality:

1. The first approach is based upon the flow load in the event of a decline in the standard water level.
2. A more detailed analysis, in which a lower representative value for the flow load can be used, is based on the assumption that the combined probability of not closing and this representative flow load complies with the stated structural requirement.

Climate change and rising sea levels

Rising sea levels will mean that measures have to be taken to manage the exchange with the North Sea and the effect of the tide on Lake Grevelingen. The point at which this becomes necessary will depend upon the rate of sea-level rise. What is relevant is the increase in the level of the low tide at the Brouwersdam. The assumption is that the sea level can rise by around 25 cm before it does not drop enough to permit an exchange of the tidal volume at Grevelingen through a flood barrier in the Brouwersdam (MER 2016; § 9.7.5). Based upon the scenario of a rapid increase in the rate of sea-level rise, this will be the case in around 2050.

It is possible to compensate for sea-level rise in various ways. However, the basic assumption is that the flood barrier will be designed more robustly from the outset. This means taking into account the capacity associated with the required outflow in a future year and then widening the opening or raising the mid-position water level every now and then. ‘Pinching’ will therefore be necessary in the initial years at high and low tides. This can be achieved using doors or turbines (to provide resistance). The turbines can then be removed after a certain period. Using turbines that can also pump will increase efficiency, but may make the system more expensive.

Incidentally, climate robustness means more than just adapting to rising sea levels. Account must also be taken of the expansion of water as a result of the increase in temperature. This is beyond the scope of the market consultation, but would have to be discussed in the plan development phase.

Selection of flood barrier location

In the ***SNIP Grevelingen study*** (preliminary study 2008-2009), three possible locations for a new flood barrier were investigated:

- A location to the north of the Kabbelaarsbank (the northern closure gap).
- A location in the Middelplaathaven.
- A location south of the Kabbelaarsbank (the southern closure gap).

The preliminary study concludes that the Middelplaathaven location is less well-suited for the construction of a flood barrier.
In terms of costs, the preliminary study gives no preference to the northern or southern location for the flood barrier. Preference is given to the construction of a flood barrier in the northern closure gap on the basis of the following considerations:

- The fact that the existing Brouwers Sluice can remain in operation and can continue to contribute to the (limited) topping up of Lake Grevelingen, and the fact that water level management is possible through two openings instead of one. At the southern location, Brouwers Sluice is considered more troublesome because of space considerations.
- An extra flood barrier remains in existence for the exchange of fish and marine mammals between Grevelingen and the North Sea.
- Because there is more space in the northern closure gap and more initiatives are in progress in the south (Brouwers Island).
- It is likely that the water quality problems in the northern channel (10 metres deep) will be easier to resolve than those in the southern channel (40 metres deep).

The ***MIRT Grevelingen study*** (2010 – 2012) included more investigation into a variant with a tidal power plant than the SNIP study. This gave rise to another reason to choose the northern location.

- The fact that marine mammals cannot pass through the tidal power plant, so the possibility of migration via Brouwers Sluice (south) must be retained.

Morphology

The MIRT study for a flood barrier including tidal power plant (north side) also investigated the effects upon morphology in the Voordelta area and in Grevelingen. Its conclusions are as follows:

- In the situation with tidal power plant, the Bollen van de Ooster will migrate more quickly to the south-east than in the situation without a tidal power plant.

- The Bollen van de Ooster area of tidal flats will probably increase faster with a tidal power plant than without. A tidal power plant is thus a positive, rather than a negative, for the development of the Bollen van de Ooster.
- The dynamics in the area between the Bollen and the Brouwersdam will increase in the situation with a tidal power plant. Channels may become deeper or will be able to stay open longer.
- The relative effect of the tidal power plant on the beach at the Brouwersdam seems small. It is possible that in the long-term the reduction in the size of the beach will proceed somewhat less quickly than in the situation without a tidal power plant. Interpretation by experts is needed.
- The recommendation is to install the tidal power plant in as northerly a location as possible.
- The flow rates in Lake Grevelingen increase to a maximum of 0.4 m/s in the main channels and to 0.8 m/s at the threshold between the southern and northern channels. This will give rise to erosion here at the openings and create a short-circuiting channel between the tidal power plant and the southern channel.
- The concentrations of sludge will increase locally to a maximum of 0.12 kg/m^3. This local increase will only occur as long as erosion takes place and there is still sludge on the seabed. In the vast majority of Grevelingen, sludge concentration will scarcely change in relation to the current situation. It can be concluded that the effects are thus highly localised.

