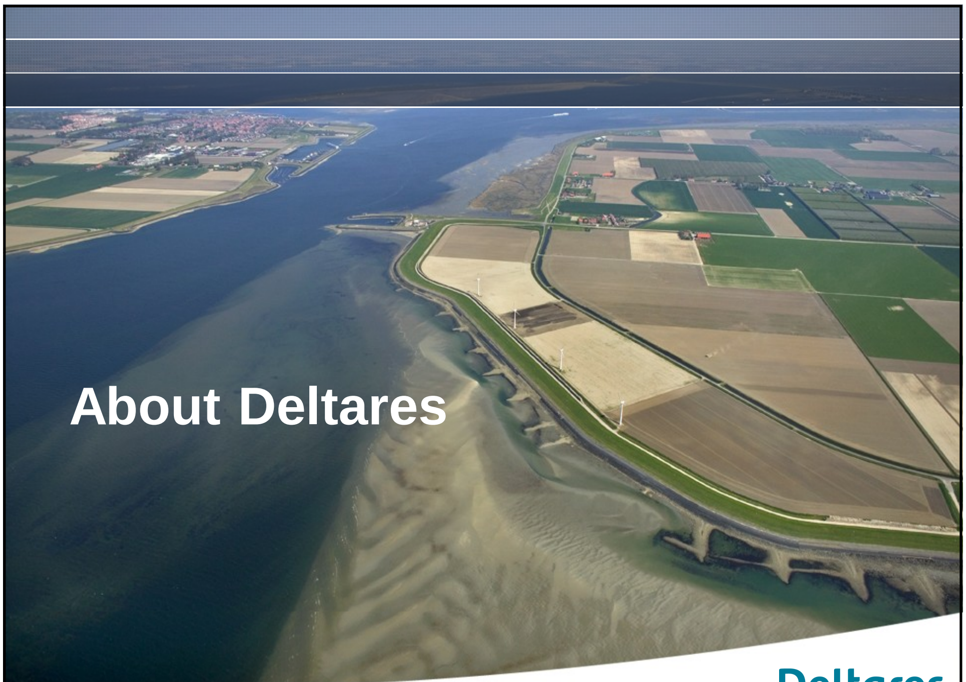
Deltares

Enabling Delta Life

Ocean Energy at Deltares

Presentation for lunch lecture TUDelft

27 juni 2016



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Deltares

Deltares is an not for profit research institute for hydraulics and geotechnics that provides a high standard of expertise and advice.
We work closely with governments, businesses, universities and research institutes in The Netherlands and abroad.

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Deltares - History

In 2008, 4 Dutch institutions with a combined history of more than 400 years established Deltares:

- **WL | Delft Hydraulics –** hydraulic engineering and integrated water management
- **GeoDelft –** geo-engineering
- A part of **TNO Built Environment and Geosciences** – soil and groundwater
- Sections of **Rijkswaterstaat** *(*RIKZ, RIZA and DWW) **–** integrated water management and hydraulic engineering.

WL | delft hydraulics

GeoDelft

TNO | Knowledge for business

Rijkswaterstaat

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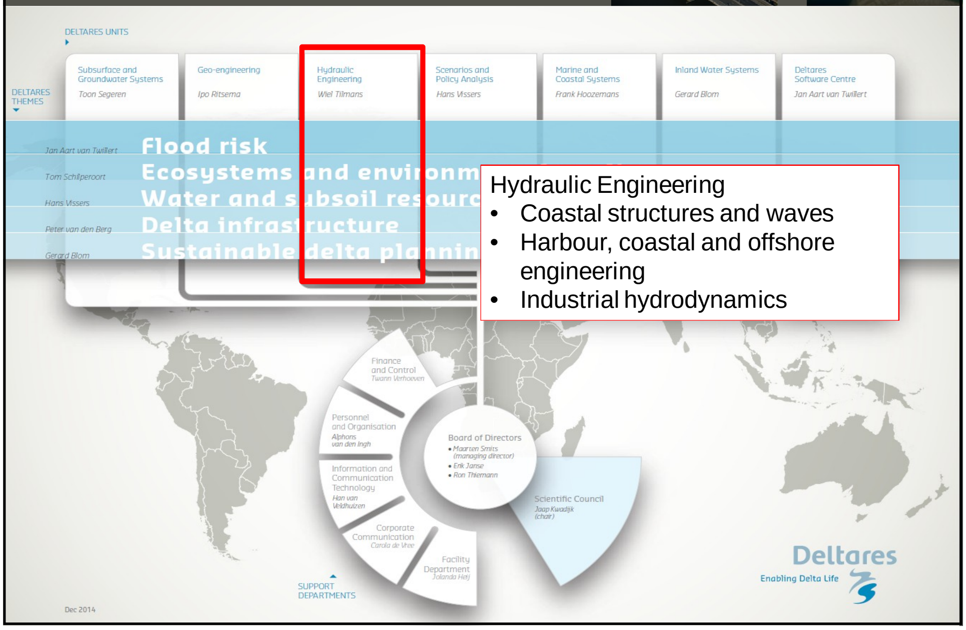
Deltares - Organisation

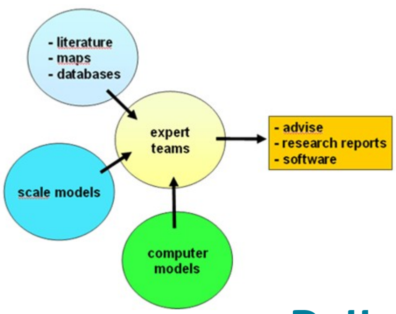


Hydraulic Engineering

- Coastal structures and waves
- Harbour, coastal and offshore engineering
- Industrial hydrodynamics

Deltares – Key aspects

- Independent not-for-profit research institute for hydraulics and geotechnics
- ± 850 highly skilled specialists (mostly PhD and MSc)
- High tech laboratories with state-of-the art testing facilities and techniques
- Developer of open source software packages, such as Delft 3D to model marine flows.
- Working on different fields of renewable energy (Tidal energy, Hydropower, Wave energy, Wind energy, OTEC, Blue energy, Smart grids, geothermals, ATES)
- ISO9001 quality methodology



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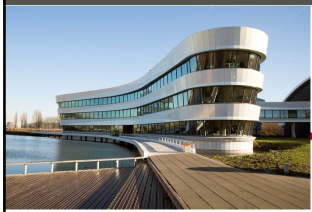
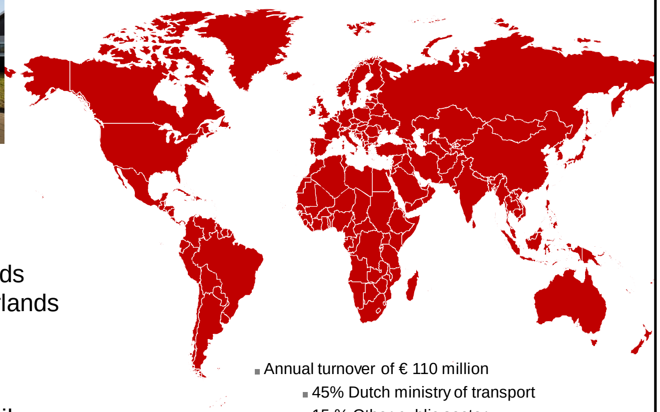
Deltares - Offices





