COASTLINE CHANGES AND MARINE AGGREGATE EXTRACTION: A REVIEW OF CURRENT KNOWLEDGE AND PRACTICES IN FRANCE

STUDY REPORT

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ARTELIA Passion & Solutions
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Cerema CLIMAT & TERRITOIRES DE DEMAIN
UNPG UNION NATIONALE DES PRODUCTEURS DE GRANULATS

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TEXTS

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MAIN SUMMARY

DETAILED SUMMARY

PREAMBLE TO THE ENGLISH VERSION

At the request of the Union Nationale des Producteurs de Granulats (French National Union of Aggregate Producers), Cerema and Artelia performed a study in 2021 entitled "COASTLINE CHANGES AND MARINE AGGREGATE EXTRACTION: A REVIEW OF CURRENT KNOWLEDGE AND PRACTICES".

This study aims to summarise the state of the art of knowledge in this field, describe the factors involved in coastline change, and explain how this topic is addressed in the impact assessments required by applications for licences to extract marine aggregates in France, using as examples the last two licences granted on the Atlantic and English Channel coasts of the country.

The Marine Aggregates Committee of the UNPG started working on the topic of the coastline back in 2019, owing to misinformation being circulated among the general public. Coastline erosion, or "retreat", was becoming an issue of major concern among local communities and elected officials, in relation to certain offshore industrial activities including marine aggregate extraction.

The subject is also raised in a wide variety of publications on a European and global scale. For instance, the United Nations Development Programme examined the issue of marine sand extraction and its potential consequences for the environment. However, the procedure for handling licence applications in France bears no resemblance to the approaches presented in these publications.

This is why it seemed appropriate to provide an English version of this study, to give the players concerned a greater understanding of marine aggregate extraction in France and how it is assessed in licence applications.

This study includes a reminder that some simple criteria to be followed to limit the impact of a potential licence area on the coast were defined by scientists in the 1980s. These criteria concern extraction depth, dredging area geometry, and distance to the coast. They have ensured that the aggregate licence areas operated in France over the past thirty years have been positioned correctly, and it has been established today that the existing sites have no demonstrable impacts on the French coast. This is quite simply because impact avoidance and mitigation measures were implemented during project construction.

This study is supplemented by summary sheets designed to reach a wide audience, thus meeting the objective of providing knowledge to improve understanding.

FOREWORD

Mindful of the need to provide the regions of France with sustainable supplies of materials, our profession instigated the development of marine aggregate extraction some thirty years ago at the request of the French government, in order to support the phasing-out of extraction from alluvial valleys. It has done so with a concern for respecting the marine environment. It has also participated in a number of scientific programmes on a European and even international scale (the ICES), to improve knowledge of its impacts and adapt its operating methods. These initiatives have provided means of controlling the impacts of marine aggregate extraction and contributing to improving knowledge of the marine environment.

Being of land-based origin and having the physical and chemical characteristics of land-based alluvial deposits, the marine aggregates extracted from the French maritime domain are a resource in their own right, playing a vital role on work sites and in major structures all over the country, as well as in certain agricultural products. This industry also contributes to the maritime economy and the economies of the areas in which it operates.

Marine aggregate extraction is subject to a strict regulatory environment, to which our profession has adhered and adapted as requirements have evolved over the years. In this context, it embarked in 2012 on discussions regarding the French "National strategy for sustainable management of marine and land-won aggregates and quarry materials and substances" and participated in the working group on marine aggregates ("GTGM"), which drew up a methodological guide to the production of guidance documents on the sustainable management of marine aggregates ("DOGGM"), which was published in November 2016 by the French ministry for the environment.

This guide made it clear that the issue of the impact of offshore marine aggregate extraction on coastline erosion deserved special attention. The Marine Aggregates Committee of the French National Union of Aggregate Producers (Union Nationale des Producteurs de Granulats - UNPG)[1], wished to make available to everyone a scientific and technical information document giving an overview of the relationship between marine aggregate extraction and coastline change[2]. The UNPG therefore appointed the engineering consultancy Artelia and the public agency Cerema (Centre for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning) to produce this study. The resulting report is divided into four chapters:

- A general introduction to the subject (written by Cerema),
- A summary of knowledge of various sedimentary provinces along the North Sea, English Channel and Atlantic coasts (written by Cerema),
- A summary of scientific knowledge of the various hydrosedimentary processes that can result in marine aggregate extraction having an impact on the coastline (written by Artelia),
- Feedback from France (written by Artelia).

An additional section describing French regulations governing marine aggregate extraction (written by Cerema) is appended to this report. It provides insight on the licences required for this activity, and some important information on the procedure to be followed to obtain an exploitation permit ("AOTM"), which requires an impact assessment in order notably to avoid any impacts for the coastline (AMC approach: Avoid-Mitigate-Compensate).

In a second phase, in cooperation with the French Ministry for the Ecological and Solidarity-based Transition (MTES), the UNPG plans to supplement this report by drafting and publishing a methodological guide to assist marine aggregate producers in drawing up their impact assessments on the topic of the coastline.

Laetitia Paporé,
Chair of the Marine Aggregates Committee of the UNPG

1 UNPG-GM, https://www.unicem.fr/accueil/la-federation/syndicats/partenaire-amont-incontournable-de-la-filiere-construction/

2 To find out more: http://sablesetgraviersenmer.fr/pages/erosion-cotiere.html

GLOSSARY AND ABBREVIATIONS

Basic knowledge of how the French coastline is managed is required in order to understand this report in full. A useful reference document is the methodological guide to coastline management (in French) published in 2010 by the French Ministry of Ecology, Energy, Sustainable Development and the Sea [3]. This document contains a detailed description of coastal environments and a technical glossary, which we have adopted here, supplemented with a few terms of particular importance for the subject of this report.

Technical terms

These terms appear in **bold** in the body of this report, to indicate that their meaning can be found in this glossary.

Bank: Offshore accumulation of alluvium (sand, gravel, shingle), subject to the action of waves and currents which modify its shape and position.

Bar: An underwater alluvial bank that outcrops slightly below the lowest astronomical tide level, thus posing a hazard for shipping, especially at mouths of rivers and lagoons or off large beaches (an offshore bar).

Chart Datum (CD): In this report, seabed elevations and water depths are given in metres with reference to chart datum (mCD, the plane to which all depths on a nautical chart are referred.

Closure depth: maximum depth beyond which longshore drift is almost nil and vertical changes in seabed elevation are minimal or even imperceptible over a given period (1 year, 10 years, etc.).

Dredging area: a man-made (anthropogenic) excavation in the seabed or on land.

Longshore drift/longshore transport/littoral drift: transport of sand, gravel and shingle parallel to the shore, under the action of oblique waves breaking on the beach.

Stratigraphy: description of the strata, or layers, of terrain forming the earth's crust with a view to studying its history.

Abbreviations and acronyms

AMC: Avoid - Mitigate - Compensate

AOTM: Autorisation d'ouverture de travaux miniers (permit to open mining works)

AOT: Autorisation d'occupation temporaire (temporary occupation permit)

APP: Autorisation de prospections préalable (prior exploration permit)

BRGM: Bureau de Recherches Géologiques et Minières (French Geological Survey)

Cerema: Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement (Centre for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning)

CERC (Coastal Engineering Research Center): US Army Corps of Engineers research facility which draws up manuals and best practice guides for coastal engineering operations

CETE: Centre d'études techniques de l'équipement (a public research and development, innovation and engineering organisation)

Cetmef: Centre d'études techniques maritimes et fluviales (Institute for Maritime and Waterways Studies)

CICGBDS: Commission inter-régionale de concertation pour la gestion de la baie de Seine (inter-regional consultation commission for management of the Seine bay)

CNRS: Centre national de la recherche scientifique (French National Centre for Scientific Research)

DIRM NAMO: Direction interrégionale de la mer Nord Atlantique-Manche Ouest ([Interregional Directorate for the North Atlantic and Western English Channel)

DOGGM: Document d'orientation pour une gestion durable des granulats marins (guidance document on the sustainable management of marine aggregates)

DRE: Direction régionale de l'Équipement (regional public works directorate)

DREAL: Direction régionale de l'Environnement, de l'Aménagement et du Logement (French Regional Directorate for the Environment, Development and Housing)

3 "La gestion du trait de côte" ("Coastline Management") was published in 2010 by Editions QUAE in Brest. Available as an e-book at https://www.quae.com/produit/885/9782759209880/la-gestion-du-trait-de-cote

DROM: Départements et régions d'outre-mer (overseas departments and regions of France)

DSF: Document stratégique de façade (sea basin strategy document)

DYNALIT: French national coastline observation system

EDF: Électricité de France (French electric utility company)

EEZ: Exclusive economic zone

ESTRAN: Espace scientifique et technique des ressources aquatiques et de la navigation (Scientific and Technical Space for Aquatic Resources and Navigation - an association)

GEMEL: Groupe d'étude des milieux estuariens et littoraux (Estuary and Coastal Area Study Group)

GIE: Groupement d'intérêt économique (economic interest group)

GIE GMN: Groupement d'intérêt économique « Granulats Marins de Normandie » ("Normandy Marine Aggregates" Economic Interest Group)

GIE GMO: Groupement d'intérêt économique « Granulats de la Manche Orientale » ("East Channel Aggregates" Economic Interest Group)

GIP: Groupement d'intérêt public (public interest group)

GIS: Groupement d'intérêt scientifique (scientific interest group)

GRESARC: Groupe de recherche sur les environnements sédimentaires aménagés et les risques côtiers (research group on developed sedimentary environments and coastal risks)

ICES: International Council for the Exploration of the Sea

Ifremer: Institut français de recherche pour l'exploitation de la mer (French National Institute for Ocean Science)

IGN: Institut national de l'information géographique et forestière (French National Institute of Geographical and Forest Information)

INSU: Institut national des Sciences de l'univers (French National Institute of Sciences of the Universe)

LCHF: Laboratoire central d'hydraulique de France (French Central Hydraulics Laboratory)

MEDDE: Ministère de l'Écologie, du Développement durable et de l'Énergie (French Ministry of Ecology, Sustainable Development and Energy)

MEDDTL: Ministère de l'Écologie, du Développement durable, des Transports et du Logement (French Ministry of Ecology, Sustainable Development, Transport and Housing)

MEEDDM: Ministère de l'Écologie, de l'Énergie, du Développement durable et de la Mer (French Ministry of Ecology, Energy, Sustainable Development and the Sea)

MEEM: Ministère de l'Environnement, de l'Énergie et de la Mer (French Ministry of the Environment, Energy and the Sea)

MIACA: Mission interministérielle d'aménagement de la côte aquitaine (Interministerial Mission for Development of the Aquitaine Coast)

MINEFI: Ministère de l'Économie et des Finances (French Ministry of the Economy and Finance)

MSFD: Marine Strategy Framework Directive

MSPD: Maritime Spatial Planning Directive

MTES: Ministère de la Transition écologique et solidaire (French Ministry of Ecological Transition and Social Affairs)

OLIBAN: Observatoire du littoral bas-normand (Lower Normandy coastal observatory)

OREAP: Organisme régional d'études pour l'aménagement de la Picardie (regional working group for the development of Picardy)

PAMM: Plan d'actions pour le milieu marin (marine environment action plan)

PER: Permis exclusif de recherche (exclusive exploration permit)

PER GMH: Permis exclusif de recherche des granulats marins havrais (exclusive permit to explore marine aggregates off Le Havre)

ROL: Réseau d'observation du littoral (coastal observation network; here, in the Normandy and Hauts-de-France regions)

Shom: Service hydrographique et océanographique de la Marine (French Naval Hydrographic and Oceanographic Service)

SIEGMA: Suivis des impacts de l'extraction de granulats marins (Monitoring the impacts of marine aggregate extraction)

UNPG: Union Nationale des Producteurs de Granulats (French National Union of Aggregate Producers)

COASTLINE CHANGE: GENERAL INTRODUCTION TO THE SUBJECT

1.1 INTRODUCTION

Local communities are paying increasing attention to processes of coastline erosion and "retreat" as they witness areas of dense urban development very close to the sea coming under threat with each passing storm, and existing sediment stocks becoming insufficient to reconstitute beaches and protect exposed assets along the coast.

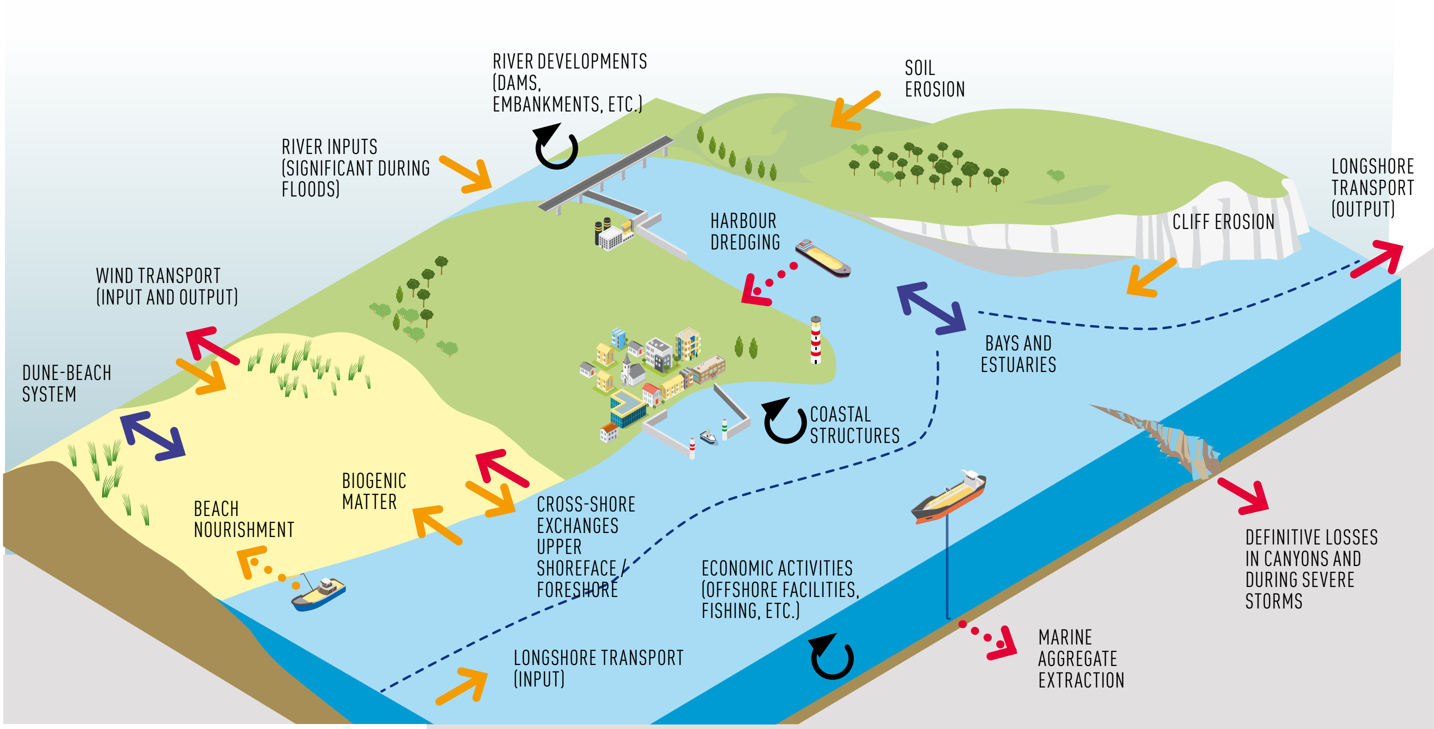
In 2012, France hence adopted a national strategy for integrated coastline management (MEDDTL, 2012) with the aim of encouraging adaptation to and anticipation of coastal erosion processes, enabling appropriate choices to be made and steps to be taken to protect against future shifts driven by climate change. To date, implementation of this national strategy has been underpinned by two action programmes (2012-2015 and 2017-2019 - MEEM, 2017) which have placed the priority on developing and sharing knowledge in order to gain a full understanding of these complex processes.

The first two chapters of this document hence aim to provide a neutral, informative introduction to the current state of knowledge on coastline change and how it is affected by human development and activities. It draws in particular on the results of work carried out in this area by Cerema in the context of France's national strategy for integrated coastline management, including production of a national indicator of coastal erosion and updating of the "Sedimentological catalogue of the coasts of France".

1.2 FACTORS INFLUENCING COASTLINE CHANGE

The "coastline" [4] corresponds here to the coastal area at the interface between the land, the sea and the atmosphere. It evolves naturally and continuously according to its intrinsic nature (type of coast, arrangement of and resistance from terrain, topography of the hinterland, etc.) and under the effect of atmospheric factors (winds, low-pressure areas, precipitation, etc.) and hydrodynamic factors (sea level, waves, associated currents, river flows). Its equilibrium depends on the sediment fluxes and is expressed in terms of the balance between marine and fluvial inputs and biogenic matter (maerl, shell sand) on the one hand, and offshore and onshore losses (extraction, dredging, structures blocking sediment transport, etc.) on the other hand. These sediment fluxes are evaluated at the level of "coastal cells", compartments of coastline within which most of the sediment movements are self-contained (see **Figure 1**). The offshore limits of these compartments are difficult to ascertain. The concept of "closure depth" corresponds to the seaward limit of significant morphological changes to the beach profile (Hallermeier, 1981; Sabatier et al., 2004). This shoreface area is subject to wave action and contains most of the sediment exchanges affecting the position of the coastline (Sabatier et al., 2004). Beyond this depth, sediment movements take place but their mechanisms of action and their interactions with the coast are still largely unknown and a major subject for research.

4 The administrative French definition of "coastline" is provided by the Shom and corresponds (in translation) to "the highest astronomical tide level (coefficient 120) in normal weather conditions (no onshore wind, and average atmospheric pressure of 1013 hPa)". However, this technical and geometrical definition does not take the dynamics of coastal areas into account. The expression is hence used incorrectly to refer to the coastal fringe that shifts under the three-fold influence of marine, terrestrial and atmospheric factors.



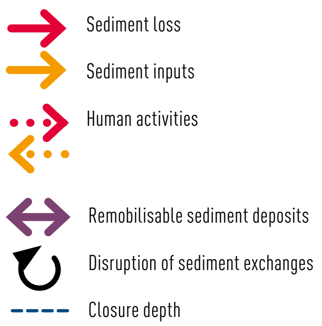


Figure 1 – ***Sediment exchanges within a coastal cell***
(modified according to MEDDE, 2015)

The text below was written on the basis of the brochure (in French) "Développer la connaissance et l'observation du trait de côte. Contribution nationale pour une gestion intégrée" ("Developing knowledge and observation of the coastline. National contribution for integrated management") (MEDDE, 2015)

1.2.1. THE PHYSICAL PROCESSES

1.2.1.1. A matter of time scale...

A coastline evolves at a variety of time scales from an instantaneous event (a storm) to changes in sea level over thousands of years, and depending on the nature of the coast and the intensity of the natural erosion processes taking place. The whole system can be modified by tectonic processes over long time steps (isostasy[5], glacio-isostasy, volcanic activity, etc.), but also as a result of recent human actions (**Figure 1**). An approach using a variety of time (and spatial) scales must hence be adopted to understand current coastal dynamics.

A large proportion of the sediment stocks on today's coasts are legacy sediments from the last major rise in sea levels, which occurred during the period known as the "Flandrian" marine transgression. In many regions of the world, the mobility and present-day depletion of this stock are the primary causes of coastal instability. Coastline change is, therefore, driven day to day by numerous factors specific to individual settings.

5 A vertical adjustment of the position of the Earth's crust in response to variations in surface loads (an application of Archimedes' law of buoyancy to the equilibrium of the Earth's crust) (MEEDDM, 2010).

1.2.1.2. ...and types coast

The morphology of sedimentary shores (beaches, dunes, etc.) is characterised by alternating phases of erosion and accumulation which are particularly visible at a seasonal scale. During storms, this type of coast generally undergoes erosion followed by a phase of reconstruction during calm periods. These changes are normal and reversible, and illustrate the ways in which accretion and depletion are shaped by weather and tidal forcing. Some scientists refer to these fluctuations as the "degree of freedom" or as the coastal system "breathing" [6]. The adjustment capabilities and rates of coastal systems also depend on their "sediment budget":

- when a sediment budget is in deficit, the forms of accumulation adapt to significant wave motion but the long-term trend is one of retreat: erosion with potential for coastline retreat;
- when a sediment budget is in surplus, beyond the capacity for reversible morphological adaptation during and after periods of strong wave motion, the trend within this system will be accretion.

At an annual scale, average erosion rates can in some cases exceed 3 m/yr. During high-intensity or repeated storm events, instantaneous retreat due to erosion can even reach several tens of metres (as was the case during the successive storms during the winter of 2013-2014 which hit the Atlantic coast of France).

Impact of storms on sedimentary shores

(according to the methodological guide to "Coastal risk prevention plans" published by the MEEM in 2014)

In the case of sandy flat coasts, extreme storm events can cause considerable coastal dune erosion and significant coastline retreat. For instance, on the Atlantic coast of France, the observations taken following storm Xynthia estimated average retreat in the order of 10 m, and locally up to 30 m (**Garcin et al., 2011; **Figure 2**). However, extreme localised retreat of this type can be regained over several seasons of less significant erosion, especially when the dune ridge is not affected by the presence of coastal structures and retains a degree of resilience (Illustrated **Figure 3** and **Figure 4**).

Figure 2 – *Retreat of the dune at La Tranche-sur-Mer, Vendée, following storm Xynthia – March 2010*
(Photo: © Bruno BERENGER, Cerema)

6 The coastal system comprises all the physical natural forms of the coast that interact from a sedimentary point of view (e.g. a dune ridge with a dry beach and an underwater beach or a rocky cliff with a strand).

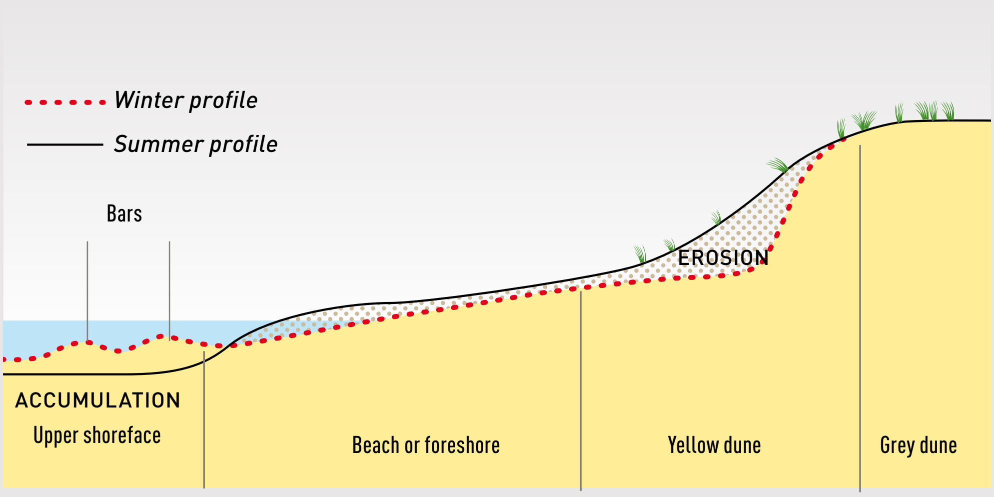


Figure 3 – *Seasonal changes between the beach and the dune*
(produced by: Cloarec C., Perherin C., Gaultier D., based on PRAT M.-C., EUCC-France, in "Guide de gestion des dunes" - Guide to dune management)

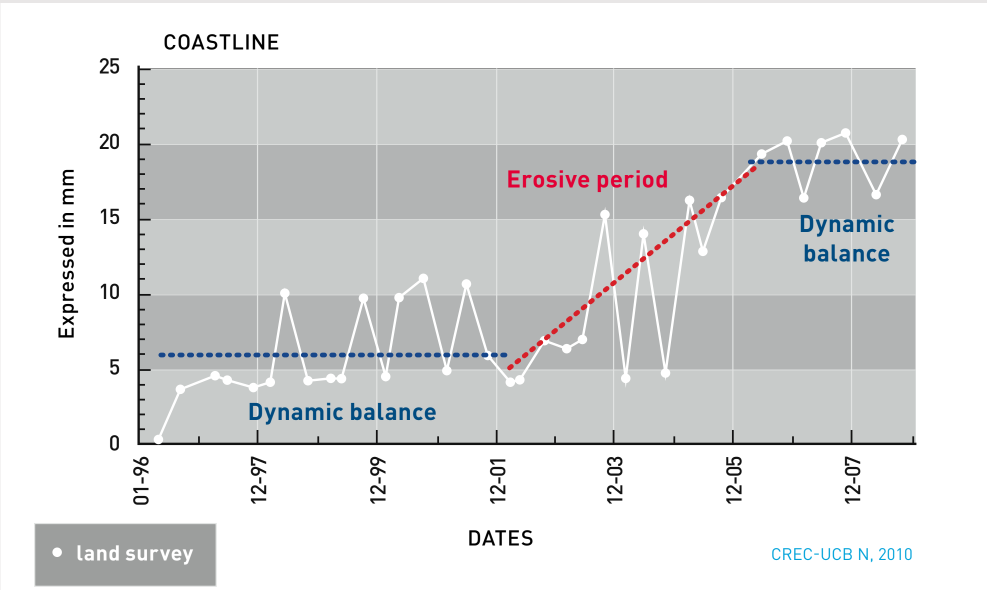


Figure 4 – *Example of coastline position measurements on a sedimentary shore of the west Cotentin peninsula (CREC-UCBN, 2010) showing seasonal variability around a relative stable position from 1996 to 2001, then a marked trend towards accretion between 2002 and 2006 and then further dynamic equilibrium between 2006 and 2008. The amplitude between two dates can be up to 12 metres. It should be noted that this variation is only valid for this specific measuring point and does not indicate a trend that can be generalised.*

Cliff coasts and rocky coasts retreat steadily at a rate that varies depending on their composition, under the combined effect of the sea and atmospheric factors such as temperature (freezing and thawing) or precipitation (water infiltration). Their largest movements are sudden and occasional in terms of both time and space. During a major collapse or slide, instantaneous retreat at the top of a steep can reach several metres, or even several tens of metres. However, at a scale of several decades, average rates of coastline change rarely reach 0.5 m/yr.

