Paimpol-Bréhat TIDAL TURBINE Test Site

TEST SITE DOCUMENTATION

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History of the document

Version	Date	Authors	Comments
1.1	17/02/2021	Florence Lafon, Nicolas Gérard, Nicolas Vaissière (EDF) Lucille Furgerot, Emmanuelle Suel, Marlène Kiersnowski (SEENEOH)	

Disclaimer
This document is the deliverable WP T1.2.1 of the TIGER project.
This document is for the use of prospects and stakeholders wishing to know the characteristics of the Paimpol-Bréhat tidal test site.

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ABBREVIATIONS & DEFINITIONS

ADCP Acoustic Doppler Current Profiler
CTH Cable Termination Head (equipped with the High Voltage Junction Box)
Developer refers to the technology developer, turbine manufacturer, candidate for a demonstration.
Demonstrator refers to the device intended to be tested, the tidal turbine and its foundation.
HVJB High Voltage Junction Box (equipped with diver wetmate connectors)
MGD0 Gravity based structure located near the CTH. Can be used to secure some equipment (jumpers) on the seabed.

I - INTRODUCTION

1 - History of the site and recent developments

France possesses the second largest tidal resource in the world, with more than 3 000 MW exploitable in two main areas in Northern France (off the coasts of Bretagne & Normandie). This natural asset goes together with an industrial ecosystem that creates synergies and value in the fields of energy, oceanography, naval, materials.

To launch the development of tidal energy in French waters, EDF decided in 2008 to develop a first full-scale tidal demonstration array. The Paimpol-Bréhat demonstration project consisted of an array of two OpenHydro tidal turbines, an offshore subsea substation containing an AC/DC converter module, a 15 km DC cable exporting power from the converter module to the shore (landfall in the “Anse de Launay”) and connected to an onshore transformer.

Each stage of the project has led to major results and lessons learnt: public acceptance and planning consent, permitting procedures, environmental impact assessment and monitoring, export cable design, installation and stabilization, power conversion and connection system specifications, fabrication and installation, marine operations procedures allowing safe deployment and recovery of the devices and commissioning tests proving the proper operation of the optical and electrical interfaces. Between 2010 and 2016, OpenHydro/Naval Energies have deployed and tested in real conditions four 16m-diameter turbines: two first turbines in stand-alone (2010/2011 and 2013/2014) and then two turbines connected to the grid deployed in 2016 and recovered in 2017.

Since 2019, the site hosts the 1 MW Hydroquest/CMN ocean prototype for a full-scale grid-connected testing.

Beyond the Hydroquest/CMN experiment, EDF is investigating the future use of the site, with the aim of allowing the assets in place (onshore substation, export cable, existing consent) to benefit the ocean energy sector.

In this context, the Brittany Regional Council, through its association “Bretagne Ocean Power”, has decided to support EDF in the definition of the future of the test site. They have asked SEENEOH, grid connected test site for small tidal devices located in South West France (Bordeaux), to assist them in this work and share their experience as a multi-technology tidal test site.

2 - The TIGER project: enhancing tidal energy technologies at the European level

The Paimpol-Bréhat site is part of the TIGER project. The Tidal Stream Industry Energiser Project, known as TIGER, is an ambitious €45.4m project, of which €29.9m (66%) comes from the European Regional Development Fund via the Interreg France (Channel) England Programme. This project aims at developing Tidal Stream Energy in France and in the UK and accelerate the deployment of Tidal Stream Energy in the FCE region, with significant economic benefits for coastal communities. It addresses the need to reenergise the stalled Tidal Stream Energy sector in France and in the UK. The project will build cross-border partnerships to develop new technologies, test and demonstrate them at

a number of locations in and around the Channel region and use the learning from this development to make a stronger, cost-effective case for Tidal Stream Energy as part of the FR/UK energy mix[1].
Within the TIGER project, the purpose of the Paimpol-Bréhat site is to contribute to the merge of the industry of tidal turbines, a marine renewable energy (MRE) producing electricity from the kinetic energy of oceanic, marine, estuarine, and fluvial currents.

3 - Geographical location and site organization

The Paimpol-Bréhat tidal site is located in Brittany, in the Department of Côtes d'Armor, at the North East of the Bréhat Island.

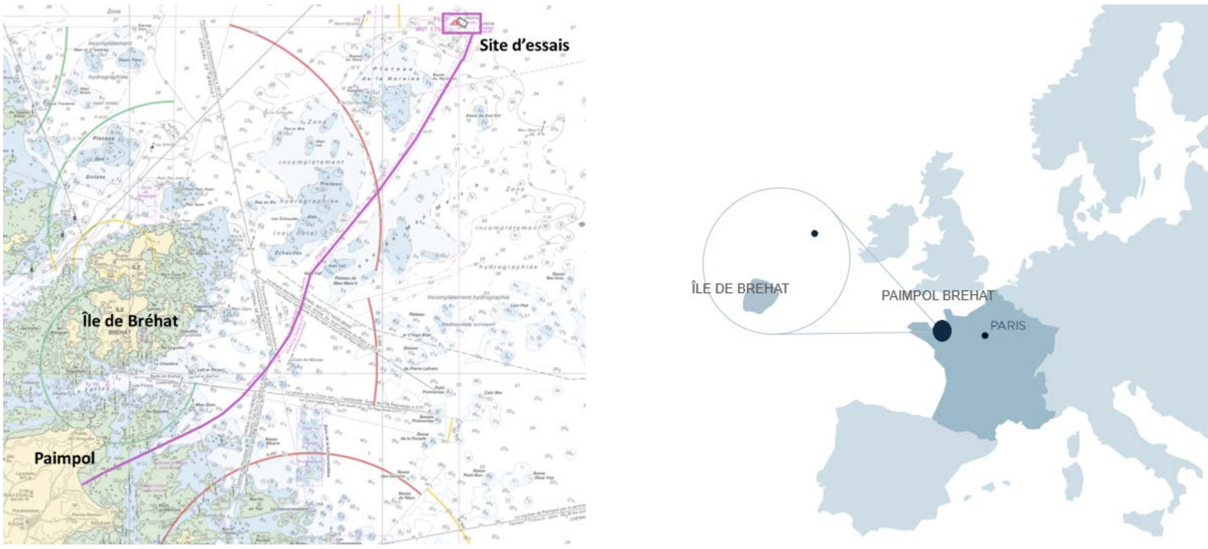

Figure 1: Location of Paimpol-Bréhat tidal site

The consented area (3.5ha granted for a duration of **15 years, starting from 2012**, with possible extension over 15 additional years) is limited by A, B, C, D, which coordinates are in WGS84-UTM30 N:

	UTM30 N	WGS84 (°')
A	(508096; 5417267)	48°54.49751667'N 2°53.3708833'O
B	(507884; 5417389)	48°54.5635333' N 2°53.5443333'O
C	(507954; 5417512)	48°54.6298667' N 2°53.4868667'O
D	(508164; 5417390)	48°54.56385' N 2°53.31505'O

EDF is the beneficiary of the permits and is consequently responsible for the activities occurring in the area of the test site and related to its status as concessionary body, such as the consenting process. EDF also ensures compliance with procedures on the operation. EDF has a wide range of expertise that can be provided to the technology developers in order to address technical issues.
SEENEOH is the manager of an intermediary-scale tidal test site and assists EDF in the permitting process as well as in the operation of the test site. The skills of SEENEOH in the field of tidal site characterization and environmental monitoring, mechanical engineering & structure at sea, operation & maintenance are put at the service of the site owner and the technology developer.

[1] https://interregtiger.com/

Bretagne Développement Innovation (BDI) is the regional development agency of Bretagne. Deeply involved in the MRE activities in the region, BDI will be responsible for coordinating the regional supply chain and for maximising the local political support.

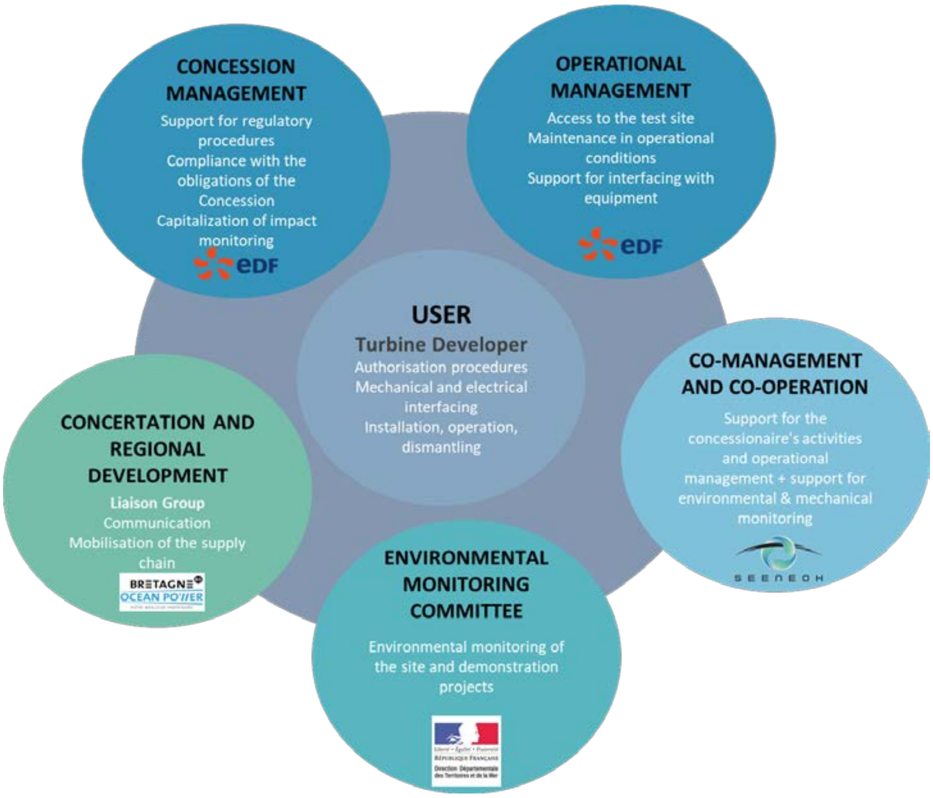

Figure 2: Organization chart

II - CONSENTING AND ADMINISTRATIVE REQUIREMENTS

1 - Consent and permits

1.1 - Environmental Permit & Public Maritime Domain Licence

Paimpol-Bréhat site benefits from full consenting procedures with two main authorizations granted:

- The Environmental Permit[2], granted by decree (prefectural order) of March 30th, 2011
- The Public Maritime Domain Licence[3] (the Concession), granted by decree (prefectural order) of May 9th, 2011

The main characteristics of the consent are described below:

- The authorizations have initially been obtained by EDF for the deployment of up to 4 OpenHydro turbines on a specified public area (the Concession); the dictates regarding occupation of the consented area, works conditions and environmental monitoring are related to this former technology
- The duration is 15 years starting from 2012 so the permit expires in 2027
- The Concession is a rectangular area of about 3,5 ha (250m x 140m)
- The Concession stipulates that all equipment installed should be able to be removed (gravity-based solutions)
- The environmental monitoring of the site is shared with the authorities and the local stakeholders (scientific experts, environmental associations, local fishermen…)
- Marine works must be compliant with French laws
- External marine activities have been restricted in order to gain for Concession area

1.2 - Administrative process for testing a new technology

To date, the test of a new Demonstrator on site requires a modification of the Environmental Permit and of the Public Maritime Domain Licence. Depending on the nature of the project and its presumed effects or impacts on the environment, the modification may either be supported by a comprehensive Environmental Impact Study or an Environmental Impact Statement.
The determination of the process is decided by the local authority based on a case-by-case study.
In both cases, specific environmental measures may be required by the environmental authority and included in the amended permits.
The duration of the process varies depending on the procedure. One can expect a 12-months process if an EIA is requested and a 6-months process in case only an Environmental Impact Statement is asked. This duration is indicative and will also depend on the developer's diligence in drawing up the documents explaining his demonstration project and answering the questions posed.
The process can be described as follows:

[2] In French: Autorisation au titre du code de l'environnement

[3] In French: Concession d'utilisation du domaine public maritime en dehors des ports

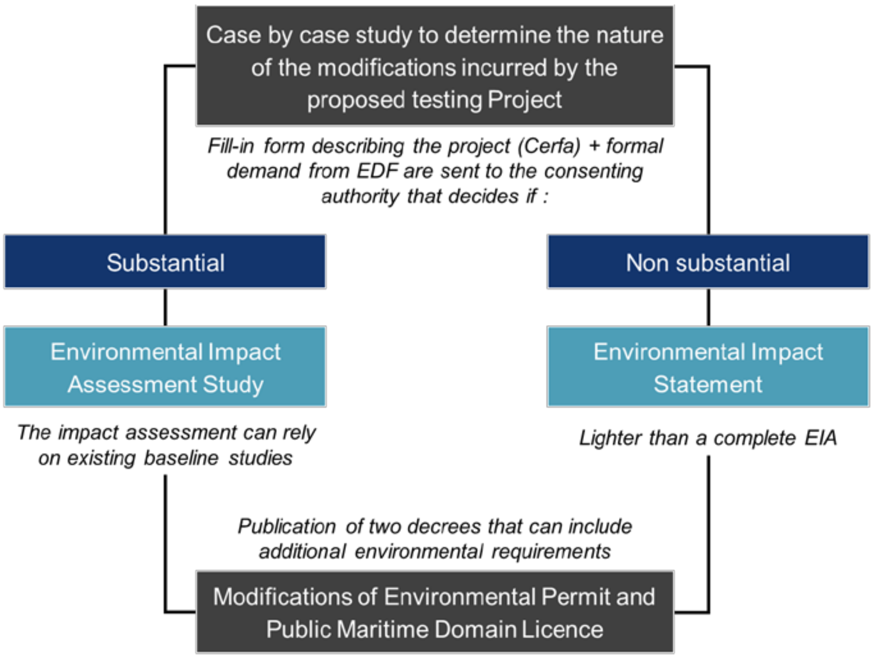

Figure 3: Process for testing a new technology on Paimpol-Bréhat Test Site

In parallel to the consenting process, a tripartite Collaboration Agreement between the user, EDF and SEENEOH is established in order to specify the roles and scope of each within the framework of the demonstration project. This Collaboration Agreement is a prerequisite from the consenting authority before assessing the consent application.

III - ENVIRONMENTAL DATA

1 - Geophysical data

Several types of geophysical surveys were carried out specifically for the development of the test site (side-scan and bathymetry). The other geological and sedimentological data are recovered from open-source sites.

1.1 - Geological context

The test site is located on a unit of the Armorican massif called Trégor (see the Geological map notice of Tréguier). This plateau presents a gentle slope towards the English Channel. The plateau is deeply incised by two rias, the Trieux to the East and the Jaudy to the West, whose orientation is guided by the NNE-SSW tectonic accidents. The test site is located to the north of an E-W accident which separates two distinct geological zones. More specifically, the test site substrate is composed by granites and granodiorites as shown on the map in Figure 4.
In addition, a last fracture orientation of N140° to N160°, inherited from the aborted Atlantic pre-rifting of the Permo-Trias is observed.

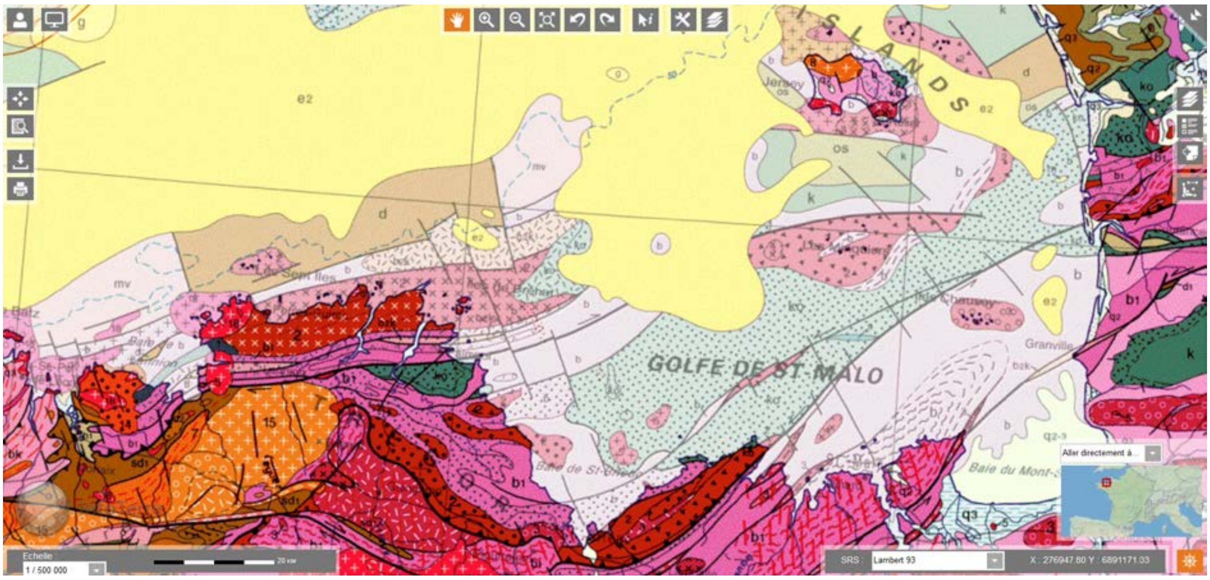

Figure 4 : Geological map. Source: Info Terre[4]

1.2 - Bathymetry

Two main bathymetries were carried out to improve knowledge of the test site:

- A bathymetric survey over a wide area around the test site and the cable route led between 2008 and 2011 (Creocean, 2008). The size of the area surveyed around the test site is 2550 m x 1450 m (370 ha), and the cable route is a 13 km long and 500 m large corridor from the site to the coastline (Figure 5). The size of the grid cell is 1 m.

[4] http://infoterre.brgm.fr/viewer/MainTileForward.do

- A higher-resolution bathymetry focused on the test site (IX Survey, 2013) carried on in 2012 (Figure 6). The result data are presented by a grid with cell of 0.1 m x 0.1m. The surveyed area is around 8 ha.

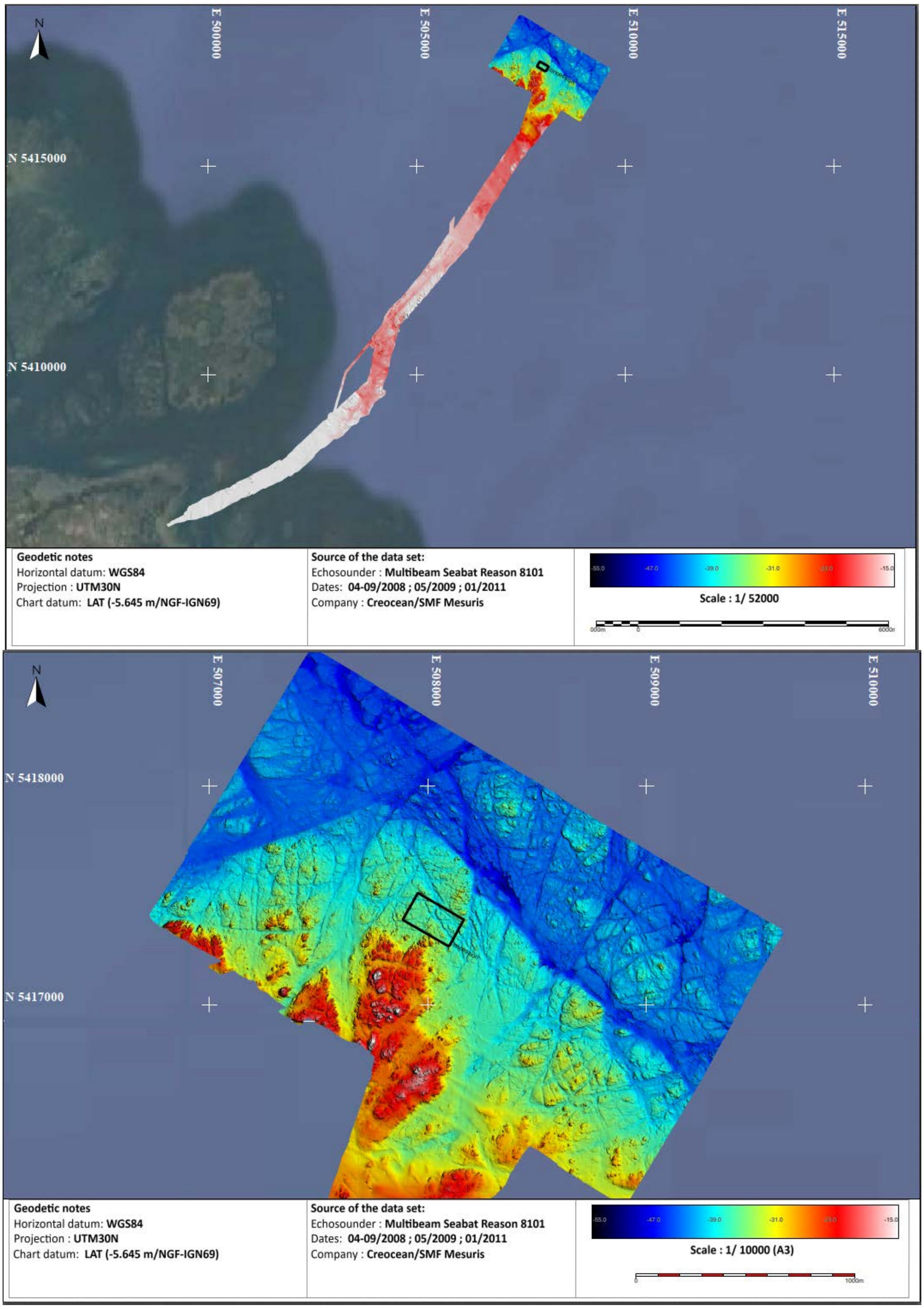

Figure 5: Bathymetric survey led by Creocean from 2008 to 2011 (color scale between -55.0 and -15.0 m LAT), high panel: Complete bathymetric survey with the site area and the cable route – low panel: bathymetric chart centred on the test site area. Boundary of test site is indicated by the black rectangles.