Offices in:
- Delft, The Netherlands
- Utrecht , The Netherlands
- Singapore
- Dubai, UAE
- Jakarta, Indonesia
- Rio de Janeiro, Brazil
- Silver Spring, USA (Affiliate)

- Annual turnover of € 110 million
  - 45% Dutch ministry of transport
  - 15 % Other public sector
  - 15 % Dutch private sector
  - 25% International clients

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Deltares - Testing facilities

- Flumes and basins
- For wave and flow testing
- Up to scale 1:1 (DeltaFlume)

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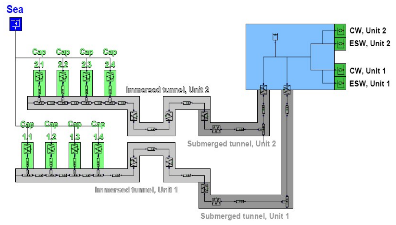
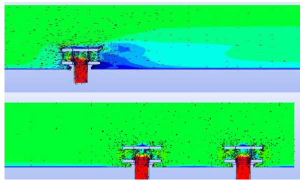
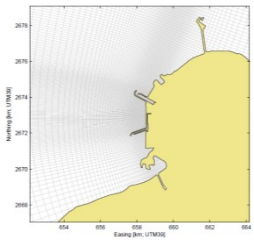
Deltares - Specialist software

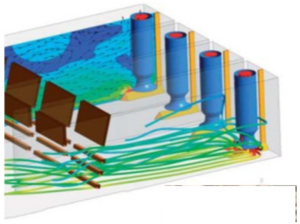
Develop and maintain (a.o):

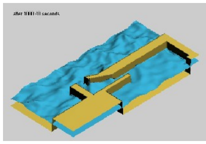
- WANDA Waterhammer and Transients
- Delft3D (Open Source)
- CFD – StarCCM+ / CFX / OpenFOAM
- COMFLOW
- CORMIX – Delft3D dynamic coupling
- Pharos / Triton











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Ocean energy

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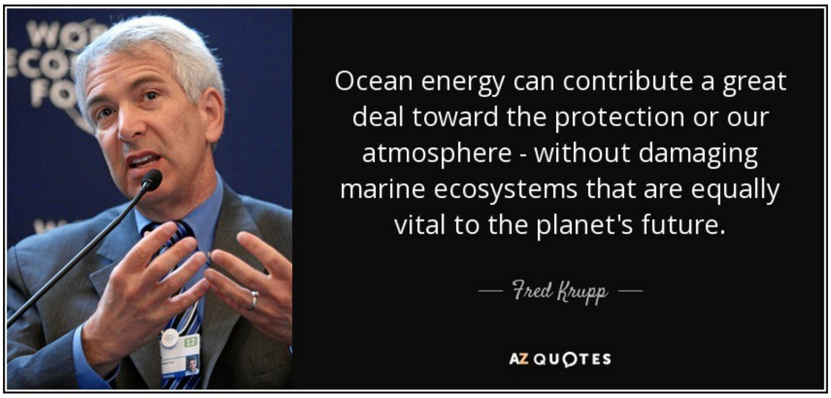
Potential of Ocean Energy



Fred Krupp
president of Environmental Defense Fund, a United States-based nonprofit environmental advocacy group.

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Tidal energy

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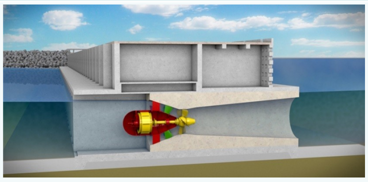
Tidal Energy

The world in Tidal Energy can be split in 2 parts:

Tidal stream energy	Tidal range energy
Generation of energy based on tidal current velocity	Generation of energy based on head difference between upstream and downstream
	
Afsluitdijk, NL Eastern Scheldt, NL Orkney (UK), Forge (Can) (testing)	Swansea Bay, UK La Rance, France Sihwa, South Korea
100-200 kW / turbine	20 MW / turbine

Tidal stream energy

Deltares role:

Assistance to developers / operators to optimize and to address potential risks

In the field of:

- Energy optimisation
- Environmental impacts

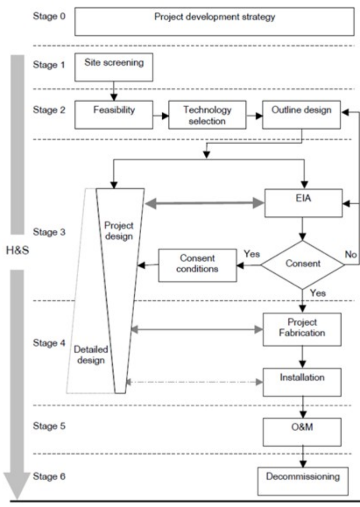
Project development Marine Renewable Energy

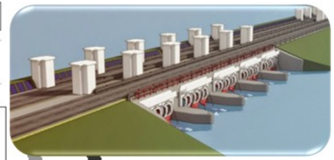
Pilot projecten:

Oosterschelde

Afsluitdijk

Project Brouwersdam





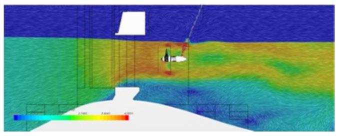
EMEC (2009). Guidelines for Project Development in the Marine Energy Industry.

Eastern Scheldt Storm Surge Barrier

Roompot section
Opening R08
39.5 m wide
Sill at -9.5 m
Array of 5 x Tocardo T200 in 2015
CFD: STAR-CCM+

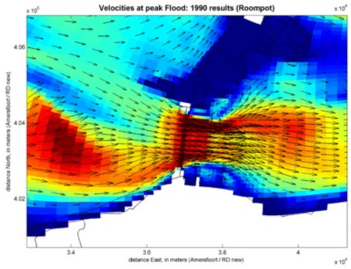
16 May 2014

Tidal Turbines Eastern Scheldt SSB



Approach

- Near-field model for effect of turbines on the flow through the specific gate
  steady state runs, free surface flow (2 phase flow), CFD model resolving turbines
- Validation:
  - 2011 ADCP measurements (Tocardo), water levels ES inside & outside
  - new measurements 2015 for situation with turbines (Tocardo)
- Application modelling instruments.
  Analysis energy production, environmental effects, optimization.
  Input for turbine design tools (flow velocity, shear, turbulence, wave)



