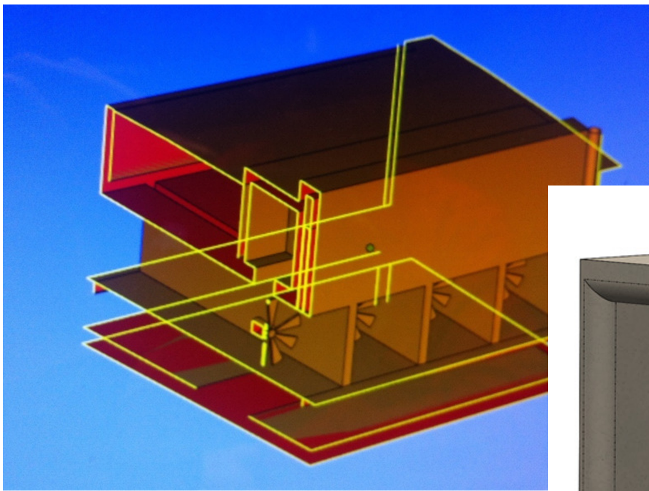
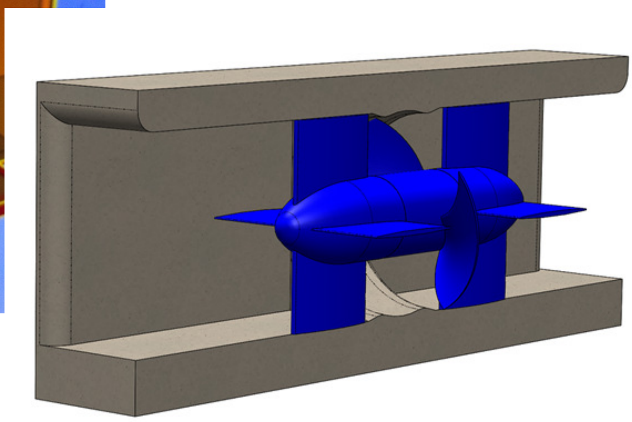
Optimised Configuration
of
TPP Brouwersdam





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Pro-Tide-NL

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Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

INTERREG IVB

Contents

1. EXECUTIVE SUMMARY & RECOMMENDATIONS

The findings of this project work package can be summarised as:

1. On the basis of information provided regarding Civil Constructions (IV-Infra) and turbines (Pentair-Fairbanks-Nijhuis), an optimised configuration for the tidal power plant Brouwersdam is synthesised.
2. Regarding the civil construction, both the ducted- and venturi configuration are considered as developed in the project with IV-Infra, the duct configuration being about 40 % less expensive than the venturi configuration
3. Regarding the turbines:
   a) Both Duct- as well as the Venturi turbines are technically viable options. Both turbines perform similar regarding efficiency and cavitation.
   b) Due to lower hydraulic conduit friction (higher flow rate), fewer duct turbines are required to full fill hydraulic demands (facilitate a certain flow).
   c) Investment costs of the duct turbine are roughly a factor 1,7 higher than the venturi turbine.
   d) Operation and Maintenance costs of the turbines are 2,5 % of the investment costs
4. Regarding the alternatives: The total (civil+turbine) investment costs of the ducted configuration is (slightly) lower than that of the venturi configuration. The O&M costs of the venturi configuration is however considerably less than that of the ducted configuration. As the duct turbine has been examined for fish friendliness, for the time being this configuration is chosen for further evaluation. An alternative configuration would be to combine the less expensive duct civil structure with the less expensive venturi turbine, housed in a steel venturi.
5. A hydro-energetic model is built in Microsoft Excel, to calculate the tidal statistics at Lake Grevelingen, depending on turbine characteristics and number of turbines. The numerical model has been checked by Deltares and found adequate for the current purposes.
6. As the requirement regarding an average 50 cm tidal-range at Lake Grevelingen is shown to be not feasible, a new requirement is formulated on the basis of the prime parameter for improvement of water quality, being the daily average flood or ebb flow. The new requirement states that for the tidal power plant and for the Brouwersluice together, the total daily average flow should amount to 1050 m^3/s. Further restrictions are set regarding tidal-range.
7. Above requirement is (almost) met with a tidal power plant as originally planned housing 15 duct turbines and length 135 meter of the powerhouse. The daily average flow is 936 m3/s, with an average tidal-range at Lake Grevelingen of 34 cm.

8. Economic viability is straightforwardly examined using a simple NPV-analysis of the tidal power plant (175 M€, 2,3 M€/a, with electricity sales) relative to a sluice gate only (81 M€, 0,6 M€/a). The tidal power plant Brouwersdam appears to be on the threshold of economic viability. At a discount rate of 5% and 15-years subsidy of 15 ct/kWh, break-even is indicated after roughly 15 years. The business case is shown to be very sensitive to either the discount rate and the electricity sell-price.
9. Options for improvement of the economic viability exist, as will be outlined in the recommendations

Recommendations:

In addition to the obvious improvement of a higher sell-price of tidal electricity (as in the UK, 0,42 €/MWh), several technological options for optimisation of the tidal power plant have been identified:

1. Reduction of investment costs:

a) Reduction of material input.

b) Possibly by pumping (using the same turbine equipment) as a means to attain a larger tidal-range at Lake Grevelingen (with a smaller power plant). With positive or negative head "Pump-assisted positive discharge".

2. Reduction of O&M-costs:

a) Combination of the less expensive duct civil structure with the less expensive venturi turbine, housed in a steel venturi.

b) Elongating the maintenance interval (as demonstrated in pumping station IJmuiden).

3. Optimisation of energy output:

a) Optimisation of power output through latching (for a short while holding-up) of the water level in Lake Grevelingen.

b) Also through pumping (as done in state of the art tidal power plants).

c) Operation of the power plant in Flood-mode, especially during neap-tide, possibly attractive because of the asymmetric (lowered) mid-level of Lake Grevelingen.

2. TIDAL POWER PLANT COMPONENTS

2.1 Civil Construction

Options for civil construction have been explored and optimised in the Pro-Tide project, in cooperation with the engineering firm IV-Infra (Spengen, 2015).
Following the advice of Pro-tide's R&D-advisory board (Berkel, 2014) and preliminary investigations of Delft University (Welsink, 2014), attention was focussed towards costs-reduction of the civil construction, through:

1. Smart phasing.
2. Innovative configurations and constructions.
3. Application of innovative materials.

Within the search for new options, in total 23 options for civil construction were generated and evaluated by a multi-disciplinary team with civil engineers, mechanical engineers, costs-engineers and tidal energy experts.
After selection on multi-criteria two options remained: 1) As the reference; the classical venturi-type of power plant, very similar to the existing tidal power plants, and 2) a "Lego" type of barrier, comprising straight walls and ducts with square cross section, see figure 2.1.