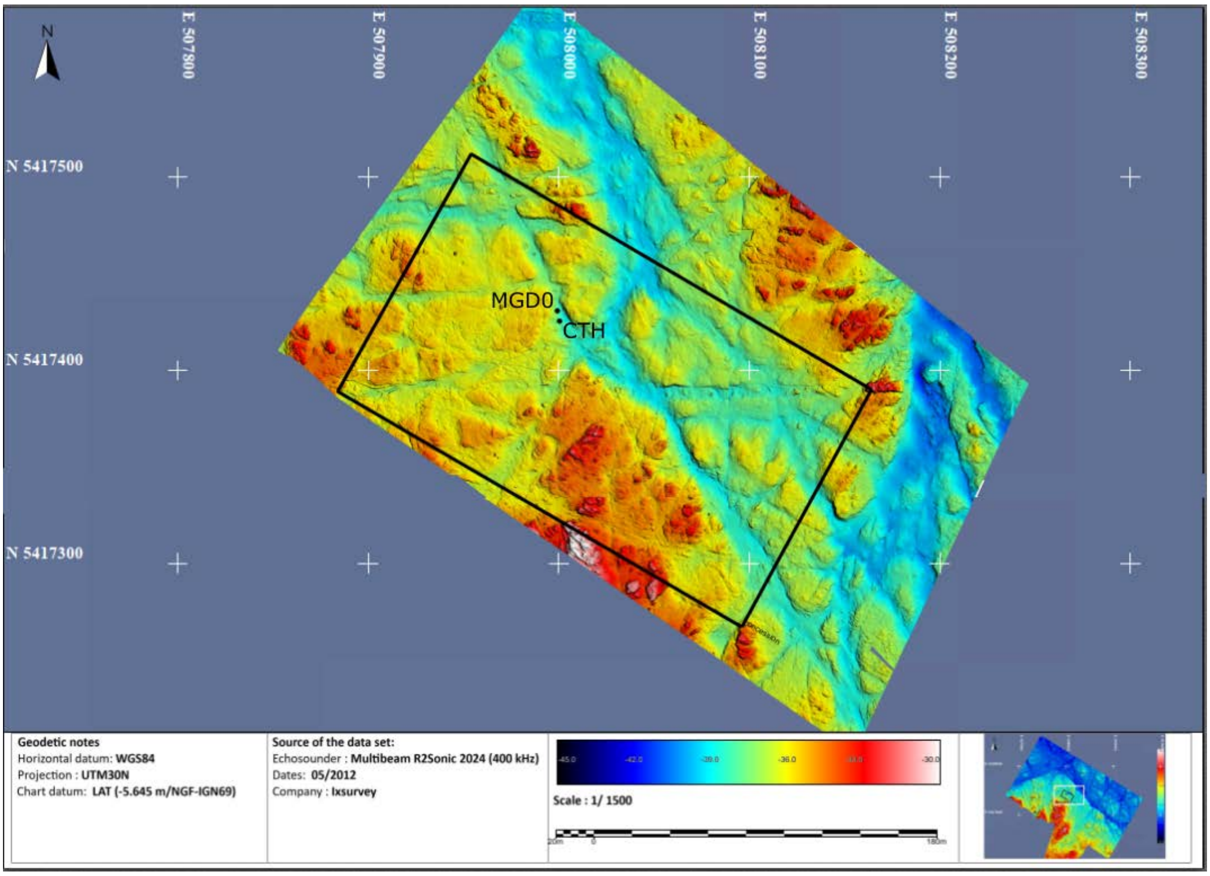

Figure 6: Bathymetric survey of the test site led by IX Survey in 2012, grid cell 0.1, with the position of the CTH and MGD0

The seabed has a rugged morphology with relief linked to tectonic accident. The three main structural directions described in the geological context are observed: N60-N70°, N90°-N110° and N130° to N160°. These directions correspond to 3 fracture systems that affect the rocks of the Peri-Armorican basement.
Rocky outcrops are observed in the southwest up to -10 m LAT (in red on the bathymetric map color scale).
The sea bottom elevation over the test site varies between -26 m LAT and -42 m LAT.
Erosional channels are observed over the entire area mainly oriented north/northwest and north. The deepest erosional channel crosses the area from north/northwest to south/southeast, with a maximum width of 35 m and maximum slope failure of 30°.

The position of the cable termination head (CTH) for the export cable and the MGD0 are the following:

	UTM30 N	WGS84 (°')
CTH	(508000.4 E ; 5417425.5 N)	(48°54.5815' N ; 2°53.44897' O)
MGD0	(507999.2 E ; 5417430.8 N)	(48°54.586' N ; 2°53.44995' O)

They are positioned in a small canyon at 37 m LAT (Figure 6), bathymetric profiles over them are presented on the Figure 7

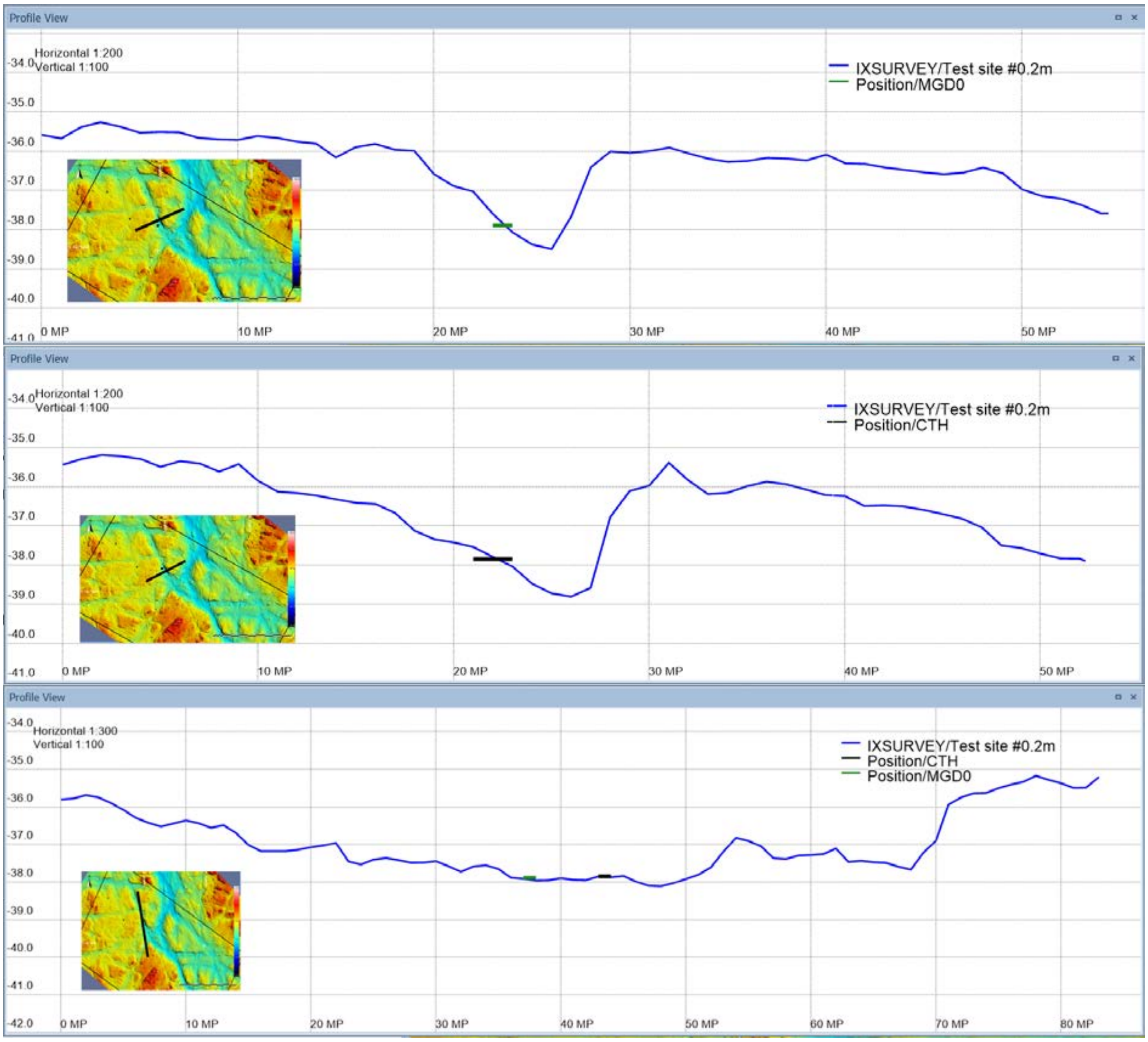

Figure 7 : Bathymetric profiles over the position of the CTH and MGD0

1.3 - Nature of the seabed

Several methods were applied at the test site and on the cable route to analyse the nature of the seabed: high-resolution side scan sonar surveys (2008 and 2012), analysis of bathymetric chart and sediment samples with a grab (Figure 8).

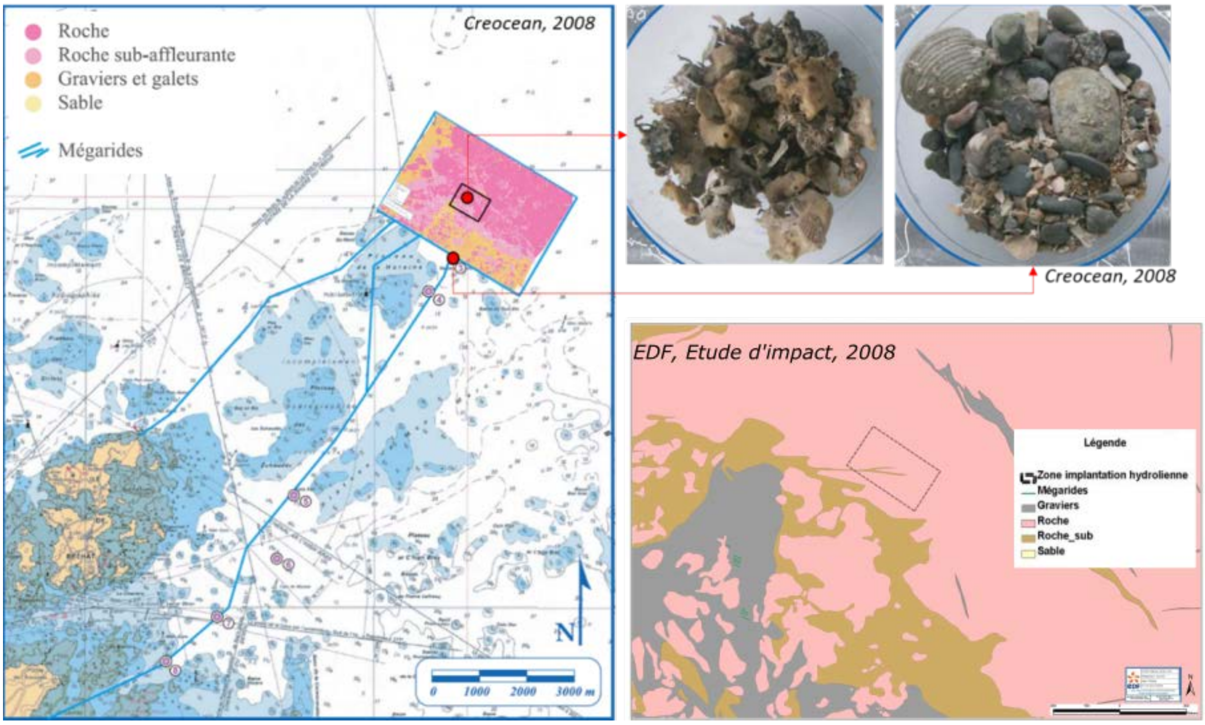

Figure 8: Nature of the seabed of the test site - Pink areas are outcrop rocks.