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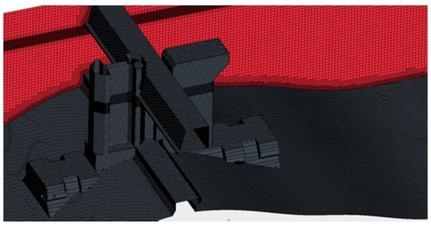
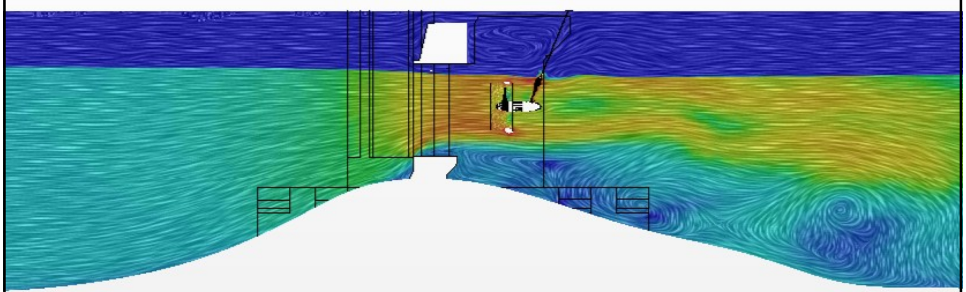
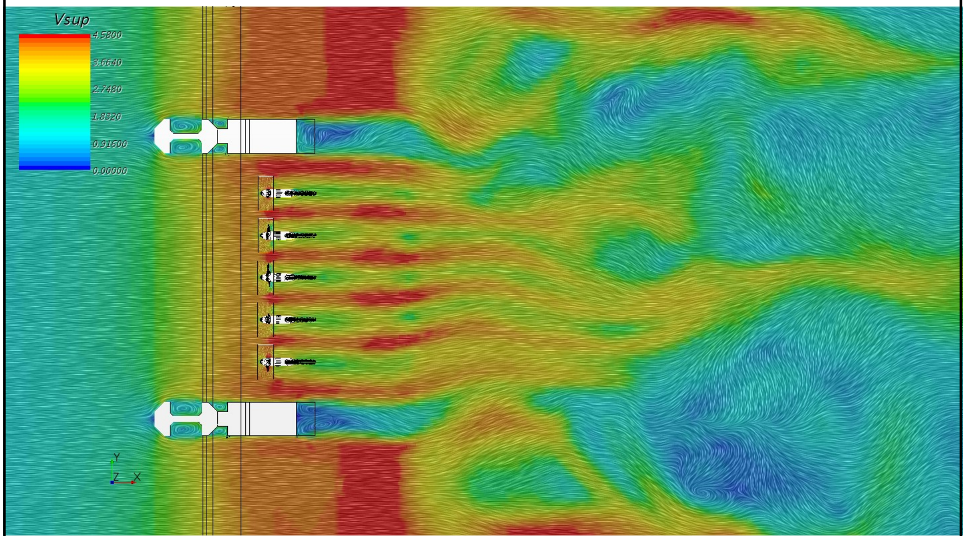
CFD, velocity on vertical cross section





Velocity on a horizontal cross section



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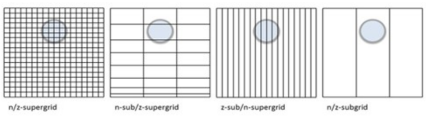
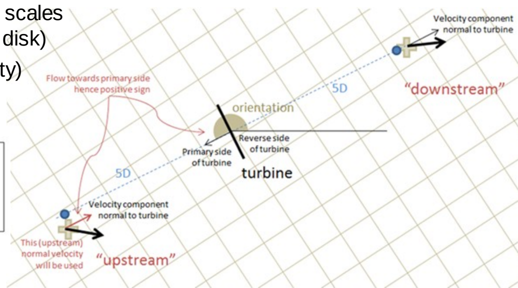
Horizontal-axis tidal current turbines in Delft3D

Implementation of Tidal Turbines in Delft3D-FLOW

- Bi-directional HATT (aligned with grid)
- Actuator disk
- Sigma and z-layers (incl. NH)
- Turbine attached to floating platform or fixed above seabed
- Curvilinear grid, FM anticipated
- Various vertical and horizontal scales (sub-grid – fully resolved rotor disk)
- Look-up table C_t, C_p(ref. velocity)





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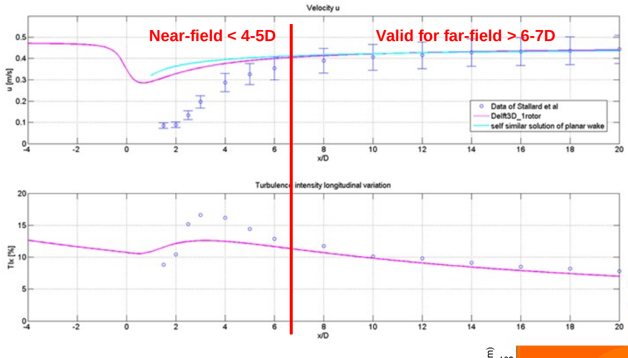
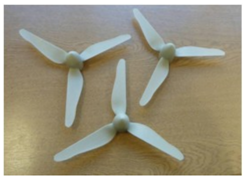
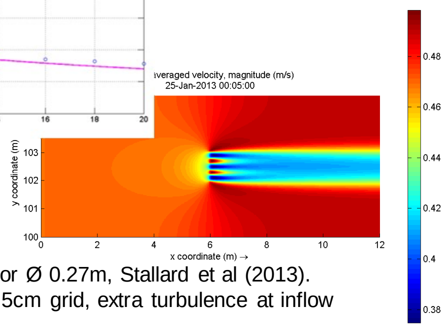
Horizontal-axis tidal current turbines in Delft3D

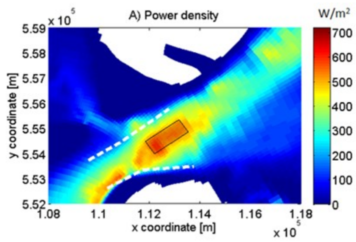


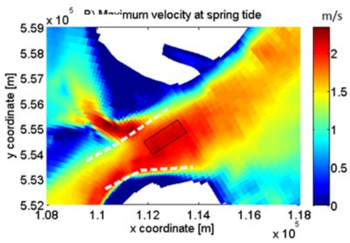




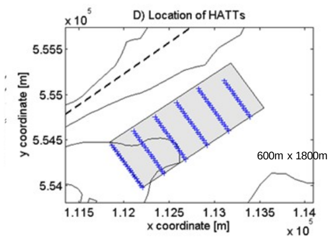
Lab tests 1:70. Flume 5x12m, H= 0.45m, Rotor Ø 0.27m, Stallard et al (2013).
Model: z-layer, NH, 31 layers (1.5 cm), 2.5x2.5cm grid, extra turbulence at inflow