Natural coastal habitats contribute to environmental resilience, by reducing the impact of factors driving change and acting as a "buffer zone" against coastal erosion and flooding. Some habitats play a special role, such as dune ridges, seagrass beds, mangroves and coral reefs. Protecting natural habitats, whether marine or terrestrial, hence also helps to prevent coastal erosion and flooding. The sustainability and adaptability of these continuous systems, stretching from the seabed to the backshore, depend directly on free sediment exchanges between these different components. And yet this freedom is often disrupted by structures or human interventions. Any disruption or interruption in the exchanges of sediment between the seabed and the beach and even the backshore makes these coastal systems less resilient and adaptable and can exacerbate their erosion.

1.2.2. ANTHROPOGENIC IMPACTS

Human intervention affects the coast - from the hinterland to the marine environment - in many ways. The main impact is still coastal hardening. Land use in these areas has undergone profound change over the centuries, from food production and defence during the Middle Ages to seaside recreation in the second half of the twentieth century. These widespread human activities, meeting the needs of the economy, tourism, agriculture or urban development, have thus contributed for several decades to localised disruption of the functioning of coastal natural environments. Nearly 16,000 coastal developments and structures have been identified in mainland France and the five overseas departments and regions of France (Cerema and MTES, 2018[7]) and more than half of their total length corresponds to structures built with a view to holding the coastline in place or combatting local effects of erosion. Most of these coastal developments appeared as of the 1960s; between 1960 and 2010, the number of groynes was multiplied by 5.5 and the number of port jetties by 2.3 (Cerema and MTES, 2018). These developments affect a total length of coastline of about 3100 km, representing an average hardening rate of about 30% [8]. And yet such developments are not an effective remedy against erosion in the long term; they even accelerate the processes by shifting them along the coast (as is the case with revetments, groynes and breakwaters) or lowering the beach due to increased reflection of wave energy at the toe of the structures (as is the case with revetments, sea walls and embankments).

7 See https://www.cerema.fr/fr/actualites/cartographie-ouvrages-amenagements-littoraux-methode, https://www.cerema.fr/fr/actualites/cerema-elabore-premiere-cartographie-nationale-ouvrages, https://www.cerema.fr/fr/actualites/cartographie-ouvrages-amenagements-littoraux-realisee-cerema and http://www.geolittoral.developpement-durable.gouv.fr/cartographie-nationale-des-ouvrages-et-r502.html

8 On the basis of the Histolitt® reference coastline (Shom-IGN), 35% in mainland France and 13% in the overseas departments and regions of France.

These direct impacts, which are considerable in themselves, can be heightened by:

- changes to sediment inputs from rivers as a result of human intervention in catchment basins, in particular the construction of dams and embankments along watercourses, and past excavation of materials from river beds[9] , which limit and reduce the circulation and volumes of sediment reaching the coast,
- the cumulative impacts of offshore uses and activities (trawling, offshore wind farms, aggregate extraction, on-land processing of sediment dredged from harbours, etc.) which disrupt longshore drift and can deplete the sediment stock available within the coastal system,
- and environmental pollution, one of the leading causes of seagrass bed, mangrove and coral reef degradation.

Although these cumulative impacts are known in qualitative terms, they are difficult to quantify. It is preferable to assess them at the coastal cell scale, and this requires local, case-by-case study. Moreover, as stated earlier (**see 1.2**), activities generating sedimentary impacts beyond the closure depthe[10] can potentially have impacts onshore driven by deep sedimentary movements (**see chapter 3**). But these sediment transport processes and onshore impacts are difficult to assess and remain subjects for research.

1.2.3. HARBOUR DREDGING, BEACH NOURISHMENT AND OFFSHORE AGGREGATE EXTRACTION

Offshore, the main seabed sediment extraction activities that lead to sediment resuspension and/or loss in marine and coastal systems are harbour dredging, dredging with a view to beach nourishment, and marine aggregate extraction.

Harbour dredging is carried out with the aim of maintaining or improving shipping conditions (maintaining approach channels, deepening or developing new harbour areas). Littoral drift[11] often causes sediment blocked by structures or trapped in a sheltered zone to deposit in harbour areas. Depending on the grain size distribution of the dredged sediment and any health risks associated with it, it may then be dumped at sea, deposited on the foreshore, or reprocessed on-land. Sediment that is returned to the marine or coastal environment can then contribute once more to the system equilibrium, especially in the case of sedimentary shores (which must be analysed at coastal cell level), while sediment that is managed on-land represents a definitive loss for the systems. It should, however, be noted that sediment dredged in harbour basins is generally composed mainly of fine elements that contribute little to the budget of coastal cells, and can contain high concentrations of heavy metals and organic matter. Data on sites used to dispose of sediment dredged from harbours is monitored and analysed by Cerema on behalf of the French ministry for the environnement[12]. The estimated average volume dredged for harbour operations was about 38.5 million m^3/yr between 2006 and 2015[13].

In the case of dredging performed for beach nourishment purposes, the sediment extracted is deposited directly on the foreshore or the upper shoreface and thus supplies the

9 Extraction from the channel migration zones of watercourses (the area within the high-water bed inside which the low water bed can shift) was forbidden in France in 1994 by ministerial decree (decree of 22 September 1994 relating to quarrying and primary processing facilities for quarry materials).

10 Such as aggregate extraction within a licence area located beyond the closure depth of a coastal cell.

11 Transport of sediment parallel to the shoreline under the effect of waves and marine currents

12 Further information can be found at: http://www.geolittoral.developpement-durable.gouv.fr/sites-d-immersion-des-sediments-de-dragages-r396.html

13 http://indicateurs-biodiversite.naturefrance.fr/fr/print/indicateurs/evolution-du-dragage-dans-les-ports-maritimes shoreface/beach/dune system. The grain size distribution and biogeochemical properties of this sediment must be checked and be consistent with the receiving environment to be replenished. In particular, if a beach is to be replenished durably, the median diameter of the sediment must be at least equal to or greater than that of the sediment in the receiving system. In 2019 Artelia drew up an inventory of major operations, involving more than 150,000 m^3, carried out between 2000 and 2019 in France. In total, they represented 14 million m^3, in other words 0.7 million m^3/yr.

Marine aggregate is extracted for use outside its system of origin, and is therefore a pure loss for that system. Extraction operations mainly concern sediment in the form of sand, gravel or shingle. The inventory drawn up by UNPG between 2000 and 2019 indicated an output between 3 and 4.5 million m^3/yr.

It is necessary to analyse the potential impacts of these three activities:

- on the physical and biological natural environment (fauna, flora, turbidity, etc.); this is difficult to do, especially as regards cumulative aspects,
- on coastline change, which must be done at coastal cell scale and take into consideration the physical and environmental characteristics of the cell, especially the depth at which the site is located, its distance from the shore, the extraction depth, and the type of sediment extracted.

French legislation on marine aggregate extraction requires an impact assessment to be performed (**see appendix**).

Impacts of marine aggregate extraction on coastline change in France

Coastal erosion is a natural process that can be exacerbated by human activities restricting exchanges of sediment or even reducing onshore inputs. Marine aggregate extraction hence disrupts the marine environment in the same way as other activities or the construction of coastal structures or river dams. These impacts have been known for a long time, and provisions to mitigate them are included in current French regulations governing such activities. To date, no study in France has shown that the coastline is retreating as a direct result of offshore aggregate extraction alone.

1.3. OVERALL CHANGES TO THE NORTH SEA, ENGLISH CHANNEL AND ATLANTIC COASTLINES OF FRANCE

The work carried out in the context of the French *National strategy for integrated coastline management* to produce the national indicator of coastal erosion (Cerema and MTES, 2017[14]) and to update the "Sedimentological catalogue of the coasts of France" ("Coastline change and dynamics" collection)[15] established an overview of erosion processes and factors driving coastline change in the "sedimentary provinces" of the North Sea, English Channel and Atlantic coasts of mainland France (abbreviated NSCA hereafter). Along this NSCA coast, seven sedimentary provinces averaging several hundred kilometres in length have hence been delimited, within which the processes of coastline change are relatively self-contained. Knowledge of these provinces is currently being summarised under the coordination of Cerema[16]:

- 1. From the Belgian border to Pointe du Hourdel (Nord, Pas-de-Calais and Somme *départements*)
- 2. From Pointe du Hourdel to Cap d'Antifer (Somme and Seine-Maritime)
- 3. From Cap d'Antifer to Cap de la Hague (Seine-Maritime, Calvados and Manche)
- 4. From Cap de la Hague to Pointe de Corsen (Manche, Ille-et-Vilaine, Côtes-d'Armor and Finistère)
- 5. From Pointe de Corsen to Pointe de Chemoulin (Finistère, Morbihan and Loire-Atlantique)
- 6. From Pointe de Chemoulin to Pointe de Suzac (Loire-Atlantique, Vendée and Charente-Maritime)
- 7. From Pointe de Suzac to the Spanish border (Gironde, Landes and Pyrénées-Atlantiques)

The national indicator of coastal erosion (Cerema and MTES, 2017) gives an estimation of past long-term average rates of coastline change (generally over a period of more than 50 years) and is calculated over a stretch of natural coast every 200 m. The national indicator is available for all of mainland France and the French overseas departments and regions (DROM), excluding French Guiana, where the processes are cyclical, on a scale that cannot be compared with the rest of the country, and difficult to observe. The national indicator does not take variations in coastline elevation into account (such as erosion resulting in a lowering of the foreshore) and is not calculated next to coastal structures and developments that hold the coastline in place; these have been listed by Cerema and the MTES (2018). It therefore cannot be used to evaluate the potential efficiency of coastal defences put in place or to identify sites where nourishment has taken place. On the other hand, for the first time, it provides a means of quantifying in detail the rates of coastline change and visualising the geographical distribution of its intensity in a coherent manner across the entire territory of France.

14 Further information can be found at: https://www.cerema.fr/fr/actualites/indicateur-national-erosion-cotiere and http://www.geolittoral.developpement-durable.gouv.fr/indicateur-national-de-l-erosion-cotiere-r473.html

15 Further information can be found at: http://www.geolittoral.developpement-durable.gouv.fr/dynamiques-et-evolution-du-littoral-synthese-des-r462.html

16 The fascicles and their related atlases are published and available for download free of charge on the Cerema website, and the associated geographical information system data can be found at the Géolittoral website.

The indicator shows that the intensity of the erosion process varies very widely in the NSCA provinces, sometimes over short distances, and it also confirms that no region is spared (**Figure 5** and **Figure 6**). The results for the NSCA coasts (21% retreating, 13% advancing and 67% imperceptible) are very similar to those calculated at a national level (19%, 12% and 70% respectively), indicating that similar trends are underway along the coasts of mainland France and even its overseas departments and regions.

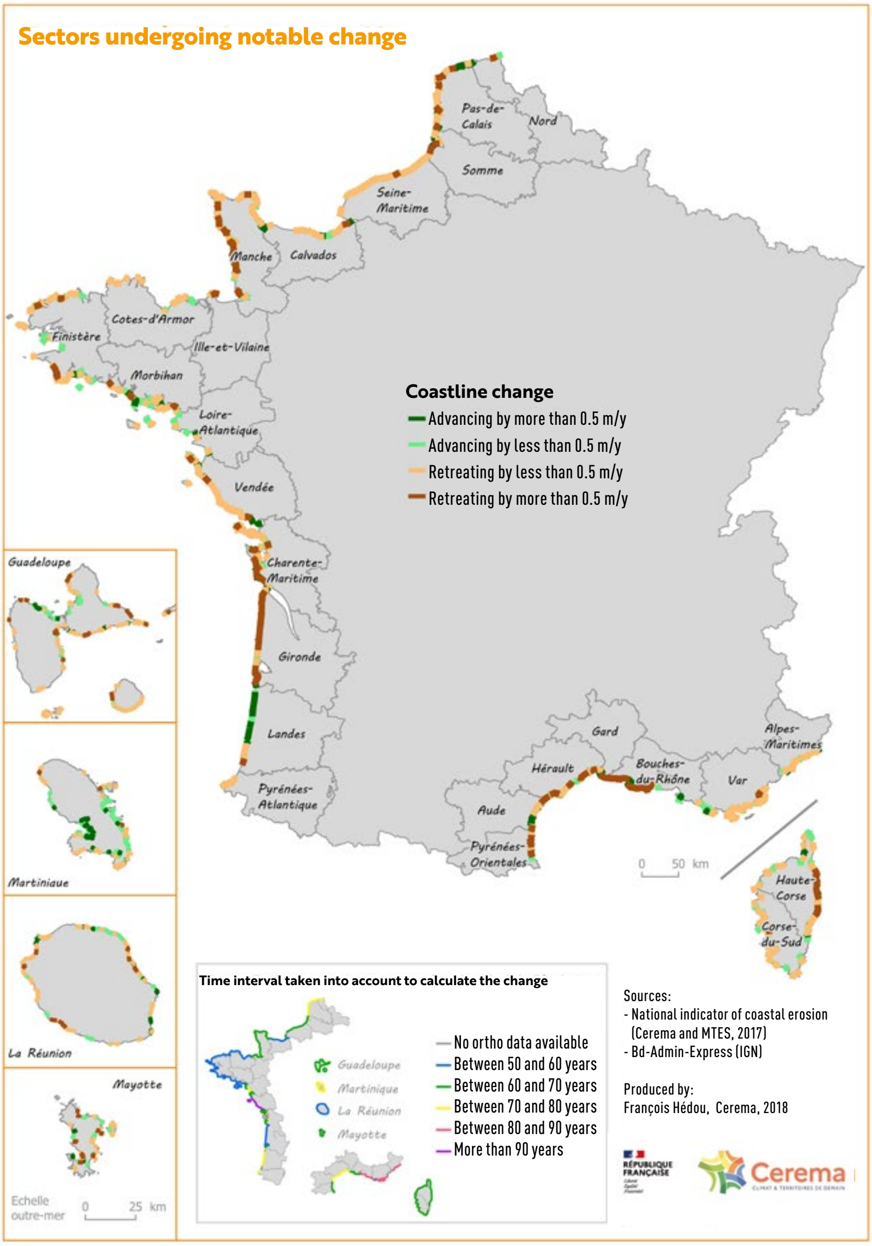


Figure 5 – *Representation at a national scale of coastline change according to the national indicator of coastal erosion (Cerema et MTES, 2017).*
NB: at this scale, variations within ± 0.1 m/year are not mapped and priority is given to presenting "notable" changes. Representations at larger scales, which are more detailed, indicate substantial nuances in local rates of variation.

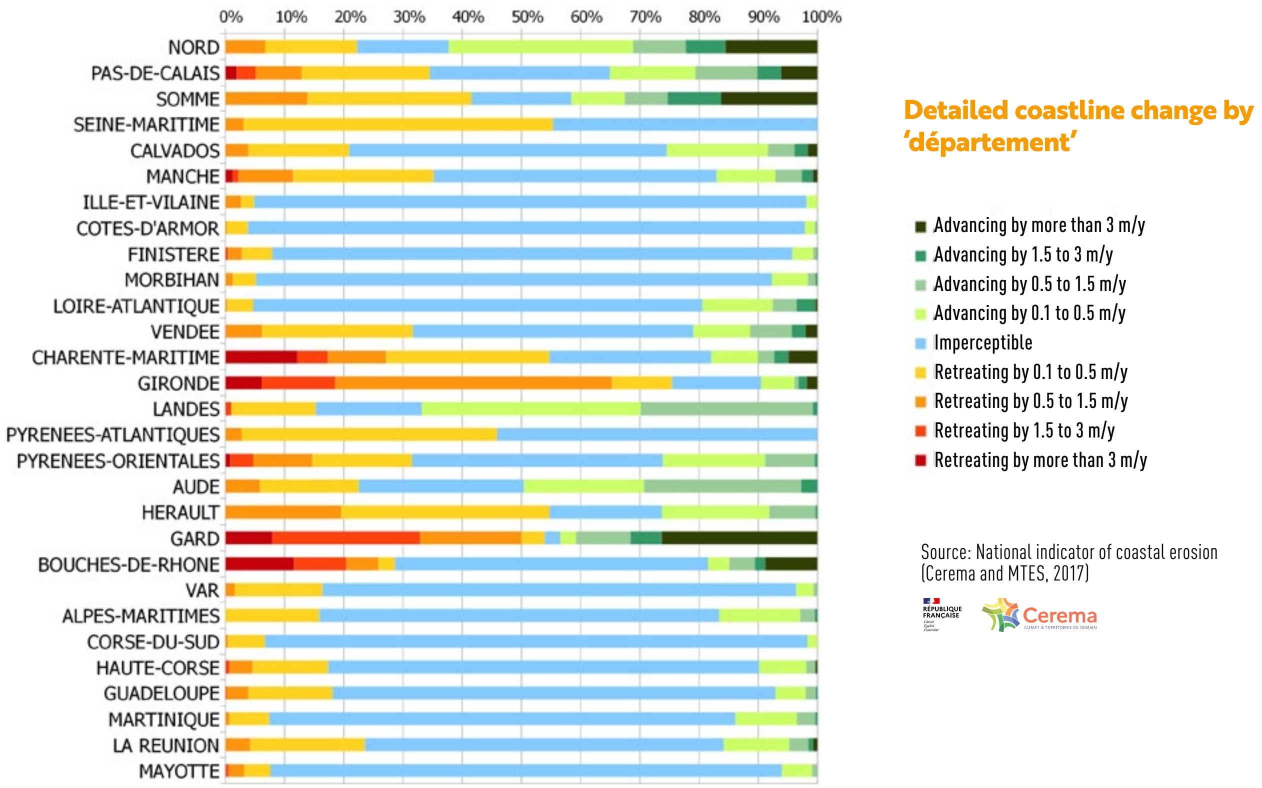


Figure 6 – *Histogram of rates of coastline change by 'département' (mainland France and DROM) according to data from the national indicator of coastal erosion (Cerema and MTES, 2017). N.B.: Imperceptible changes correspond to rates of variation within ± 0.1 m/yr.*

Along the NSCA coasts, at least 50% of the coasts of three départements (Seine-Maritime, Charente-Maritime and Gironde) are retreating, whereas less than 10% of the coasts of the four départements of Brittany and Loire-Atlantique are retreating. However, some départements only affected by coastal retreat for short distances overall may be facing significant retreat in a few highly localised areas. For instance, just 4% of the coastline of Côtes-d'Armor is retreating, but this can be problematic in some specific locations owing to the presence of exposed assets close to the coast. Of the 567 municipalities along the NSCA coasts in which a national indicator of coastal erosion has been calculated, 324 have at least one sector affected by coastline retreat. This means 57% of the municipalities along these coasts are facing a coastline retreat issue. In 26 of these municipalities, sections of coastline are retreating at a rate of more than 1.5 m/yr.

These results can also be evaluated by type of coast (**Figure 7**). Cliff coasts account for half (50%) of the natural environments recorded in national indicator profiles along the NSCA coasts. These coasts can undergo occasional sudden change during mass collapses or slides, but on the whole the cliff fronts change very little. Over the period studied for the national indicator, the change is hence imperceptible at 90% of these profiles. Coastline retreat is nevertheless observed on 10% of these profiles, especially in sectors of sedimentary rock cliffs such as in the départements of Seine-Maritime and Pyrénées-Atlantiques. Sandy flat coasts account for 46% of the natural environments in the national indicator along these coasts, and have the highest and most widely contrasting rates of change, with 34% retreating, 24% advancing and 42% stable.

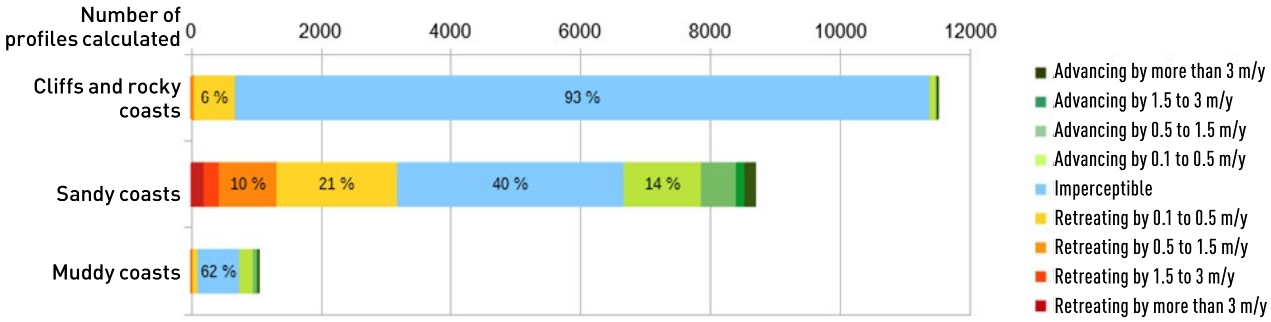


Figure 7 – *Coastline change at a national level* *(mainland France and DROM – excluding French Guiana)* ***by type of coast*** *(Cerema and MTES, 2017)*

Source: National indicator of coastal erosion (Cerema and MTES, 2017)

By assuming that a retreat calculated on a single profile can be extrapolated over a 200 m-long straight sector of coastline (the distance between profiles), it is possible to obtain an idea of the land areas gained or lost. In mainland France and the DROM (excluding French Guiana), an estimated total surface area of 30 km² was lost in the sectors subject to retreat over the 50 years between 1960 and 2010. This corresponds roughly to 4,200 football pitches. Using the same calculation basis, the estimated losses amount to 18 km² on the NSCA coasts, in other words 60% of the surface area lost along the coasts of France (excluding French Guiana). Three *départements* of mainland France, two of which lie on the Atlantic coast, and which each lost just over 5 km² of land in 50 years, account for half of the total area lost: Gironde (retreat along almost the entire length of its sandy coast), Charente-Maritime (retreat south-west of the island of Oléron and at La Tremblade) and Bouches-du-Rhône (retreat at a particularly high rate in the Camargue area). There are, however, some places where the land is advancing naturally, such as various river mouths to the south of the Somme bay. Even so, at the scale of mainland France and the French DROM (excluding French Guiana), the national balance between gains and losses of land remains negative, with a budget deficit for natural areas estimated at –6 km² between 1960 and 2010, and –5 km² for the Atlantic coast from Pointe de Corsen to the Spanish border.

A more precise analysis of coastline changes can be obtained at sedimentary province level. When the information is available, the analysis is performed at coastal cell level. If it is not, a breakdown based more on the types of coast, called “morphosedimentary units”, is made.

SUMMARY OF KNOWLEDGE OF VARIOUS SEDIMENTARY PROVINCES ALONG THE NORTH SEA, ENGLISH CHANNEL AND ATLANTIC COASTS

2.1. INTRODUCTION

Applications to extract marine aggregates do not concern all the sedimentary provinces of the NSCA coasts. Therefore, this summary of knowledge will only concern the following provinces:

- 2. From Pointe du Hourdel to Cap d'Antifer (Somme and Seine-Maritime)
- 3. From Cap d'Antifer to Cap de la Hague (Seine-Maritime, Calvados and Manche)
- 4. From Cap de la Hague to Pointe de Corsen (Manche, Ille-et-Vilaine, Côtes-d'Armor and Finistère)
- 6. From Pointe de Chemoulin to Pointe de Suzac (Loire-Atlantique, Vendée and Charente-Maritime)
- 7. From Pointe de Suzac to the Spanish border (Gironde, Landes and Pyrénées-Atlantiques)

Within each of these provinces all the past and present human interventions will be summarised, and wherever possible the importance of each one in terms of sedimentary dynamics and coastline changes will be assessed. The possibility of assessing the relative contribution to these changes from aggregate extraction will thus be specified, in light of current knowledge.