The bedrock outcrops over the whole test site area. The strong currents have removed any significant area of soft sediment so sedimentary deposits are almost non-existent, consisting of coarse sands in fine veneer on the rock or in micro-depressions. Some sedimentary veneers are observed on the rocky plateau; they are generally located in fracture corridors. The thickness of coarse sediments is mostly low to extremely low. The rock is mostly colonised by encrusted fauna (example of the first sample Figure 8 where sponges were collected). These observations are confirmed by some seismic profiles available in the study of Creocean (2008).
No geotechnical investigations have been carried out on the site.

1.4 - Magnetometry

Magnetic survey led in 2008 over the test site area and the cable route did not show anomalies which could match with the presence of an object. The main anomalies observed are fitting with the bathymetric structures (crack, fault, …) (Creocean, 2008).

2 - Meteocean data

2.1 - Sea levels

The characteristic tidal levels are provided by SHOM at Ile de Bréhat for several tidal conditions. They are specified in Table 1. On this side of the Channel, the area is macrotidal with specific hypertidal zones.
The coasts of the Channel have a semi-diurnal tidal regime (Figure 9).

		Ile de Bréhat (m CD)
Highest astronomical tide	HAT	11.68
Mean High Water Springs	MHWS	10.55
Mean High Water Neaps	MHWN	8.20
Mean Sea Level	MSL	5.95
Mean Low Water Neaps	MLWN	3.75
Mean Low Water Springs	MLWS	1.35
Lowest Astronomical Tide	LAT	0.1

Table 1: Tidal levels for several tide condition. Source: SHOM (2019)

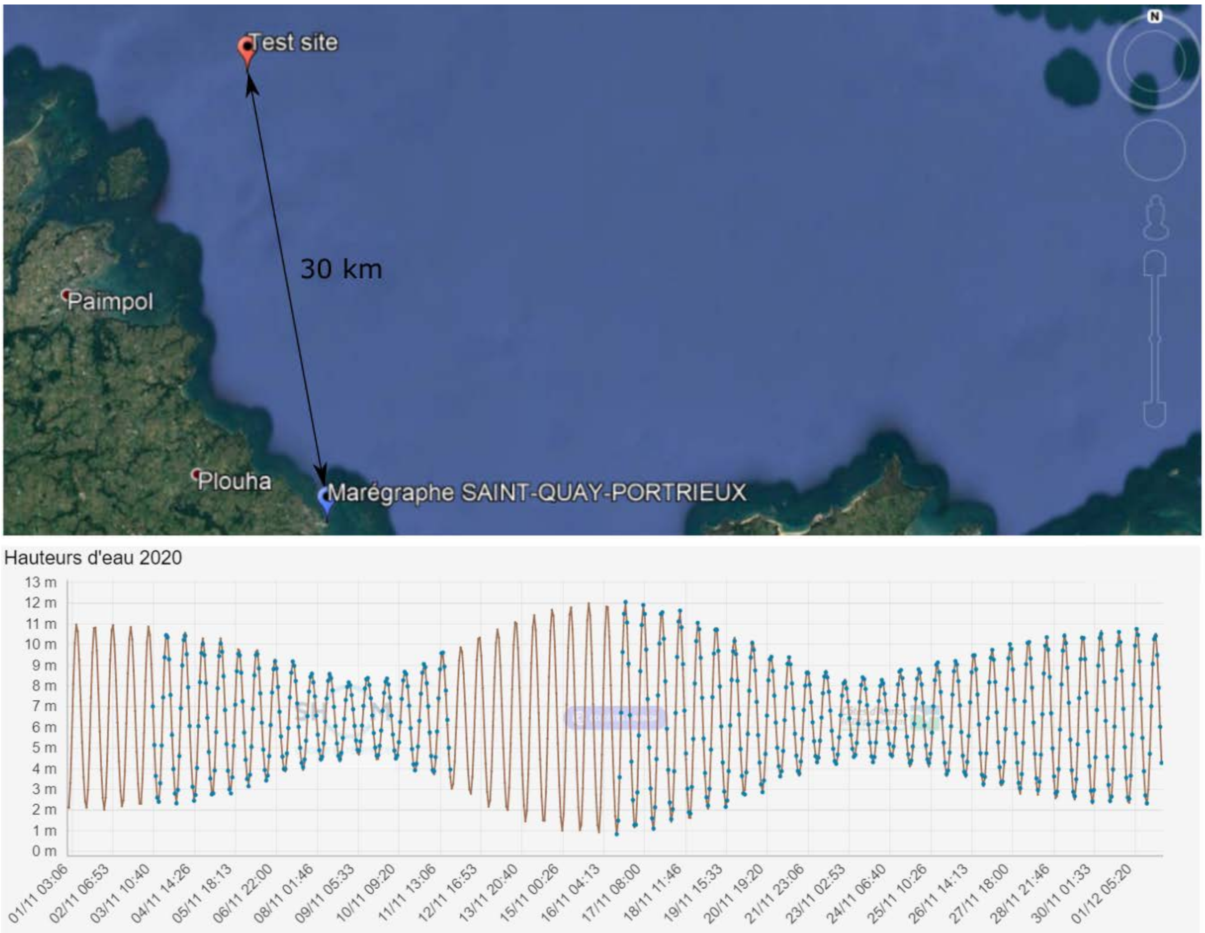

Figure 9 : Location of the tide gauge and tide evolution at Saint-Quay-Portrieux (30km from the test site) from 01/11/2020 to 01/12/2020 (source: data.shom)

At Bréhat Island, the hydrographic zero (0 m CD) is located at - 5.50 m IGN69.

2.2 - Currents

2.2.1 - ADCP measurements

EDF have conducted several ADCP measurements campaigns over the test site area. The most relevant surveys for the purpose of assessing the tidal velocities on the test site are located in Figure 10:

- ADCP measurements carried at 2 points in southeast part of the test site area (Figure 10) from Sept. 3rd to Nov. 4th 2011 (NortekMed, 2011).
- ADCP measurements carried at 2 points in northwest part of the area from 9th of April to 3rd of July 2014 (NortekMed, 2014).

Data sets processed and averaged over 10 minutes are available on request.
In addition to these two datasets, current velocities along the water column were measured with ADCPs between the 13th and the 18th of June 2010 at 5 points A, B, C, D, E, located along the cable route (IXSurvey, 2010). The tide coefficients for the measurement period covered the range 75-91. This data allows to better understand the current velocity in the bottom layer, from 0.4 m to 3 m above the sea bottom. Point E is located inside the test site.

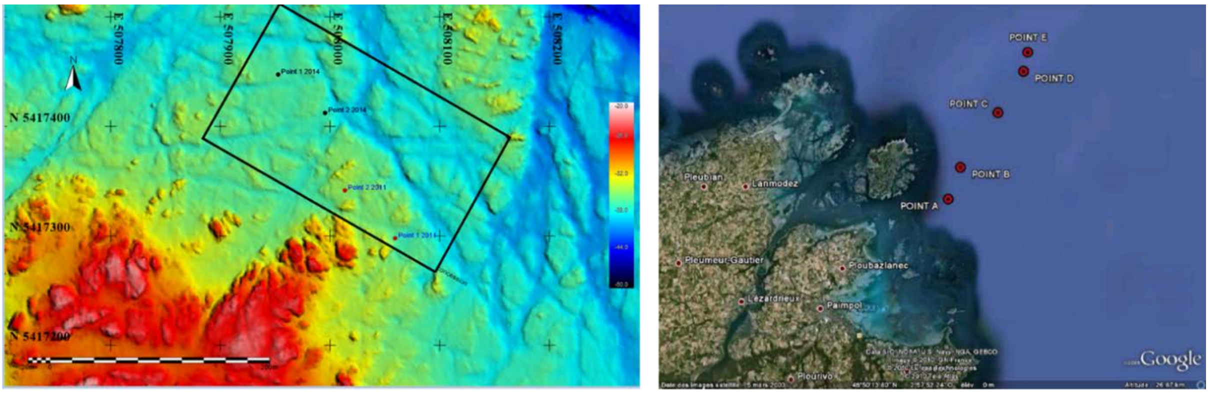

Figure 10: Location map of ADCP measurement points: Studies at the test site on the left and studies along the cable on the right

Figure 11 shows the times series of current velocity and rose direction for 3 different layers (2.5, 20.5 and 30.5 m above the bottom) during whole measurement period for point 1 from 2011 study (Nortek, 2011). The detailed statistics (rose of directions, histogram of velocities, and velocity-direction correlogram) and other measurement points are presented in the report of NortekMed (2011 and 2014).

Current on the test site is clearly tide-induced with two very marked alternating currents: the ebb and the flood tidal phases. The flood current is directed towards the ESE and is relatively homogeneous over the water column (between 110 and 120°N). Current velocities associated with the flood are very strong, up to 3.2 m/s at the surface and 2.2 m/s near the bottom. The ebb is directed towards the NW with a distinction between the bottom (rather towards the NNW) and the surface. Maximum velocities are lower than during the flood with 2.4 m/s at the surface and 1.4 m/s near the bottom.
An asymmetry of current and direction is observed over the entire test area.