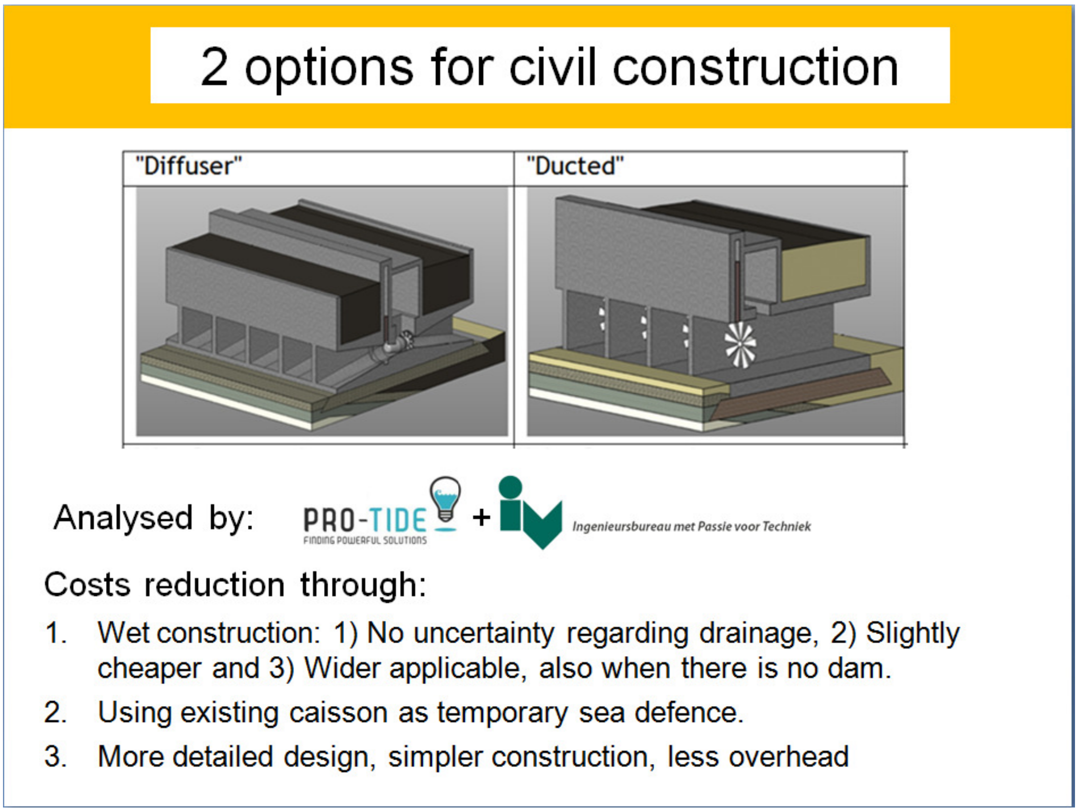

Figure 2.1 Selected (2) options for Ultra Low Head Tidal Power Plants.

Both options were designed for structural integrity and stability, taking extreme weather conditions and sea states into account.
After detailed costs analysis, both options displayed in figure 2.1 showed to be significantly less expensive than previous designs (Mooyaart, 2010). Inter-comparison of the two options showed that the duct-type construction was less expensive, especially because of the straightforward shape (flat walls, rather than double-curved walls of the venturi-type). The duct-type showed to be 43 % less expensive than the venturi type. Figure 2.2 gives the 4 costs-analysed data points, represented by wet surface (intake/discharge m^2), and the linear approximations.

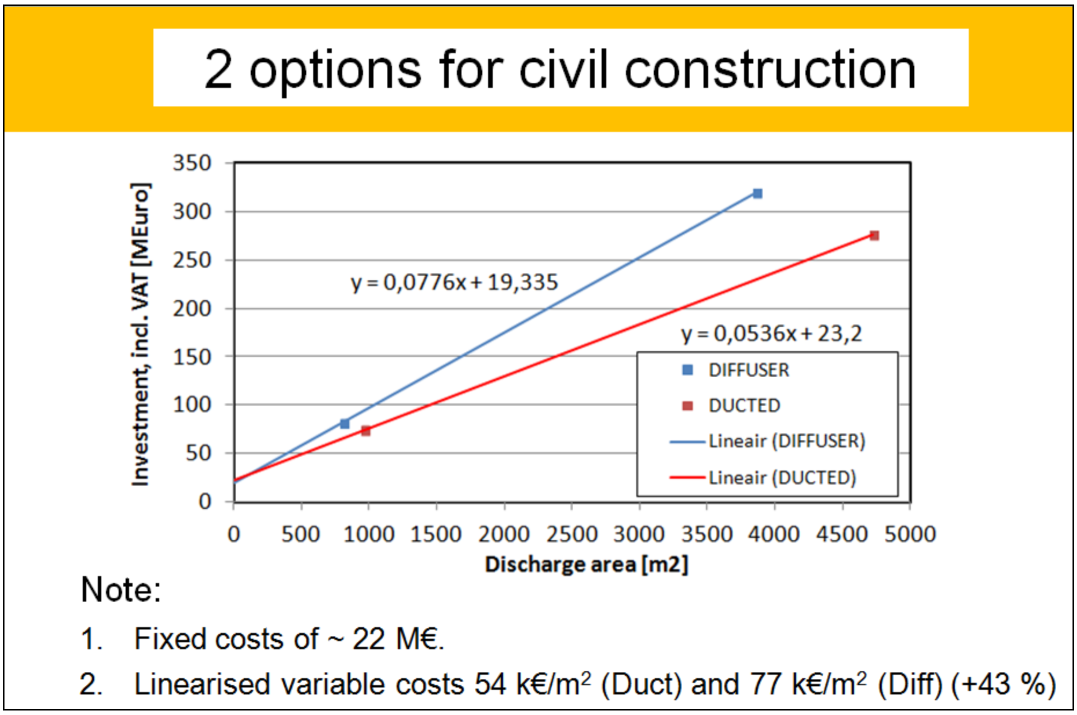

Figure 2.2 Costs for the venturi- and duct-type civil constructions, as a function of wet surface, all-in (i.e. including VAT)

For a more detailed description, see Van Berkel, 2015.

2.2 Turbines

Regarding the turbines, candidates for Best Available Technology (BAT) were identified by the R&D-advisory board of the Dutch Pro-Tide project, see Van berkel, 2014 and Van der Klip, 2015.
In a carefully executed process, an inventory has been made of all world-wide available turbine techniques, and presented in categorised overview. In cooperation with turbine manufacturers, factsheets were made describing the technique and quantifying the discriminating parameters (on costs, performance and fish-friendliness).
The best candidate for the Brouwersdam has been selected by means of a Multi-Criteria Analysis (MCA), executed by the members of the R&D-advisory board and 3 external

experts on marine technology, turbine technology and civil construction (Van Berkel 2014).

When it comes to application of pressure-turbines, the best candidate selected for the Brouwersdam is the Modified Bulb Turbine, which is based on the bulb turbine technology, further developed towards low costs, fish-friendliness and (for tidal application) bi-directionality. Amongst others, the modified bulb turbine is manufactured and marketed by Pentair-Fairbank-Nijhuis in Winterswijk (NL).