The information given below is based on the documentation gathered by Cerema in the context of updating the "Sedimentological catalogue of the coasts of France" (see footnote 15).

2.2. FROM POINTE DU HOURDEL TO CAP D'ANTIFER (SOMME, SEINE-MARITIME)

2.2.1. CURRENT KNOWLEDGE OF COASTLINE CHANGE

The province stretching from Pointe du Hourdel to Cap d'Antifer comprises two coastal sectors with very distinct morphological characteristics:

- a sedimentary shore from Pointe du Hourdel to Ault-Onival (~29 km), corresponding to the "Bas-Champs" coastal plain of Cayeux lying at an elevation below the highest known water level and composed of a shingle ridge ending at the spit at the Somme estuary,
- a chalk cliff coast from Ault-Onival to Cap d'Antifer (~113 km), corresponding to the "Côte d'Albâtre" ("Alabaster Coast"), and interspersed with "valleuses" (dry hanging valleys) and low valleys carrying coastal rivers, the mouths of which provide natural settings for harbours and/or seaside resorts where most of the housing is located.

The coastline of the province is mainly natural, but punctuated by a large number of cross-shore structures (groynes, harbour jetties, etc.) affecting nearly 43% of its length. 330 coastal defence structures have been identified along the province, of which 220 are cross-shore (Cerema-MTES, 2018). Consequently, the coastline within this province is changing not just under the influence of natural hydrodynamic factors (waves, sea level, currents, etc.) but also, and above all, due to the impacts of human development and activities (structures, material extraction, etc.).

Coastline change within the province is described by several research papers, coastline observatories (the coastline observation network (ROL) of Normandy and Hauts-de-France, the DYNALIT national observation service, within the CNRS/INSU, associations including GEMEL Normandie and ESTRAN) and studies relating to the two EDF nuclear power plants built along the coast. The national indicator of coastal erosion (Cerema, 2018) provides a basis for analysing medium- to long-term coastline change (from 1947 to 2014 from Cap d'Antifer to Paluel, 1947 to 2013 from Paluel to Le Tréport, and 1947 to 2007 from Le Tréport to Pointe du Hourdel): 56% of the coastline is hence retreating (49% of which at rates between 0.1 and 0.5 m/yr and 7% between 0.5 and 1.5 m/yr), 5% is accreting, and 39% is stable or changing imperceptibly.

The coastal cells in this province are well understood on the whole, owing to the significant impact of large structures on sediment transport, and they can be mapped for the purpose of analysing the coastline changes taking place (**Figure 8**). However, while most of the onshore sediment movements are longshore (the resulting longshore sediment transport being mainly oriented south-west to north-east), very little is known about any movement perpendicular to the coast anywhere in the province. The province also features a backshore shingle ridge, which generally runs along the foot of cliffs or along revetments at river mouths, and ends in the Picardy coastal plain at an unrestricted spit at Pointe du Hourdel.

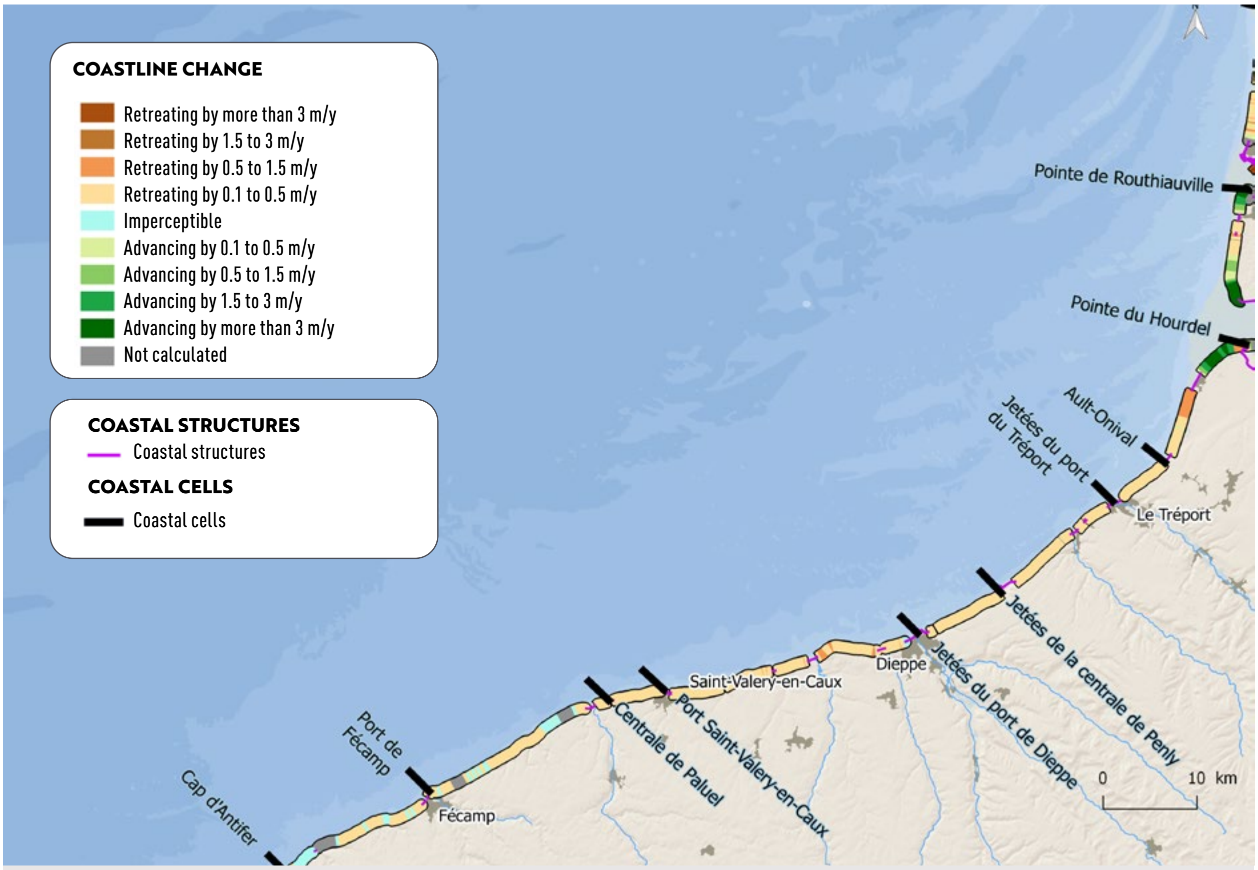


Figure 8 – *Known coastal cell boundaries and coastline change*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

2.2.2. KNOWLEDGE OF IMPACTS OF HUMAN ACTIVITIES

Historically, given its location facing England and its intermediary position on the shipping lanes between the Atlantic and the North Sea, port activities within the province have focused on fishing and trade. Thanks to its location between two major European capitals - Paris and London - the Côte d'Albâtre has undergone rapid residential and economic development since the nineteenth century. After people first began coming to "take the waters" in 1750, many seaside resorts sprang up and developed (Corbin, 1988; Deprest, 1997; Meur-Férec, 2006; Letortu, 2013). Simultaneously, the wooden harbour jetties that had been built in the seventeenth century and were making regular maintenance necessary in the approach channels, were extended seawards to limit the obstruction of harbour entrances by shingle. This was done in Fécamp in 1850, Saint-Valery-en-Caux in 1860, Le Tréport in 1882 and Dieppe in 1913 (Bellin, 1764; Latteux, 2001; Letortu, 2013).

After World War II, tourism turned into mass tourism (Letortu, 2013). Industrial activities developed in these coastal towns, drawing large populations close to the coast (Meur-Férec, 2006; Letortu, 2013). Longshore structures such as revetments and embankments were built along beaches to create promenades. Towns also built cross-shore structures (e.g. groynes) to act as sea defences (Augris et *al.*, 2004; Letortu, 2013). These structures formed obstacles to the transport of sediment, especially shingle, splitting the shingle ridge which used to run from Cap d'Antifer to Pointe du Hourdel into seven segments (Letortu, 2013). Sea defences are still being built or consolidated today to protect urban areas from the onslaught of the sea. Industrial development along the coast continued in the twentieth century with the construction of new jetties at the channels of the nuclear power plants of Paluel in 1978 and Penly in 1981, and was given a further boost in early twenty-first century by the creation of offshore wind farms.

Other activities can have a direct or indirect impact on onshore sediment inputs and, hence, on changes to the coastline and seabed. Shingle was collected manually from the beaches up to 1950, but extraction from beaches was forbidden as of 1970 other than in special cases. Following the ban on gravel pits in the stream beds of rivers, the exploitation of marine aggregates developed on an industrial scale (Dolique, 1999; Letortu, 2013). Fish-farming and fishing also require the construction of facilities that can influence sediment dynamics. And lastly, statutory zoning with a view to protecting the environment contribues indirectly to protecting the coastline and its sedimentary equilibrium.

2.2.3. MARINE AGGREGATE EXTRACTION ACTIVITIES

Within the province, 4 licence areas, concerning 6 marine aggregate extraction sites, were authorised and active in 2020 (**Table 1** and **Figure 9**). In addition to these offshore sites, one onshore extraction site, located on the foreshore at Pointe du Hourdel, is covered by a temporary permit ("AOT") to occupy the public maritime domain ("domaine public maritime") at Pointe du Hourdel (**Figure 9**).

License area	Date of last issue of licence	Location	Surface area(km²)	Authorised quantity
Granulats marins de Dieppe	17/04/10	Off the coast of Dieppe	5,9	375,000 m³/yr for 15 years then 500,000 m³/yr for 15 years
Gris-Nez	17/04/13	Off the coast of Dieppe	2,36	270,000 m³/yr for 30 years
Côte d'Albâtre	02/12/11	Offshore between Fécamp and Dieppe	34 (2 sites)	600,000 m³/yr yr for 5 years then 1,800,000 m³/yr for 15 years
Saint-Nicolas	10/03/13	Offshore between Antifer and Saint-Valery-en-Caux	25 (2 sites)	3,000,000 m³/yr for 30 years

Table 1 – *Details of marine aggregate deposits located between Cap d'Antifer and Pointe du Hourdel (GESLAIN, 2014 ; MEEM and MINEFI, 2016)*

In the English Channel, the potentially extractable resources have been estimated using the geostatic method to amount to 149 billion m³ within the EEZ, of which nearly 117 billion m³ in the palaeo-valleys (Augris *et al.*, 2006 ; MEEM and MINEFI, 2016). In particular, the sand and gravel resources off Dieppe amount to nearly a billion m³ (DRE Haute-Normandie and CETE Normandie-Centre, 2000; Latteux, 2001). The marine mineral resources currently exploited in the eastern English Channel therefore come mainly from two types of sedimentary deposit: palaeo-valleys and relict coastal sediment banks.

Palaeo-valleys, dating back to the Quaternary Period and located at depths of 30 to 40 m, are submerged extensions of present-day river valleys and have the same sedimentary origins as the land-based alluvial deposits. They are infilled with coarse sediment (siliceous sand and gravel) along with blocks several tens of centimetres in diameter, mainly granite, probably dating to the end of the last glacial period. This is the case with the "Côte d'Albâtre" and "Saint Nicolas" licence areas (Claveleau, 2007).

The relict coastal sediment banks are composed mainly of coarse sands and shingle, as in the case of the "Granulats marins de Dieppe" and Gris Nez" licence areas (Duclos, 2012). In these areas, materials are extracted from a relict shingle ridge located off the coast of Dieppe at a depth of 15-20 m that indicates the former location of the shoreline during the Quaternary Period (Claveleau, 2007; **Figure 9**).

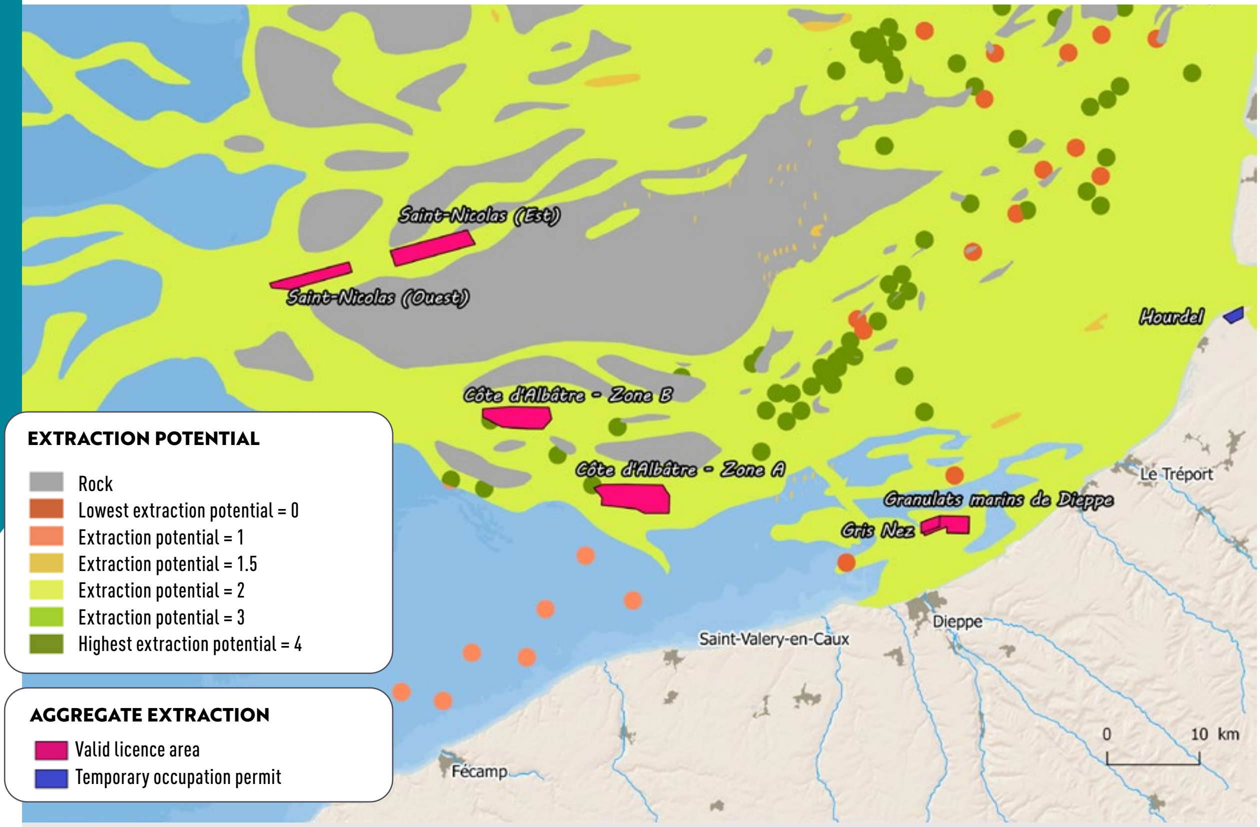


Figure 9 – *Location of marine aggregate extraction sites in relation to the nature of the seabed and their extraction potential*

- Sources: Extraction potential (Ifremer, March 2020) and aggregate extraction data (Ifremer, April 2020)
- Base map: ESRI Shaded Relief, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

2.2.3.1. History of aggregate extraction in the province

L'exploitation des cordons de galets sur le littoral commence au XIXe siècle et s'intensifie au Exploitation of the shingle ridges along the coast began in the nineteenth century and intensified during the twentieth. Between Antifer and Le Tréport, 3,000,000 m^3 of shingle was extracted between 1900 and 1972, in other words half of the stocks that existed at that time (LCHF, 1986a; Costa et *al.*, 2007):

- in the Dieppe-Ault zone, approximately 1,000,000 m^3 of shingle was extracted between 1913 and 2001, of which 800,000 m^3 in Dieppe (Latteux, 2001; Sogreah, 1994);
- between Fécamp and Le Tréport, 415,000 m^3 of shingle was extracted between 1946 and 1970 in two major zones, Dieppe and Le Tréport, with volumes amounting to 235,000 m^3 and 180,000 m^3 respectively (Letortu, 2013).

Along the "Bas-Champs" coast of Cayeux, pebbles were first extracted in 1840 for regional use, and were traded on international markets as of the end of the nineteenth century. Extraction was on a small scale - by hand or with a shovel - until around 1950, when it started being industrialised (see box below). In 1900, 100,000 tonnes of pebbles were extracted, compared with 15,000 tonnes 40 years previously. Bastide et *al.*, 2005 propose an estimate of the tonnages of pebbles extracted at Le Hourdel during the twentieth century, although it is not easy to make a distinction between those that were extracted from the foreshore and those that were taken from the onshore quarry. Moreover, evidence of former illegal extraction of pebbles has prompted some authors to increase this estimate (Augris et *al.*, 2004; Letortu, 2013). A series of studies performed by Artelia (1992 to 2018) at the Hourdel quarry site did not reveal any interaction between the exploitation of this quarry and the hydrosedimentary dynamics of the coastline.

Pebbles of an exceptional purity

Cayeux pebbles are formed from flint resulting from erosion of the Picardy cliffs and as such have the particular feature of being made up of practically pure silica (nearly 99%) (OREAP, 1975; http://www.cayeux-sur-mer.fr/economie-et-developpement/industrie-du-galet/, site consulted on 13 February 2020). The pebbles can be used in two ways: either "unfired", in other words as they are, sorted, calibrated or crushed, or "fired", in other words calcinated on-site at temperatures between 1000 and 1600°C (OREAP, 1975).

Unfired pebbles are used in different ways depending on their colour and shape (OREAP, 1975), the most highly sought-after being blue pebbles for the ceramics and porcelain industry (with some exported to Great Britain for the production of flint glass). Round pebbles are hand-selected and used as crushing agents in the ceramics, chemical and paint industries or for grinding minerals. Pebbles in other colours (grey, yellow, brown or white) are used either un-crushed for decoration (walls, tiles, slabs, etc.) or crushed in building construction (concrete, sandblasting, building façade renovation, marble sawing, sandpaper, etc.), water filtration, or poultry feed (as grinding elements).

The use of fired pebbles, which produce an extra white, pure cristobalite following heat treatment, depends on their silica content and the calcination temperature; they are then ground to different grain sizes before use (OREAP, 1975). Fired at 1,000 and 1,200°C, they are used in the composition of light-coloured asphalt mixes and certain concretes (white mass concrete, architectural concrete) respectively. The purest silica pebbles are calcined at very high temperatures (1,500-1,600°C) to transform them into extra white cristobalite silica[17] and ground for use in ceramics, paints, polishing pastes, but also dental and surgical cements. The different grain sizes give rise to several varieties of silica for specific uses, such as increasing the cohesion of concrete and paints in the case of the Farsil variety (between 20 and 44 microns), the cohesion of renders and road paints (to enhance their brightness and adhesion) in the case of the Minigrain variety, which has a slightly larger grain size, and the production of white concrete, architectural concrete and concrete road signs in the case of the Grenette variety, which has an even larger grain size (OREAP, 1975)..

The impact on changes to the shingle ridge of past foreshore extraction and of dredging operations in harbour approaches without restitution in the natural environment is revealed through the state of the ridge during the 1939-1945 period, when both of these activities were substantially reduced on account of the war, especially in Saint-Valery-en-Caux (LCHF, 1987; Latteux, 2001), Criel-sur-Mer (Teisson, 1989; Latteux, 2001) and Ault-Onival (Dallery, 1955; Latteux, 2001).

The extraction of shingle from the beaches of Normandy and Picardy was restricted and regulated in 1972 and banned definitively in 1983 (Latteux, 2001; Letortu, 2013). At present it is only authorised on the shingle ridge of the "Bas-Champs" coast to the north of Cayeux-sur-Mer, in the deposition zone at the end of the spit, to the tune of 55,000 tonnes/yr. The fraction of sediments extracted from the shingle ridge with a grain size between 20 and 40 mm is made available for nourishment purposes (between 50 and 100,000 m^3/yr) in order to maintain the Bas-Champs breakwater (shingle ridge consolidated by 104 groynes) in Cayeux.

17 Cristobalite is a mineral composed of silica - silicon dioxide SiO_2 - with traces of other minerals (Fe, Ca, Al, K, Na, Ti, Mn, Mg, P). Cristobalite is only stable above 1,470°C, but it can crystallise and persist metastably at lower temperatures (source: http://destinationbaie-de-somme.over-blog.com/2015/10/le-galet-de-cayeux-sur-mer.html, site consulted on 13 February 2020). Cristobalite is insensitive to chemical attack of any kind (OREAP, 1975).

A principle of one tonne returned for every tonne extracted is imposed, ensuring that the sedimentary balance of the ridge is maintained (source: http://www.cayeux-sur-mer.fr/economie-et-developpement/industrie-du-galet/, site consulted on 16 May 2019); the shingle placed as compensation is taken from onshore quarries. The Mollière deposition zone is currently exploited as a "classified facility" ("installation classée") to maintain the beach and the ridge.

The first licence to extract aggregates from the eastern English Channel was granted for the area off the coast of Dieppe in 1979. The aim was to reduce the pressure on the gravel pits in the coastal valleys (materials were taken from the high water beds of rivers) while maintaining the capacity to meed the needs of large construction sites of the 1980s, especially Penly nuclear power plant (Claveleau, 2007). The licence area is located 5 km off the coast of Dieppe, at depths between 10 and 15 m CMH [18] over a surface area of 5.9 km². Extraction for commercial purposes began in 1980 in the western zone of the site, and extended eastwards as of 1993 (Duclos, 2012; Quemmerais-Amice et al., 2012). Two extraction sites have been authorised and active within the province since 2005, both off the coast of Dieppe: the "Granulats Marins de Dieppe" and "Gris Nez" areas. At the same time, two more marine sites were selected to explore aggregate resources: the "Côte d'Albâtre" site divided into two zones (zone A and zone B, exploration started in 2003) and the "Saint-Nicolas" site also divided into two parts (east and west, exploration started in 2005) (Augris et *al.*, 2006). The exploration permits led to the granting of extraction licences for the "Côte d'Albâtre" site as of 2011 and for the "Saint-Nicolas" site as of 2013.

2.2.3.2. Volumes extracted

Between 1980 and 1987, economic interest group "GIE Graves de mer" extracted more than 3 million tonnes of materials consisting mainly of sand and shingle (Costa, 1997; Latteux, 2001). The four licence areas in the province have a total authorised volume of 2,770,000 m3. The volume actually extracted is in the order of 800,000 to 1,000,000 m³ and can vary widely from one year to the next depending on the needs of the market (**Table 1**). In Dieppe, between 2004 and 2005, the intensity of extraction was in the order of 1 h/ha/yr (Desprez and Lafite, 2014). The licences to exploit the four marine aggregate deposits (siliceous sands and gravels) in the province have been granted for a period of 30 years.

2.2.3.3. Monitoring of impacts

Applications for licences to extract marine aggregates are accompanied by an impact assessment and environmental monitoring of the impacts of extraction on the marine environment, in order to determine any mitigation measures required. The summary produced by GIS SIEGMA (Desprez et *al.*, 2012) presents the results from the monitoring performed at the pilot sites of Dieppe and the Seine bay between 2003 and 2012. Geslain (2014) produced a summary of the results from monitoring and assessing the impact of marine aggregate extraction on ecosystems and biodiversity, which showed that the impact was mostly limited to the licence area and over a period depending on the extraction pressure and the hydrosedimentary conditions in the sector. The PhD thesis of Duclos (2012) analysed the morpho-sedimentary impacts of marine aggregate extraction in the eastern basin of the English Channel (Dieppe and Seine bay sites). In Dieppe, the following hydrosedimentary impacts were recorded:

- alteration of the sedimentological nature of the seabed, with a 10% increase in fine sand noted between 2004 and 2005 (Le Bot et *al.*, 2010; Desprez et al., 2012),
- morphological and sedimentary restoration within a period of 10 years (Le Bot et al., 2010; Duclos, 2012).