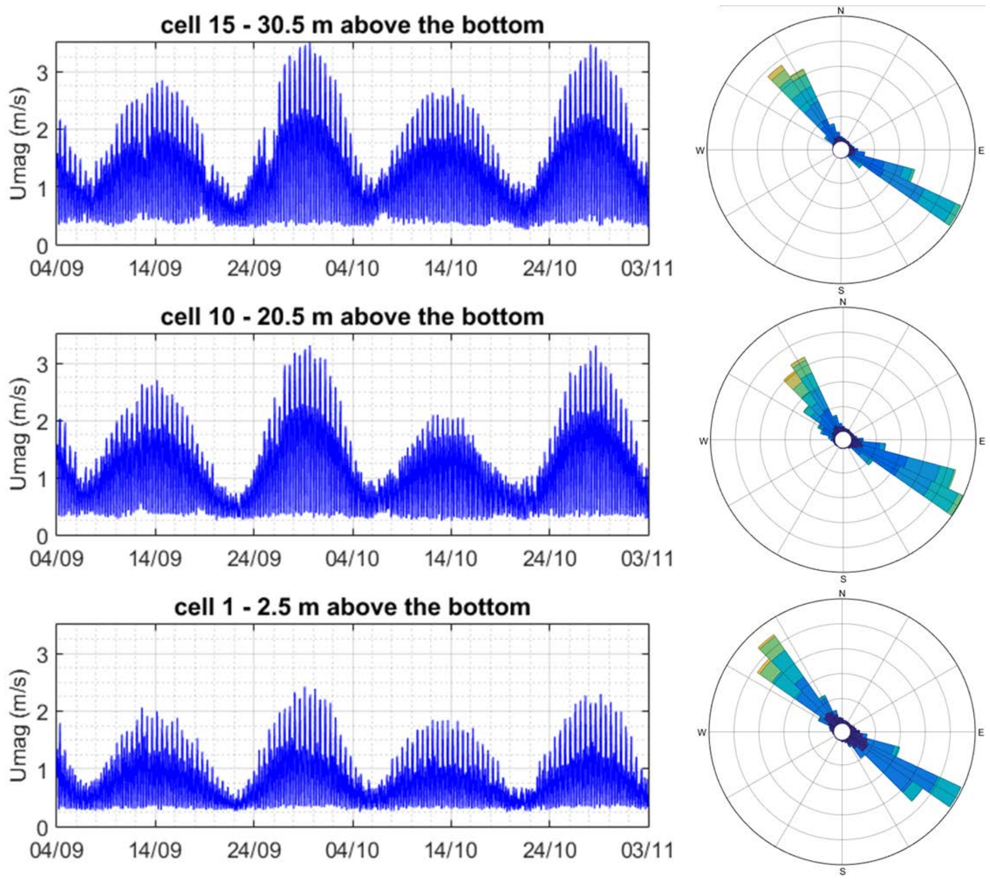

Figure 11: Times series of current speed (left panel) and rose directions (right panel) measured at Point 1 at 3 different depths (2.5, 20.5 and 30.5 m above the bottom). Data: NortekMed, 2011.

2.2.2 - **2D Numerical modelling**

Current velocities have been computed using a local 2D hydrodynamic model based on the TELEMAC-2D software for several tide conditions (EDF R&D, 2009). The results of the model have been validated against in-site measurements. The velocities are depth-averaged (derived from shallow water equations). The results can be used to assess the spatial variability of the current velocities over the test site.

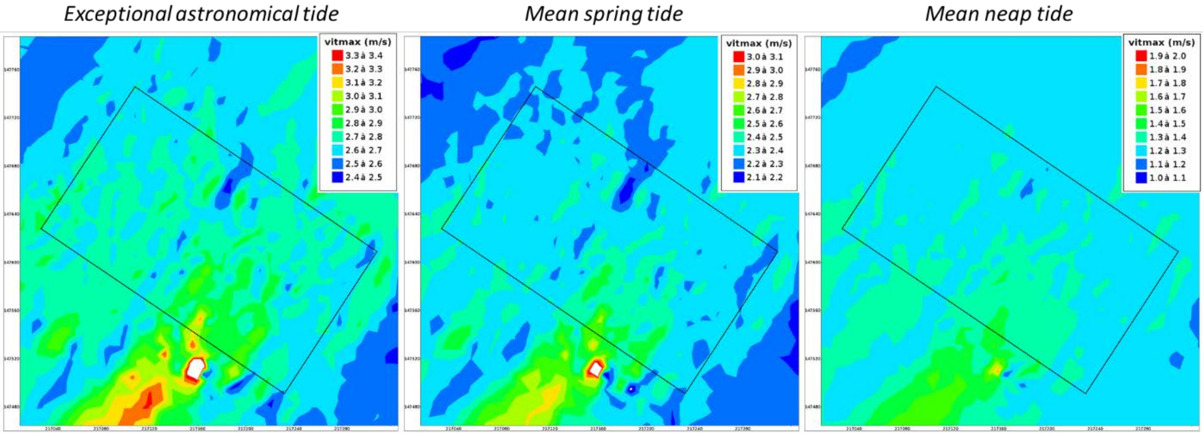

Figure 12: Depth-averaged velocity derived from Telemac-2D simulation of a 1) exceptional astronomical tide, 2) Mean spring tide and 3) Mean neap tide

The range of maximum depth-averaged velocity over the test site are summarized in Table 2 for 3 typical tide conditions:

Tidal condition	Tidal coefficient	Range of maximum depth-averaged velocity over the test site (m/s)
Exceptional spring tide	120	[2,4 ; 3,1]
Medium spring tide	95	[2,1 ; 2,8]
Medium neap tide	45	[1,1 ; 1,5]

Table 2: Maximum depth-averaged current velocities at the Paimpol-Bréhat site

2.3 - Waves

2.3.1 - Data sources

Extreme and mean wave conditions were computed by EDF R&D at Paimpol-Bréhat site using a wave propagation model, based on the TOMAWAC spectral wave code (release 6.0). The model construction and results are presented in detail in (EDF R&D, 2010).
Note: Given the progress achieved in the simulation field over the last decade the input wave data accuracy could be improved by carrying out a long term hindcast, simulations using a local coupled wave and hydrodynamic model.

2.3.2 - Extreme sea states parameters

Waves characteristics have been evaluated using data from ANEMOC numerical data base (Lafon & Benoit, 2006). The spectral significant wave height (Hm0) and associated peak period (Tp) were evaluated offshore for 6 propagation directions (90°N; 120°N; 150°N; 180°N; 210°N; 240°N) and combined with 3 values of sea level (Mean Low Water Springs; Mean Sea Level; Mean High Water Springs). Characteristics are presented in 3 tables for 3 return periods: yearly, 10-yearly and 50-yearly. These offshore wave conditions were then used as inputs to the local numerical model.
The simulations were performed with steady hydrodynamics conditions, that is to say, with a constant water level and without any effects related to ambient current.

RETURN PERIOD : 1 YEARS						
OFFSHORE SEA-STATES CONDITIONS			Sea Level (m CD)	Site point WGS84-UTM30 (508006 E; 5417456 N) Bottom elevation (model) : - 36 m CD		
Propagation direction (deg)	Hm0 (m)	Tp (s)		Dir (deg)	Hm0 (m)	Tp (s)
90	7	15	1.35 m (MLWS)	123	4.0	14.9
			6.09 m (MSL)	120	4.0	14.9
			10.80 m (MHWS)	118	4.0	14.9
120	6.7	13.4	1.35 m (MLWS)	136	6.0	13.3
			6.09 m (MSL)	135	6.0	13.3
			10.80 m (MHWS)	133	6.1	13.3
150	3.2	9.3	1.35 m (MLWS)	159	2.8	9.3
			6.09 m (MSL)	160	2.9	9.3
			10.80 m (MHWS)	160	2.9	9.3
180	2.6	7.7	1.35 m (MLWS)	182	2.4	7.7
			6.09 m (MSL)	183	2.5	7.7
			10.80 m (MHWS)	183	2.5	7.7
210	2.9	8.1	1.35 m (MLWS)	211	2.7	8.0
			6.09 m (MSL)	211	2.7	8.0
			10.80 m (MHWS)	210	2.8	8.0
240	1.9	5.8	1.35 m (MLWS)	241	1.7	6.0
			6.09 m (MSL)	240	1.7	6.0
			10.80 m (MHWS)	239	1.7	6.0

Table 3: 1-year return period sea-states parameters at Paimpol-Bréhat site

RETURN PERIOD : 10 YEARS						
OFFSHORE SEA-STATES CONDITIONS			Sea Level (m CD)	Site point WGS84-UTM30 (508006 E; 5417456 N) Bottom elevation (model) : - 36 m CD		
Propagation direction (deg)	Hm0 (m)	Tp (s)		Dir (deg)	Hm0 (m)	Tp (s)
90	9.4	17.1	1.35 m (MLWS)	126	5.4	17.0
			6.09 m (MSL)	123	5.4	17.0
			10.80 m (MHWS)	120	5.5	17.0
120	9.1	15.1	1.35 m (MLWS)	138	8.1	15.1
			6.09 m (MSL)	136	8.1	15.1
			10.80 m (MHWS)	135	8.2	15.0
150	5.7	10.4	1.35 m (MLWS)	159	4.7	10.3
			6.09 m (MSL)	160	4.9	10.3
			10.80 m (MHWS)	161	5.0	10.3
180	4.8	8.5	1.35 m (MLWS)	182	4.1	8.5
			6.09 m (MSL)	183	4.2	8.5
			10.80 m (MHWS)	183	4.3	8.5
210	4.4	9.9	1.35 m (MLWS)	211	3.8	9.9
			6.09 m (MSL)	211	4.0	9.9
			10.80 m (MHWS)	210	4.1	9.9
240	3.1	6.9	1.35 m (MLWS)	241	2.8	7.1
			6.09 m (MSL)	240	2.8	7.1
			10.80 m (MHWS)	240	2.8	7.1

Table 4: 10-years return period sea-states parameters at Paimpol-Bréhat site

RETURN PERIOD : 50 YEARS						
OFFSHORE SEA-STATES CONDITIONS			Sea Level (m CD)	Site point WGS84-UTM30 (508006 E; 5417456 N) Bottom elevation (model) : - 36 m CD		
Propagation direction (deg)	Hm0 (m)	Tp (s)		Dir (deg)	Hm0 (m)	Tp (s)
90	11	18.4	1.35 m (MLWS)	127	6.38	18.5
			6.09 m (MSL)	**124**	**6.42**	**18.5**
			10.80 m (MHWS)	121	6.47	18.5
120	10.7	16.1	1.35 m (MLWS)	138	9.55	15.9
			6.09 m (MSL)	**137**	**9.59**	**15.9**
			10.80 m (MHWS)	136	9.64	15.9
150	7.5	11	1.35 m (MLWS)	159	5.93	11.0
			6.09 m (MSL)	**160**	**6.17**	**11.0**
			10.80 m (MHWS)	161	6.36	11.0
180	6.3	8.9	1.35 m (MLWS)	182	5.12	9.1
			6.09 m (MSL)	**183**	**5.36**	**9.1**
			10.80 m (MHWS)	184	5.50	9.2
210	5.4	11	1.35 m (MLWS)	211	4.62	11.0
			6.09 m (MSL)	**211**	**4.88**	**11.0**
			10.80 m (MHWS)	210	5.02	11.0
240	3.9	7.5	1.35 m (MLWS)	241	3.47	7.7
			6.09 m (MSL)	**240**	**3.58**	**7.7**
			10.80 m (MHWS)	240	3.56	7.7

Table 5: 50-years return period sea-states parameters at Paimpol-Bréhat site

2.3.3 - **Mean wave climate**

An analysis of mean wave climate was also carried out using the local wave model. Hourly sea-states parameters extracted from the ANEMOC numerical wave database (point C854) were imposed on its boundaries over a period of 5 years, from 1997/01/01 to 2001/12/31. The simulations were performed with steady hydrodynamics conditions that is to say with a constant water level equal to mean sea level and without any effects related to ambient current. A statistical analysis was then performed to determine the percentiles Q of spectral significant wave height and to build a Hm0 - Tp scatter diagram (Table 7).
The results were extracted at a grid point representative of the test site conditions.
The percentiles Q of spectral significant wave height at Paimpol-Bréhat site is given in Table *6*.