The **Grevelingen and Volkerak-Zoommeer Government Development Plan** (2013 – 2015) is based upon the MIRT Grevelingen study and thus the northern location. This primarily discusses reducing the tide and increasing the exchange between the North Sea and Lake Grevelingen. The effects of this upon the functions of Lake Grevelingen are mapped out. The MER also notes that the precise location and dimensions of the flood barrier are not yet known, and the effects of the installation therefore cannot yet be fully established.

With regard to the Voordelta it states that an open connection in the Brouwersdam between the Grevelingen and the North Sea will lead to an increase in sandbanks, the Bollen van de Ooster, in the Natura 2000 Voordelta that directly adjoins the Brouwersdam.

This means that seals and bottom feeders that live there will gain a larger area where they can live and rest. The same increase in tidal flats may come at the expense of the area of shallow water and channels.

The size of this area is, however, not a limiting factor for achieving the maintenance objectives for species and habitats that are dependent upon shallow water and channels. After all, an open connection between the Grevelingen and the Voordelta increases the migration options for fish and seal species in the Voordelta, which is beneficial for the quality of the Natura 2000 area. No significant negative effects upon the Voordelta can be expected as a result of the proposed system change.

Additional insights into the morphology of the Voordelta (2017)

An extra motivation from the point of view of morphology on the Voordelta arose from the expert session on morphology held in 2017. It is expected that a flood barrier at the southern location will give rise to extra pressure (coastal erosion) on the coast of Schouwen.

From the expert session(s)

The southern flood barrier and probability of coastal erosion at Schouwen

A southern flood barrier is associated with serious erosion risks for the coast of Schouwen:

1. An eddy on the southern edge of the flood barrier can lead to erosion of that part of the coast, which is already subject to erosion. It is not clear whether an eddy will in fact arise, or how powerful this will be.
2. The jet of clear water that arises on the sea side of the flood barrier at low tide can give rise to coastal erosion at Renesse. The position and direction of the flood barrier will determine the point at which the jet reaches the coast. It can be seen at the Oosterschelde storm surge barrier that the size of such a jet can be considerable.
3. The southern flood barrier will lie close to the coast of Schouwen. As a result, the scour hole will not be far from the beach. This can result in Rijkswaterstaat having to defend the area with rockfill or frequent supplementation.
4. It is likely that the soil of the Brouwershavense Gat contains difficult-to-erode clay layers. Since the installation of the Brouwersdam, a considerable amount of sediment has been deposited there in a quiet area, and the flat bottom that can be seen in the profiles proves that the bottom is made up primarily of fine sediment that has fallen from the water column. Due to the hard layers, erosion can occur at unexpected places, and even closer to the coast than expected.

Safety for fish and marine mammals

Policy for the granting of water rights licenses for hydropower plant in national waters

On 2 December 2014, Rijkswaterstaat published the policy for the granting of water rights licenses for hydropower plants in national waters. The policy contains standards for fish kill in hydropower plants, but offers room for experimentation for new, innovative techniques. By issuing this policy, Rijkswaterstaat intends to provide a clear national framework for the licensing of hydropower plants in national waters.

The **cumulative** fish injury rate of 10%, as stated in this policy, is applicable to populations of priority fish species migrating downstream that are injured by passing hydropower plants. The cumulative fish injury rate of 10% represents the total of direct fish mortality and, where known, delayed mortality. The fish injury rate of 10% applies for the entire route (Lake Grevelingen including Brouwersdam and Grevelingendam) within which hydropower plants can be realised.

Despite the fact that there is no hydropower plant as described in the policy, the system is applied as if there were.

Moreover, according to the Water Act, the technologies that will be used satisfied the definition of 'best available technology'. This means that if hydropower plants can be realised that comply with stricter standards, this is also covered by the standard.

Brouwersdam hydropower plant

A facility for the production of sustainable electricity must be integrated into its environment safely. With regard to the tidal power plant, the main issue here is the safety of fish, marine mammals and other mammals (human beings and seals). It is assumed that smaller organisms (order of magnitude <1 cm) can pass through the turbines unimpeded.