18 CMH: Chart datum of Le Havre

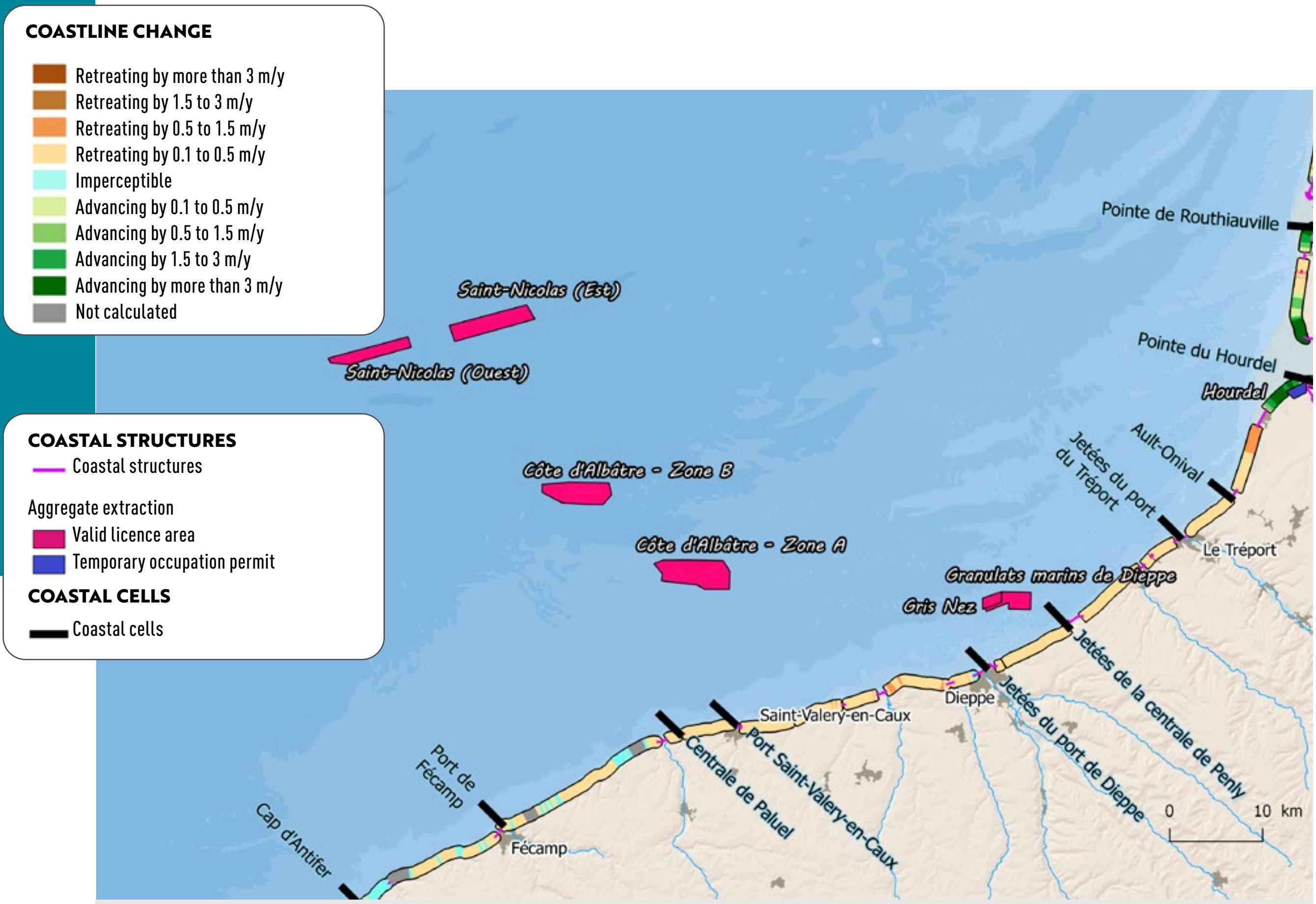


Figure 10 – *Locations of marine aggregate extraction sites, boundaries of known coastal cells and coastline change*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

KEY FIGURES FOR THE PROVINCE:

LENGTH OF COASTLINE:
142 km

TYPES OF COAST:
68% cliffs and rocky coasts
21% coasts undergoing deposition
11% hardened coasts

ÉCOASTLINE CHANGE
56% retreating (of which 49% at between 0.1 and 0.5 m/yr),
39% changing imperceptiblye
5% accreting

COASTAL CELLS:
9 cells (well identified)

LENGTH AFFECTED BY COASTAL DEVELOPMENT:
43 km
(i.e. 30% of the coastline)

ANTHROPOGENIC IMPACTS
Extraction sites authorised in 2020:
4 licence areas (6 offshore sites)
+ Bas-Champs active shingle ridge

Link between extractions and coastline change:
not established for the offshore sites, mitigating measures on the Bas-Champs ridge helping to maintain the Bas-Champs breakwater

2.3. FROM CAP D'ANTIFER TO CAP DE LA HAGUE (SEINE-MARITIME, CALVADOS, MANCHE)

2.3.1 CURRENT KNOWLEDGE OF COASTLINE CHANGE

The sedimentary province between Cap d'Antifer and Cap de la Hague stretches for 435 km and is composed of four morphosedimentary units:

- Pointe de Caux, between Cap d'Antifer and Cap de la Hève, corresponds to a cliff coast with a wide rocky outcrop and a shingle ridge,
- The Seine bay, stretching for nearly 280 km between Cap de la Hève and Saint-Vaast-la-Hougue, is characterised by alternating cliff coasts, many of them with a rocky outcrop, sandy to sandy-silty depositional coasts with a relatively undeveloped dune system protecting low-lying and potentially flood-prone land from the sea, and sandy-muddy or muddy depositional coasts corresponding to the Seine, Touques, Dives, Orne and Seulles estuaries and Les Veys bay,
- The east coast of the Cotentin peninsula (from Saint-Vaast-la-Hougue to Pointe de Barfleur) and the north coast of the Cotentin (from Pointe de Barfleur to Cap de la Hague) are two units with a very jagged overall alignment, characterised by alternating narrow, closed coves, long sandy beaches and very resistant rocky capes (sheer rocky coasts).

Nearly two-thirds of the length of this province hence consists of sandy and muddy depositional coasts, with rocky cliff coasts accounting for 35%. However, with a cumulative total of 254 km of identified coastal structures and developments (Cerema-MTES, 2018), nearly 59% of the coastline of the province is affected by development. The sectors most heavily transformed by human activity correspond, firstly, to port infrastructure (Grand port maritime du Havre, Caen-Ouistreham, Cherbourg-Octeville, etc.), and, secondly, to the depositional coasts between Honfleur and Asnelles-sur-Mer ("Côte de Grâce", "Côte fleurie", "Côte de Nacre"), to mention just this part of the coast. This last section has been significantly altered by human activity and features a large number of defences, both cross-shore (to combat erosion) and long-shore (structures replacing the coastline).

The boundaries of the ten coastal cells (**Figure 11**) in the province are both natural (e.g. the "hydraulic groynes" represented by the Seine estuary, Les Veys bay or Cap d'Antifer) and man-made (e.g. the jetties in the ports of Cherbourg, Grandcamp and Ouistreham, which block a large proportion of the sediments transported by littoral drift). In this regard, some of the boundaries are debatable since they are not necessarily very clearly defined: the boundary set at the jetties of Grandcamp port could easily have been placed between Pointe du Hoc and Pointe de la Percée, which corresponds to a littoral drift divergence zone (Levoy and Larsonneur, 1995).

Between Cap d'Antifer and Cap de la Hague, since publication of the "Sedimentological catalogue of the coasts of France" (LCHF, 1986), overall coastline change has been studied in the context of academic research programmes and monitoring campaigns conducted in various coastal sections of the province (Maquaire, 1990; Levoy et Larsonneur, 1995; Gresarc, 2000; 2006; Lesourd, 2000; Stépanian, 2002; Garnaud, 2003; Delsinne, 2005; Elineau, 2013; Lissak et al., 2013; Rolnp and Dreal-BN, 2014) as well as in numerous papers published by GIP Seine-Aval. The atlas of the coastal observation network (ROL Normandie et Hauts-de-France)[19] is a mine of information on coastline and seabed changes drawn from these works.

19 https://rolnp.maps.arcgis.com/apps/MinimalGallery/index.html?appid=1a1f60310d0541839a848efeae421c99

The long-term trends in coastline change can be obtained via the national indicator of coastal erosion (Cerema, 2018), which provides the rates of change within the province over more than 70 years. Generally speaking the coastline within the province is changing slowly (a few tens of centimetres per year), with possible alternating periods of erosion and accretion on some depositional coasts. The authors quoted above confirm the orders of magnitude of change given by the national indicator, but add nuances and further details obtained by using new high-resolution and high-frequency techniques, as well as by adopting a multi-source and multi-temporal diachronic approach. Some sectors that are particularly erosion-prone, and the estuaries, have undergone more localised studies that cannot necessarily be extrapolated to the province as a whole.

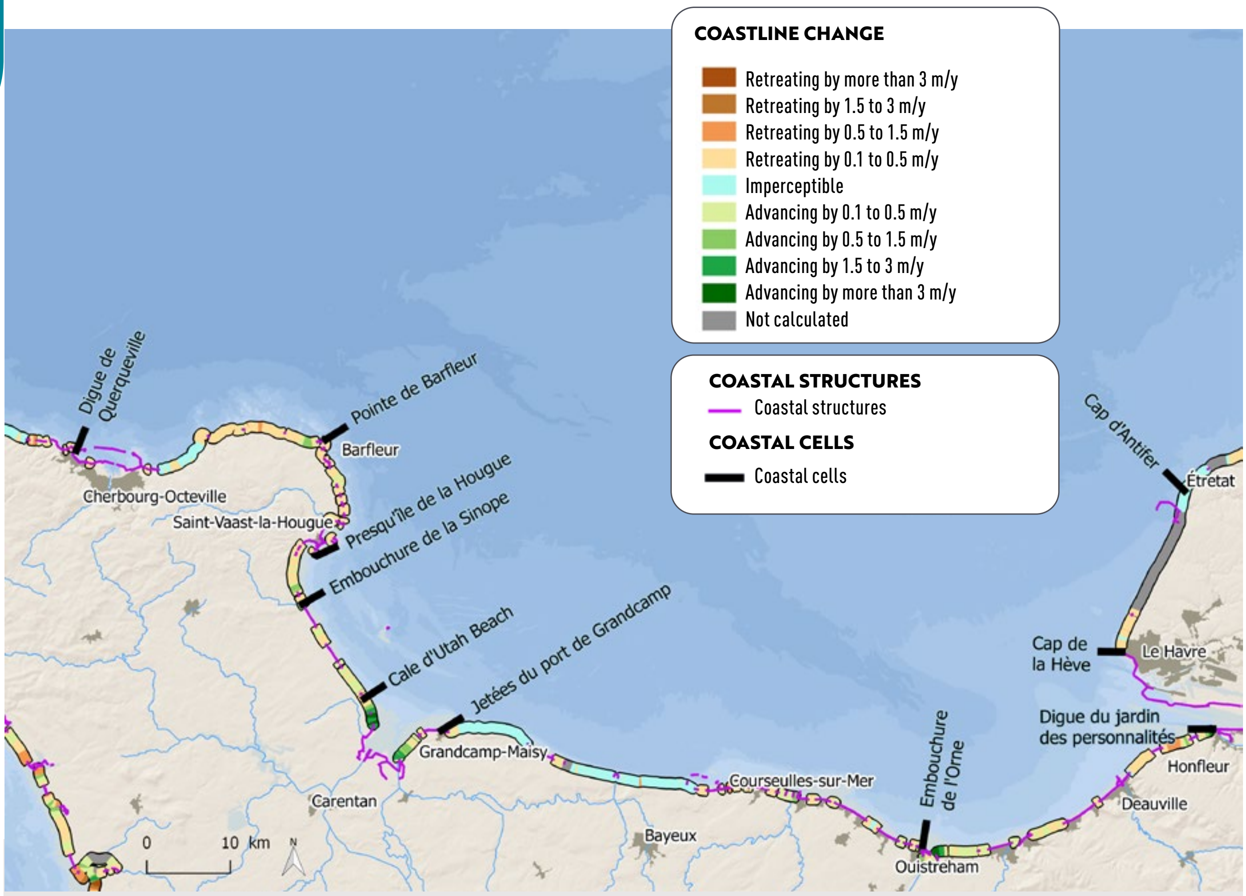


Figure 11 – *Locations of marine aggregate extraction sites, boundaries of known coastal cells and coastline change*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

On a historical scale, the coastline of the province is relatively stable or retreating slightly (± 0.5 m/yr), but a few localised sectors are accreting at a rate of several metres per year (Cerema, 2018):

- the cliffs and rocky coasts are retreating over 22% of their total length, at rates varying between 0.1 and 0.5 m/yr depending on the nature of the materials reinforcing the slope base;
- the sandy or sandy-silty depositional coasts are either accreting (nearly 27%) or eroding (nearly 30%) with rates of retreat exceeding 0.5 m/yr;
- the muddy depositional coasts are accreting (nearly 70%) but some of them (about 15%) may nevertheless be affected by rates of retreat exceeding 0.5 m/yr.

This province is hence characterised by spatially variable coastline change resulting from the wide variety of coastal forms, against a backdrop of fragile sediment budgets. At a scale of the last century, the areas that have changed the most are the estuaries (Seine, Dives, Orne, Seulles, Les Veys bay, etc.), whose geomorphological features have migrated seawards and downdrift. Widespread accretion has hence resulted in significant development of sandy spits and been accompanied by erosion on the opposite banks, which in many cases have required consolidation works. The Seine estuary has changed dramatically, infilling at a rate of 2 to 5 million m³ per year, resulting in sedimentation and causing the deposition zone to migrate downstream. Between 1960 and 2000, the –2 m isobath of the banks of the Seine migrated westwards at about 100 m per year. These different forms of coastline change highlight the presence of much more localised dynamics and the need to study the coast of the province at several spatial scales.

Present-day sediment inputs to the province are very small, consisting mainly of debris from retreating cliff coasts. The small rivers (excluding the Seine) contribute little to the sediment budget. River inputs mainly comprise small quantities of fines which are captured by the estuaries, acting as sediment sinks; the bays hence feature high concentrations of fine particles. Instead, most sediment movements stem from a redistribution of legacy sediments, such as flint shingle and gravel, deposited during the Holocene marine transgression and reworked since then. The present sediment stocks include a large proportion of shell fragments, most of which are generated locally and currently (mainly whole shells and mollusc debris). A small proportion comes from reworked old organisms. Bioclastic sediments locally account for a substantial proportion of the coarse sediments (sands) within the province (up to 100% in the Seine estuary, with on average 30% bioclasts). No detailed estimates of this bioclastic production are available.

Sediment movements within the province are mainly longshore, with the resulting transport being oriented southwards in the case of the coasts of Le Bec, the Caux area and the east coast of the Cotentin peninsula, and eastwards in the case of the coast of the Calvados *département*. There is no significant longshore drift on the north Cotentin peninsula. These two directions of transport converge on the Seine bay and towards Les Veys bay. There is a small amount of localised reverse drift in the river mouths and north of Quineville, for instance on the east Cotentin coast. These directions of transport are consistent with the asymmetric nature of the north-easterly tidal currents, associated with north-easterly prevailing waves. The updated sediment volumes displaced off the coast of the province are not known. The province also features sedimentary dynamics perpendicular to the coastline, especially in the sectors with sand bank and alternating sand bank/tidal pool systems, but little is known about these movements and they have not been quantified in detail.

2.3.2 KNOWLEDGE OF IMPACTS OF HUMAN ACTIVITIES

The coastline of the province was developed and urbanised over two main distinct periods, to harness its natural assets which include extensive access to the sea, good-quality coastal waters (except during very rainy periods), the highest tides in Europe, and its proximity to the Paris region and the Seine corridor.

Over the nineteenth century and up to the early twentieth, the growing popularity of seaside tourism drove expansion of the small towns and villages along the coast. This development mainly benefited the eastern areas, the "Côte fleurie" (Auge area), the "Côte de Nacre", where a number of resorts such as Trouville-sur-Mer, Deauville and Houlgate gained a reputation for their casinos and their sea bathing, as well as the Bessin area to the west, with resorts such as Arromanches-les-Bains and Grandcamp-les-Bains, later renamed Grandcamp-Maisy.

The coastal railways and seafront villas that sprang up during that period demonstrate the strong appeal of the coast.

After the war, particularly in the 1960s and later in the 1980s, intensive development resulted in increasing "urban sprawl", first around the historic towns and villages along the main communication routes, and then towards and along the seafront with the development of coastal urban centres (new housing, services, car parks, campsites, etc.) spread in a haphazard manner along the coast of the province. Increasing land-use pressures led to buildings being constructed "right on the shore" on land of low value and in some cases exposed to risks, such as on the cliffs of the “Cirques des Graves” and at Les Fosses du Macre in the towns of Villerville and Cricqueboeuf, Mont Canisy, on the cliffs of Saint-Come-de-Fresné, on sandy coastal belts and dunes such as those in Houlgate and Lion-sur-Mer, and on coastal marshes, such as those in Asnelles and Ver-sur-Mer.

These land- and tourism-related pressures are leading to overcrowding in some sectors, with harmful effects for fauna and flora (especially due to the trampling of dunes), and making it necessary to build longshore and cross-shore structures to protect the many exposed elements located in sandy low-lying areas from erosion and coastal flooding. The beaches and areas used for the D-Day landings in June 1944 have become destinations for “commemorative” tourism, which is vital to the economy of many towns and villages to the west of a line running between Caen and Ouistreham.

Ports have developed since the eighteenth century, thanks to the proximity of the Channel Islands and Great Britain. The "historic" ports such as Le Havre and Cherbourg-en-Cotentin, which prospered during the heyday of transatlantic crossings (on ocean liners such as the Titanic and the France), have gained a new lease of life through the development of other port activities. Today, eighteen ports (excluding the artificial port of Arromanches built during the invasion of Normandy in 1944) and two anchorage areas are spread along the coasts of the province from Cap d’Antifer to Cap de la Hague. The infrastructure at these sites reaches for varying distances out to sea, with potential impacts for sedimentary dynamics. The main port activities relate to trade, freight and/or passenger transport (car ferry routes), the petrochemicals industry, fishing, pleasure boating and military uses. Given the strong dynamics in the Seine bay and the configuration of these ports, they require occasional and regular maintenance dredging, in turn requiring offshore dumping areas if the sediment quality allows.

Les Veys bay underwent widespread land reclamation as of the early nineteenth century, ending in 1905. Some natural areas in Les Veys bay are now protected and have been incorporated into the Cotentin and Bessin Marshes Regional Natural Park.

The province lends itself well to the development of marine resources:

- fish farming, including shellfish farming (mussels and oysters), fishing, offshore salmon farming and seaweed production;
- aggregate production, with several sites suitable for extraction;
- marine renewable energy.

Statutory zoning with a view to protecting the environment is contributing indirectly to protecting the coastline and its sedimentary equilibrium by limiting the potential impacts of these activities.

2.3.2. Marine aggregate extraction activities

Within the province, 3 licence areas, concerning 3 marine aggregate extraction sites, were authorised and operating in 2020 (**Table 2** and **Figure 12**).

License area	Date of last issue of licence	Period of validity	Status	Location	Surface area(km²)	Authorised quantity
Baie de Seine	2013	25 ans	Extraction	Seine bay, administrative area of Grand port maritime de Rouen	8,2	500,000 m³/yr min. to 1,650,000 m³/yr max
Manche Orientale	2012	30 ans	Extraction	East of Barfleur	61	3,000,000 m³/yr
Granulats Marins Havrais	2019	30 ans	Extraction	Off the coast of Le Havre	10	500,000 m³

Table 2 – ***Details of aggregate deposits located between Cap d'Antifer and Cap de la Hague*** *(MEEM et MINEFI, 2016 ; updated by the UNPG)*.

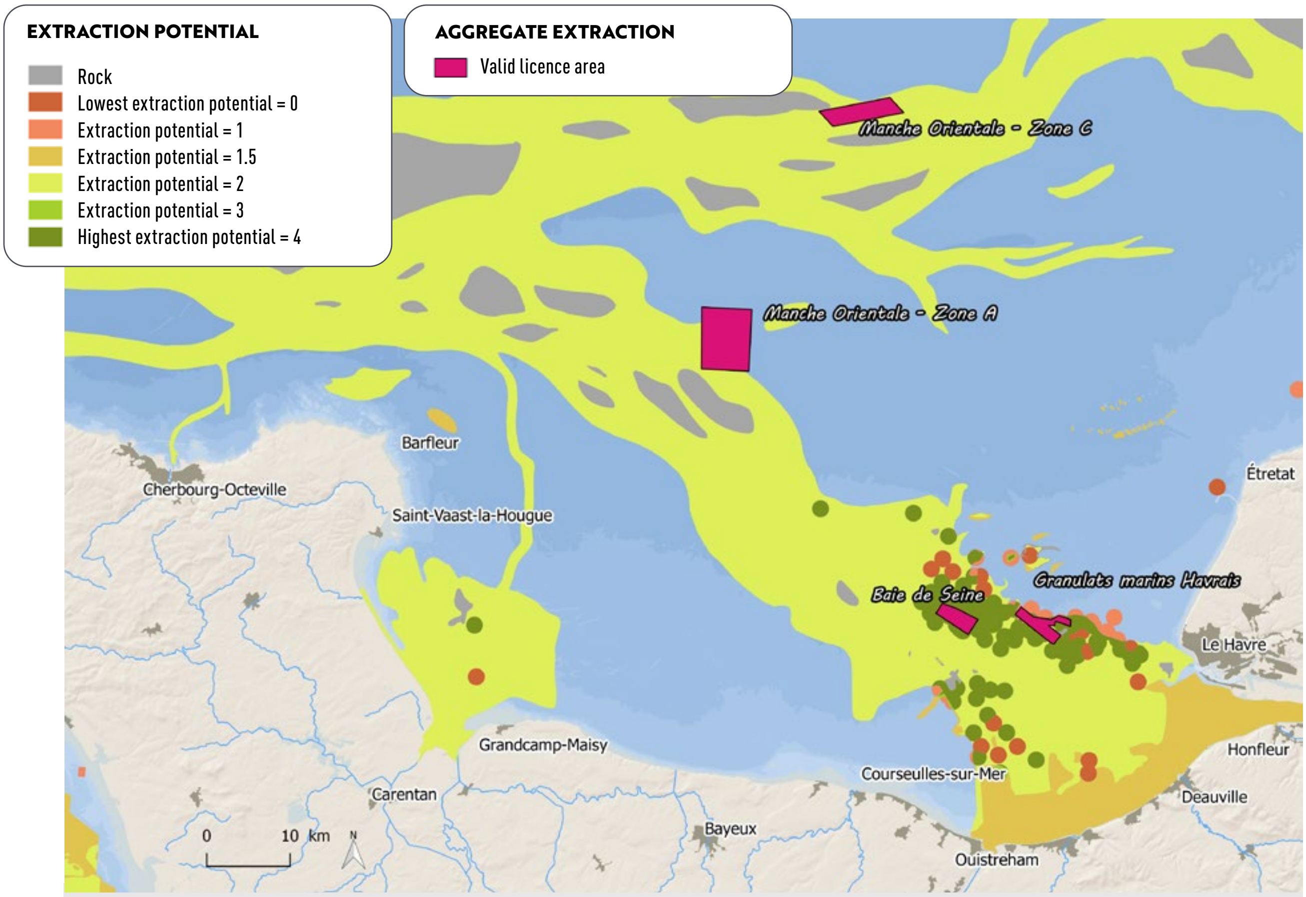


Figure 12 – *Location of marine aggregate extraction sites in relation to the nature of the seabed and their extraction potential*

- Sources: Extraction potential (Ifremer, March 2020) and aggregate extraction data (Ifremer, April 2020)
- Base map: ESRI Shaded Relief, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

EIn the English Channel, the potentially extractable resources have been estimated using the geostatic method to amount to 149 billion m3 within the EEZ, of which nearly 117 billion m^3 in the palaeo-valleys (Augris et al., 2006; MEEM and MINEFI, 2016). The marine mineral resources currently exploited in the eastern English Channel come mainly from palaeo-valleys dating back to the Quaternary Period and located at depths of 20 to 45 m. The deposits correspond to extensions of present-day river valleys and have the same sedimentary origins as the land-based alluvial deposits. They consist of coarse sediments (siliceous sand and gravels) in the two licence areas located off the coast of Le Havre (**Figure 12**): the "Baie de Seine" and "Granulats Marins Havrais" (GMH) areas.

The first applications to extract marine aggregates from the Seine bay date back to the late 1980s. In the face of sudden demand and a large number of projects, the fishing sector mobilised in force to obtain a freeze on these applications within a relatively small maritime area. To assess the possibility of opening the Seine bay up to aggregate extraction, an inter-regional consultation commission for management of the Seine bay, the CICGBDS, was created in 1993. This led to the introduction of experimental extraction in 1996 within the area of the licence initially granted in 1989. This experimental extraction was subsequently monitored by GIS SIEGMA (a scientific interest group created to monitor the impacts of marine aggregate extraction) between 2006 and 2012.