Q (%)	Hm0 (m)
10	0.41
20	0.55
30	0.68
40	0.81
50	0.96
60	1.14
70	1.35
80	1.63
90	2.09
95	2.47
99	3.27

Table 6: Percentiles Q of spectral significant wave height at Paimpol-Bréhat site

		Tp																			
		2<<3	3<<4	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<<17	17<<18	18<<19	19<<20	20<<21	TOTAL
Hm0	0-0,5	0	0.6	2.6	3.9	6.8	28.9	39.7	39.9	23.3	6.7	5.4	1.7	0.2	0.1	0.1	0.1	0	0	0	160
	0,5-1	0	1.2	21.2	25.1	19.6	36.2	43.2	46.4	59.1	48.4	34	18.7	8.5	2.4	0.6	0.5	0.1	0	0.1	365.3
	1-1,5	0	0.1	2	31.9	19.3	21.2	17.2	17.5	23	27.1	20.2	19.4	17.9	8.4	2.4	2	0.5	0	0.1	230.2
	1,5-2	0	0	0	4.4	23	15.3	8.9	11.6	12.9	11.6	9.7	7.1	9.6	8.4	3.5	2.9	0.3	0.5	0	129.7
	2-2,5	0	0	0	0	7.7	11.9	5.4	5.2	5.8	4.2	5	3.4	4.2	5.5	4	3.1	1.9	0.2	0	67.5
	2,5-3	0	0	0	0	0.1	5.6	1.9	2.9	3.7	2.4	2.5	2.1	2.6	1.3	1.4	1	1.5	0.5	0	29.5
	3-3,5	0	0	0	0	0	1.3	0.7	0.5	1.6	0.9	1.1	1	1.8	1.4	0.2	0.5	0	0	0	11
	3,5-4	0	0	0	0	0	0	0.1	0.3	0.9	0.6	0.5	0.5	0.7	0.7	0.1	0.2	0	0	0	4.6
	4-4,5	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.3	0.3	0.4	0.3	0	0	0	0	1.6
	4,5-5	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.3	0.1	0	0	0	0	0.7
	5-5,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5,5-6																				0
	6-6,5																				0
	6,5-7																				0
	7-7,5																				0
	7,5-8																				0
	TOTAL	0	1.9	25.8	65.3	76.5	120.4	117.1	124.3	130.4	102	78.6	54.3	45.9	28.9	12.7	10.3	4.3	1.2	0.2	**1000**

Table 7: Scatter diagram Hm0-Tp at Paimpol-Bréhat site

For the purpose of design values of maximum wave heights (Hmax) shall then be derived from sea-states parameters taking into account a shallow water distribution model for wave heights and state-of-the art breaking criteria, and wave kinematics shall be computed.

2.4 - Weather

The climate is mainly influenced by perturbations coming from the Atlantic Ocean, bringing a humid and temperate weather. Averages temperature and rainfalls are described in Table 8:

T°C	J	F	M	A	M	J	JY	A	S	O	N	D
Min	5.1	5.0	6.0	7.0	9.5	11.9	14.2	14.8	13.5	11.1	8.1	6.4
Max	9.2	9.5	10.9	12.0	14.8	17.3	19.7	20.3	18.8	15.7	12.3	10.3
Avg	7.2	7.2	8.5	9.5	12.2	14.6	16.9	17.5	16.2	13.4	10.2	8.4

R mm	J	F	M	A	M	J	JY	A	S	O	N	D
Avg	81.5	70.7	60.6	53.7	57.6	42.4	37.1	38.8	57.5	76.6	86.8	93.0
Nb d	14.2	12.2	11.9	10.4	10.3	7.7	6.6	6.7	10.0	12.3	14.5	14.7

Table 8: Climate conditions of the test site (Temperature above and rainfalls below)

Wind measurements over a 40-years period (1962 to 2002) show the following characteristics:

- From January to March and October to December: most frequent winds from southwest and strongest winds from west-northwest,
- From April to September: most frequent and strongest winds from west-northwest.

The steady wind from west-northwest can be higher than 8 m/s (15 knots)
The best period for intervention at sea happened in summer due to the Azores High which influences climate until North of France and brings stable good weather.

3 - Marine ecology

3.1 - Physico-chemical characteristics

The salinity, temperature and turbidity are the main physico-chemical characteristics studied over the test site. The average salinity is 35 PSU. Temperatures show a classic seasonal cycle between 7-8°C in winter and 19-20°C in summer at the surface. In some years, highest values can reach 21°C and lowest values can reach 5°C. Turbidity is most of the time below 3 NTU but it's strongly dependant on the season, hydrodynamic events, whether conditions and pollution. Highest turbidity observed during the measurement campaign led by Ifremer (from 1994 to 2004) was 14 NTU.

3.2 - Chlorophyll and Phaeopigments

According to the data from Ifremer from 1994 to 2004 concentrations of chlorophyll a is below 3 µg/L most of the time. It can reach 4 to 6µg/L due to planktonic bloom usually in spring and autumn. Concentration of phaeopigments varies between 0.2 and 0.8 µg/L with maximum value above 2 µg/L. It follows the same seasonal variation as the chlorophyll a with a little delay.

3.3 - Marine life

3.3.1 - Marine mammals

Several technics can be considered to characterise the marine mammal's population on the test site and its surroundings. First, observations from the program SCANS II and follow up of the standings (RNE studies in 2005 and 2006) have been used.
Then some acoustic studies allow to determine the presence of marine mammals. Indeed, they use acoustics to find their way through space, communicate and hunt their prey. This ability is vital for their survival in the marine environment. It is particularly used for socialization, identification of individuals and coordination of activities. Frequency and intensity discrimination are crucial for the detection, orientation and interpretation of acoustic signals in a noisy environment. Possible interactions with mammals may be sensitive. The Paimpol-Bréhat site studied by SINAY in 2010, with CPods, shows a relatively high frequency of marine mammals. However, the study area is more a transit area than a habitat for dolphins and porpoises in view of the results obtained. Moreover, the various analyses carried out show that there is no interaction between the anthropic activity detected in the area and the interception of marine mammals.

3.3.2 - Fish

Fishery resources are varied and abundant. The Horaine cantonment zone is home to shellfish: spider crabs, lobster, crabs, etc. The species of fish that frequent the installation of the test site are sea bass, mackerel, pollack, etc... Other species of commercial value, such as monkfish, sole, skate, scallop, clam, or sea almond are not present on the area of the test site.

3.3.3 - Benthos

A study from Ecosub in 2009 has shown a limited faunistic cover of the seabed, 5 to 10%. This habitat is defined as a EUNIS A4.131: bryozoan turf and erect sponges on tide-swept circalittoral rock (the EUNIS habitat classification is a comprehensive pan-European system for habitat identification).

Figure 13 : Left: Pachymatisma johntonia (size: 40 cm) and a sponge Adreus fascicularis. Right: colourful colony of Corynactis viridis (jewel anemone). Source: Ecosub.

3.4 - Bio-colonisation

The test site presents a strong biological activity and therefore a significant colonisation of the installations. The colonisation of cables and mattresses have been very well studied as well as the potential impact of the magnetic field of the cable on marine life.

Figure 14: Photograph of iron shells and concrete mattresses used to protect an unburied cable at the tidal Paimpol-Bréhat turbine test site, France (Olivier Dugornay, 2013).

Colonisation is gradual with also a high seasonal variability (winter/summer). The study of Taormina (2019) shows that Barnacles are the first colonisers of the barren artificial habitats and form a secondary substratum that facilitates the settlement of a variety of ascidians. Ascidians, together with the remaining barnacles, then allow for the settlement of more complex and long-lived taxa, such as various macroalgae, kelp, hydroids etc. Barnacles had facilitated ascidian settlement which in return contributed to their disappearance.

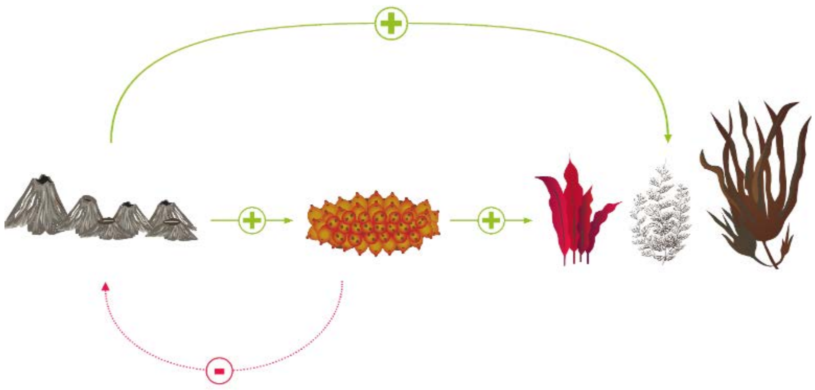

Figure 15: Conceptual diagram of the facilitation cascade that occurred on artificial habitats of the Paimpol-Bréhat tidal test site.

According to the installation environments, Taormina (2019) proposed three scenarios for bio-colonisation i) natural habitats, ii) iron shell and iii) mattresses.