Most (international) research focuses upon the safety of fish. The importance of fish mortality by turbines and pumps is so great that work is currently underway on a Dutch (NEN) standard to determine the fish injury rate due to passage through turbines and pumps.

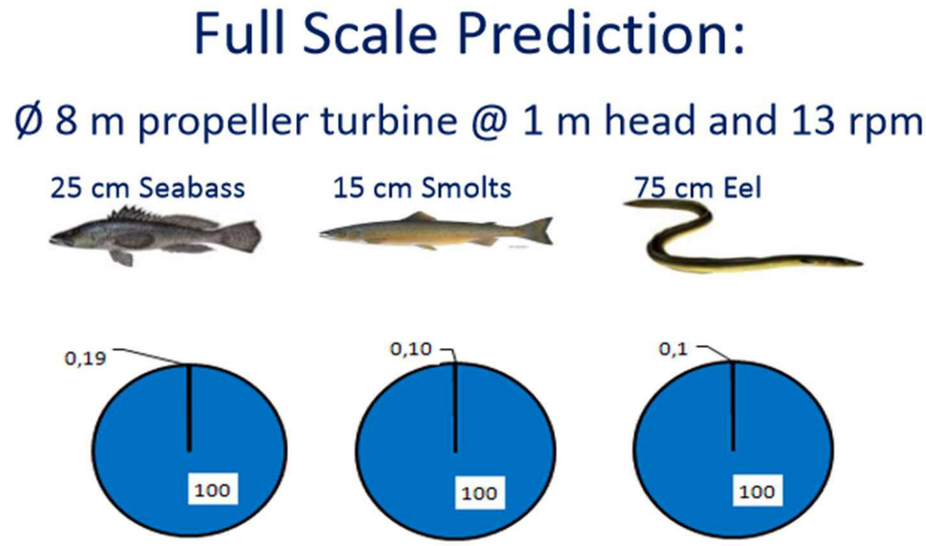
For general species, a standard of 10% mortality/injury applies, where populations are not unjustifiably under pressure. In the current situation, this applies to generally prevalent saltwater species that are also present in relatively large numbers in the Voordelta and the North Sea.

For species that migrate between saltwater and freshwater and vice versa at any point in their life cycle, a stricter standard may well be appropriate. This applies to species such as eel, sturgeon, salmon, flounder, three-spined stickleback, allis/twait shad, houting, river lamprey, smelt, sea trout and sea lamprey. Because there is hardly any inflow of saltwater into Lake Grevelingen, the required freshwater/saltwater gradient is absent. Furthermore, Lake Grevelingen is currently not part of the route that many of these species travel in their migration towards saltwater. Therefore, for the majority of the species, migration via the flood barriers in Lake Grevelingen is mainly down to coincidence and affects only small numbers. Any deaths during passage will therefore not affect the population as a whole, meaning that a mortality rate of 10%, as is also applicable for common species, will be sufficient.

Species such as eel, flounder and three-spined stickleback travel to the coast by selective tide transport. The probability of these fish entering Lake Grevelingen is therefore greater than the probability for fish species that actively and specifically migrate in the direction of a saltwater attraction flow. Because species such as flounder and three-spined stickleback are common species, it can be assumed that a generic standard of 10% is also sufficient for these species. However, eel are protected under the Nederlandse Aalbeheerplan (Dutch Eel Management Plan).

The fish damage to be expected if turbines are actually installed in the Brouwersdam is important.

In the framework of the EU Pro-Tide project, model fish-safety calculations were performed that were checked using a 1:16 scale model of the turbine that may be used in the Brouwersdam. See Van Esch, 2015, Van Berkel, 2015 and Van Berkel, 2017.



Figuur 14: Model-based, measurement-validated damage percentage for sea bass, salmon smolts and eel for turbines in the Brouwersdam (Van Berkel, 2017)

Less is known about safety for human beings and sea mammals than for passing fish. It is clear that human beings must not get into the ducts. At the current tidal power plant (river plant and barrages) there is therefore a ban on swimming and navigation in the vicinity (300 meters?) of the tidal power plant. This zone is indicated by a line of buoys. At river power plants, a coarse grating (bar spacing 10 cm) is installed in front of the inflow opening to prevent floating debris from damaging the turbines on the river. A coarse grating is not used on tidal power plant because the turbines are larger and the quantity of harmful floating debris smaller.