Simultaneously, several licence areas were active in the Seine bay (**Table 2**, **Figure 1**2):

- a licence granted in 2012 to the "Granulats de la Manche Orientale" economic interest group (GIE GMO) on the continental shelf in the Seine bay: this licence concerned two sectors located north-east of Barfleur over a surface area of 61 km^2;
- following a period of experimental extraction, an extraction site was allocated under a licence to the "Granulats Marins de Normandie" economic interest group (GIE GMN) in 2013, covering a surface area of about 8.2 km^2 for the duration of the licence area called "Granulats marins de la baie de Seine" located on the continental shelf off the coast of Le Havre within the administrative area of the port of Rouen authority (Grand port maritime de Rouen);
- a 30-year licence granted in 2019 on the edge of the approach channel to the port of Le Havre to exploit the "Granulats Marins Havrais" area.

The three licence areas concerned by this fascicle have a total annual authorised volume of 3,500,000 m^3. The "Baie de Seine" licence area will be exploited to a maximum depth of 2.50 m; the others are being exploited over an average thickness of 1 to 5 m.

Applications for licences to extract marine aggregates are accompanied by an impact assessment and environmental monitoring of the impacts of extraction on the marine environment, in order to determine any mitigation measures required. The summary produced by SIEGMA GIS (Desprez et *al.*, 2012) presents the results from the monitoring performed at the pilot sites of Dieppe and the Seine bay between 2003 and 2012. Geslain (2014) produced a summary of the results from monitoring and assessing the impact of marine aggregate extraction on ecosystems and biodiversity. The PhD thesis of Duclos (2012) analysed the morpho-sedimentary impacts of marine aggregate extraction in the eastern basin of the English Channel (Dieppe and Seine bay sites).

Generally speaking, the monitoring results showed that the spatio-temporal impacts in the licence area are limited, and that the site is recolonised over a number of years after it ceases to be exploited, with the initial conditions restored over a period of time dependent on the pressure of extraction and the hydrosedimentary conditions in the sector. These studies are explained in detail in the summary produced by GIS SIEGMA (Desprez and Lafite, 2014) for the Seine bay pilot site between 2003 and 2012 (Claveleau, 2007); they demonstrate the advantages of long-term monitoring and of retaining feedback.

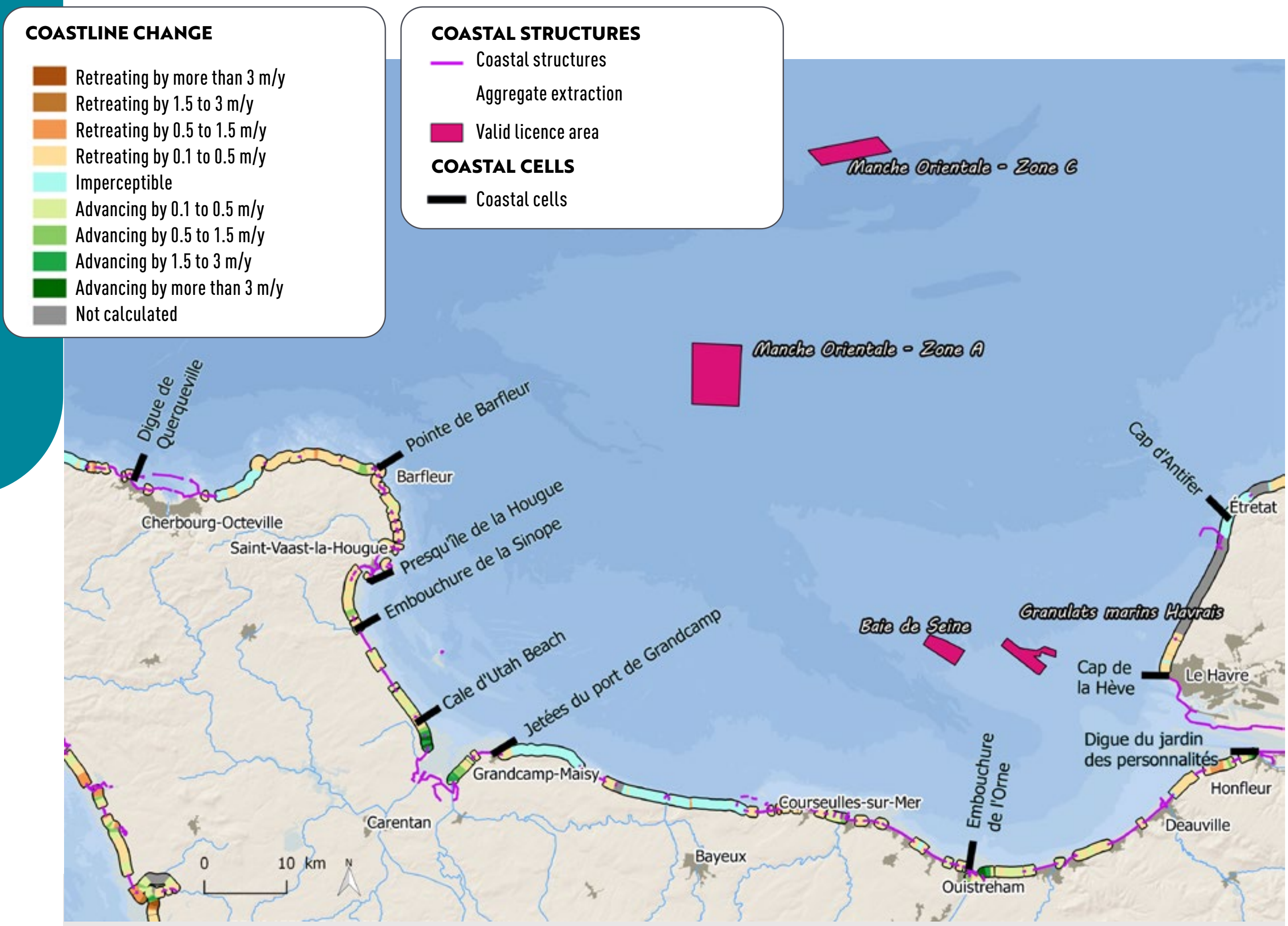


Figure 13 – *Locations of marine aggregate extraction sites, boundaries of known coastal cells and coastline change*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

KEY FIGURES FOR THE PROVINCE:

LENGTH OF COASTLINE
435 km

TYPES OF COAST:
22% cliffs and rocky coasts
42% coasts undergoing deposition
36% hardened coasts

ÉVOLUTION DU TRAIT DE CÔTE

24% retreating (of which 21% at between 0.1 and 0.5 m/yr)

59% changing imperceptibly

17% accreting

COASTAL CELLS:
10 cells (well identified)

LENGTH AFFECTED BY COASTAL DEVELOPMENT

254 km
(i.e. 58% of the coastline)

ANTHROPOGENIC IMPACTS

Extraction sites authorised in 2020:
3 licence areas (4 offshore sites)

Link between extractions and coastline change:
not established

2.4. FROM CAP DE LA HAGUE TO LA POINTE DE CORSEN (MANCHE, ILLE-ET-VILAINE, CÔTES-D'ARMOR, FINISTÈRE)

2.4.1. CURRENT KNOWLEDGE OF COASTLINE CHANGE

LIt is difficult and risky to attempt to break down the Norman-Breton Gulf (also known as the Bay of Granville) into coastal cells, on account of the complex natural processes, especially ocean currents, at play there. Moreover, the length under consideration and the fragmented nature of the coasts do not simplify the task of summarising current knowledge of coastline change. At a general level, three large morphosedimentary units can be defined, and possibly broken down further (Figure 14):

- from Cap de la Hague to Pointe du Roc, the west coast of the Cotentin peninsula,
- from Pointe du Roc to Pointe du Grouin, the bay of Mont-Saint-Michel,
- from Pointe du Grouin to Pointe de Corsen, the north coast of the Armorican Massif.

Offshore, bio-lithoclastic sediments enter the Norman-Breton Gulf between Bréhat and Guernsey. To the south, they are conveyed from west to east and deposited at the back of the large bays of Saint-Brieuc and Mont-Saint-Michel. They pass to the north of Les Minquiers and the Chausey islands towards the Catheue sand bank, the eastern end of which is connected to the Cotentin coastal prism. The sands thus skirt around Guernsey to the south, and then turn north towards Aurigny. They accumulate on the Serk, Aurigny and Schôle banks and are then pushed by the currents in the Alderney Race ("Raz Blanchard" in French) towards the Ecréhous islands and Jersey. Sediments are transported from south to north off the Cotentin peninsula from Lessay to Jobourg, and concentrate to the north of Carteret on the Surtainville bank. This bank supplies a process of littoral drift oriented north-south. The beaches of Vauville are supplied with sand from the subtidal dunes by coastal counter-currents. These sediment movements, established at the end of the Holocene marine transgression, have formed sandbanks more than 30 m high and a coastal prism 5 to 10 m thick (Walker, 2001).

The nearshore sediment dynamics of the west Cotentin coast have been monitored by the Manche departmental authority via a network of 39 measuring stations located between Saint-Germain-sur-Ay and Le Rozel, in the context of the Lower Normandy coastal observatory (OLIBAN). The results of this monitoring show that the overall sediment budget is in a slight deficit on this coast and that the vast majority of the coastline is subject to slight erosion (-0.12 m/yr). Few areas are subject to accretion, but the values there are very high, especially in the "havres" (coves), such as the Havre de Portbail, which is silting up at an average rate of more than 3.2 m/yr. This change seems to be irreversible in the short or medium term: the spits are becoming longer and the tidal deltas are accreting, leading to gradual closure of the entrance channel. Moreover, this infilling is reducing tidal current velocities, further accelerating the deposition of sediment. The cove of Portbail is hence thought to be infilling with marine sediment at a rate of 18,000 to 25,000 m³ per year, with an added input of 9,000 m³ due to bank erosion, and could hence be completely covered with vegetation on a 2030-2050 time scale (GRESARC, 2002; Levoy, 2007; Biotope, 2014).

Movements of sediment in the various bays of the north Armorican Massif are mainly related to ocean currents and tidal processes; these bays are undergoing sedimentation with fine particles.

In the bay of Mont-Saint-Michel, a study of the interaction between vegetation and sedimentation shows siltation rates varying between 0.2 and 10 cm/yr. The volume of sediment inputs carried by tides is driving the deposition of "tangues" (fine sediment specific to this bay) followed by a process of vegetation, with salt marshes spreading at a rate of 17 ha/yr (Bonnot-Courtois, 2012).

The gulf of Saint-Malo is located in a region where the hydrodynamic forces are particularly efficient. However, Cap Fréhel provides this bay with shelter, and sedimentation with fines (silt and fine sands) is aggravating the siltation processes (Vaucourt and Bonnot-Courtois, 1992).

In the bay of Saint-Brieuc, the sediment gradient ranges from fine to coarse from onshore to offshore and from west to east. Sediment distribution is disrupted by rocky outcrops, with coarse particles often concentrating close to shoals. Similarly, between the rocky zones and the coast, the stronger currents in the Saint-Quay and Erquy channels wash away the fines, leaving only the coarsest particles in place (Augris and Hamon, 1996). The bay of Saint-Brieuc has three zones with different coastal dynamics (Bousquet-Bressolier and Bonnot-Courtois, 1998):

- the east coast, formed of rocky cliffs and exposed to north-westerly waves, is subject to wave attack and continental drift as well as continental erosion of the cliffs due to solifluction.
- the bay head, which is very sheltered, is gradually silting up and undergoing localised dune erosion as a result of visitor overcrowding;
- the west coast is not very exposed to hydrodynamic forces and is undergoing mainly continental erosion of its loose cliffs, while marine erosion is limited to south-east of Pointe de Pordic.

The "Sillon de Talbert", a sand, shingle and gravel spit located in the municipality of Pleubian in the *département* of Côtes-d'Armor, has been retreating at accelerating rates for the past three centuries. This can partly be explained by the low inputs of materials, in the current context of a sediment deficit (Stéphan et *al.*, 2010).

Some bay-head beaches in the Lannion area are accreting. This is the case with Saint-Michel-en-Grève beach, where 60,000 m³ of sand accumulated on the upper foreshore between 1998 and 2003 (Stephan and Suanez, 2004), as well as, in the Finistère *département*, the sites of Le Dossen in Santec, Kerfissien in Cléder, Keremma in Tréflez, and Les Blancs-Sablons in Le Conquet (Cetmef et *al.*, 2011).

The foreshores lying at the north-western outlets of the "abers" (coastal inlets) are vast expanses of fine to medium sand, in the case of the areas exposed to westerly waves. The presence of large numbers of islets or rocky outcrops prevents the deposition of fines. The bays located on the south sides, such as Les Anges bay on the south side of the aber Wrac'h, are more silted up as they are more sheltered (Hily, 2005).

It is vital to note that the current accumulations - and position of the coastline - are legacies from the Holocene marine transgression. These accumulations are currently varying around a stock that can be considered finite at a regional level. As regards the province, knowledge of the sediment sources - in terms of both quantities and qualities - still varies widely. The contribution of erosion of portions of cliff to sediment inputs in a given cell has been estimated at different places over periods that were relatively short compared to the long periods over which these processes take place. As regards the clastic and biodetritic processes that produced the sands and shingle, some localised work and measurements have examined and sought to quantify these two aspects: estimates of the rock volumes produced by mass movement in rocky cliffs, changes to some portions of loose cliffs and quantification of the products removed, and biodetritic production (Hénaff, 1998; Hénaff et Bodéré, 2001). These studies show clearly that these various sediment sources are insufficient in light of the erosion that is occurring on the coastal accumulations.

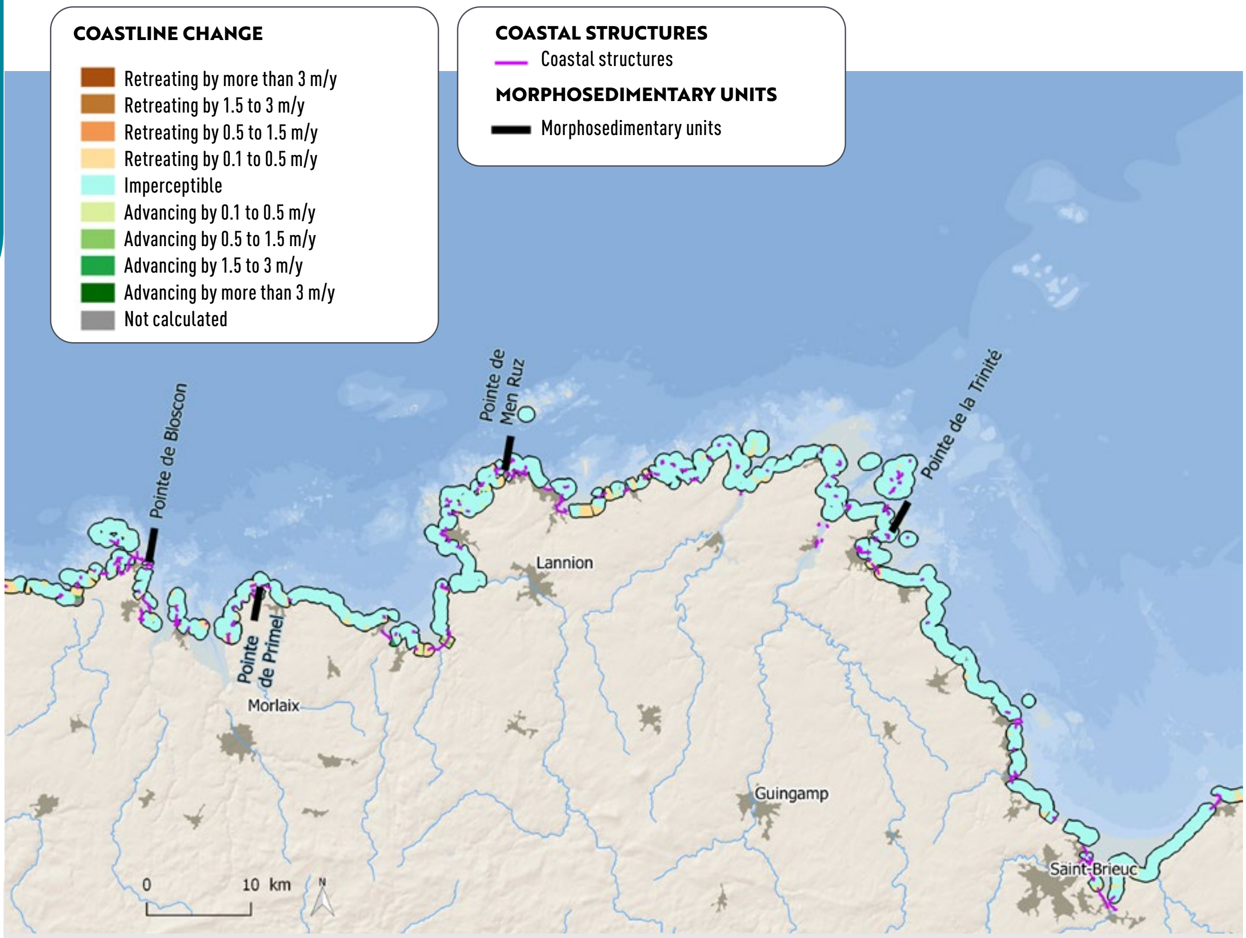


Figure 14 – *Known morphosedimentary unit boundaries and coastline change. N.B.: in this area, the coastal cell boundaries have not been established.*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

2.4.2. KNOWLEDGE OF IMPACTS OF HUMAN ACTIVITIES

The first structures built to protect against coastal erosion and hold the coastline in place date back to the Middle Ages. They became more widespread in the nineteenth century, accompanying the creation of seaside resorts and the growth of tourism. In Brittany, many defences were built between 1970 and 1993 in parallel with the increasing pace of construction along the coast and the growing numbers of visitors, which in turn made the coast more vulnerable (Hénaff, 2004).

Some sectors of the province, such as the coves and marshes, are sheltered and tending to infill; works are being carried out in these places with the aim of preventing - or at least mitigating - the siltation processes. Other coastal sectors are exposed to waves and tending to retreat, and have undergone development in order to either lessen the force of the hydrodynamic forces which carry sediments away or to retain the sediments in place. The province also features numerous polders. These areas of land reclaimed from the sea, as early as the twelfth century in the bay of Mont-Saint-Michel, were long used to increase the sizes of farms, and houses have been built on them in the more recent past (Casset, 2011).

On the west coast of the Cotentin peninsula, many coves have been developed in order to increase the areas of usable agricultural land and support the growth of seaside tourism, especially southwards from Cap de Flamanville, where the coast is becoming increasingly urbanised. Since the second half of the nineteenth century, the coves have suffered the impacts of the construction of defences and ports along the coast and even right inside them, and are tending to accrete. A notable example is the cove of Barneville-Carteret, which saw a phase of land reclamation in the second half of the nineteenth century: an area of about 100 ha was embanked in order to create new agricultural land and support the urbanisation of Barneville-Plage. This urbanisation was carried out on the dune ridge (Germain, 2006; Levoy and Larsonneur, 1994). The coastline of the cove is held in place by the structures built to reclaim the former tidal marshes, while the inlet has been channelised by further structures including protective walls (Levoy and Larsonneur, 1994) and embankments (Germain, 2006). The cove also provides shelter for some large harbour facilities and a wet dock, further accentuating the human impacts. In the late twentieth century a second phase of developments began with the construction of rockfill structures to prevent coastal erosion including a groyne, a backshore revetment and a breakwater.

The bay of Mont-Saint-Michel is marked by historic land reclamation works carried out since the twelfth century and by present-day shell-fish farming, which are key drivers of bay sedimentation. The land reclamation began in the Dol marsh, with the construction of dykes and drainage systems to dry out the land. The various rivers that flow into the bay, such as the Sée and the Sélune, disrupted the infilling process and their meanders often caused dykes to fail. The Roche-Torin dyke, built in 1862 to combat these meanders, caused the coastline to advance. It is estimated that 20 to 30 million m^3 of sediment were deposited on the south side of the dyke between 1860 and 1921. Polders were also created to the west of Mont-Saint-Michel between 1858 and 1934, and the resulting deposition during that period is thought to have amounted to 45 to 50 million m^3 (Migniot, 1998). An insubmersible causeway to Mont-Saint-Michel was built in 1878-1879, guaranteeing access to the mount in all weather conditions. It has not been possible to demonstrate the impact of this causeway on bed sedimentation, but it certainly played a role in the infilling of the areas to the east of the mount. It also eliminated the strong currents that disrupted navigation (Migniot, 1998). As of 2014, in the context of the project to restore the maritime character of Mont-Saint-Michel, a bridge was built to connect Mont-Saint-Michel and the mainland, and the causeway was gradually dismantled (Bonnot-Courtois, 2012).

From Pointe du Grouin to Pointe de Corsen, the north Brittany coast is marked by the historical development of seaside towns such as Saint-Malo and Saint-Brieuc. Saint-Malo was partially developed on a former tidal marsh that was gradually embanked from the fourteenth century. This low-lying and mostly flat area covers about 450 ha, from the walled city in the west to Paramé in the east and Saint-Servan in the south, and is protected by several structures managed by different authorities (DREAL Bretagne, 2014).

2.4.3. MARINE AGGREGATE EXTRACTION ACTIVITIES

Within the province, 3 licence areas, concerning 3 marine aggregate extraction sites, were authorised and operating in 2020 (**Table 3** and **Figure 15**).

Site	Département	Morphosedimentary unit	Year works started	Duration of extraction
La Cormorandière	Côtes-d'Armor	Cap Fréhel-Pointe de la Trinité	unknown	unknown
La Horaine	Côtes-d'Armor	Cap Fréhel-Pointe de la Trinité	2010	25 year
Les Duons	Finistère	Pointe de Primel-Pointe de Bloscon	2011	25 year

Table3 – *Extraction sites operating between Cap de la Hague and Pointe de Corsen* (Ifremer, 2015)

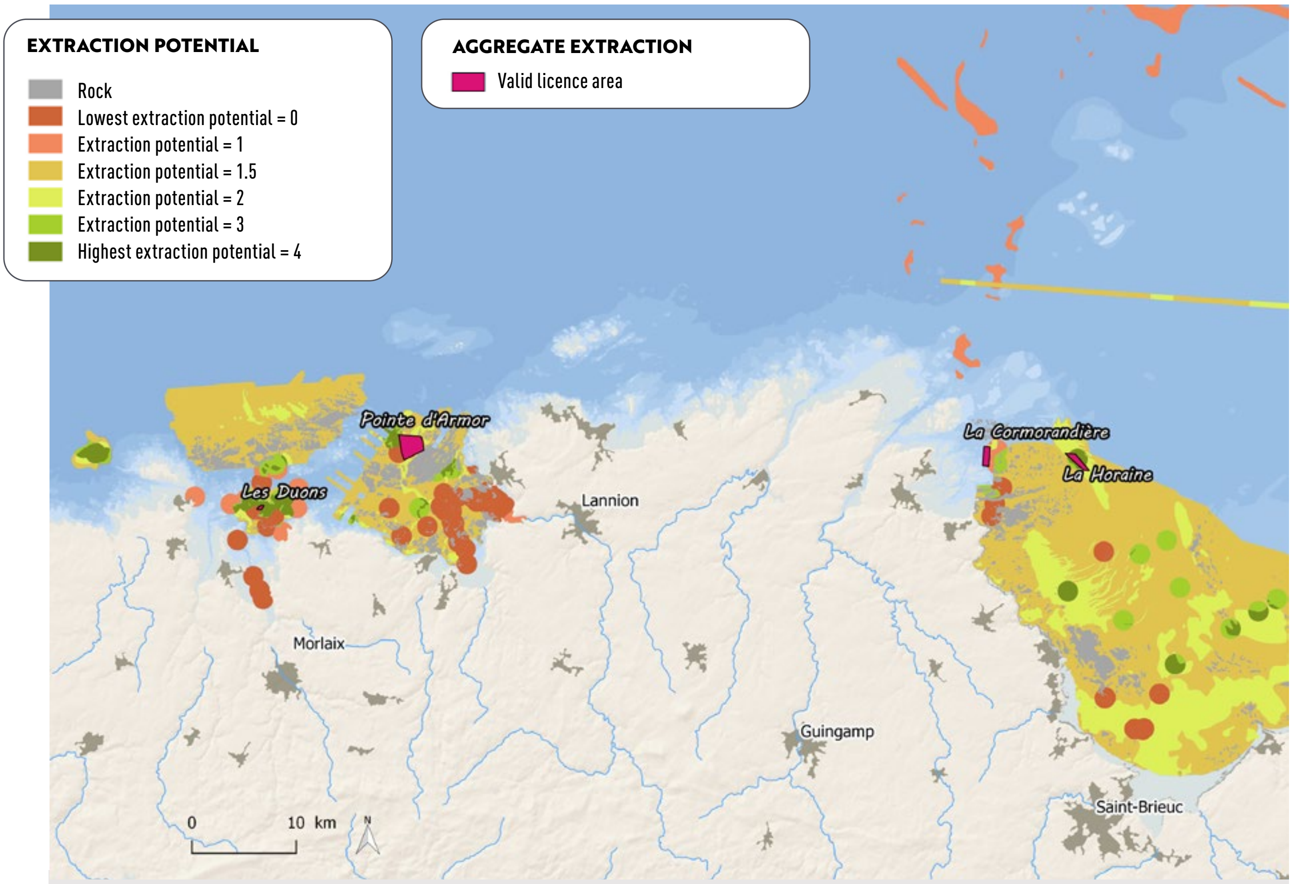


Figure 15 – *Location of marine aggregate extraction sites in relation to the nature of the seabed and their extraction potential.*
NB: The Pointe d'Armor licence area has been authorised but is not operating.