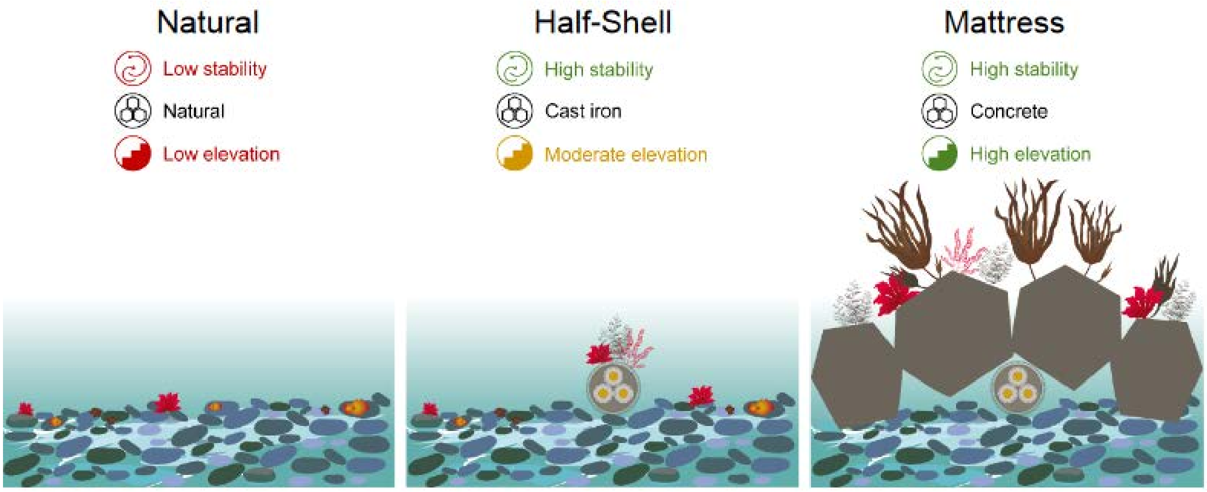

Figure 16: Conceptual diagram of the epibenthic colonisation of the three different habitats of the Paimpol-Bréhat tidal test site: Natural habitats (left), half-shells (middle) and mattresses (right) (Taormina, 2019).

Natural habitats are dominated by unstable pebbles and are highly exposed to sediment scouring; the epibenthic community is thus characterised by encrusting taxa. Half-shells (middle) constitute a stable cast iron habitat moderately exposed to sediment scouring due to moderate elevation; the epibenthic community is thus characterised by erect taxa with moderate structural complexity (i.e., hydroids). Mattresses constitute a stable concrete habitat marginally exposed to sediment abrasion as their anchor point is high above adjacent sediments; the epibenthic community is characterised by various erect taxa with complex morphology (i.e., kelps).

Deployment of artificial structures in the Paimpol-Bréhat tidal test site resulted in the addition of stable substrata in an environment where natural hard substrates are highly mobile and strongly exposed to sediment abrasion due to strong hydrodynamic conditions.

These safe houses of stability allow for structurally complex epibenthic communities to flourish, which facilitates an overall increase in local diversity as lack of stable natural hard substrates limits the development of mature epibenthic communities. Nevertheless, epibenthic communities colonizing artificial habitats are unlikely to have reached their climax at the end of the study of Taormina (2019).
Another study of Taormina et al. (2020) on the impact of magnetic field on lobsters shows that there was no anthropogenic magnetic field impact on juvenile European lobsters, whether coming from DC or AC power cables with realistic intensity values. The ability to find a shelter after a 1-week exposure remained unchanged and no avoidance or attraction to anthropogenic magnetic field can be demonstrated.

3.5 - Acoustic

The natural acoustic underwater environment is very noisy in all frequency ranges due to the turbulence generated by the current in the entire water column, but also due to sediment transport which seems to occur in a deep bathymetric "channel" near the test site, according to the study carried on by Altran in 2009 for one day with two hydrophones [Altran, 2009].
A new acoustic baseline survey is scheduled in 2021.

4 - Anthropogenic activities

Many users of the sea coexist in this area. The different activities listed below are identified and quantified in the Sea Enhancement Scheme (Schéma de Mise en Valeur de la Mer - SMVM) covering the area of Trégor-Goëlo, comprising 27 municipalities and having been approved in December 2007.
This maritime spatial planning document is integrated into the regional and national planning strategies set out in the Strategic Façade Documents[5]. The Annex 8 of this document describes the priority set up in the area of Northern Bretagne, identified as area 5b in Figure 17:

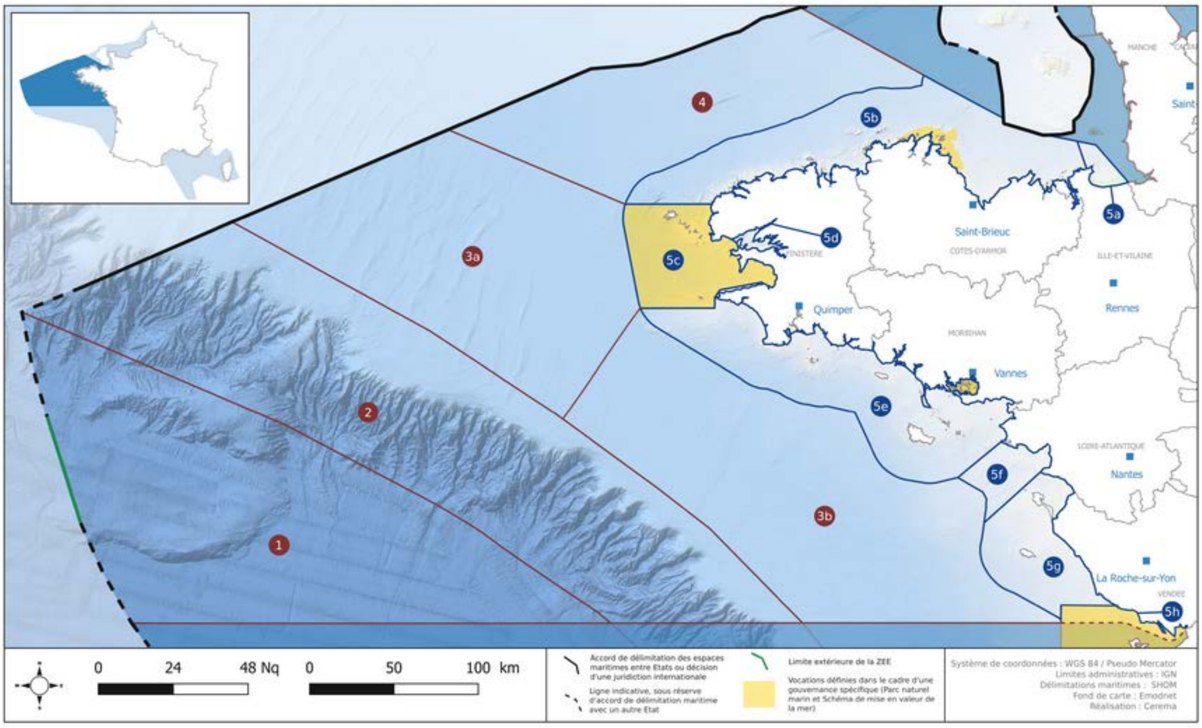

Figure 17: Map of priorities issued by the Strategic Façade Document

[5] http://www.dirm.nord-atlantique-manche-ouest.developpement-durable.gouv.fr/IMG/pdf/synthese_vf_cle6e72f2.pdf

Northern Bretagne – Area 5b:

“Priority [is given] to sustainable fisheries and aquaculture; ensuring that, in order of importance, renewable marine energy, sustainable boating and tourism coexist alongside each other; preserving habitats with a high ecological value, birds and marine mammals. This zone includes the perimeter of the SMVM of Trégor-Goëlo, which defines vocation zones within the framework of specific governance.”

4.1 - Trade

The importance of the food-processing sector in the Côtes-d'Armor explains the preponderance of trade in the products of this sector. In fact, they represent more than half of the tonnage of goods traded, but these exchanges are mainly by road transport.
Despite its strategic location, commercial maritime transport from the ports of Paimpol and Ploubazlanec is currently non-existent (commercial service only, in the port of Paimpol). The Department's 4th and 3rd largest ports in terms of annual traffic are those of Lézardrieux and Pontrieux.

4.2 - Extraction of marine materials

The marine materials exploited are silica sand, maerl and shellfish sand.
Silica sand is mined in the downstream part of the Jaudy estuary, with a maximum quota of 25,000 tons per year. It is used for the prefabrication of concrete products, and to correct other sands lacking fine elements.
The extraction of maerl is subject to local regulations. It is restricted to two deposits on the SMVM territory, that of Lost Pic, near the pointe de Plouézec and that of the lighthouse of La Croix (west of the island of Brehat). The extraction of shellfish sand has been included in the regulations mentioned for maerl, which have been in place since 1996.
In the area, two sites are exploited: la Cormorandière (1.1 km2), north of the Lost Pic deposit, and la Horaine (1.3 km2, north of the Lost Pic deposit. The deposit is located off the point of Plouha, outside the sector of the Horaine itself). All the exploited deposits are far from the La Horaine site.

4.3 - Commercial fishing

The maritime district of Lannion-Paimpol stretches along the western part of the Côtes-d'Armor coastline, from Plouha to Trédrez-Locquémeau. Parking ports are spread out along the coasts of the district and 26 landing points are listed.
The district has 15 parking ports for 107 registered fishing vessels.
The fisheries practised in the maritime district are managed by fishing licences, allocated by the Regional Committee for Fisheries and Marine Livestock of Brittany, according to very strict allocation criteria. These licences allow limited access to the resource. In the maritime district of Paimpol, all trades are subject to licensing.
Regarding the fishing fleet of the Paimpol maritime district, 104 ships were registered in the Paimpol maritime district throughout 2007, 6 were registered in the district during 2007 and 10 left the district. Thus, 120 ships were registered in Paimpol during 2007, but only 114 were considered active for at least one month during 2007. The fishing fleet is characterized by small vessels (mostly less than 12m), exclusively coastal and very multitask. The main activities are the scallop dredge, the fish net and the crustacean trap targeting lobster in particular. Within the Horaine Box, anglers and longliners are permitted to work. This fishery involves 60 vessels with a longline/line licence, but only about 10 actually practice these trades in the Horaine area. They mainly target sea bass, pollack and mackerel.

4.4 - Shellfish farming

At the departmental level, shellfish farming generates an estimated turnover of 28 million euros for a production of 14,820 tons. On the area of Trégor-Goëlo, shellfish production is centred on 3 sectors, in which the production of hollow oysters dominates.

The Bay of Paimpol is the most important, with 550 ha exploited (mainly oysters) by about a hundred oyster farmers. Then, the Trieux estuary and its extension between the Talbert furrow and the island of Bréhat, are home to 80 ha of oyster beds and 10 km of mussel beds, operated by local producers. Finally, the Jaudy estuary as far as the island of Er constitutes the third production sector with 70 ha of oyster beds distributed among about thirty oyster farmers, most of them being local.

4.5 - Pleasure-boating and fishing

On 31 August 1998, the pleasure craft fleet in the maritime district of Paimpol (from Plouha to Plestin-les Grèves) amounted to more than 17,000 registered boats, including nearly 13,000 of less than 2 tons (excluding the disappearance of registrations, which represent about 20% of the registered fleet of boats over 2 tons, and 50% for boats under 2 tons) (source SMVM, 2007).

For the SMVM sector of Trégor-Goélo, we arrive at an estimate of the pleasure craft fleet of about 3,600 to 3,800 "active" vessels (including 400 to 500 over 2 tons). Motor boats are largely dominant (83% of the registrations in 1998, for example).