A swimming ban is not enforceable for seals. We know that seals can swim unimpeded through the existing two ducts (6x6 metres) of the Brouwers Sluice (length 190 m). The (potential) danger is from the turbines. Although these rotate relatively slowly (13 rpm at a fall of 1 metre), their large dimensions (diameter of 8 metres) nevertheless results in a peripheral speed of almost 5.5 m/s. The question here is whether a swimming seal will notice, and if so avoid, an approaching blade, and what damage a collision would cause, see Wood, 2016.

In principle, the following measures are available to prevent injury to sea mammals:

1. Repelling of sea mammals by light, sound and other types of vibration. Such measures have been investigated for fish with varying success and it is not known whether this approach will also work for sea mammals. We know that sea mammals can be scared by turbine noise, see Hastie, 2017.
2. Repelling sea mammals by screening with a coarse grating. This intrinsic solution is technically possible, but has consequences: costs may rise due to the need for a cleaning installation to clear accumulating dirt from the grating, and the flow rate and amount of electricity produced will be affected by the increased hydraulic resistance. There remains the question of

whether a grating cleaner is strictly necessary as the flow through the grating reverses 2x per day, thus possibly removing any accumulated dirt.

3. Stopping or draining the turbines when a marine mammal approaches. Like the systems already in use to detect birds and bats near wind turbines, automatic detection systems have also been developed to detect sea mammals near tidal turbines. These sonar-based systems can detect an approaching object and automatically switch the turbine off and back on again.

It should be possible to prevent damage to marine mammals by the use of one or more of these measures. No exhaustive investigation into this subject has taken place as part of the market consultation.

Appendix 4 Fact Sheet

Fact sheet
Grevelingen Tidal Project, Tidal power plant Brouwersdam variant, October 2018

Future development of the Grevelingen requires the restoration of attenuated tides to Lake Grevelingen. The Grevelingen Tidal Project is currently in the process of working out the details.

Objective

Primary objective: to improve the water quality, which will turn Lake Grevelingen back into a resilient and robust ecosystem. Realisation of a flood barrier in the Brouwersdam. A tidal range not exceeding 50 cm is sufficient. (With an annual rise in sea levels of 1 cm per year over the coming 30 years).
Secondary objective (piggy-back opportunity): production of tidal energy. Development of a tidal power plant in the flood barrier will provide opportunities for innovation and export aimed at river deltas threatened by rising sea levels.
Piggy-back opportunity: only if market parties realise the condition of risk-bearing private financing of extra investment, operation and maintenance of the plant with fish-friendly turbines.

Process and status

The public partners are seeking a private alliance partner for the plan development phase. This will give priority to the primary objective and secondarily, wishes to investigate the possibilities for energy production.

The alliance form applies for the plan development phase after the MIRT 2 decision. The purpose of this alliance is to work out the potential optimisations and required control measures. The maximum term of the plan development phase is two years. A go/no-go decision is then taken (MIRT 3). In the event of a no-go, only the basic variant of the flood barrier will be constructed.

Available information

This fact sheet describes a variant of a flood barrier with a tidal power plant, based on outcomes of Joint Fact Finding (JFF) in 2015 and an independent feasibility study of the Pro-Tide EU project. Some of the data in the JFF process are confidential. The principles of the Pro-Tide variants were tested during the public feasibility study, as described in the report on the precompetitive phase. In 2016, the estimate for the flood barrier produced a cost price with a variation coefficient of 24%. Partly on the basis of this, the public Pro-Tide variant was modified. These optimisations arising from previous variants have partly been included in this business case. In addition, an opportunity and risk dossier has been drawn up.

Principles

Maximum tide	50 cm (in accordance with Draft State Structural Vision) with 30 cm sea level rise over 30 years. Including Water Level Management requirements, this gives an annual average tidal range of 40 cm.
Fish mortality	< 1% (deviation, stating the reasons, is possible with an area-specific standard)
Energy price	€0.13 per kWh during the first 15 years. Made possible by SDE+ contribution in addition to market price. Thereafter, an energy price of €0.049 per kWh for the last 15 years.
Government contribution	€139.5 million (nominal, inclusive of VAT, price level 2016) for the flood barrier, including the necessary mitigating (environmental) measures.