- Sources: Extraction potential (Ifremer, March 2020) and aggregate extraction data (Ifremer, April 2020)
- Base map: ESRI Shaded Relief, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

Aggregate extraction began in rivers in the nineteenth century, with the focus shifting to the sea as of the 1970s. Other practices, which are now forbidden, involved taking shingle from ridges to build or maintain paths. The Germans did this in order to build the Atlantic Wall. Marine amendments such as maerl were also used in agriculture as of the seventeenth century. In the nineteenth century, materials were extracted with shovels or dredges made of fabric. In the 1930s, with motorisation, the first grab dredges emerged, and were subsequently replaced with suction dredges in the 1970s (Férec et Chauvin, 1987).

The harvesting of "tangue" could date as far back as the Middle Ages, becoming widespread following the invention of the horse collar. The exploitation of these fine coastal sediments was a major economic activity, and extraction sites were rented for high prices securing high incomes for their owners (around 45,000 francs per hectare in the 1860s). This practice seems to have been specific to the coastal *départements* of Basse-Normandie and northern Brittany, where the quality of the materials was well suited to their future uses. Some accounts also report these same practices on the coasts of northern Finistère (Roscoff, Morlaix, Brest), where the composition of some marine sand deposits is similar to that of tangue (Camuzard, 2011). The volumes of tangue extracted in the mid-nineteenth century (Pierre, 1852; **Table 4**) may be underestimated (Camuzard, 2011).

Location	Annual volume extracted
Saint-Germain bay	550,000 m³
Régnéville bay	600,000 m³
Mouth of the river Couesnon	250,000 m³
Other rivers in the bay of Mont-Saint-Michel	250,000 m³
Mouth of the river Rance and surrounding area	15,000 m³
TOTAL	**1,665,000 m³**

Table 4 – ***Volumes of "tangue" extracted annually between Cap de la Hague and Pointe de Corsen in the nineteenth century*** *(Pierre, 1852)*

Marine aggregate extraction in the province mainly concern calcareous sands and maerl. The main ports of discharge are Saint-Malo, Saint-Brieuc (Le Légué), Pontrieux, Tréguier and Roscoff. Three shell sand extraction sites were operating in the province in 2020 (**Table 3** and **Figure 15**). They were complemented for a number of years by three sites in Côtes-d'Armor where maerl was extracted, until this was banned in 2013 (**Table 5**).

Site	Morphosedimentary unit	Year works commenced	Year extraction ended
Îlot Saint-Michel	Cap Fréhel-Pointe de la Trinité	1993	2012
Lost Pic	Cap Fréhel-Pointe de la Trinité	1996	2013
La Croix	Pointe de la Trinité-Pointe de Men Ruz	1988	2018

Table 5 – ***Former maerl extraction sites between Cap de la Hague and Pointe de Corsen*** *(Abellard, 2011)*. ***NB: These three sites are all located in the* département *of Côtes-d'Armor.***

The impacts of aggregate extraction on the seabed in the province are documented in the five-yearly monitoring reports. The volumes of "tangue" extracted from the coast have modified the geometry of the deposits and the plant communities in the extraction areas, as well as the coastal dynamics, leading to coastline shifts and consequences in terms of erosion and sedimentation, even though the accounts on this subject are scant and should therefore be used with caution (Camuzard, 2011).

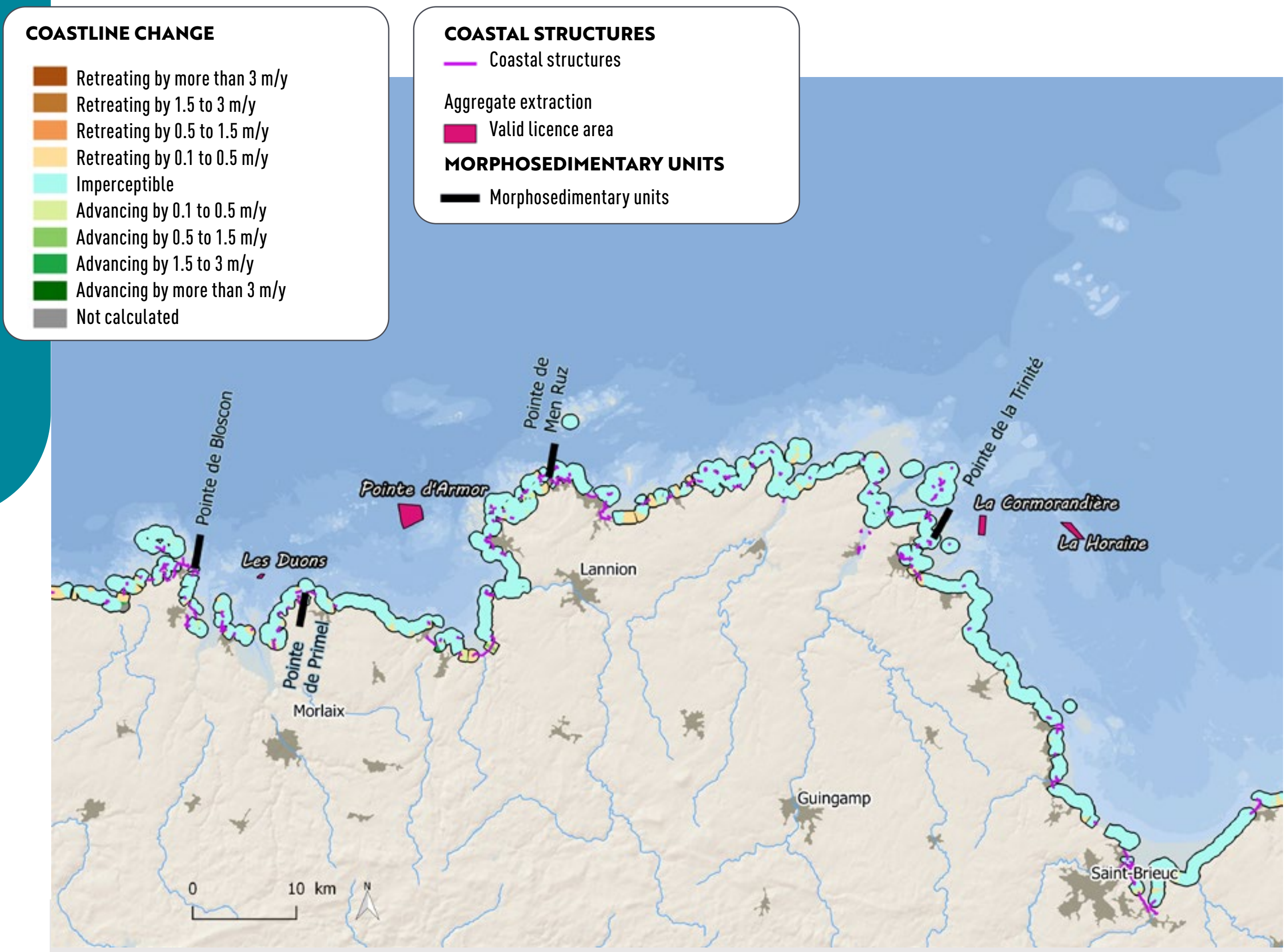


Figure 16 – *Locations of marine aggregate extraction sites and coastline change. N.B.: in this area, the coastal cell boundaries have not been established.*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

KEY FIGURES FOR THE PROVINCE:

LENGTH OF COASTLINE
1 289 km

TYPES OF COAST:
46,5% cliffs and rocky coasts
43,5% undergoing deposition
10% hardened coasts.

COASTLINE CHANGE
13% retreating
81% changing imperceptibly
6% accreting

COASTAL CELL
not clearly identified (other than the west Cotentin peninsula)

LENGTH AFFECTED BY COASTAL DEVELOPMENT
384 km
(i.e. 30% of the coastline)

ANTHROPOGENIC IMPACTS
Extraction sites authorised in 2020:
4 licence areas (3 offshore sites)

Link between extractions and coastline change:
not established

2.5. FROM LA POINTE DE CHEMOULIN TO POINTE DE SUZAC (LOIRE-ATLANTIQUE, VENDÉE, CHARENTE-MARITIME)

2.5.1. CURRENT KNOWLEDGE OF COASTLINE CHANGE

Between Pointe de Chémoulin and Pointe de Suzac, the coastline is composed mainly of dune systems and rocky coasts interspersed with estuaries: the 861 km of coastline can be broken down into 235 km hardened by man-made structures and developments along the shore (about 27%) and 626 km "natural" (55% sandy-silty depositional coasts and 18% rocky coasts). In this province, the national indicator of coastal erosion (Cerema, 2018), complemented locally by monitoring data and studies performed for management purposes at *département* or regional authority level (DHI-Geos, 2007), (Sogreah, 2012), (Cetmef and Conseil général de Charente-Maritime, 2000), provided a basis for analysing coastline change in the medium and long term: 38% is eroding, 20% is accreting and 42% is stable or changing imperceptibly. In particular, this coastline includes:

- sectors of steady sedimentary accretion over the past half-century (right bank of the river Loire as a result of infilling, south of Noirmoutier, a few sectors of the "pays de Monts" area and La Tranche-sur-Mer, the middle of Pointe d'Arçay, a few short sections in Saint-Georges-d'Oléron and Saint-Pierre-d'Oléron, Yves, around La Tremblade, and behind Pointe de la Coubre);
- many sections of coastline that are relatively stable,
- and the remainder, which is generally eroding at less than -0.5 m/yr but also includes some sections eroding faster than -0.5 m/yr, such as the west coast of La Tremblade, Les Mathes, Saint-Trojan-les-Bains, part of the east coast of Saint-Georges-d'Oléron, a few sections on the island of Ré (La Conche des Baleines beach), a few sections in Vendée (Saint-Hilaire-de-Riez, from the "pays de Monts" to the area around Le Pont d'Yeu), a few sections in Noirmoutier (Les Eloux, Luzéronde and Pointe de la Loire) and Pointe des Sableaux on the island of Yeu.

Sea defences have been built in some of these sections undergoing chronic erosion, among them Les Eloux beach, which has retreated by about -2 m/yr over the past decade in spite of increasingly imposing defence works. In other sections the coastline is retreating at significant rates that could endanger important assets in the short term, such as La Pège in Saint-Hilaire-de-Riez, where the very narrow dune ridge is subject to chronic retreat (-0.6 m/yr between 1921 and 2011). Special attention has been paid to some of these sections (defences, systematic beach nourishment, and dune reshaping when necessary following marine and weather events resulting in significant changes in shape).

The coastal cells in this province are well understood on the whole, and can be mapped for the purpose of analysing the coastline changes taking place (**Figure 17**).

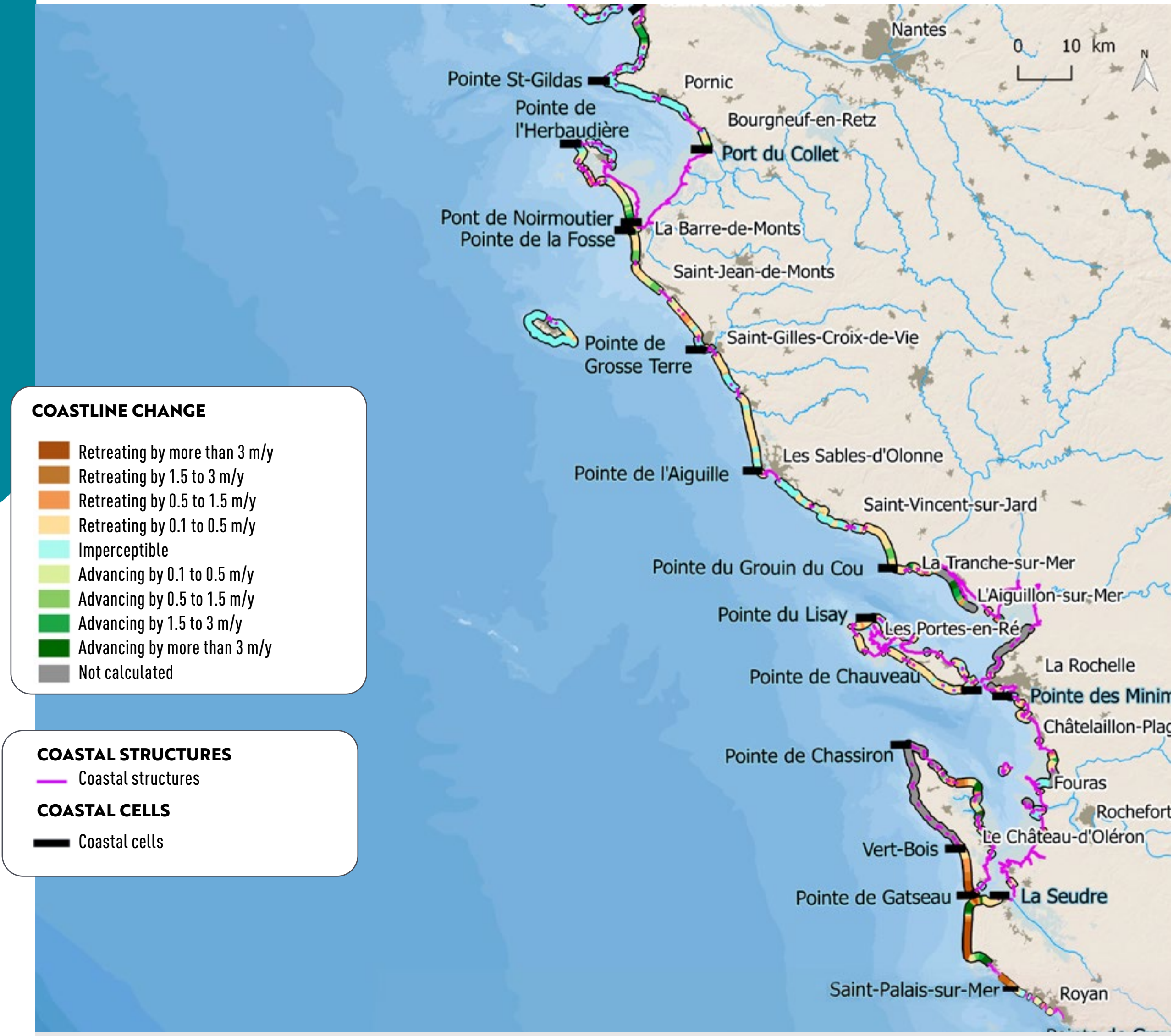


Figure 17 – *Known coastal cell boundaries and coastline change*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

However, while most of the onshore sediment movements are longshore (the resulting longshore sediment transport being mainly oriented north to south), very little is known about any movement perpendicular to the coast anywhere in the province (although some studies, in particular (Cetmef and Conseil général de Charente-Maritime, 2000), mention assumed offshore-onshore transfers of sediment in order to explain longshore drift). The province is also characterised by:

- two large estuaries with complex dynamics and large-scale movements of materials,
- the islands of Noirmoutier, Ré and Oléron, offshore continuations of the geological facies on the mainland that led to the formation of a system of bays (Bourgneuf bay, Pertuis Breton strait, and Pertuis Charentais area), with sheltered zones, complex water circulation patterns and generally moderate sand movements leading to deposition zones at bay heads (sinks for fine sediments),
- and coasts directly exposed to ocean wave action (the Vendée coast from Fromentine to Pointe du Grouin du Cou, the western coasts of the islands and the "Côte Sauvage" coast on Arvert peninsula), where sediment movements are potentially greater.

2.5.2. KNOWLEDGE OF IMPACTS OF HUMAN ACTIVITIES

The history of development in the province can be divided into several main periods:

- land reclamation in the coastal marshes from the north to the south of the province and on the three main islands, with several periods of development between the Middle Ages and the 1960s,
- holding of the positions of the dune ridges under the provisions of the imperial decree of December 1810, which led to the planting of maritime pine trees as of 1830 in order to address the risk of sand encroachment onto buildings and agricultural land (DHI-Geos, 2007),
- urban development on the dunes, which profoundly transformed the sandy coast over two distinct periods, first in the nineteenth century with large-scale works to hold the dunes in position, and then in the first half of the twentieth century with development of seaside resorts on the dune ridges of the mainland and the islands,
- widespread more recent development driven by economic activities and tourism related to the coast (oyster farming, marinas, and fishing or commercial harbours).

Other more recent activities are likely to affect sediment movements:

- marine aggregate extraction at five sites within this province which have been developed since the 1970s to meet demand for construction materials,
- development of ports, initially commercial, over the second half of the twentieth century, resulting in sediment dredging and dumping operations in order to maintain depths in the basins and shipping channels,
- and other human activities related in particular to the maritime economy (salt production, fish and shellfish farming, harbours), those induced by the growth of tourism on the coast, transport infrastructure, development of mooring areas, seaside activities, and projects linked to offshore power generation.

Statutory zoning with a view to protecting the environment is contributing indirectly to protecting the coastline and its sedimentary equilibrium by limiting the potential impacts of these activities.

RETURN TO SUMMERY >

2.5.3. MARINE AGGREGATE EXTRACTION ACTIVITIES

Within the province, 9 licence areas, concerning 9 marine aggregate extraction sites, were authorised and operating in 2020 (**Table 6** and **Figure 18**).

Within the province, applications for extraction licences have historically concerned the following four sectors, from north to south (**Figure 18**):

- Le Pilier and Grand Charpentier in the outer Loire estuary,
- Le Payré, off the coast of Les Sables-d'Olonne,
- Chassiron, off the coast of Oléron island, which has been split into four licence areas (named B, C, D, E),

Licence area	Materials	Exploitable surface area km²)	Maximum authorised quantity (m³/yr)	Decree date	Year of expiry
Pilier (1)	Siliceous	8,20	2,267,000	04/1998	2018
Grand Charpentier (1)	Siliceous	10	1,200,000 [20]	09/2007	2032
Cairnstrath SN2 (1)	Siliceous	5,6	1,400,000	03/2017	2037
Cairnstrath A (1)	Siliceous	3,6	900,000	03/2017	2037
Le Payré (1)	Siliceous	0,96	350,000	11/2013	2031
Chassiron B (2)	Siliceous	1,33	330,000	03/2003	2023
Chassiron C (2)	Siliceous	1,35	330,000	09/2015	2029
Chassiron D (2)	Siliceous	3	330,000	04/2002	2022
Chassiron E (2)	Siliceous	2	482,000	07/2006	2036
Total province	**Siliceous**	**17,84**	**4,122,000**		

NB: In this table, grey shading indicates licence areas where extraction is not taking place or has been completed.

Table 6 – *Marine aggregate extraction licence areas within the province*
(Sources: 1-DREAL Pays de la Loire; 2 - International Council for the Exploration of the Sea (ICES) 2013)

In the end, the Grand Charpentier licence area off the Loire estuary was not exploited. Le Pilier was actively exploited until 2017, and operations have continued since April 2017 at the two licence areas of Cairnstrath A and SN2 with the same maximum authorised volume as at Le Pilier.

20 The decree authorising the opening of mining works reduces the exploitable surface area to 2.6 km² and the maximum authorised quantity to 200,000 m³ per year.

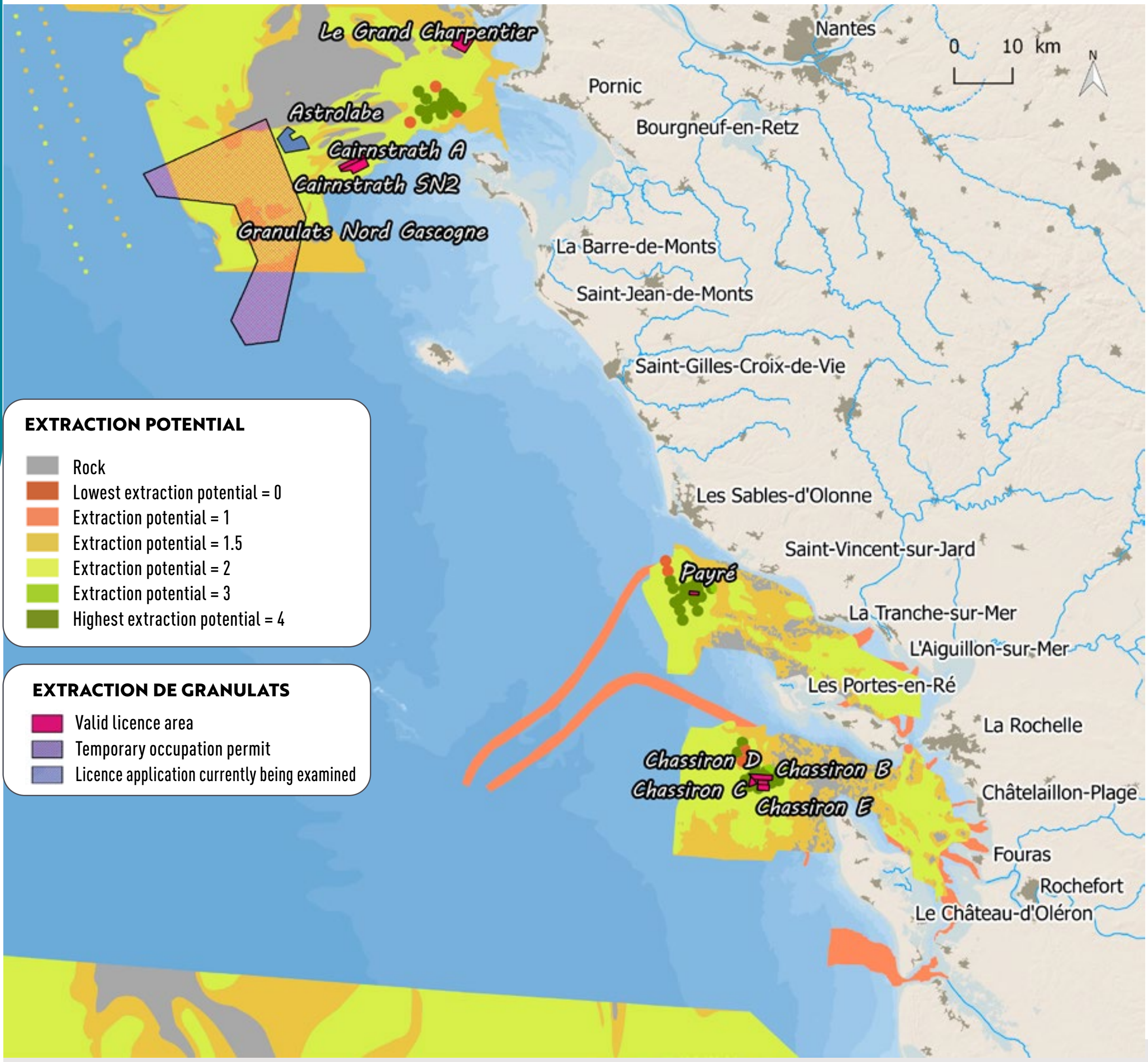


Figure 18 – *Location of marine aggregate extraction sites in relation to the nature of the seabed and their extraction potential*

- Sources: Extraction potential (Ifremer, March 2020) and aggregate extraction data (Ifremer, April 2020)
- Base map: ESRI Shaded Relief, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

The main deposits, which were identified during exploration campaigns conducted between 1974 and 1979, are located off the Loire estuary, in the Pertuis Charentais area, and off the Gironde estuary (Augris et *al.*, 2006). The estimate of the resource (quantity, extent and nature of the sediments) was clarified in the mid 1980s, confirming the previous investigations carried out when the national inventory was drawn up in the 1970s (Augris *et al.*, 2006 ; **Table 7** and **Figure 18**).

Sector		Volume (Mm³)
Saint-Nazaire		13,400
Pertuis charentais	**Pertuis d'Antioche**	904
	Pertuis Breton	579
Gironde		650
Total		**15,533**

Table 7 – *Estimated aggregate resources at the 4 licence areas* (Augris et al., 2006)

All the sites in the province concern siliceous aggregate extraction. The resource exploited corresponds to accumulations of siliceous gravel and sand at the bottom of palaeo-valleys dug by the rivers on the continental shelf off the mouths of the Loire, the Charente and the Gironde and formed during the Quaternary glaciation periods.

At the scale of the province, the licences to extract siliceous materials represent a total authorised volume of 5,722,000 m³ for a cumulative licensed surface area of 38 km² (**Table 6**). Over the entire Atlantic coast, production amounted to 5.9 Mt in 2007, of which 77% concerned the province according to the mining title application concerning the "aggregates off the coast of the Gironde" exclusive exploration permit (Créocéan, 2009). At the extraction sites in the "Pays de la Loire", on average 2.2 Mt were extracted annually between 2011 and 2016 (**Table 8**).