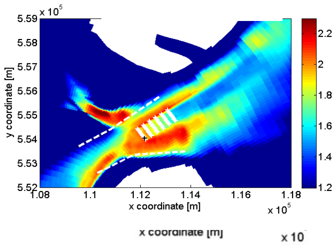
Case: Marsdiep tidal farm





Model: Elias (PhD, 2006) → 10 sigma layers





Total farm: 28,5 MW

123 HATTs at 1D and 20D spacing. Tocardo T500: D = 14m, rated power 232kW at 2m/s

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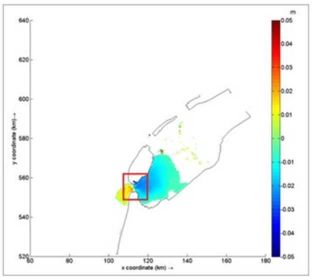
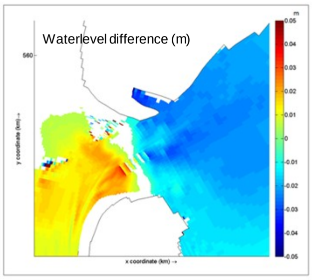
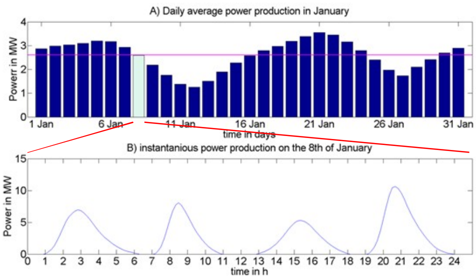
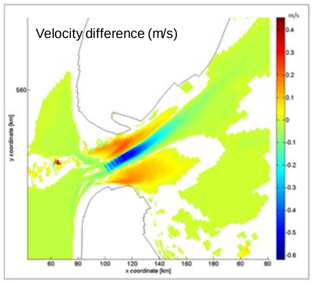
Power production & hydrodynamic effects

Mungar (2014), MSc Thesis









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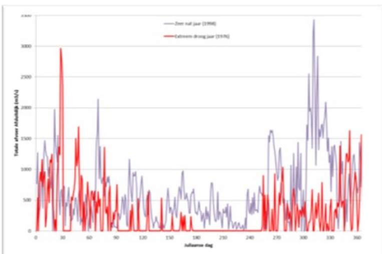
Further work

Hydrodynamics:

- **Validation CFD modelling** with measurements (Oosterschelde, Afsluitdijk)
- **Effect on bed protection** (Oosterschelde)
- **Morphology** (Oosterschelde, Marsdiep)
- **Availability of water at Afsluitdijk**



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Tidal range

Deltares tasks:

Assistance to developers / operators to address potential risks

In the field of:

- Energy optimisation
- Environmental impacts

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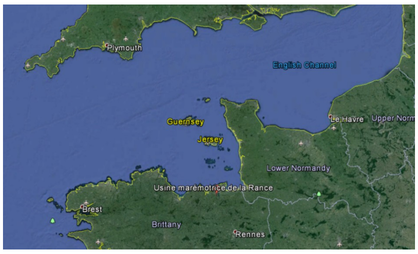
Tidal barriers

Tidal barriers worldwide

Location	Country	Year	Power [MW]	Operation
Annapolis	Canada	1984	20	Ebb / flood
La Rance	France	1966	240	Ebb / flood
Sihwa	South Korea	2011	254	Flood
Swansea	United Kingdom	2019	320	Ebb / flood



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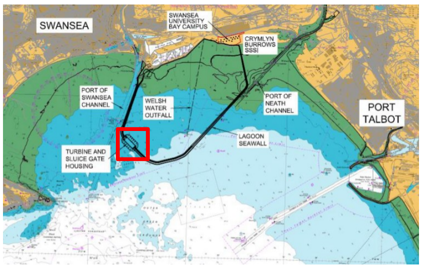
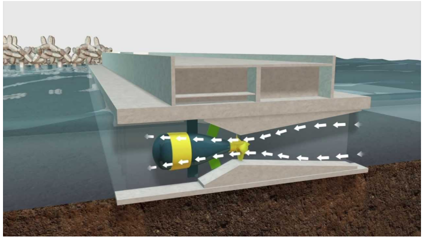
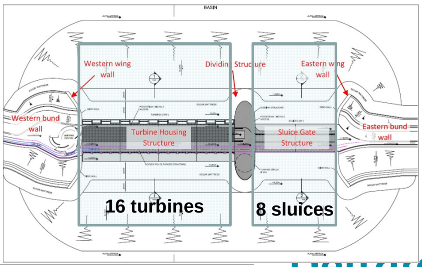
Topics to consider for Tidal Lagoons

TLSB is developing a tidal lagoon in Swansea Bay to generate 320MW of renewable energy by means of tidal turbines.







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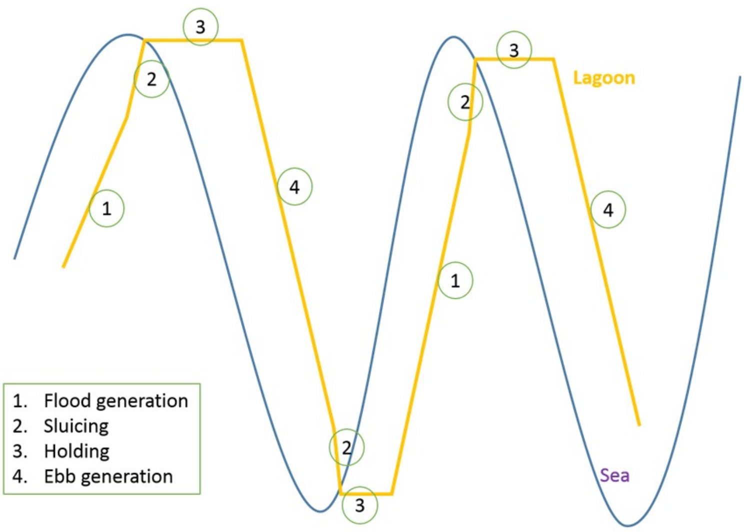
Generation of Energy principle



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Goal of Deltares work

Turbine manufacturer has full understanding of its turbine and its production under ideal approach flow conditions (pipe flow).

> The objective of the hydraulic studies is to investigate the flow patterns towards the tidal turbines and sluice gate structures to optimize these flow patterns in order to obtain an optimal hydraulic design with minimal hydraulic losses.