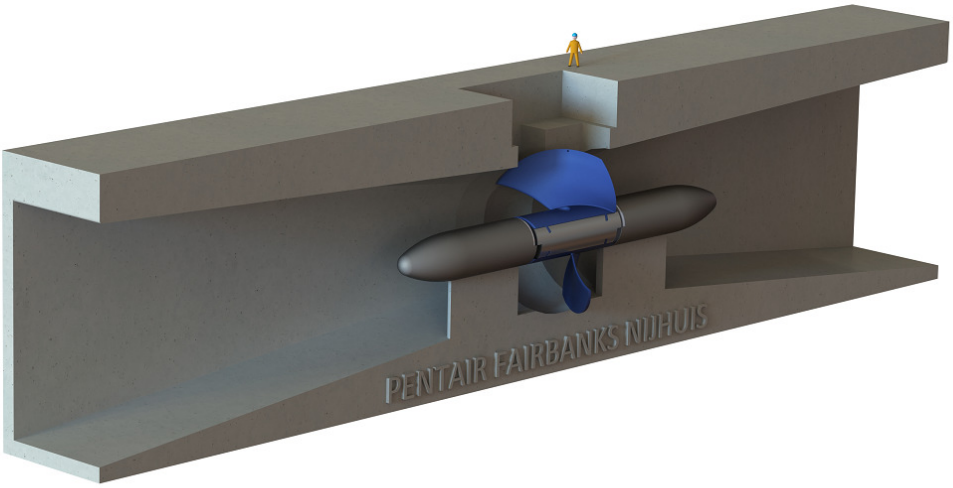

Figure 2.3 Bi-directional tidal turbine, marketed by Pentair-Fairbanks-Nijhuis.

After selection by Pro-tide's R&D-advisory board, it was decided to test the bi-directional turbine for fish friendliness. This is done in a purpose built field-laboratory at the banks of the NederRhine, at Nuon/Vattenfall's hydropower plant at Maurik (GLD), see figure 2.4.

Figure 2.4 Lifting the modified bulb turbine (venturi-type) into position into Pro-Tide's field-laboratory, for tests on fish friendliness, Maurik, May 2015.

Tests (see Vriese, 2015) , in combination with model based prediction of fish friendliness for the full scale (8 meter diameter) device, see (Van Esch, 2015) show that the modified bulb turbine exhibits excellent fish friendliness characteristics: The fish survival rate (for Eel, Seabass and Salmonide Smolts) is better than 99,8 %.

For this optimisation of TPP-configuration, two types of modified bulb turbines were evaluated by Pro-Tide in cooperation with Pentair-Fairbanks-Nijhuis.

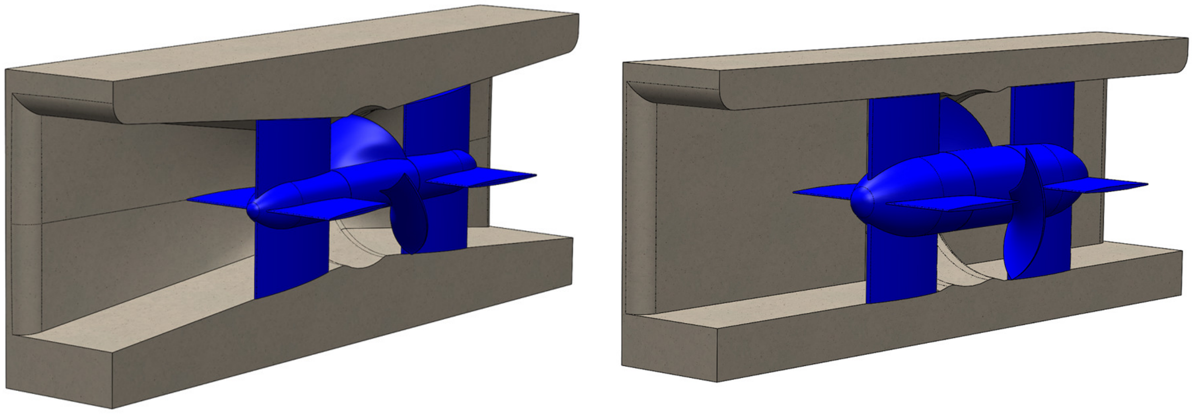

Figure 2.5 Turbine-options: Left: Venturi-turbine and right: Duct-turbine (source: Pentair-Fairbanks-Nijhuis)

For proper evaluation in combination with the civil construction options outlined in section 2.1, the two turbine-types have been analysed by Nijhuis, regarding:

1. Technical performance (Head/Flow rate-relation, Power output and efficiency)
2. Net Positive Suction Head (NPSH) and submergence.
3. Costs.

2.2.1 Technical performance

Insight in the technical performance (Head/Flow rate relation, power output and efficiency) is given by figure 2.6.
Note that the graphs provide machine performance for a single speed (rpm) only. If, by virtue of frequency control, speed is adaptable to varying conditions, e.g. machine efficiency can be kept at a near-maximum level, say 80 % over a wide range speed of head and flow rate.