Period	2011	2012	2013	2014	2015	2016	Average 2011-2016
Total tonnage (millions of tonnes)	2,83	2,76	2,24	2 ,00	1,92	1,62	**2,23**

Table 8 – ***Total weight of aggregates extracted from sites in the Pays de la Loire region between 2011 and 2016*** *((according to DREAL Pays de la Loire in DIRM NAMO, 2019)*

The impact monitoring imposed on applicants in the zone influenced by the licence areas concerns morphobathymetric and biosedimentary aspects and impacts on fish. Monitoring of the Chassiron extraction sites, for which several licences have been granted since 1984, was made compulsory by the State when it issued its third licence and was set up in practice as of 2001. This monitoring involves a detailed survey of the seabed (baseline conditions) and five-yearly monitoring over a surface area of 60 km². The five-yearly monitoring conducted between 2006 and 2011, compared with baseline conditions established in 2001-2002, confirms that the sedimentary impacts remain consistent with those predicted by the studies performed before the works started. The morphology of the accumulations observed reveals highly mobile unconsolidated sediment over the sill between the islands. However, on the date the monitoring was carried out, this process, which most likely reflects a net transfer of materials from offshore to the Pertuis d'Antioche strait, is not affected by the extraction of materials (Walker et *al.*, 2014).

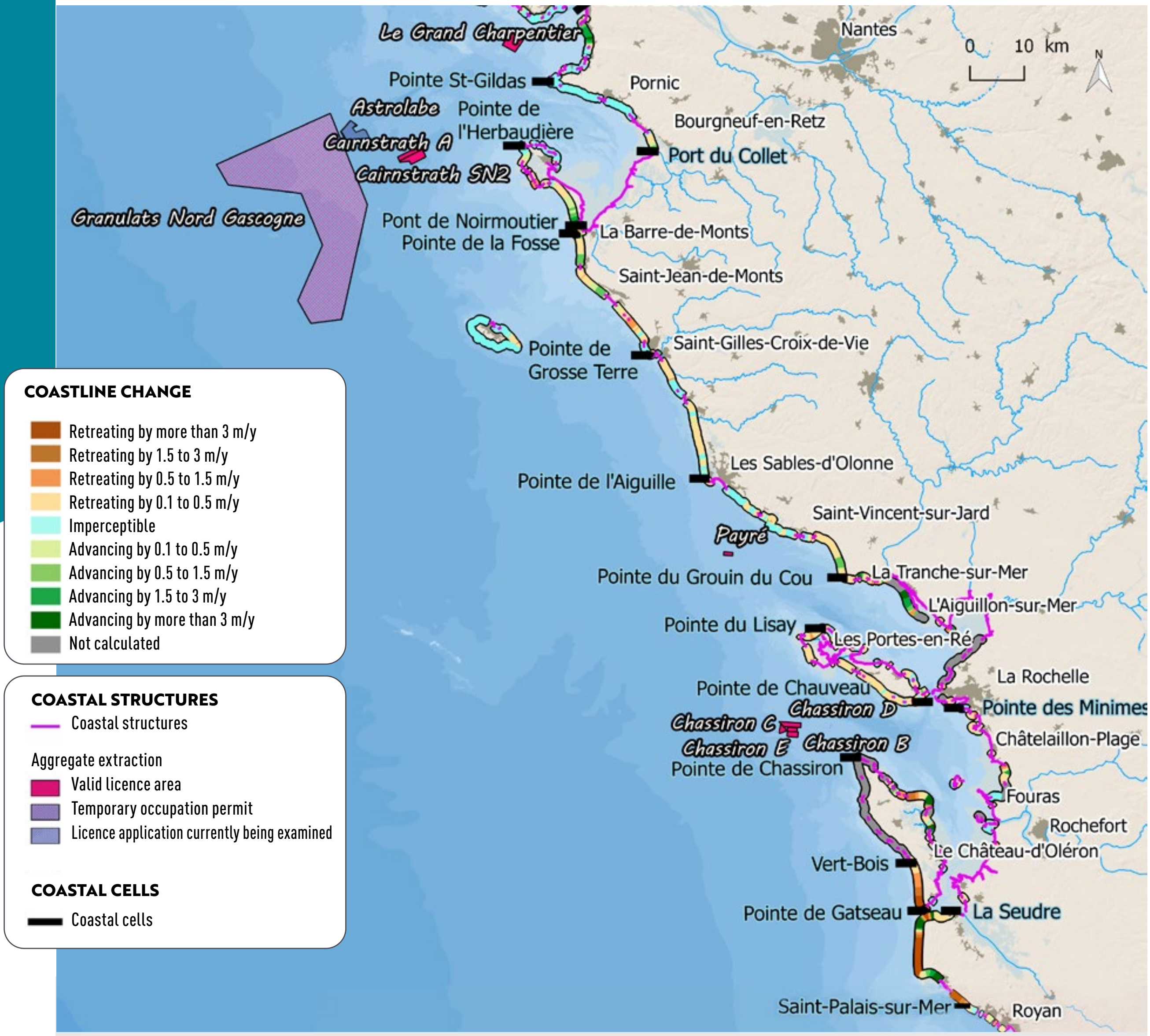


Figure 19 – *Locations of marine aggregate extraction sites and coastline change*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

KEY FIGURES FOR THE PROVINCE:

LENGTH OF COASTLINE:
861 km

TYPES OF COAST:
18% cliffs and rocky coasts
55% undergoing deposition
27% hardened coasts.

COASTAL CELLS
18 cells identified

LENGTH AFFECTED BY COASTAL DEVELOPMENT
478 km
(i.e. 56% of the coastline)

COASTLINE CHANGE
37% retreating (of which 24% at between 0.1 and 0.5 m/yr)
43% changing imperceptibly
20% accreting

ANTHROPOGENIC IMPACTS
Extraction sites authorised in 2020:
8 licence areas (7 offshore sites)

Link between extractions and coastline change:
not established

2.6. FROM POINTE DE SUZAC TO THE SPANISH BORDER (GIRONDE, LANDES, PYRÉNÉES-ATLANTIQUES)

2.6.1. CURRENT KNOWLEDGE OF COASTLINE CHANGE

Between Pointe de Suzac to the north of the Gironde estuary and La Bidassoa, marking the border with Spain, the sedimentary province running along the Atlantic Ocean can be divided into four very different morphosedimentary units:

- the estuary and mouth of the Gironde, where channels (natural and man-made) and banks of sand and silt shift constantly in complex patterns, under the effect of waves, the typical currents of both coastal and river systems, and the continual movement of sedimentary materials with widely varying densities,
- a long, very straight sand and dune coastal fringe, generally oriented north-south and subject to two predominant mechanisms: littoral drift, which moves large quantities of sediment along the shore, and ocean wave action, which constantly alters the shoreline topography and constitutes the key driver of coastal erosion, with wide contrasts between seasons,
- Arcachon Bay, a vast expanse of lagoon formed by the Leyre estuary, whose mouth, bounded to the west by Cap Ferret, forms a gap of about 3 km the sandy coastline; its system of narrow channels called "passes" make it a very particular coastal cell within the province,
- the rocky coasts of the Basque Country, stretching for 40 km between Biarritz and Hendaye, which are more resistant to the energy of ocean swell and retreating less due to erosion, but which also feature areas of significant land instability that is problematic as it isolates the sandy foreshores of bay heads or pocket beaches with very active dynamics.

It is obvious that the coastline is changing in widely contrasting ways from one unit to another, without even examining the coastal cell scale (**Figure 17** and **Figure 20**).

The beds in the Gironde estuary vary widely, with some zones entirely sandy while others consist of gravel, others are muddy and clayey, and others are rocky. These beds, dotted with numerous sand banks and islands, are constantly changing. The LCHF (French Central Hydraulics Laboratory) performed studies there in its very early days (LCHF, 1959, 1963; Migniot, 1969) and these have been followed up by extensive academic research (for example Braud, 1986; Howa, 1987; Mallet, 1998; Phan, 2002; Saari, 2008; Jalón Rojas, 2016). The morphological and sedimentary dynamics driving these changes are complex. They are controlled by the waves and currents resulting from the combination of sediment inputs from rivers and the rising and falling of tides. In addition to this natural mechanical control, these beds vary widely in nature from one place to another and in line with the effects of physical and chemical estuarine processes - stratification, mixing and formation of suspended sediments (Allen, 1972; Allen et *al.*, 1979; Sottolichio and Castaing, 1999; Benaouda, 2008; Billy et al., 2012) - as well as the impacts of large-scale human activities related to shipping, fishing and tourism.

From the Gironde estuary to north of the Adour river mouth, the coast is sedimentary and forms a system combining beaches and coastal dunes. Generally speaking, and with the exception of a few localised sectors, especially around river mouths (estuaries, Arcachon

Bay and the small coastal rivers called "courants landais"), it is retreating at average rates in the order of 2.5 m/yr in Gironde and 1.7 m/yr in the Landes (Bernon et *al.*, 2016). Even the first documents to be published reported that almost the entire Aquitaine coastline was retreating steadily (Buffault, 1930; 1942; Fabre, 1939). The fortifications of the Atlantic Wall (thick walls, bunkers, artillery emplacements, etc.), built over the course of the Second World War, would later act as clear landmarks attesting to the encroachment of the sea in subsequent years (Manaud, 1998). More recently still, buildings constructed on the sandy coast have been directly threatened by this encroachment. A notable example is the building called "Le Signal" in the town of Soulac-sur-Mer (Gironde), which had to be evacuated during the winter of 2013-2014.

To quantify the displacement of the dune coast, the LCHF made observations along the entire Aquitaine during the period 1977–1979 (LCHF, 1979) and conducted large-scale studies in the Arcachon Bay (LCHF, 1969; 1973) and Soulac-sur-Mer sectors (LCHF, 1982). Regular observations, complemented by inspections conducted after the strongest storms, have been made since the 2000s by the French National Forestry Office (ONF) and the French Geological Survey (BRGM) in the context of the Aquitaine Coastal Observatory (OCA). The dune toes remained stable or advanced between 2003 and 2006, but the trend then reversed and erosion increased between 2007 and 2008, except in the Gironde estuary, Arcachon Bay and Capbreton sectors, where accretion predominated (Mugica et Mallet, 2008). New quantifications of coastline retreat have hence been proposed in recent years (Bernon et al. 2016; BRGM and ONF, 2018; Cerema, 2018). These are consistent on the whole, with the exception of the sediment cell stretching from Biscarrosse (south Salie) to Hossegor (Notre-Dame beach), which the OCA (BRGM and ONF, 2018) describes as undergoing widespread retreat over the 1950-2014 period, whereas the national indicator of coastal erosion (Cerema, 2018) demonstrates that the beaches of the Landes tended to accrete over the 1934-2011 period. These figures are backed up by a number of studies including those performed by Manaud et *al.* (2001), for example.

Quantitative estimates of sediment fluxes have been made at a variety of scales (work of the LCHF, OCA, various academics) using in situ measurements or numerical models, and their results seem to be consistent as regards the sandy coast (Idier et al., 2013). Significant prospects for improving knowledge have been opened up by the deployment of more precise, repetitive observation resources (LIDAR, DGPS, ground-based and drone photogrammetry, etc.) and more sophisticated models of morphological changes to shorelines (Marieu et *al.*, 2017; Biausque, 2018).

Even though the landscape of the sandy coast is highly uniform, the direction of littoral drift is inverted twice: with divergence on either side of the Gurp cove to the north, and convergence on either side of the Capbreton canyon ("gouf"). The sedimentary dynamics of the sandy coast are also influenced by the breach formed by the mouth of Arcachon Bay. Continuous longshore drift gives way to complex mechanisms driving the formation and disappearance of sand spurs, displacement of sand banks located both inside and outside the bay, and morphological transformations of the shores and bed. Many facets of this area remain largely unknown, in terms of both how it functions and its fate in the face of changes in hydrodynamic forcing and the sand volumes mobilised. The "gouf de Capbreton", an underwater canyon whose head is close enough to the coast in the south of this sector to influence its sedimentary dynamics, forms a sediment sink supplying the abyssal plain of the Bay of Biscay. However, recent research work (Mazières, 2014) suggests that different types of sediment transport are possible in this sector, potentially putting sediments from the shore back into circulation in the deepest parts of the continental shelf under certain wave conditions.

Along the rocky coastline of the Basque Country, the presence of beaches and the changes they are undergoing are related to factors including the fragility of the upper sections of the cliffs overlooking them. A surface layer of alterite which is particularly prone to gravity-driven instability, especially during heavy rainfall, maintains the long-term presence of a cliff-foot beach (Genna, 2004). Regular observations are also made in this sector, including monitoring of movements in the continental coastal profile and the mechanisms associated with wave action (Garnier and Millescamps, 2014; Garnier, 2013; Peter-Borie et *al.*, 2009).

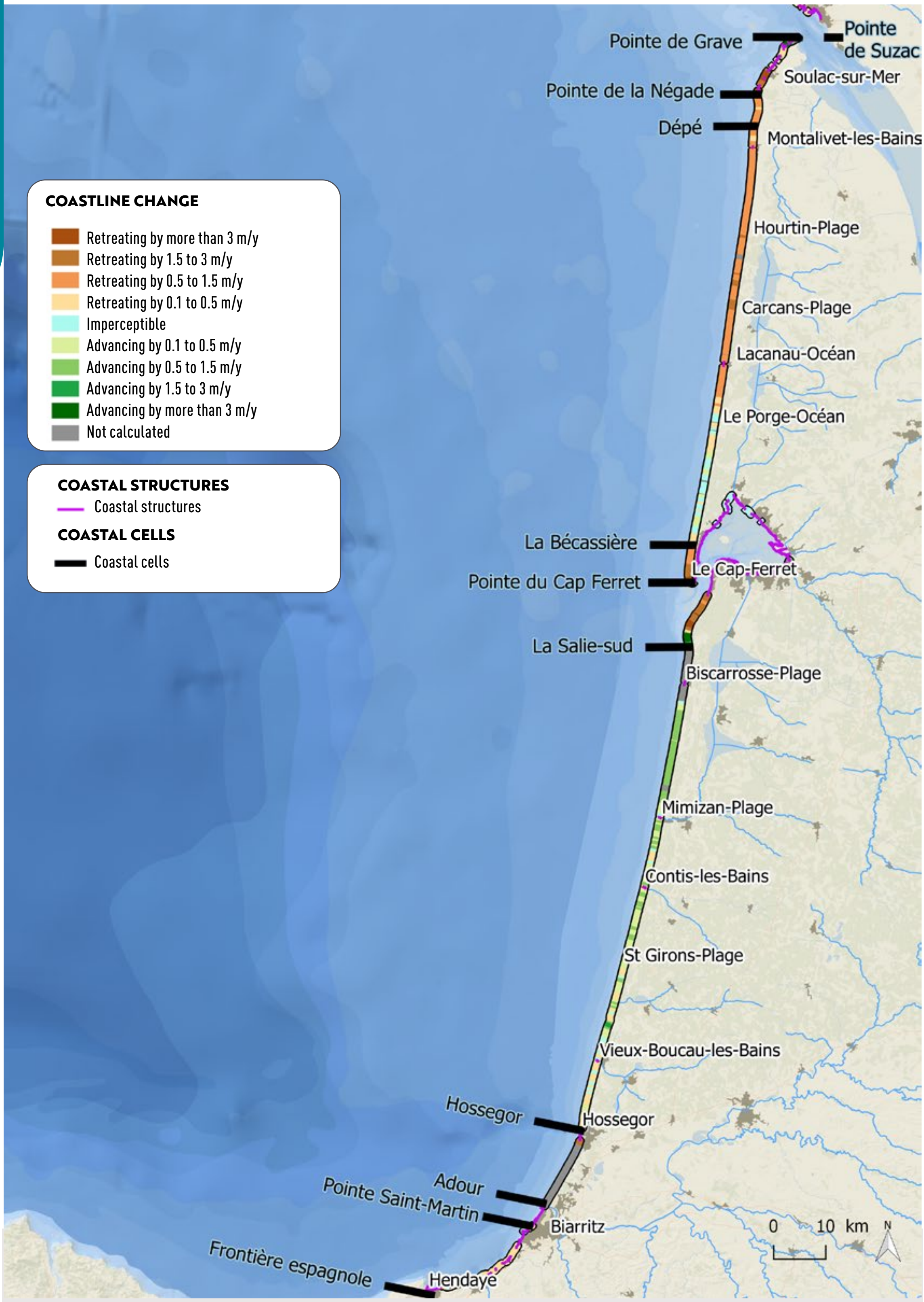


Figure 20 – *Known coastal cell boundaries and coastline change*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

2.6.2. KNOWLEDGE OF IMPACTS OF HUMAN ACTIVITIES

The Aquitaine province has been marked by human developments, essentially the draining of coastal marshes and gradual urbanisation along the shoreline. The first known developments here - some of which can still be seen today - date back to experimental beginnings in the second half of the eighteenth century. The main aims at that time were to reclaim land from the sea in order to create more agricultural land and drain wetlands in order to improve health. The coastal dunes, which were mobile until major operations were undertaken in the eighteenth century to hold them in place, bear the mark of human activity. The dune ridge separating them from the sea, which has become the hallmark of the Aquitaine coast, has undergone work in order to protect them. Maintained by "cantonniers de la dune" ("dune workers") in the period after it was held in position and then reshaped mechanically between 1958 and 1980, it is now managed using a more flexible control approach that aims to restrain coastal erosion while allowing the dune shapes to change as freely as possible (Manaud, 1998).

The growth of tourism, on a small scale during the inter-war period but much more rapidly after World War II, drove development along the coast, much of it under the aegis of the State via the "MIACA" (Interministerial Mission for Development of the Aquitaine Coast) between 1967 and 1988 (GIP Littoral aquitain, 2007). Seaside resorts sprang up along the sandy coast, extending the centres of various inland towns of Gironde and the Landes towards the sea front - among them Lacanau-Océan, Biscarrosse-Plage, Mimizan-Plage and Hossegor. This tourist and economic development increased the number of exposed key assets within the region, making it more vulnerable to coastal risks such as coastal flooding in the dune areas and the hardened low-lying areas. In attempts to address this heightened vulnerability, works along the coast included the building of structures to protect against coastal flooding (dykes and breakwaters), maintain the coastline (revetments, walls) or combat erosion in sandy sectors (groynes). Sediment dredging and dumping operations were carried out in order to maintain shipping channels and replenish beaches. Such developments remain localised and large stretches of coastline have been untouched by large-scale works. Nevertheless, hydropower development schemes (dams) on rivers and the extraction of sediment in rivers and estuaries (mainly the Gironde and the Adour) are reducing the alluvial inputs reaching the sea (Manaud, 1998). Other activities can also have a direct or indirect impact on onshore sediment inputs, such as human development along the coast and the expansion of on- or offshore activities (tourism, fishing, fish- and shellfish farming, sediment extraction, marine renewable energy, etc.). Statutory zoning with a view to protecting the environment is hence contributing indirectly to protecting the coastline and its sedimentary equilibrium by limiting the potential impacts of these activities.

A regional coastal strip management strategy, approved by the State and the local authorities along the Aquitaine coast in 2012, defined the broad outlines of a sustainable approach to this issue. It stipulated the creation of local strategies, led by the local authorities, to fine-tune these outlines and adapt them to local needs (GIP Littoral Aquitain, 2012). On 1 July 2017, all the authorities considered to take priority on account their exposed assets (Lacanau, Lège-Cap Ferret with the Arcachon Bay channels, Mimizan, Capbreton and the Basque Country urban area) set about drawing up a local erosion management strategy. Half of them have already completed the study phase, and are now considering operational implementation.

2.6.3. MARINE AGGREGATE EXTRACTION ACTIVITIES

Within the province, one licence area concerning one marine aggregate extraction site was authorised and operating in 2020 (**Table 9** and **Figure 21**).

License area	Date of last issue of licence	Period of validity	Location	Surface area (km²)	Authorised quantity
Platin de Grave	25/07/03	20 years	at the mouth of the Gironde estuary	10,22	400,000 m³/yr

Table 9 – *Details of the marine aggregate deposit located between Pointe de Suzac and the Spanish border*

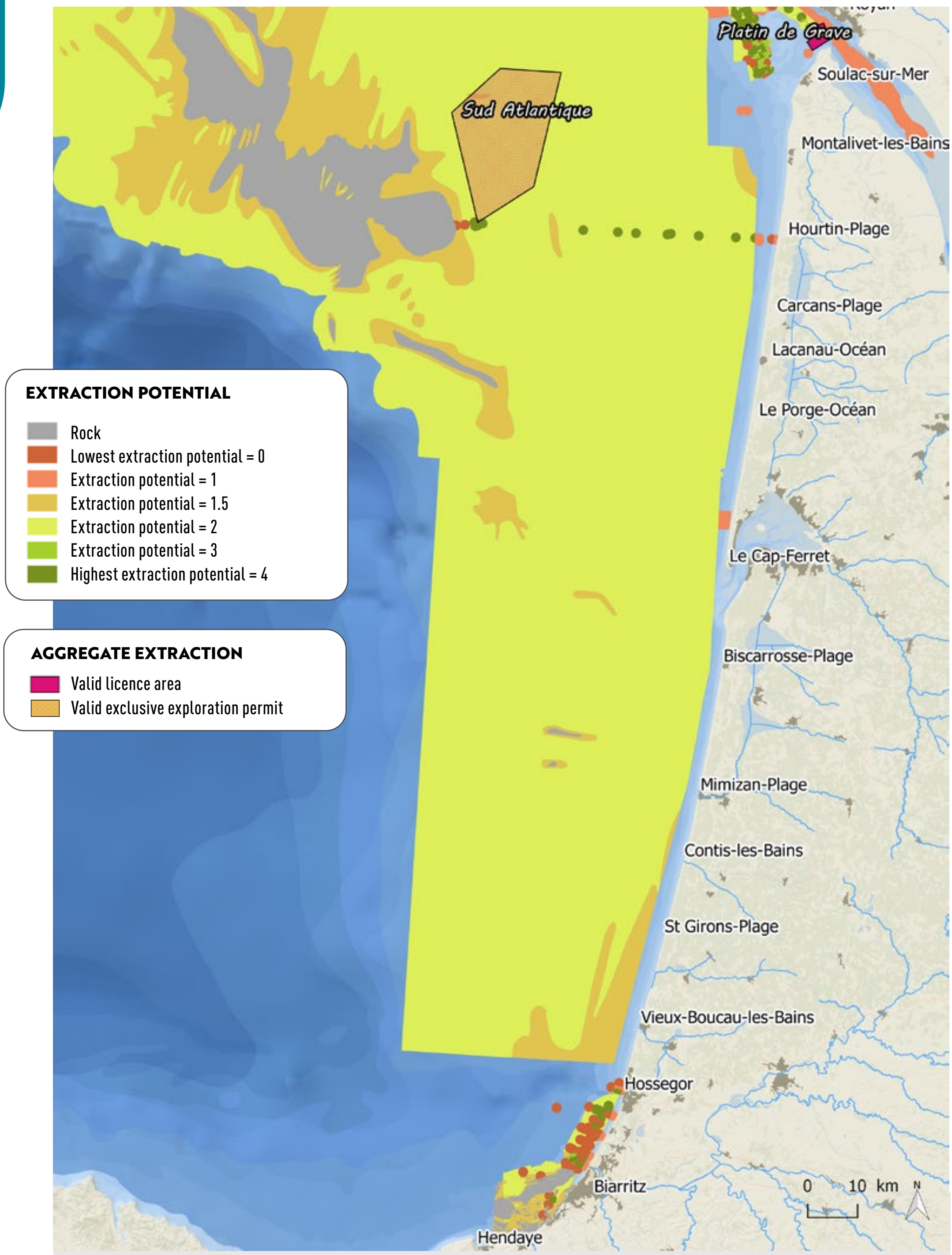


Figure 21 – *Location of marine aggregate extraction sites in relation to the nature of the seabed and their extraction potential*

- Sources: Extraction potential (Ifremer, March 2020) and aggregate extraction data (Ifremer, April 2020)
- Base map: ESRI Shaded Relief, Bd-Topo IGN
Produced by: Cerema, JUNE 2021

Sediment extraction operations carried out in rivers and, more specifically, in the beds of the Garonne and the Adour, reduced sediment inflows reaching the sea and depleted the stock of materials, disrupting the conditions required to maintain the natural equilibrium and resulting in erosion and harm on a scale resulting in these operations being abandoned (Beaudelin, 1989). At a national level, as extraction in alluvial valleys became more difficult owing to the constraints of urban planning, protection of sites, and preservation of aquifers and the environment in general, and to meet ever-increasing demand for aggregates, new sources of supply were sought, leading, from 1969, to surveys of the thickness of unconsolidated sediment covering the French continental shelf (Augris and Cressard, 1984).