To do this, the project consist of several subtasks, which are linked to each other:

- Hydrodynamic modelling
- Scour assessment
- CFD modelling
- Physical modelling

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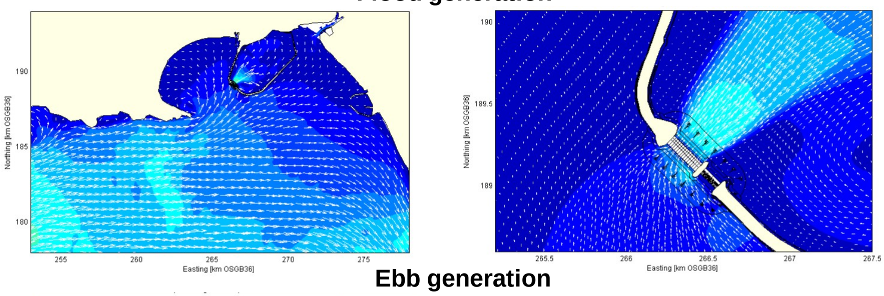
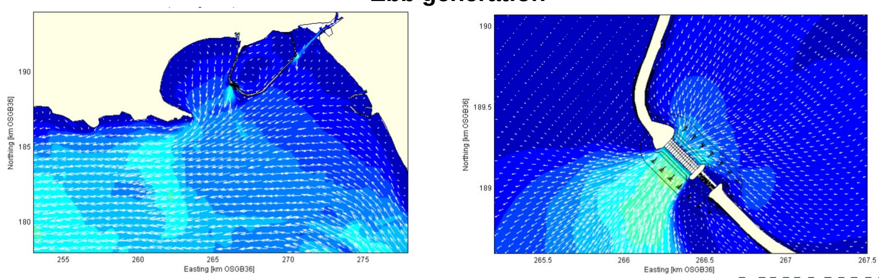
Hydrodynamic modelling

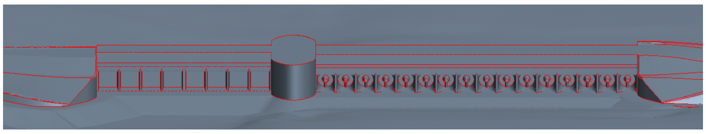
Flood generation



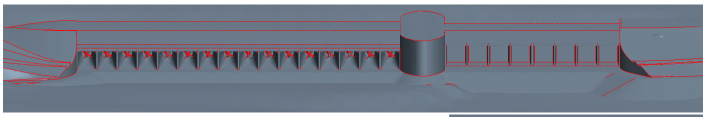
Ebb generation



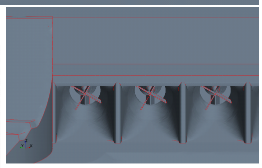
CFD modelling



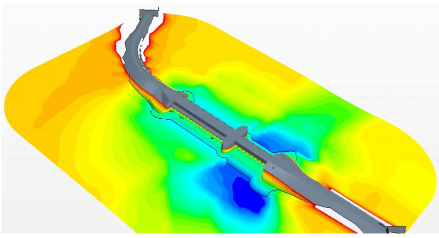
Basin side



Sea side



Sea side detail



bathymetry

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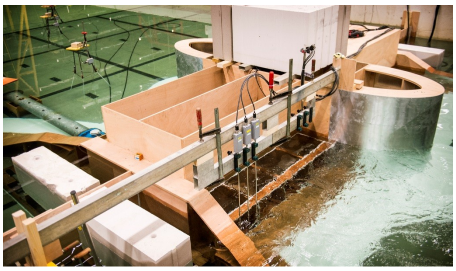
Photo of the physical model

Rotational physical scale model

Turbine at scale of 1:35

Outflow from turbines



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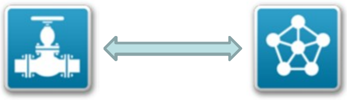
Coupling of computer codes

To design a plant, the connection between the marine environment and the energy production is important. To make this possible, Deltares couples its hydraulic software packages.

Wanda | Delft3D



Turbine characteristics | Marine conditions

Advantages:
Obtain energy output directly from hydrodynamic simulation

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Wave energy

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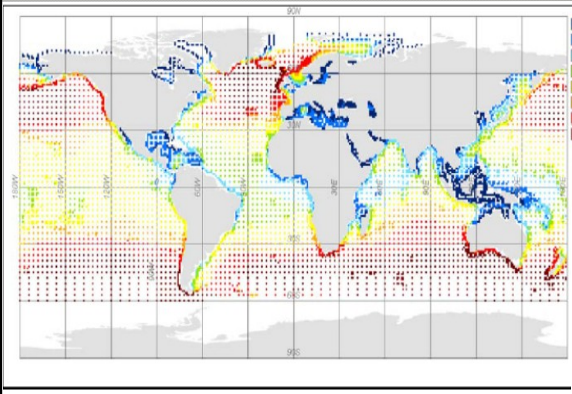
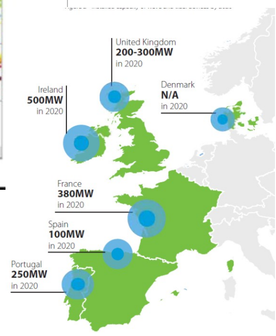
Global Theoretical Wave power



Installed capacity of wave and tidal devices by 2020

(European Ocean Energy, Industry Vision Paper 2013)



- Annual global gross theoretical wave power
- 2.1 TW average Wave Power
  (Gunn et al. 2012)

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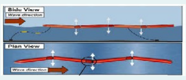
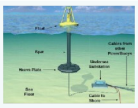
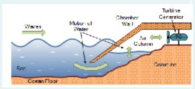
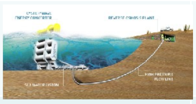
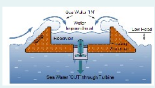
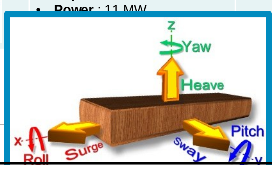
Examples WEC Types (First generation)

WEC types	Principle	Characteristics	Company & Location
		• **Type**:Attentuation (A) • **Length** : 150 m • **Diameter**: 3.5 m • **Depth**: 50 m • **Power** : 750 kW	• **Name** : Palamis • **Company** : Babcock's and Brown • **Testing** : EMEC (Orkney) • **Farm** : Aqucadoura Wave Farm, 2.5MW (northwest coast of Portugal) (2008)
 		• **Type**: Point Absorber (B) • **Length** : 43 m • **Diameter**: 10 m • **Depth**:15-55 m • **Power** : 150-205 kW	• **Name** : PB150 PowerBuoy • **Company** : Ocean Power Technology • **Testing** : Ocean test of New York (2015) • **Farm** : ? • **Right picture:** Location: Pecém – Ceará, Basil (2013)
		• **Type**: Oscillating water column (D) • **Chamber** : 4x3x10 • **Depth**:15 m • **Power** : 300-500 kW	• **Name** : PB150 PowerBuoy • **Company** : Ocean Power Technology • **Testing** : Technology tested in Scotland • **Farm** : 16 Wells turbines, Mitruku, Spain (2011)
		• **Type**: Surge Converter (C) • **Width** : 26 m • **Depth**:10-15 m • **Power** : 800 kW	• **Name**: OYSTER 800 • **Company** : AquaMarine Power • **Testing**: EMEC, ORKNEY • **Farm**: Consent Scottish government, develop 40MW, north-west coast of Lewis, Scotland (2011-2012)
		• **Type**: Overtopping (C) • **Width x Length** : 390x220 m • **Height :** 19 m • **Depth**: >30 m • **Power** : 11 MW	• **Name**: Wave Dragon • **Company** : Wave Dragon ApS (Denmark) & TecDragon (Portugal) • **Testing**: Nissum Bredning, 20kW (scale 1:5 Wave Dragon) **Farm**: First phase, 50MW, Portuguese coast (date ?)