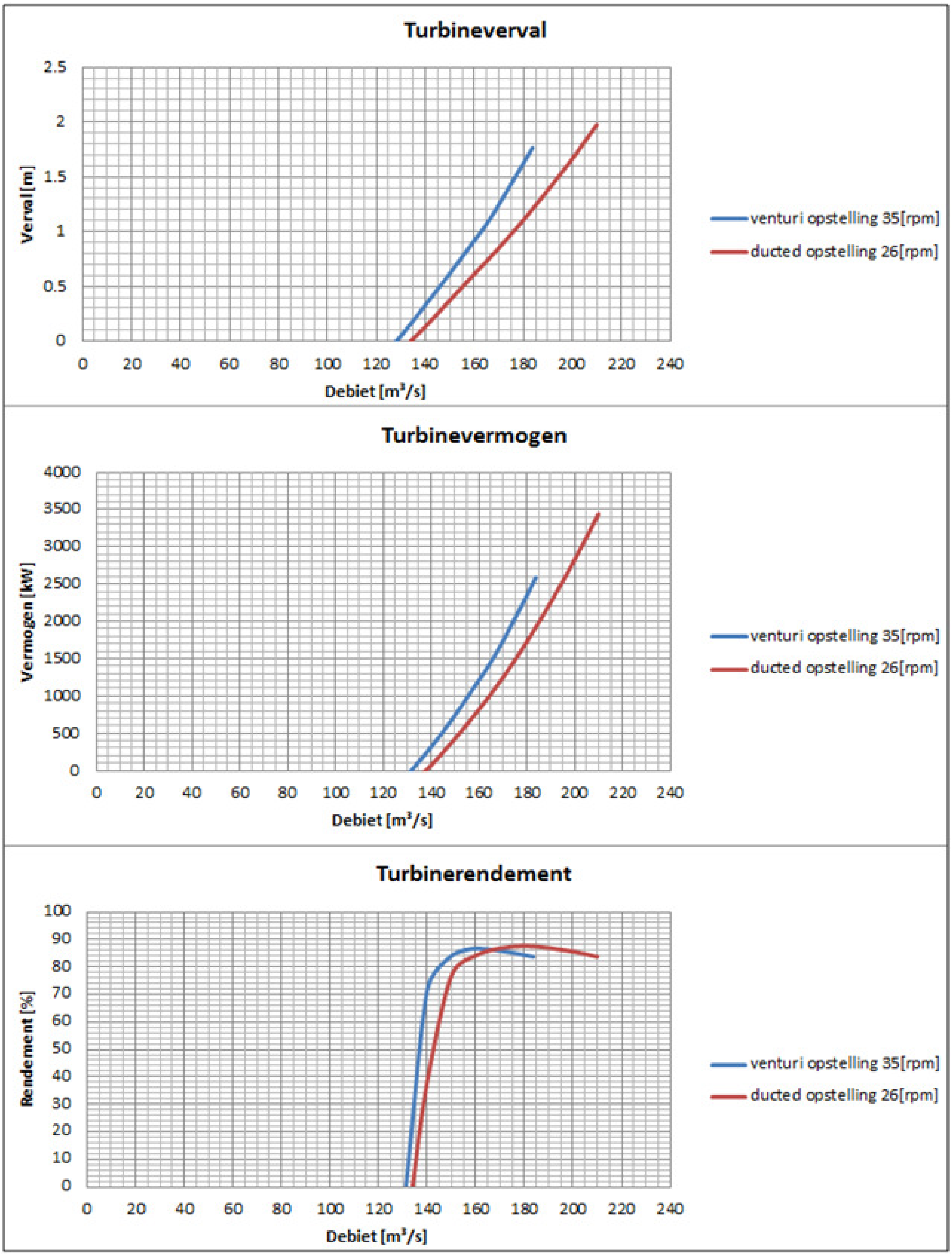

Figure 2.6 Graphs for (top: Head/Flowrate-relation, middle: Power output and bottom: Efficiency), for a speed of 35- and 26 rpm for the venturi and ducted turbine respectively.

The graphs indicate that both turbines perform similar. Due the lower losses in the hydraulic conduit, the duct-turbine operates at a higher flow regime. In principle this means that for a given flow rate, a smaller number of duct-turbines is required, compared to the venturi turbine.

2.2.2 NPSH/Submergence

Also with respect to cavitation, the two turbines behave similar, as shown in figure 2.6.

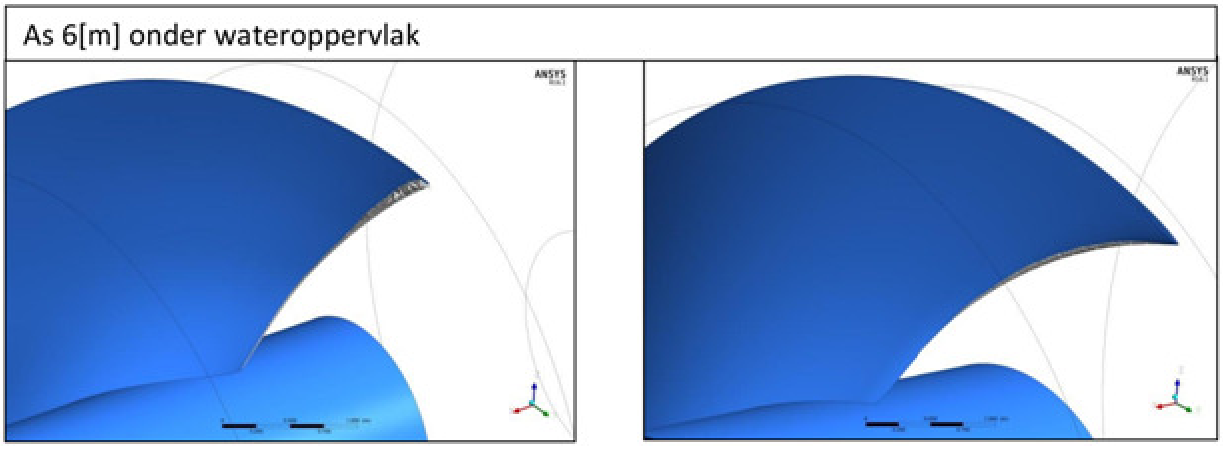

Figure 2.6 Low pressure zones (depicted in gray) at the leading edge of the venturi turbine (left) and the duct-turbine (right).

On the basis of the NPSH-analysis, it can be concluded that both turbines behave similar, the duct turbine even better than the venturi turbine, especially since it must be taken into account the rotor tip of the Ø 8 m duct turbine, because of the larger rotor diameter, is 1.1 meter closer to the water surface than the tip of the Ø 5,8 m venturi turbine.

Regarding submergence (which needs to be sufficient to avoid entrainment of air into the turbine water flow), it is stated that the top of the water intake, at maximum flow conditions (3 m/s intake velocity) should at least be 2 meter below the water level.
As the lowest allowable water level (at intake) is the lower limit of the water level in Lake Grevelingen (-50 cm), the intake should be positioned 2,5 meter below NAP.

2.2.3 Costs

Table 2.1 and 2.2 give the initial (investment) costs-specification of the two turbine-types,

Table 2.1 Costs, Venturi turbine, based on production in China (Meijnen, 2015)

Nr Turbines [-]	Hardware [kEuro/Turbine]	Projectkosten [kEuro/Turbine]	Installatie [kEuro/Turbine)	Totaal [kEuro/turbine]	Totaal [MEuro/turbine]
1	2443	800	50	3293	1,46
4	2198	429	49	2676	1,19
10	2109	284	47	2440	1,08
20	2064	208	46	2318	1,03
40	2031	152	44	2227	0,99
60	2018	127	43	2188	0,97

Table 2.2 Costs, Ducted turbine, based on production in China (Meijnen, 2015)

Nr Turbines [-]	Hardware [kEuro/Turbine]	Projectkosten [kEuro/Turbine]	Installatie [kEuro/Turbine)	Totaal [kEuro/turbine]	Totaal [MEuro/MW]
1	4295	800	100	5195	2,21
4	3866	429	97	4392	1,86
10	3708	284	94	4086	1,73
20	3628	208	91	3927	1,67
40	3572	152	89	3813	1,62
60	3547	127	86	3760	1,60

Also operation and maintenance (O&M) costs are specified. When related to the investment costs these costs typically are 2,5 %.

3. HYDRAULIC MODELLING, ENERGY YIELD AND TIDAL STATISTICS

3.1 Hydro-energetic model

The hydro-energetic model is built to predict the energy output of the tidal power plant Brouwersdam and the resulting water level (variance) at Lake Grevelingen.
Input is the water level variation at the North Sea ("Brouwershavense gat") at a 10 minutes time base, and the turbine characteristics specified by Nijhuis (Meijnen, 2015).
For versatility the model is built in Microsoft Excel by Pro-Tide (this report), see figure 3.1 for a screen-shot.
The numerical model calculates the resulting water level at Lake Grevelingen, on the basis of the North Sea level and the turbine flow of the preceding time step. Time stepping (time integration throughout a whole year) is done Euler explicit. For accuracy, a 10 minutes time step is adopted.