Specifications		
Variant 2018	18 ducts, 11 with turbines	
Dimensions of dam	Length: 168 m Width: 49 m	Flood barrier design 2016, 15 ducts, excluding sea level rise
Civil construction	Civil engineering duct, concrete construction	including single-acting vertical rising sluice gates
Installed capacity	24.9 MW	
Type of turbine	8 m diameter	Pro-Tide 2015
Number of turbines	11 turbines	Business case and design 2018
Flow surface	1,152 m^2	18 ducts 8 x 8 m
Full load hours	2400 hours	60 GWh/y divided by 24.9 MW
Nominal investment (rounded off, inclusive of VAT)	Total €220 million: • €151.5 million, €130 million of which for civil engineering and €21.5 million for mitigating measures • €55 million turbines and connection costs	Formal government contribution fixed at €139.5 million (€118 million flood barrier and €21.5 million mitigating measures). The amount for the flood barrier is based on the 2016 forecast, which did not yet take account of sea level rise.
Maintenance costs	1.2%/y civil engineering; 2.5%/y turbines	Exclusive of demolition costs at end of service life
Result of business case 2018		
NPV of flood barrier	-/- €130 million	Civil construction bandwidth of 23% 2018 not yet established in decision.
NPV of tidal power plant	€8.8 million	PP 10 years, WACC 5.56%
SDE subsidy total	€72.9 million	
SDE+ subsidy, net present value	€48.6 million	
SDE+ subsidy per year	€4.9 million	
DEI subsidy	€4 million	Innovation subsidy
EU subsidy	€2 million	EU subsidy: Innovation fund
Internal Rate of Return (IRR)	7.7%	
Energy yield	60 GWh/year	Further optimisation possible
Avoided CO_2 emissions	30 kton/year	
LCOE value	90.7 €/MWh	compared with wind at sea 84 -90 €/MWh (Source: ECN 2016)
Number of households	17,000 approx.	Average households 3.5 MWh/y
Fish safety	<1% (Pro-Tide test set-up)	This is a potential turbine variant

Risks	
Design	1. Sea level rise scenario >1 cm/y, tidal range is realised (public) 2. Feasibility of risk of failure on closing the gates in connection with new water safety standards (public)
Granting permits	3. Delays in granting permits due to objections from the surrounding area (public) 4. Delays in granting permits in connection with passage for fish/marine mammals (private) 5. Delays in applications for subsidies for energy component (private)
Mitigating measures	6. Additional costs of mitigating measures (€21.5 million approx.) for nature compensation (related to reduction in tidal range in Lake Grevelingen; applies for tidal power plant and flood barrier (public)
Opportunities	
Design	1. Reduce length of ducts (49 m to +30 m, for both flood barrier and tidal power plant)
Innovation and export value	2. Economic development in the region through iconic project, innovation and export value (applies only for tidal power plant)
Conclusion	
Broadly speaking, it has been concluded that the tidal power plant variant described in this document will return a NPV of €8.8 million at a discount rate (WACC) of 5.56%. This makes the business case potentially feasible given the set preconditions, circumstances, risk and opportunities and with a 30 cm rise in sea-level. In order to realize the project objectives in full, a consortium will be selected in the tender for the integral assignment from the planning phase up to and including realization and operation. One contract but cut in two phases with an explicit go/no-go decision moment. After the decision-making moment it can be decided to change the contract form if it fits better with the decision for the next phase.	
Continuation	
The next step is to put the results of this variant into a market consultation this quarter and take stock of the interest of the market players. Their reaction will be taken into account in an MIRT 2 scope decision to be taken in early 2019. Optimisations and risk management will then be worked out in an alliance form in the plan development phase, following selection of an alliance partner.	

Colophon

The Grevelingen Tidal Project
is a partnership between:

provincie Zuid Holland

Provincie Zeeland

Ministerie van Landbouw, Natuur en Voedselkwaliteit

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Ministerie van Economische Zaken en Klimaat

gemeente Goeree-Overflakkee

Gemeente Schouwen-Duiveland

staatsbosbeheer

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Rijkswaterstaat will decide which information and insights obtained from this market consultation are to be used in the preparation of any future tender.

Acknowledgements

Issue	October 2018
Realisation	Grevelingen Tidal project
Editing	Awareness, The Hague
Translation	Wordhouse, Amsterdam
Photography	Ministry of Infrastructure and Water Management (Rijkswaterstaat), Province of South Holland