IV - ELECTRICAL CONNECTION

1 - General architecture

The architecture of the test site is composed of an onshore substation located close to Anse de Launay beach (120m), connected to the distribution grid. From there, a main export cable (power and optical: 8MW – 360A – 12 OF) links the test site to the shore on a 16km distance. The main export cable is connected to a 120m long terminal cable section through a dry mate connection system, the In-Line Termination (ILT). This terminal section is equipped with a wet mate cable termination head (CTH) that includes one export power connection point and two optical connection points.
It is important to note that the export cable is operated at +/- 5kV DC. An AC/DC conversion system is then necessary to connect an AC tidal generator to the export cable.

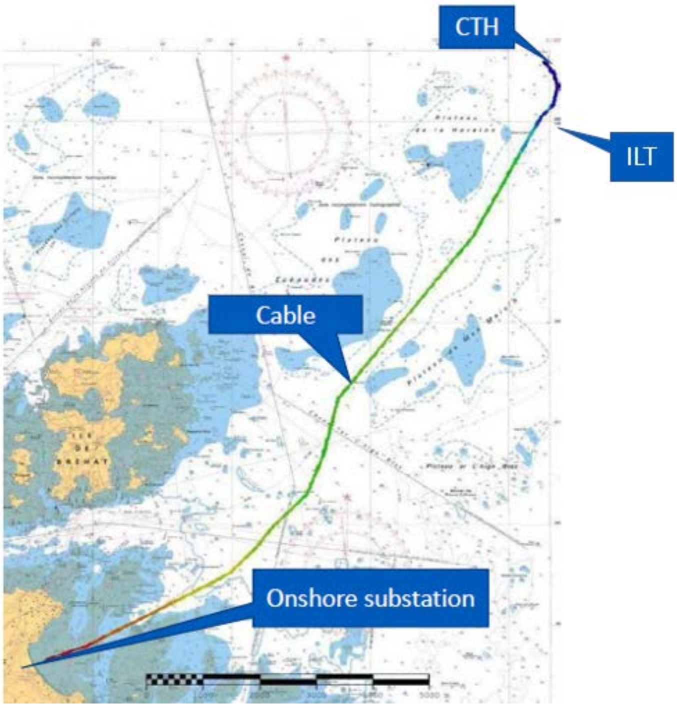

Figure 18: General electrical architecture – overview

2 - Export cable design, manufacture, and installation

The cable was specifically designed for the site in 2010. A DC connexion was preferred for several reasons. The cable is double armoured, free floading and coilable. A prototype of the cable was validated before manufacture.
The export cable structure is composed of 4 individual power cables (185 mm², copper, XLPE) and 12 single mode optical fibres. 8 fibres are connected.

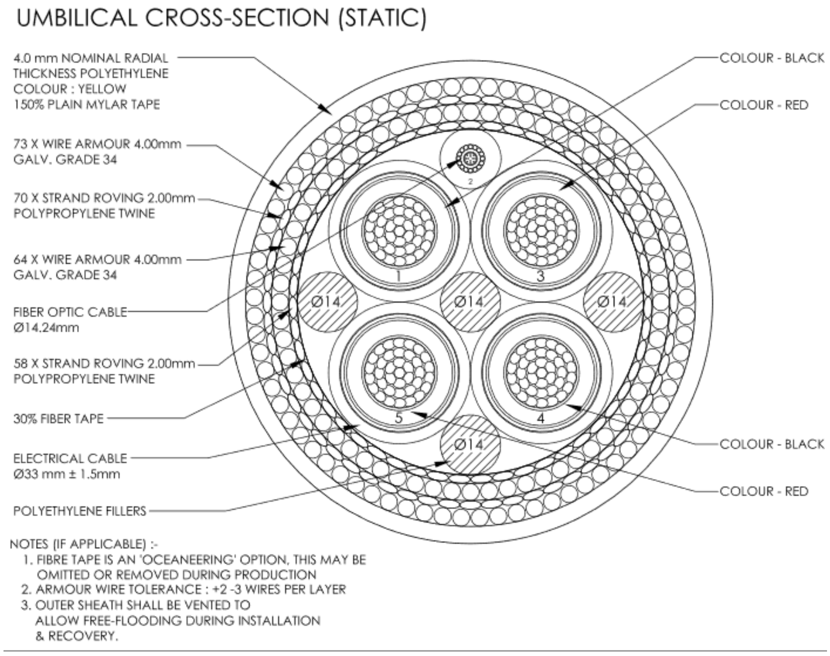

Figure 19: Export cable design

The export cable of Paimpol-Bréhat tidal site was installed in 2012. The cable was buried along the first 5 km near shore. Along the remaining 10 km, the soil nature did not allow for burial, so the cable lies on the rocky sea bottom, under severe wave and current conditions. In particular the site is exposed to long Atlantic swell. The swell dominant direction is close to the tidal current main axis, and almost perpendicular to some sections of the cable route. The cable protection is mainly ensured by articulated iron pipes, which protect the cable against abrasion and increase its linear weight.

Figure 20: Export cable installation

The cable is protected on its entire length by cast iron protective shells:

Figure 21: Cable protective shells

Additional works have been carried out during summer 2013 [Lafon et al, 2014]: an intermittent concrete mattresses protection was added over the most exposed sections in order to ensure long-term stability and a number of free spans identified through a video survey carried out with a ROV, were rectified.
In total 121 heavy-density concrete mattresses with wedged edges, weighing 11 tons each, have been installed.

Figure 22: Concrete mattresses installation

Two different methods have been used to remove or reduce the most significant free-spans: at some points, the cable was realigned off of raised seabed features. Where cable re-alignment was not possible, grout bags were installed to support the cable and reduce the free-span length. No export cable movement/instability has been detected since its installation.
The 130m long terminal section of export cable is connected to export cable main length of 15km by an In-Line Termination, which is a dry connection system.

Figure 23: In Line Termination connected

3 - The onshore substation and its equipment

The onshore substation is connected to the French national electricity grid (distribution network managed by the Transmission System Operator ENEDIS. The contract currently in force between EDF and ENEDIS provides for a maximum connected capacity of 2.5 MW.
Power export to the grid is limited to 45 kVA at low voltage (LV) and 2 500 kVA at medium voltage (MV). Depending on the needs, additional work can be considered to increase power export at low voltage up to 100 kVA.

Figure 24: Onshore substation building

The onshore substation is equipped with a DC/AC conversion system designed according to the initial demonstration project characteristics. This equipment may be used for future experimental campaigns; however, by experience, test site users would certainly wish to develop and install their own dedicated conversion and communication system. This can be envisaged with respect to available space in the onshore substation.

The onshore substation is also equipped with a communication system connected to export cable fibres. The substation holds a secure internet access for the SCADA system. It is equipped with a burglar alarm system which is monitored offsite.

The onshore substation building consists of the following rooms, as illustrated hereafter:

(1) Control room (air conditioning) including optical, telecom, control and instrumentation equipment;

(2) HT room (air conditioning) including MV and LV cubicles, metering equipment;

(3) Transformer room, including LV/MV oil insulated transformer;

(4) MV7000 room (with air conditioning) including DC/AC conversion equipment and export cable cubicle;

(5) Air/water cooler room (outside) including water coolers for MV7000 operation.

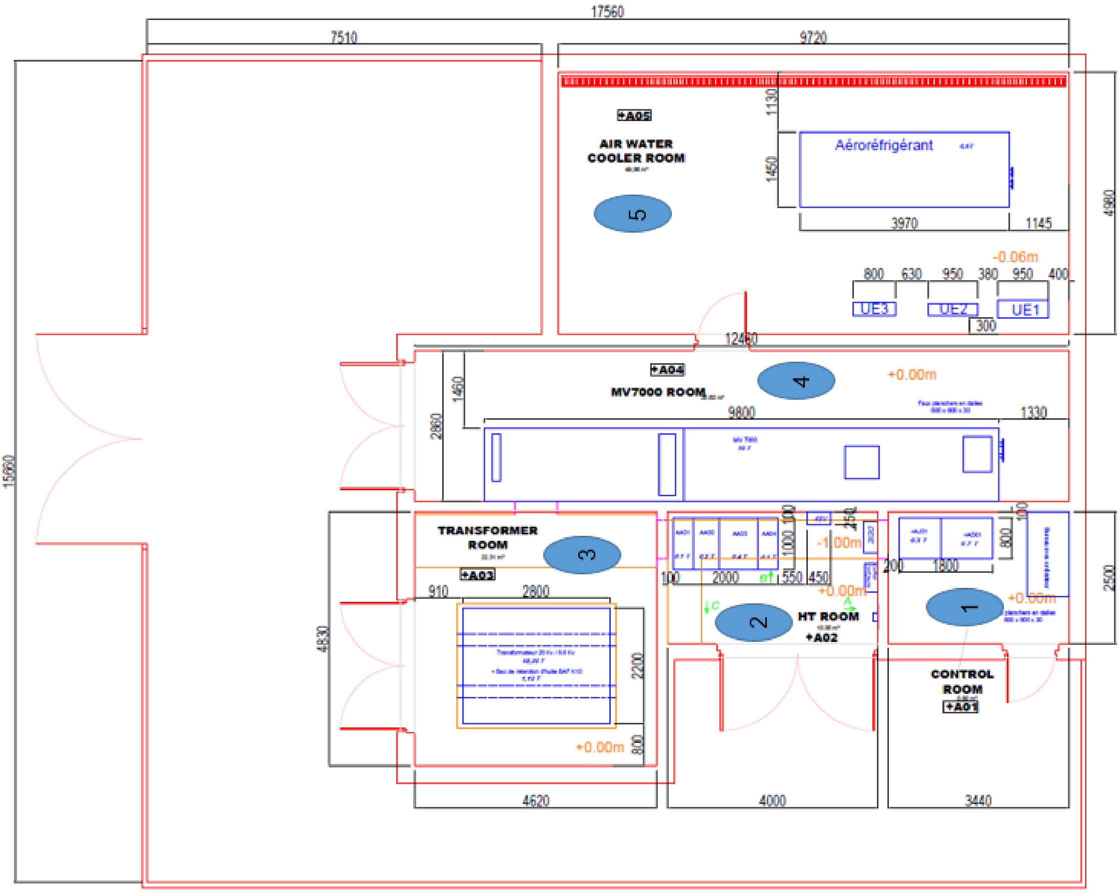

Figure 25: Onshore substation layout

4 - Subsea connection system

In order to connect the turbine to the connection equipment in place, an electrical assessment will be required to determine the several options available to the user. **It is recommended that preliminary assessment of electrical interfacing is realized as early as possible. Indeed, as the equipment in not standard, additional costs and time may arise.**

Connection to export cable is available through the high voltage junction box (HVJB) installed on the export cable termination head (CTH). The HVJB is equipped with wet mate power and optical connectors as shown in Figure 26:

Figure 26: CTH structure and detail of HVJB wet mate connectors

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