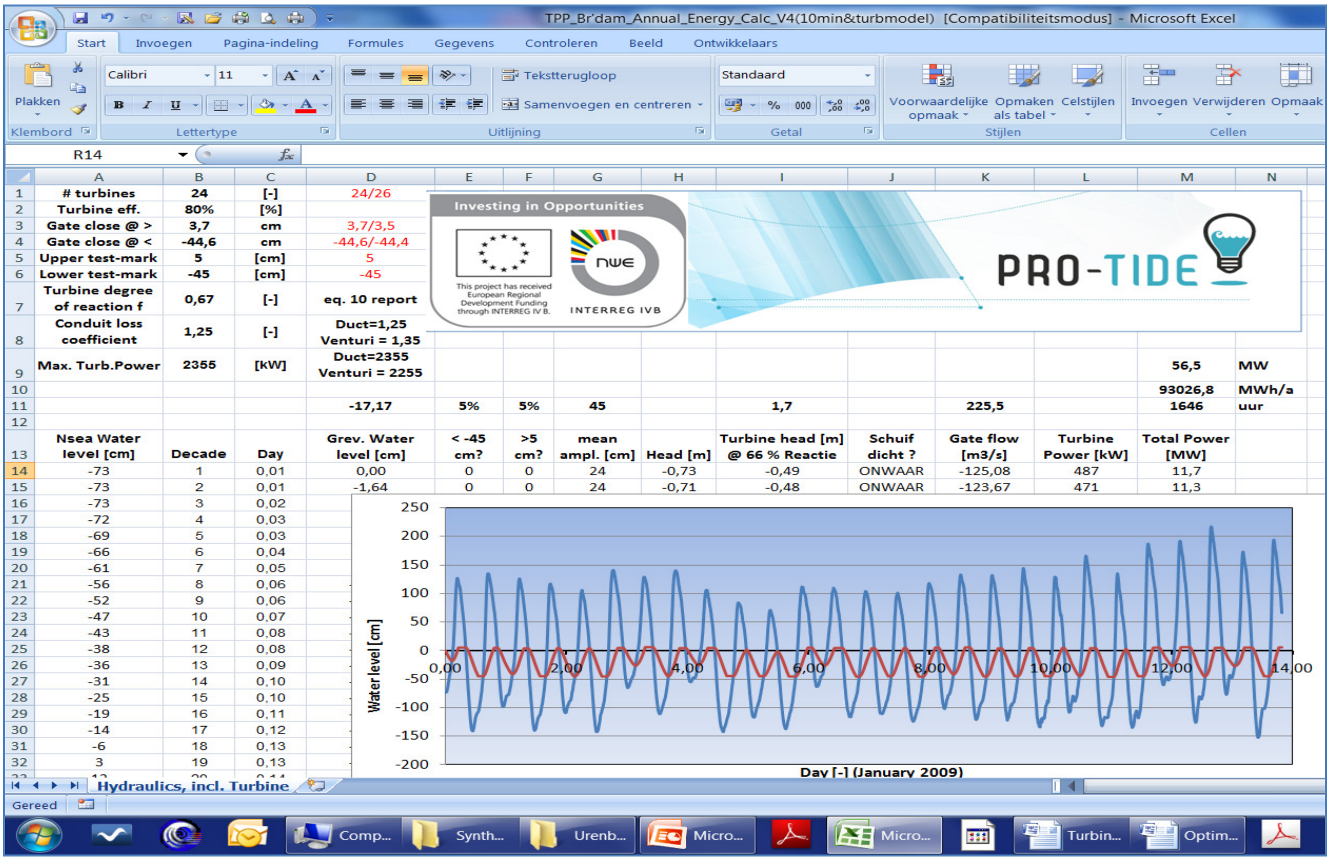

Figure 3.1 Pro-Tide's hydro-energetic model (Microsoft Excel)

Momentary turbine power output is calculated on the basis of turbine head and flow, adopting a machine efficiency of 80 % (result of detailed analysis and tests of the turbine). Summation over all (8760 x 6 = 52560 time steps) yields the annual energy output.

Action of a gate is incorporated into the model to control the water level in Lake Grevelingen. The gate closes the moment the water level approaches the +5 and -45 cm limits. By fine-tuning the precise limits, a 5 % exceedance of both limits is attained.

By varying the input parameters of the hydro-energetic model:

- Number of turbines
- Type of turbines (Duct or Venturi)
- Upper gate-action level (~ + 5 cm) + Lower gate-action level (~-45 cm),

The hydro-energetic model outputs:

- The mean tidal amplitude.
- The + 5 cm exceedance (max 5%) and the -45 cm exceedance (max 5%).
- Mean water level at Lake Grevelingen.
- Maximum head across the Brouwersdam.
- Flow rate through the Broudersdam.
- Annual energy production.

Deltares has checked the hydraulic model for consistence and accuracy, and found the model is quite adequately fit for the purpose (Kleissen, 2015).

3.2 Requirement regarding water level variation at Lake Grevelingen.

At the start of this work package, the criteria (requirement) regarding the water level variation was formulated as average 50 cm top-trough amplitude with max. 5% time exceedence to a bandwidth of 60 cm, see appendix A and (Paulus, 2015). During system simulation with the hydraulic model, it showed that the requirement regarding the water level variation could not be met. Further analysis, elaborated in appendix A, shows that the requirement cannot be met, with what power plant of sluice gate whatsoever.

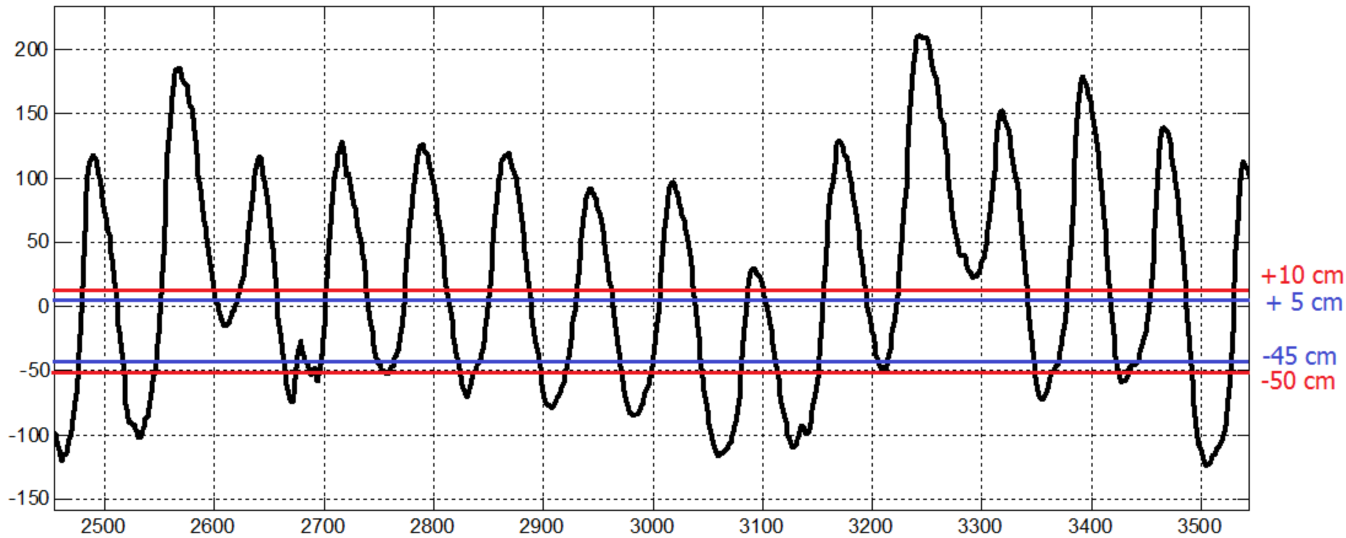

Figure 3.2 Sample of measured water level at Brouwershavensegat08-2009

On the basis of the criteria originally set by Deltares (Nolte, 2011) and in cooperation with RWS (P. Paulus), a new set of criteria is proposed:

1) The water level at Lake Grevelingen:
    a) Must always be lower than +0,10 cm NAP
    b) For max. 5 % of the time may be higher than +0,05 cm NAP
    c) Must always be higher than -0,50 cm NAP
    d) For max. 5 % of the time may be lower than -0,45 cm NAP
    e) The time average water level must be -0,2 ± 0,05 cm NAP
    f) Water levels are to be measured at gauging-pile BOM1 (centre of Lake)
2) Tidal period twice a day, with daily average flow rate of 1050 m^3/s (925 m^3/s for tidal power plant and 125 m^3/s for existing sluice gate).
3) The tidal power plant must be able to accommodate for raising sea level and, in combination with a raised mid-level, must be able to maintain the required daily average 925 m^3/s flow rate. (note: not tidal amplitude!)
4) Above demands to be tested with North-Sea level "Brouwershavense gat08-2009" as the benchmark (reference) test-year.

Requirement #8 is not included in the amended set of criteria, but added here to make the criteria tangible. It is proposed that the developer of the tidal power plant should demonstrate that the tidal power plant is able to meet the criteria, including circumstances due to:

a) Control-measures of the water level.

b) Storms.

c) Maintenance of the tidal power plant.

4. SYNTHESIS OF A TIDAL POWER PLANT

4.1 Introduction

By fine-tuning the input parameters of the hydro-energetic model, the number of turbines can be selected that -as much as possible- satisfies the requirements regarding tidal variation at Lake Grevelingen. This is done for both the venturi as well as the duct turbine.

4.2 Preliminary results for the original tidal variation requirement

As described, it became clear that the original, 50 cm average tidal-range criterion requires a relatively large number of about 25 turbines. Due to the narrow, max. 5% bandwidth of 60 cm, the installed generation capacity however cannot not be fully exploited; The machines would stay idle for a long period, which also results in a relatively small number of full load hours (~1660).

4.3 Results for the newly formulated tidal variation requirement

A more economical proposition would be to deploy a smaller number of turbines, also reflecting the new, less demanding requirement of 925 m^3/s daily average flow rate.

As a start 15 turbines are adopted in the design, which nicely fits the original 135 m long (IV-Infra), later corrected by RWS for different pricing of concrete, tooling and gate drives, and by Horvat for increased depth (submergence) of the structure, see (Lendering, 2015).

Table 4.1 provides the relevant data for the tidal power plant in ducted and in two venturi-layouts, as well as its reference the sluice gate without turbines. As the investigations by IV-Infra showed that the ducted civil construction design can be used adequately (with minor simplifications due to the absence of turbines) as sluice gate only, both the tidal power plant and the sluice gate are based on the same civil construction principle.

Table 4.1 Results regarding performance and costs

Investment costs, [M€], incl VAT	**Duct turbines, Ø 8 meter.**	**Venturi turb Ø 5,7 meter.**	**Venturi turb Ø 5,7 meter + steel venturi**	**Sluice gates only (8 x 8 m2)**
Number of turbines	15	16	16	9
Average Tidal amplitude [cm]	33	34	34	34
Daily average flow rate (Flood or Ebb)	811	829	829	838,5
Average level [cm NAP]	-14,2	-15	-15	-15
Exceedance > + 5 cm	5%	5%	5%	6%
Exceedance < - 45 cm	2%	2%	2%	2%
Maximum power output [MW]	**25**	**25**	**25**	**-**
Annual Energy Yield [GWh]	**67**	**69**	**69**	**-**
Full load equivalent [hr]	**2680**	**2760**	**2760**	**-**
Total intake area [m2]	960	1024	1024	576
Costs civil works 30 m (IV-Infra), incl VAT [M€]	75	99	78	54
Costs civil works 30 m (IV-Infra), excl. VAT [M€]	62	82	65	45
Added Costs (check RWS: concrete, ceilings, gate drives, walls) [M€]	16	17	17	10
Added costs increased depth (submergence: Horvat) [M€]	1	1	1	1
Total Civil costs, 30 m excl VAT [M€]	79	100	83	55
Contingency , 46 % of total civil costs [M€]	37	46	38	26
Civil construction costs including contingency [M€]	**115**	**146**	**121**	**81**
Turbine costs (excl. VAT) [M€]	**60**	**38**	**38**	**-**
Steel venturi's (excl. VAT) [M€]	-	-	**18**	-
Total investment [M€], excl. VAT	**175**	**184**	**177**	**81**

O&M (annual costs) [M€]				
Civil works, 1 % [M€]	0,8	1,0	0,8	0,6
Turbines, specification Nijhuis [M€]	1,5	1,0	1,0	
Total Operation and Maintenance, [M€], incl VAT	**2,3**	**1,9**	**1,8**	**0,6**

Electricity @ 150 €/MWh =< 15 years [M€/a]	**10,05**
Electricity @ 50 €/MWh > 15 years [M€/a]	**3,35**

The top part of table 4.2 provides data relating to the resulting tidal variation at lake Grevelingen. It appears that all options do not fully comply to the required 925 m^3/s daily average. The flow rate deficit however will be (party) compensated by slipping (less resistance) of the turbines at high power level, an effect which is taken into account to restrict the power rate to 25 MW, but which has not yet been taken into account in the hydraulic model. Probably also the Brouwersluis will exchange more than the 125 m^3/s as currently is foreseen.

Also note that the average tidal range is in the range of 33/34 cm, with a mid-level of -15 cm.

Table 4.1 shows that the ducted configuration offers the least total investment (175 M€), but also the highest O&M-costs (2,3 M€/a). Note that the 115 M€ investment incl. contingency for the tidal power plant corresponds with the costs specified by Horvat, if the scale factor from 40 m to 30 m wide power plant is taken into account.

The second-last column right gives costs of the configuration suggested by Pentair-Fairbanks-Nijhuis, comprising a ducted civil construction, combined with venturi-turbines, housed in a venturi made of steel (rather than concrete). Costs for a steel venturi is specified at 1,1 M€. The combined configuration probably offers a more costs effective solution; 177 M€ and 1,8 M€/a. However, as the venturi-turbines have not been evaluated on fish friendliness (see Esch, 2015), for this moment they are not considered further.