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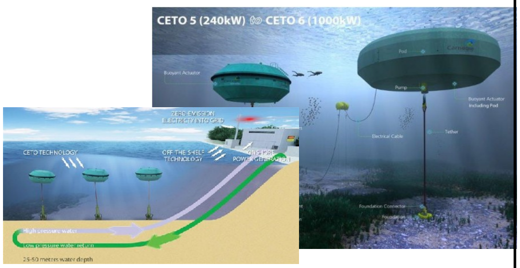
WEC Types (other examples)

- SBM Offshore
- S3 WEC
- Principle based on Anaconda WEC type
- Second Generation WEC Type
- TU Delft involved in development
- Bulged WEC + Electro Active Polymers
- Tested at ECN, Nantes France (2012)

- Carnegie (Australia)
- Name CETO 5/6
- Submerged buoy
- Diameter 11-20 m
- Location Perth
- Depth: 24-35 m, 1-2 m below surface
- Power: 250kw – 1MW (CETO 6)
- Mauritian Wave and Microgrid Design Project (2016)



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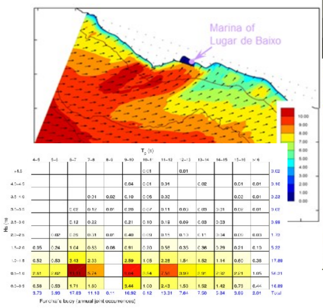
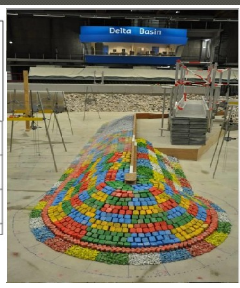
Deltares & Wave Energy





- Performing wave climate studies to select suitable locations for WEC farms
- Physical model testing as well as numerical testing of concepts (e.g. SLOW MILL),
- Effect of WEC farms on coastal structures (e.g. shoreline) and vice versa
- Performing environmental studies

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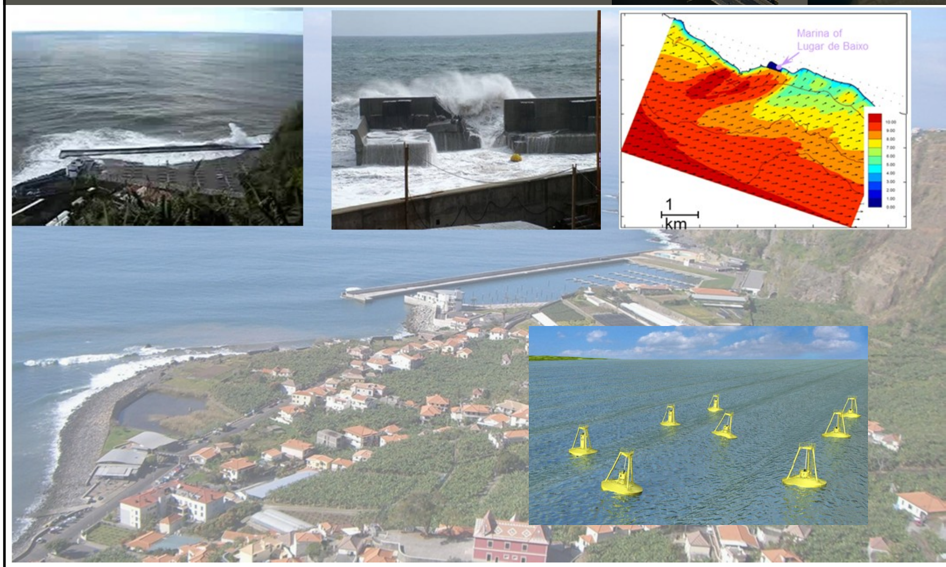
Energy Harbour concept



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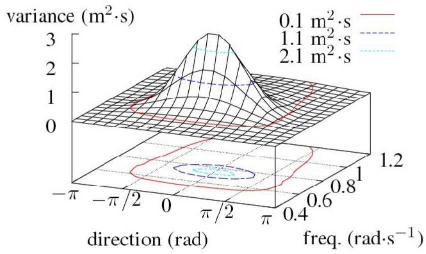
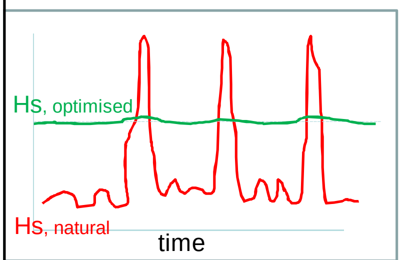
Influencing: Wave Height, Period, Direction





Hs (m) \ Tp (s)	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	>16	
>4.5							0.01		0.01					0.02
4.0–4.5						0.04	0.01	0.01		0.02		0.01	0.01	0.10
3.5–4.0				0.01	0.02	0.10	0.06	0.02				0.02	0.01	0.23
3.0–3.5			0.02	0.12	0.01	0.20	0.07	0.11	0.03	0.03	0.01	0.02	0.01	0.62
2.5–3.0			0.12	0.22		0.21	0.10	0.19	0.09	0.03	0.03			0.99
2.0–2.5		0.02	0.39	0.31	0.01	0.40	0.09	0.15	0.10	0.11	0.04	0.09	0.03	1.73
1.5–2.0	0.05	0.24	1.04	0.83	0.08	0.91	0.20	0.56	0.35	0.36	0.29	0.21	0.10	5.22
1.0–1.5	0.52	0.53	3.43	2.33		2.59	1.05	2.28	1.54	1.52	1.14	0.60	0.36	17.89
0.5–1.0	2.61	2.62	11.11	5.74		9.04	3.54	7.56	3.99	3.91	2.92	2.21	1.05	56.31
0.0–0.5	0.56	0.53	1.71	1.60		3.44	1.00	2.43	1.53	1.52	1.42	0.73	0.44	16.89
	3.73	3.93	17.83	11.16	0.11	16.92	6.12	13.31	7.64	7.50	5.84	3.89	2.01	Total

Funchal's buoy (annual joint occurrences)

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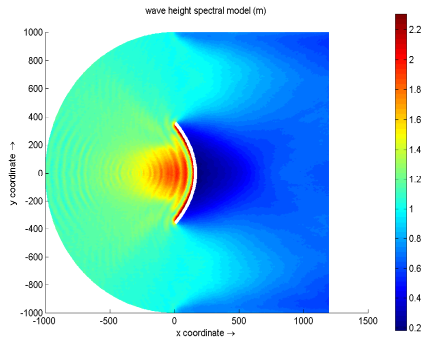
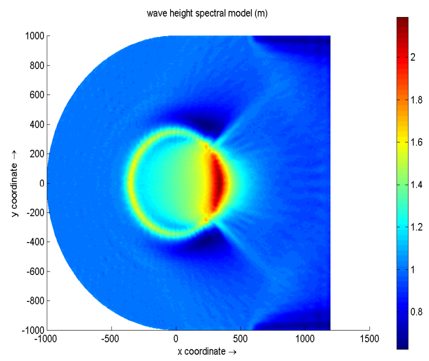
Spectral Computations: Parabolic & Shoal Concept