Table 4.1 illustrates that the total investment of the tidal power plant in ducted configuration would be 175 M€ and 81 M€ for the sluice gate only. Corresponding annual O&M-costs are 2,3 and 0,6 M€/a.
Regarding the revenues, it is assumed that for the first 15 years electricity is sold at a (subsidised) price of 150 €/MWh, and after 15 years for (unsubsidised) 50 €/MWh.

5. COSTS AND BENEFITS: NET PRESENT VALUE (NPV)

To give some insight in the economic viability of the tidal power plant Brouwersdam, here a straightforward (simplified) approach is adopted, taking into account investment costs (difference between tidal power plant and sluice gate only) and annual costs and benefits, discounted towards the current time level.
This approach does not offer the details and accuracy of the analysis done by Rebel (Jansen, 2015) and Horvat (Lendering, 2015), but is given here informatively. For a more precise treatise on the economic viability, the uncertainty and the bandwidth, the reader is referred to aforementioned reports.

5.1 Annual costs and benefits.

Figure 5.1 gives a summary of the investment costs of the tidal power plant and the sluice gate only (ref. table 4.1).

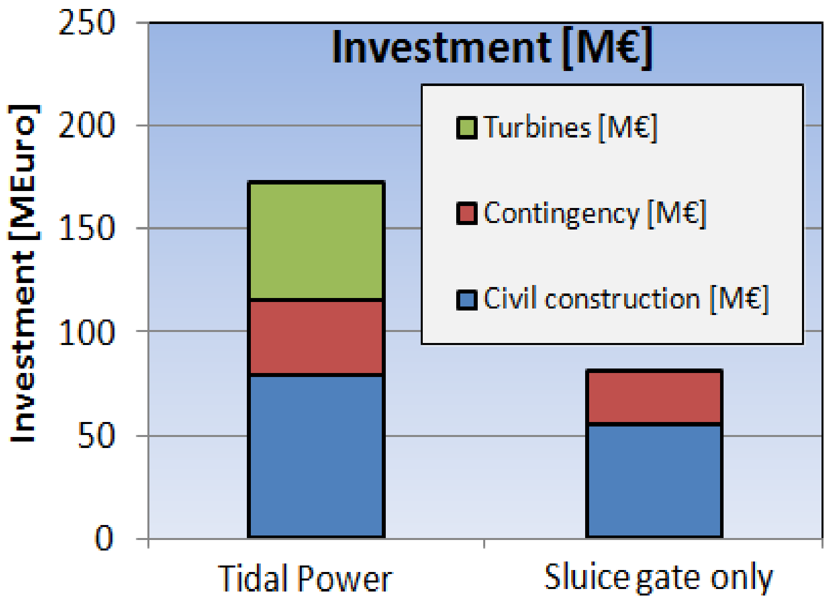

Figure 5.1 Investment costs of the tidal power plant and alternative sluice gate only.

Obviously the tidal power plant is more expensive, on the one hand due to the larger civil construction required (135 meter rather than 81 meter) and on the other hand due to the turbines. The tidal power plant is roughly twice as expensive, with the turbines roughly 1/3 of the investment costs.
Likewise, figure 5.2 summarises the annual costs and benefits of the tidal power plant and the sluice gate only (ref. table 4.1).

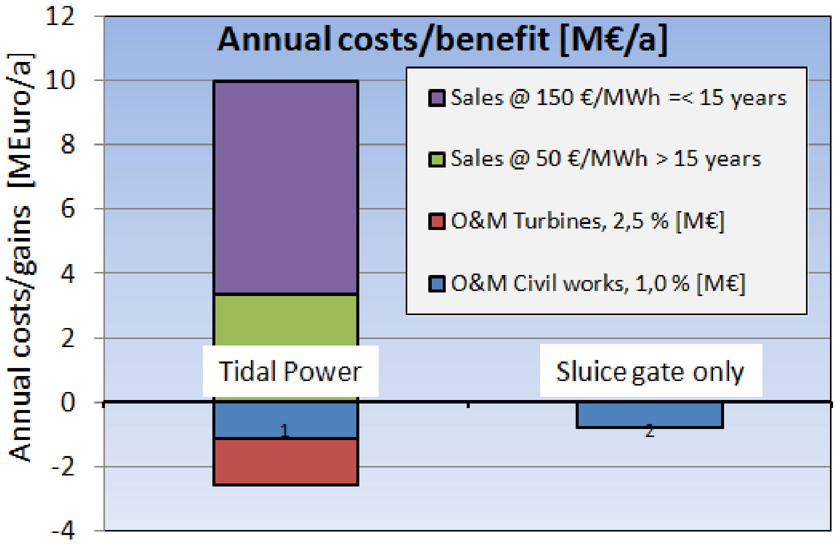

Figure 5.2 Annual costs and benefit of the tidal power plant and sluice gate only.

The figure expresses that the O&M-costs (negative in figure 5.2) of the tidal power plant is considerably higher than the O&M-costs of the sluice gate only, predominantly due to maintenance costs of the turbines.
The revenues associated with the tidal power plant outweigh the costs, especially during the first 15 years when electricity is assumed to be sold for 150 €/MWh (revenue 10 M€/a). After 15 years the revenues decrease to 3,3 M€/a (@ 50 €/MWh)

If investment costs of the tidal power plant (relative to the investment costs of the sluice gate only) and likewise the relative future costs and benefits are discounted (valued) to the present time, using a discount factor of 5%, the Net-Present-Value (NPV) of the tidal power plant follows, as shown in figure 5.3.

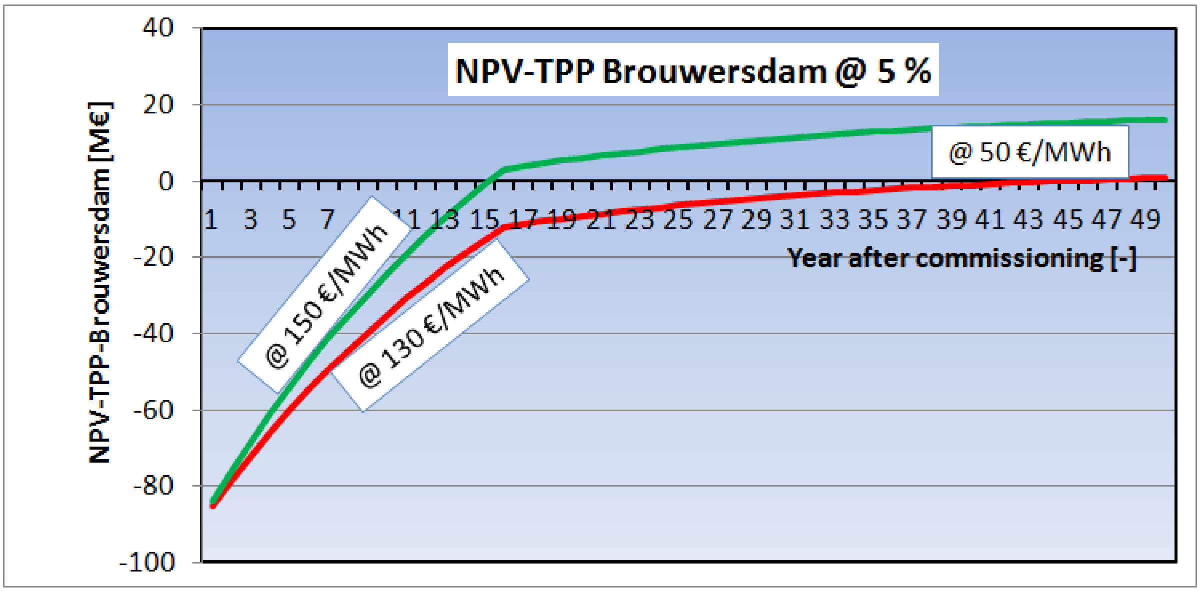

Figure 5.2 NPV of the tidal power plant Brouwersdam.