Multiple directions and periods

Parabolic



Shoal



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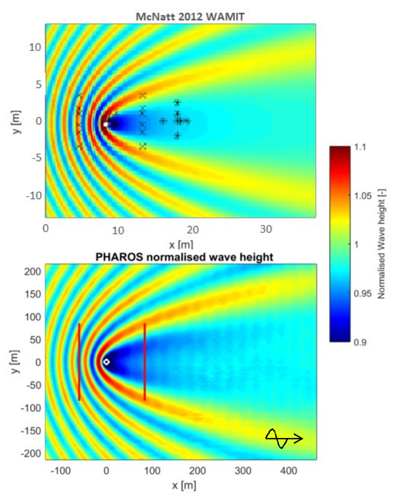
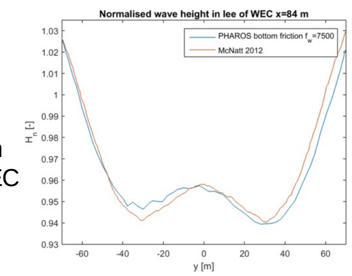
PHAROS Validation Single WEC Modeling

Results WAMIT (top) versus PHAROS (bottom)



- Comparison in lee of WEC



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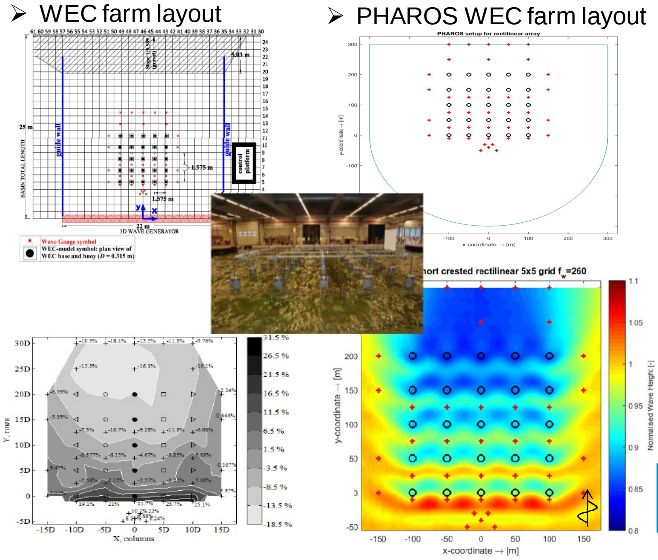
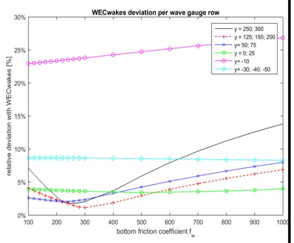
PHAROS Validation WEC-Farm Modeling

- WEC farm layout
- PHAROS WEC farm layout



Percentage deviation per wave gauge row (horizontal) (Measurement versus Pharos)



For most locations within 10% deviation

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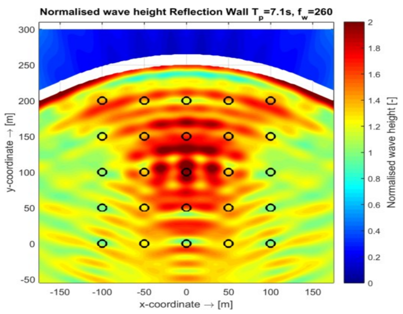
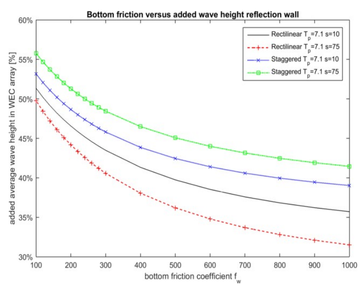
PHAROS Results Parabolic Reflector



- 5x5 WEC rectilinear array
- Irregular waves:
  - H_s=3.3m,
  - Tp=7.1s,
  - s=10 dir. spreading coefficient
  - D=10m.



- Added average wave height in WEC array (%) versus bottom friction coefficient.
- Current work:
  - Approximate energy gained by using parabolic reflector.
  - Determine translation of value fw to absorbed power by WEC device

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Ocean thermal energy conversion

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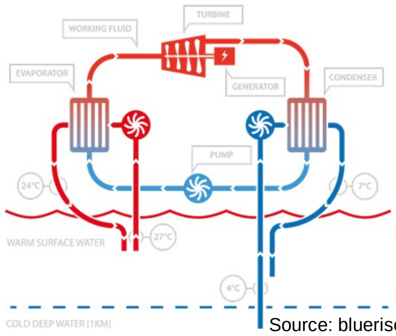
Ocean Thermal Energy Conversion

First idea:
Jacques Arsene d'Arsonval (1881), a French physicist, proposed tapping the thermal energy of the ocean

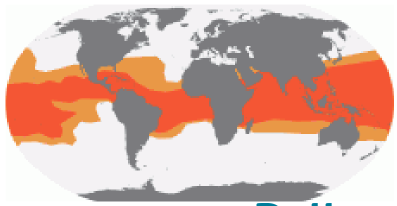
First implementation
Matanzas, Cuba in 1930. The system generated 22 kW of electricity with a low-pressure turbine

Principle:
A rankine cycle is driven by the exchanged heat.

Potential:
Temperature difference of least 20 degrees Celsius between surface and deep ocean (equator region)



Source: bluerise



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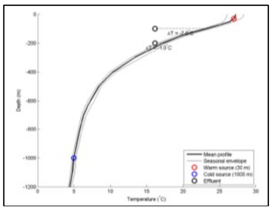
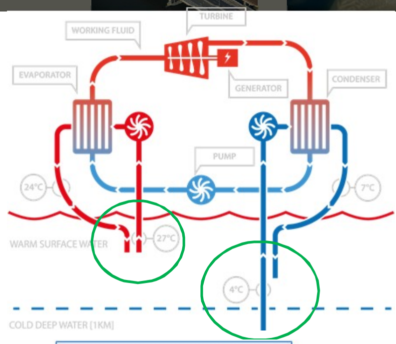
Deltares role in OTEC

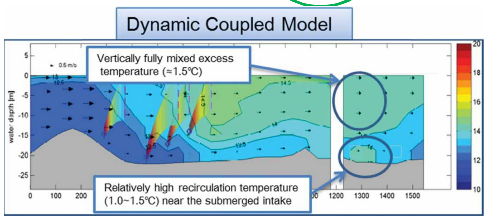
Deltares is involved in the environmental aspects of this technique at the intakes and discharges of the ocean water.

Creation of *density differences*

Density driven currents | Ecological impacts







Morelissen et al, 2013

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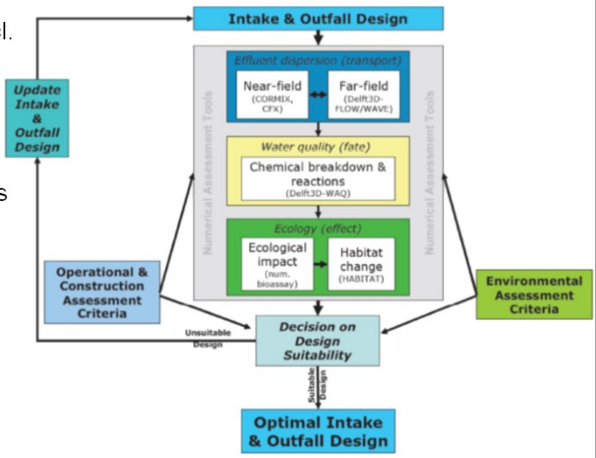
Deltares role in OTEC

- Hydrodynamic modelling, incl. near-field outfall plume assessment
- Water quality modelling
- Ecological effect modelling
  - Check against regulations
- Mitigation measures
- Cumulative effects



Friocourt et al, 2011

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Blue energy – salinity gradients

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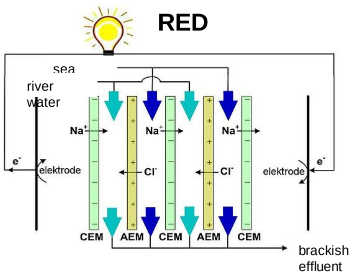
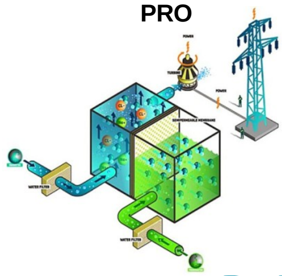
Blue energy – salinity gradients

2 Techniques:
- Reversed Electrodialysis (RED)
- Pressure Retarded Osmosis (PRO).

Breezand – Afsluitdijk (RED)
First plant in the world (50 kW)





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Blue energy – salinity gradients

Blue Energy (REDstack) at the Afsluitdijk

- Energy production & environmental effects
- Dynamics of salt & fresh water (salinity at intake, zones of brackish water)
- Silt
- Phaeocystis & macro algae

Important: large density difference between fresh and salt water required for effective energy production

↓

Understanding of plume dispersion!

16 May 2014

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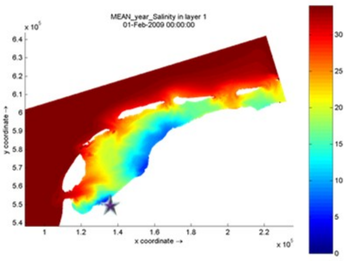
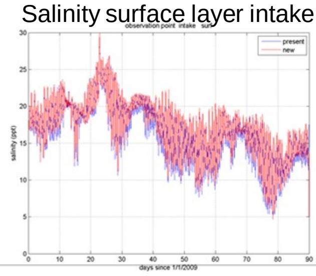
Blue Energy

Salinity



Salinity surface layer intake



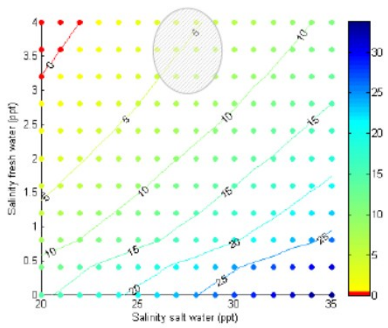


Figure 5. Net power output (MW) as function of the fresh and salt water salinity

Van der Zwan et al, 2012

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Environmental impacts

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Environmental effects

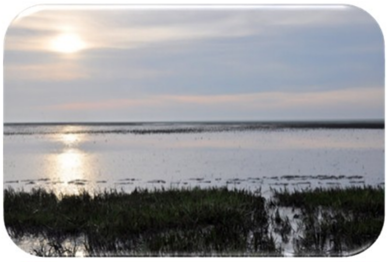
Sustainability is important for *Energising deltas*

Each structure / intervention has effects.
These need to be well documented for

- Obtaining permits
- Communication, demonstration
- Public support
- Mitigation / measures

Goal: Generic evaluation instrument that can be made specific for

- Different techniques
- Different areas



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Stress factors

Presence

- Static effects
- Dynamic effects
- Chemical effect
- Acoustic effects
- Electromagnetic effects

Energy reduction in the environment

Cumulative effects

Note:

- Near-field effects (collision of fish or seals with rotor blades) have large public impact.
- Far-field effects are less obvious but have far greater consequences

Receptors

Habitat / physical environment

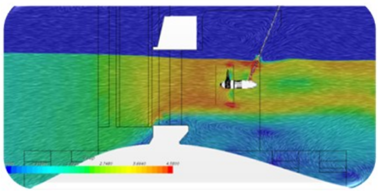
- Near-field (immediate surroundings, change of the flow, erosion near structure)
- Far-field (reduced discharge, effect on tidal range, sand demand, stratification)

Organisms

- Invertebrates
- Migrating fish
- Local fish
- Marine mammals
- Sea birds

Ecosystem -interactions

- E.g. effects via the food chain



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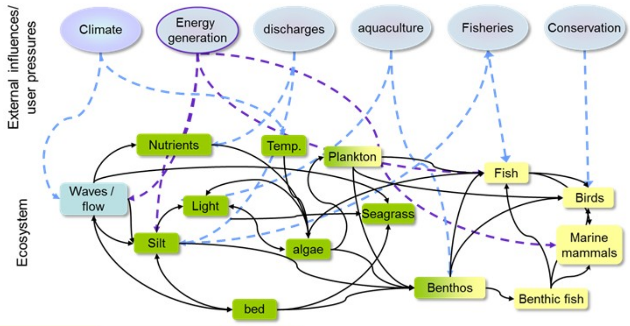
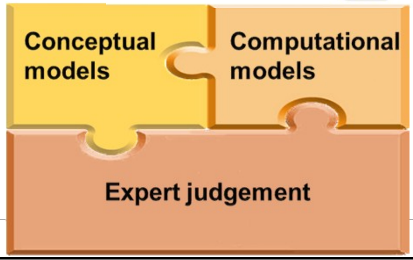
System knowledge





Deltares Enabling Delta Life

IMARES WAGENINGEN UR

NIOZ

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Further work

Ecological effects:

- **Far-field effects on** larvae and small fish for large scale application of Blue Energy
- Turbine **noise**
- **Fish friendliness** of turbines – behaviour
- **Nutrient discharge** in shallow water for OTEC applications

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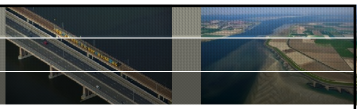
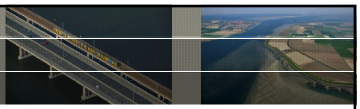


Recapping

The potential energy production of an ocean energy device does not only depend on the mechanics. System knowledge (hydrodynamically and environmentally) is as important as mechanical knowledge.

⇩

The success of ocean energy depends for a large part on understanding of system behaviour



Deltares contacts

If you are interested in doing an internship or a Master Thesis on ocean energy at Deltares, please contact:

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Arnout Bijlsma
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