As shown by the green line, the break-even point (positive NPV) for the baseline assumed 5% discount rate and 150 €/MWh sales of electricity is attained after roughly 15 years, quite coincidently at the time the sell-price of electricity drops to the assumed 50 €/MWh.
If the initial 15 years sell-price is moderated to 130 €/MWh (red line), break even effectively is not reached. A similar calculation can be given for a discount rate of 6 %, which would show break-even at 27 years.
These simple examples show that the tidal power plant is on the threshold of economic viability but that it is very sensitive to e.g. discount rate and electricity sell-price.

5.2 Further developments

Further development is necessary to make the business case of the tidal power plant more robust.
Given the insight provided by the previous chapter, economical means could be to reduce the discount rate and/or increase the sell-price of electricity. In that respect it is mentioned that tidal power developments in the UK receive a 5 ROC's (Renewable Obligation Certificate) subsidy of about 0,3 £/kWh (0,42 €/MWh), which would greatly improve the economic viability of the power plant.

Technical options for a better business case could be:

1. **Reduction of investment costs:**
   - a) Reduction of material input.
   - b) Possibly by pumping (using the same turbine layout) as a means to attain a larger tidal-range at Lake Grevelingen (with a smaller power plant). With positive or negative head "Pump-assisted positive discharge".
2. **Reduction of O&M-costs:**
   - c) Combination of the less expensive duct civil structure with the less O&M-demanding venturi turbine, housed in a steel venturi.
   - d) Elongation of the maintenance interval (as demonstrated in pumping station IJmuiden).
3. **Optimisation of energy output:**
   - d) Optimisation of power output through latching (for a short while holding-up) of the water level in Lake Grevelingen.
   - e) Also through pumping (as done in state of the art tidal power plants).
   - f) Operation of the power plant in Flood-mode, especially during neap-tide, possibly attractive because of the asymmetric (lowered) mid-level of Lake Grevelingen.

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APPENDIX A: REQUIREMENT REGARDING TIDAL AMPLITUDE

The boundary conditions regarding the water level of lake Grevelingen are adopted from (Paulus, 2015 (POGV dated 150727)):

1) The water level at Lake Grevelingen:
   a) Must always be lower than +0,10 cm NAP
   b) For max. 5 % of the time may be higher than +0,05 cm NAP
   c) Must always be higher than -0,50 cm NAP
   d) For max. 5 % of the time may be lower than -0,45 cm NAP
   e) The time average water level must be -0,2 cm NAP
   f) Water levels are to be measured at gauging-pile BOM1 (centre of Lake)
2) Tidal period twice a day, all over the lake, with exceptions possible (storms, maintenance, asymmetric level control)
3) The tidal power plant must be able to accommodate for raising sea level and, in combination with a raised mid-level, must be able to maintain the required not tidal amplitude.

As an example for further analysis, figure A.1 provides an time series of the water level at Brouwershavensegat08-2009.

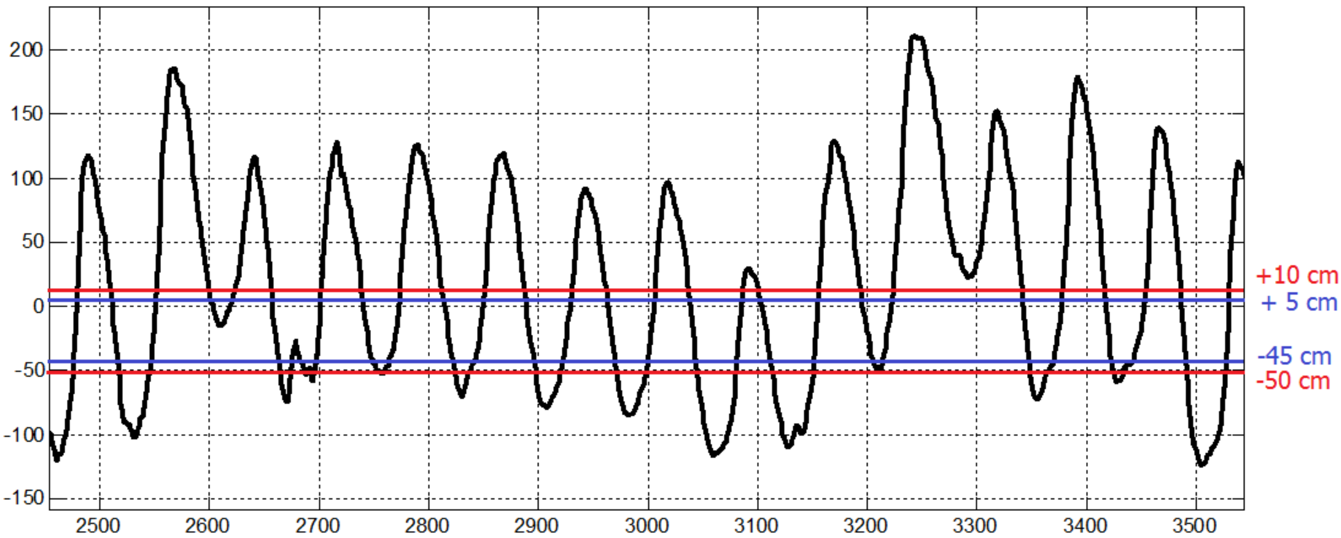

Figure A.1 Sample of measured water level at Brouwershavensegat08-2009

The nominal (95% time) tidal levels are -45 cm and +5 cm, with 5% of the time allowed excursions (to min. -50 cm and to max. +10 cm).
Seen in figure A.1 are troughs in the tidal wave that do not reach the nominal -45 cm level. Over a full year this occurs about 18 times. The total deficit (difference between the trough and the -45 cm nominal level) amounts to 430 cm.

A simple analysis may show that the excursions to min. -50 cm and max +5 cm cannot compensate for the deficit, indicated above, in order to arrive at a 50 cm mean top-trough tidal amplitude:

- A full year covers 8760/12,4 = 706 tops and 706 troughs.
- 5 % excursion to max +5 cm and 5% excursion to -50 cm yields a potential surplus of max. 706 x (5% + 5%) x 5 cm = 353 cm.
- This cannot compensate for the 430 cm deficit.
- This means that the required 50 cm average top-trough tidal variation cannot be reached, even with infinitely large sluice gates or tidal power plant

Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
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