Within the province, the marine aggregates are mainly sand and gravel (predominantly siliceous sands in the Bay of Biscay), which can be extracted in order to replenish beaches subject to erosion. At present there is only one authorised marine aggregate extraction site in the province, called "Platin de Grave". It is located at the mouth of the Gironde estuary and operated by the GSM company (Heidelberg Cement Group).

Aggregate was extracted from the Aquitaine foreshore in the early twentieth century, but this is no longer taking place (LCHF, 1987). Over an 80 km² area from the mouth of the Adour to the "gouf de Capbreton", a sedimentary surface layer between 3 and 30 m thick, representing in total 1.5 billion m³ of ungraded materials, mainly siliceous sands with an average diameter of less than 315 µm, was identified (Augris and Cressard, 1984). Within this area, a deposit estimated to contain 10 Mm³ of sands[21] has been identified off the mouth of the Adour, along the north edge of the Loutrou shelf (**Figure 22**). This deposit is thought to be composed of 10% small gravel, 15% coarse sand, 25% medium sand and 50% fine sand (Piednoir et al., 2005). This site was exploited during civil engineering works in the city of Bayonne in the 1970s, but the availability of land-won aggregates from the nearby Pyrénées made these offshore operations unprofitable and the site is not thought have been exploited since then (Piednoir *et al.*, 2005).

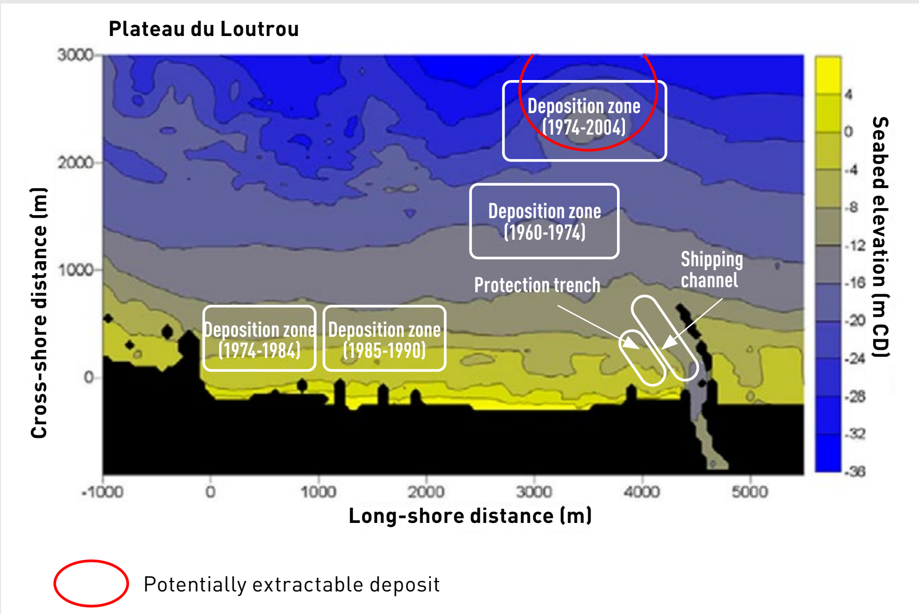


Figure 22 – ***Location of the Adour deposit and the sediment deposition zones dredged between 1960 and 2004*** *(according to Brière, 2004 amended in Piednoir et al., 2005)*

21 This deposit is thought to be composed of 10% small gravel, 15% coarse sand, 25% medium sand and 50% fine sand (Piednoir *et al.*, 2005)

The average annual volumes relating to extraction operations carried out at Platin de Grave since 1945 are summarised in Table 10 below. The rate of aggregate extraction at Platin de Grave has intensified since 1945, with the authorised extraction volumes doubling successively from 50,000 m³/yr between 1945 and 1965, to 100,000 m³/yr between 1965 and 1978, 200,000 m³/yr between 1978 and 2003, and 400,000 m³/yr between 2007 and 2023. The most recent licence authorises siliceous gravel and sand extraction over a surface area of about ten square kilometres (UNPG, 2013).

Périod	Quantity(m³/yr)	Sources and additional information
1945-1965	50,000	(LCHF, 1987)
1965-1978	100,000	(LCHF, 1987)
1978-1981	200,000	(LCHF, 1987)
1981-2003	200,000	(Département de la Charente-Maritime, Département de la Gironde, 2014)
2007-2023 (period of issue of the licence)	400,000	Surface area of licence area: 10,22 km² Materials: siliceous gravel and sand Unloading: at Les Monards and Grattequina (UNPG, 2013)

Table 10 – *History of aggregate extraction at Platin de Grave*
(LCHF, 1987 ; UNPG, 2013)

Off the mouth of the Gironde estuary, the economic interest group (GIE) "Sud Atlantique" was awarded an exclusive permit to explore marine siliceous gravel and sand, named the "PER Sud Atlantique", covering the seabed of the continental shelf off the Gironde estuary (*départements* of Gironde and Charente-Maritime), under the terms of a ministerial order dated 3 May 2016.

On the foreshore, extraction is considered a risk that can aggravate or even worsen the coastline erosion that has been taking place at the mouth of the Gironde since the mid-nineteenth century. This is why foreshore extraction has diminished over time, as awareness of the harm it can cause has grown.

Current knowledge of the potential impacts of marine aggregate extraction in the Aquitaine province was compiled by CETE Sud-Ouest (now Cerema Sud-Ouest) in 2005 (Piednoir et *al.*, 2005). Although based on interviews and not backed up by local measurements, this report affirms that the differential erosion processes, typical of those observed in the shadow areas of excavations such as those at Platin de Grave, could be driving the coastline retreat taking place at Le Verdon-sur-Mer and Soulac-sur-Mer. Three recent studies (BRGM and ONF, 2018, Castelle et *al.*, 2018 and I-Sea, 2020) based on a historical analysis of the positions of the coastline between 1950 and 2014/2019 show that, on the contrary, the coast lying in the shadow area of the Platin de Grave licence area has been accreting since 1974.

Moreover, Piednoir et al. (2005) consider that a potential extraction site is less likely to have an impact on coastline change at the mouth of the Adour, given the very low sediment fluxes.

Lastly, past dredging works in the shipping channel north of the Mâtelier deposit between 1979 and 1982 increased the rate of bank migration from 2.8 to more than 160 m/yr (Heurtaux, 2004), implying that these dredging operations were having a direct impact on the hydrosedimentary dynamics of the sediment banks in the Gironde estuary.

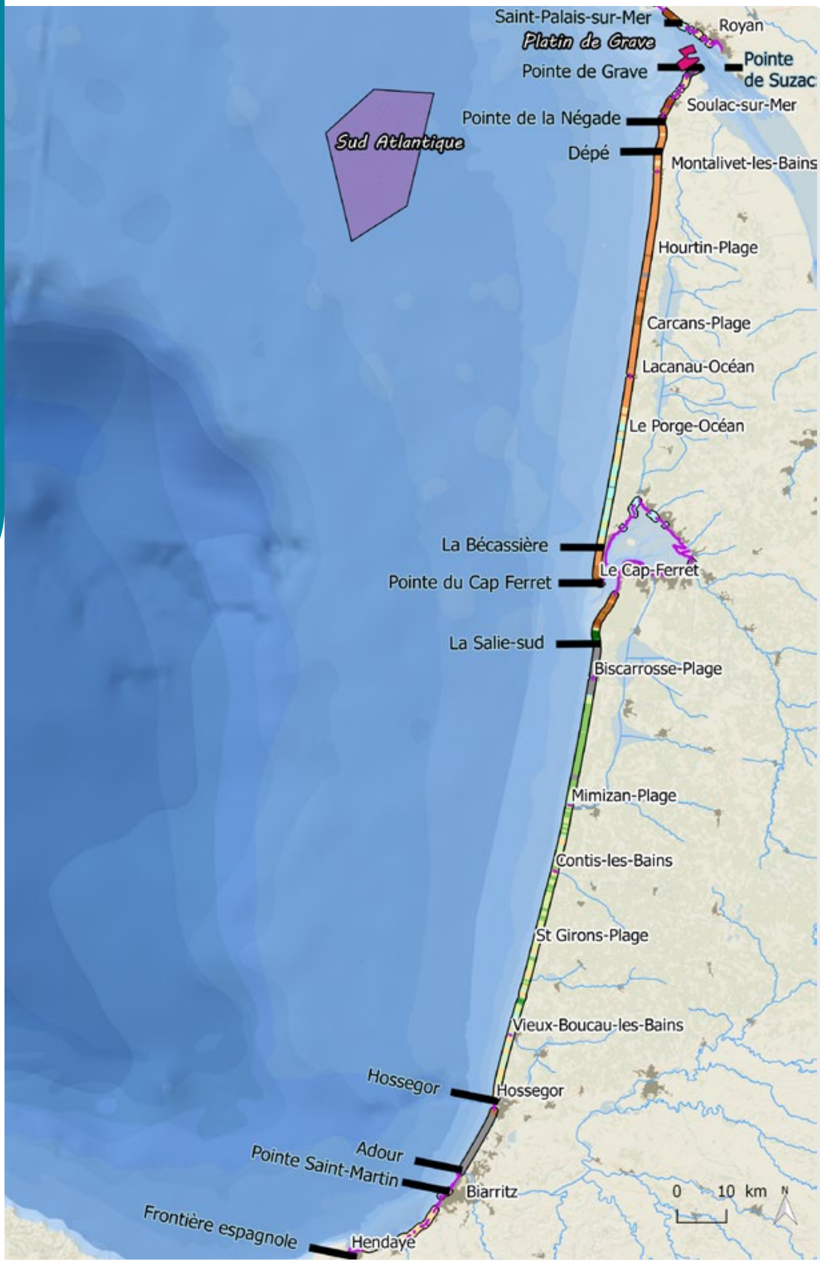


Figure 23 – *Location of aggregate extraction sites, boundaries of known coastal cells and coastline change*

- Sources: National indicator of coastal erosion (Cerema and MTES, 2018) and aggregate extraction data (Ifremer, March 2019)
- Base map: ESRI Shaded Relief, Ifremer bathymetry, Bd-Topo IGN

Produced by: Cerema, JUNE 2021

KEY FIGURES FOR THE PROVINCE:

LENGTH OF COASTLINE
628 km

TYPES OF COAST:
4% cliffs and rocky coasts
83% undergoing deposition
13% hardened coasts.

COASTLINE CHANGE

41% retreating (of which 13% at between 0.1 and 0.5 m/yr and 19% at between 0.5 and 1.5 m/yr)

16% changing imperceptibly

43% accreting (of which 20% at between 0.1 and 0.5 m/yr and 18% at between 0.5 and 1.5 m/yr)

COASTAL CELL
10 cells identified

LENGTH AFFECTED BY COASTAL DEVELOPMENT
208 km
(i.e. 33% of the coastline)

ANTHROPOGENIC IMPACTS
Extraction sites authorised in 2020:
1 licence area (1 offshore site)

Link between extractions and coastline change:
not established

SUMMARY OF SCIENTIFIC KNOWLEDGE OF THE VARIOUS HYDROSEDIMENTARY PROCESSES THAT CAN RESULT IN MARINE AGGREGATE EXTRACTION HAVING AN IMPACT ON THE COASTLINE

3.1. INTRODUCTION

The question of how a coastline is affected by an aggregate **dredging area** was examined in the early 1980s at the instigation of IFREMER (ex-CNEXO) following the inventory of mineral resources available on the continental shelf. The studies were funded with support from CEREMA (ex-STCPMVN), the decentralised services of the French Ministry of Equipment (Aquitaine Regional Division, Pyrénées-Atlantiques Regional Division), the committee in charge of managing the special levy ('taxe parafiscale') on aggregates, and the UNPG (ex "syndicat national des armateurs extracteurs de granulats marins").

The studies were commissioned from the French Central Hydraulics Laboratory (LCHF), now a part of the Artelia Group, which in the 1970s conducted several research projects studying coastal sediment movements under wave action and the protection of coasts affected by erosion such as that of Anglet (Pyrénées-Atlantiques).

3.2. FIRST STUDIES: THE CASE OF THE BAY OF BISCAY

3.2.1. PRELIMINARY RESEARCH

This preliminary research included a theoretical component to develop empirical formulae, which were validated by field measurements (Migniot and Viguier, 1980). These concluded that the limit of wave action on sand was located at a depth of -30 m**CD** off the Aquitaine coast, for wave conditions in the Bay of Biscay including a significant height of up to 7 m.

This research also demonstrated that sediment movements became significant in depths of less than -15 m**CD**, with the generation of **longshore drift** and appreciable morphological variations. This limit corresponds to what coastal engineers now refer to as the morphodynamic **closure depth**.

3.2.2. MORPHODYNAMIC CHANGES IN A DREDGING AREA IN A MOVABLE-BED SCALE MODEL

On the basis of these initial results, the studies commissioned from the LCHF between 1979 and 1983 involved performing scale-model tests of morphodynamic changes in an 800,000 m^3 dredging area (800 m x 200 m by 6 m deep) created on a uniform sandy coast (a single standard profile) representative of the Bay of Biscay (gentle slope in the order of 1.5% between -28 mCD and the coast with sand of a median diameter of 0.25 mm) subject to the representative and exceptional variations in tide level and wave conditions at this site (annual storm with a significant wave height of 5.5m and exceptional storms of 7.1 m and 8.7 m).

The first tests were performed initially in a wave flume and continued in a 3D wave and current tank, to test aspects including the influence of wave obliquity and the associated coastal currents. They tested the influence of positioning a dredging area oriented parallel to the shore at depths between –6 mCD and -25 mCD (Migniot and Viguier, 1980). **Figure 24** presents the overall layout and a typical cross-section of the seabed profile tested.

These tests showed that it was vital to position a dredging area of this type outside the upper shoreface (depth of -16 mCD) to prevent sediment transport being trapped and the dredging area quickly filling in. It was also important to allow a margin to prevent beach drawdown, which could affect the coastline, by adopting an average depth of -21 mCD.

A second series of tests (Viguier et al., 1984) then consisted in increasing the width of the dredging area (based on two alternatives 360 and then 560 m wide, creating volumes of 1.05 and 1.45 million m^3) and examining the impacts in terms of dredging area infilling and effects for the coastline, and then in testing the influence of obliquity and currents.

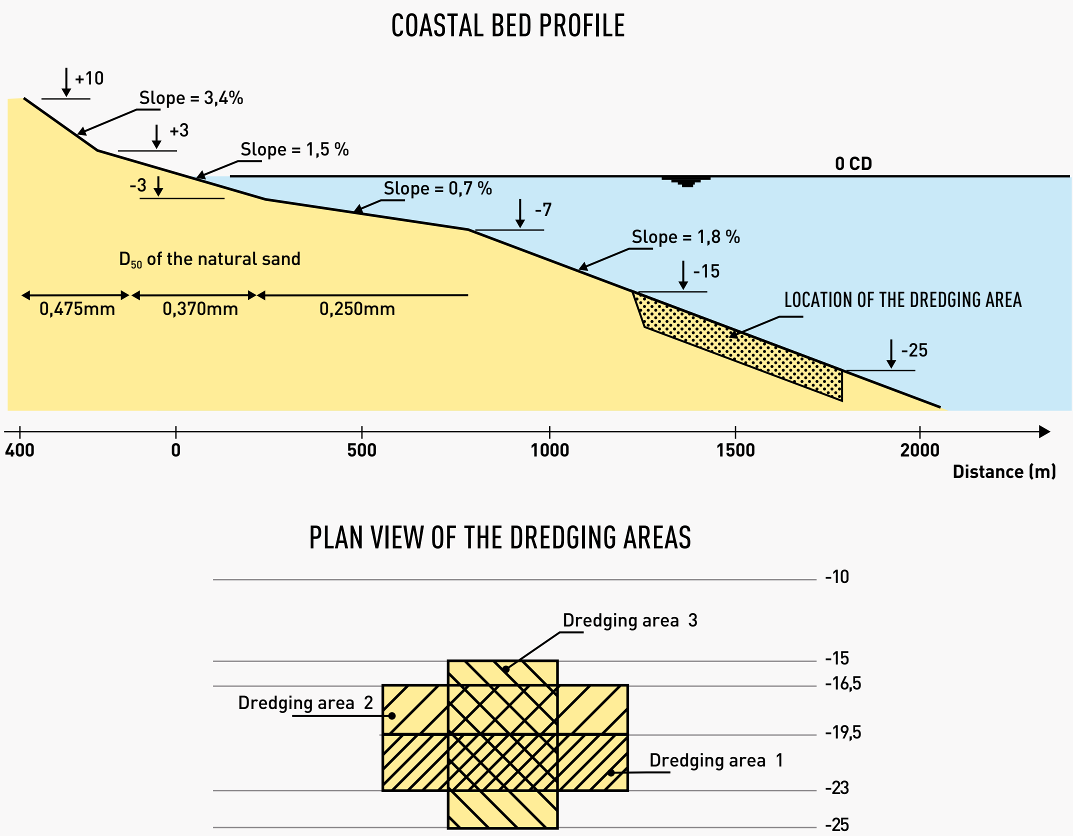


Figure 24 – ***Experimental conditions for the wave tank tests*** *(daccording to Viguier et al.,1984)*

3.2.3. IMPACTS ON THE COASTLINE AND CRITERIA TO RESPECT

The set of results obtained was analysed in order to clarify the impacts observed and obtain criteria for positioning and sizing the dredging area. Three clear potential impacts on the coast were identified (Viguier *et al.*,1984).

The first is a potential direct impact on the coast through drawdown of the upper shoreface and the beach between the dredging area and the coast. This erosion fills in the dredging area by means of onshore-offshore sediment transport. Regarding this point, the recommendation is to position the landward boundary of the dredging area (top of the slope) more than 400-500 m beyond the upper shoreface. This boundary is defined by a depth estimated to be 1.6 times the significant wave height of the annual storm[22].

The second potential impact relates to a remote impact of the dredging area, modifying the conditions of wave refraction during nearshore transformation, creating an onshore wave height and direction gradient that modulates longshore drift and then modifies the coastline, with sedimentation behind the dredging area and erosion on both sides. This is a cumulative effect that cannot be seen directly on the wave measurements.

Two recommendations are made to avoid this second impact:

- First of all, it is preferable to create a dredging area parallel rather than perpendicular to the coast, so as to limit the cross-shore distance over which wave refraction is modified,
- Secondly, limit the depth of the dredging area to ensure that the difference in wave celerity between the natural bed and the dredging area bed remains acceptable.

An empirical formula is provided for practical application. Applying this formula means limiting the (width, depth) pair to (200 m, 6 m) or (300m, 4 m) in the conditions studied.

A third potential impact concerns the rate of dredging area infilling, which in this case, in the tests performed, results in sand being trapped through longshore transport (i.e. parallel to the coast). This infilling is very significant within the upper shoreface (where longshore transport takes place), and this case was ruled out from the start for performing the physical scale model tests.

Outside this zone the tests showed that the impact remains low when the above recommendations are followed, other than in the event of a strong current (1 m/s) on the seaward side of the upper shoreface. A strong current can transport substantial quantities of sediment put in motion by waves.

3.2.4. GENERALISATION OF THE RESULTS

Following this work, Ifremer (Cayocca et Béryl du Gardin, 2003)[23] proposed a series of national recommendations to limit the impact of aggregate extraction on the coastline by drawing on the three processes identified above and adding the case of extraction on sand **banks**.

a) Drawdown of the upper shoreface and the beach between the dredging area and the coast:

This is a process that can potentially fill in the dredging area through onshore-offshore sediment transport. This impact, resulting from the dredging area being located too close within the active upper shoreface, can be avoided by positioning this area beyond a maximum depth. This is defined as the morphodynamic closure depth, which is generally more restrictive than that defined by the LCHF and estimated using the formula developed by Hallermeier (1978, 1981) and updated by Nicholls *et al.* (1998).

22 For example, in this case the significant wave height of the annual storm is 5.5m. Applying the recommendation produces a maximum breaking depth of -9 mCD. The distance of 400-500m on an average slope of 1.5% hence positions the landward boundary of the dredging area at a depth of -15 to -16.5 mCD, which is beyond the closure depth, estimated previously to lie at -15 mCD.

23 Ifremer has published these recommendations on its website: https://wwz.ifremer.fr/gm/Comprendre/Soutien-a-la-puissance-publique/Les-granulats-marins/Granulats-marins/Environnement/Effets-sur-la-stabilite-du-littoral *b) Modification of the conditions of wave refraction during nearshore transformation*

Ifremer repeated the LCHF's tests on a numerical model and was able to visualise this process, which leads to a shadow area behind the dredging area in which the wave heights diminish, thus creating a modulation in longshore transport between the unaffected zones and this shadow area (see **Figure 25**).

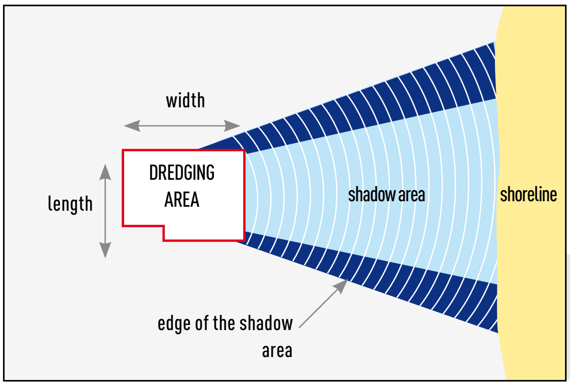


Figure 25
Effect of a dredging area on wave transformation *(according to Ifremer)*

In this regard, like the LCHF, Ifremer proposes to mitigate this impact by limiting the extraction depth and reducing the width of the dredging area, and adds a third criterion: the distance of the dredging area from the coast.

Ifremer proposes a new calculation formula to determine these three parameters. In practice, this formula is quite difficult to apply as it means calculating average wave lengths along the profile between the dredging area and the coast. Ifremer recommends conducting numerical simulations to fine-tune the calculation, which will subsequently be the rule used for implementing impact assessments.

c) Trapping of sediment outside the upper shoreface

This process is quoted by Ifremer, which recommends positioning the dredging area outside the active transport zone in order to ensure that it does not intercept longshore and cross-shore drift.

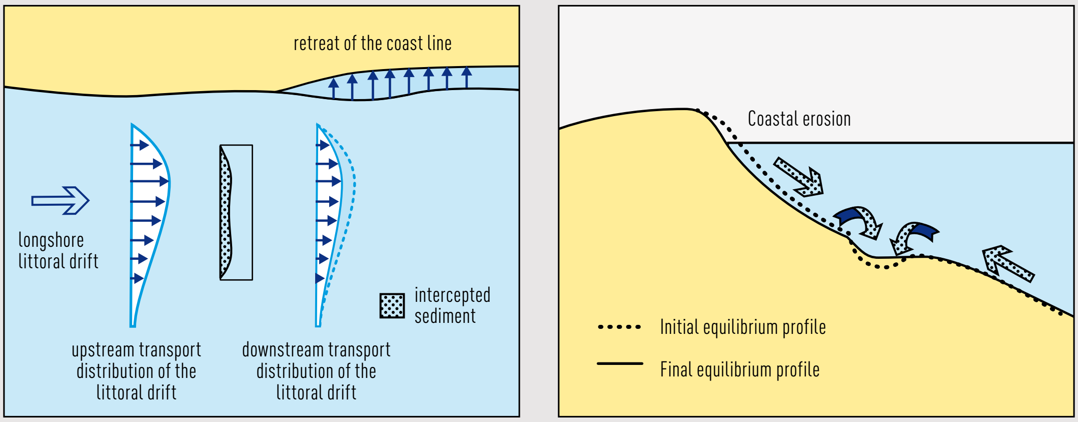


Figure 26 – ***Sediment interception methods*** *(according to Cayocca et Béryl du Gardin, 2003)*

The formula for establishing the start of sediment motion for the median annual wave conditions, developed by Hallermeier (1981), is proposed to define the limit of the active zone[24].

24 As an illustration, one can consider the case of the Aquitaine coast, with a median annual significant wave height of 1 m and a return period of 10 seconds, producing a depth of 28 m which is consistent with the values estimated by the LCHF.

d) Extraction from a coastal sand ***bank***

This fourth process, which was not studied by the LCHF, is also described by Ifremer. It involves extraction from a sand bank culminating at a depth "*d*", causing the bank elevation to be lowered by a depth "*p*" (see **Figure 27**).

In this case, Ifremer provides a qualitative recommendation for wave breaking, which is likely to be reduced. This increases the onshore wave heights, which in turn can cause coastal erosion if the reduction in sand bank height is excessive. However, Ifremer does not define the maximum extraction depth p to be respected.

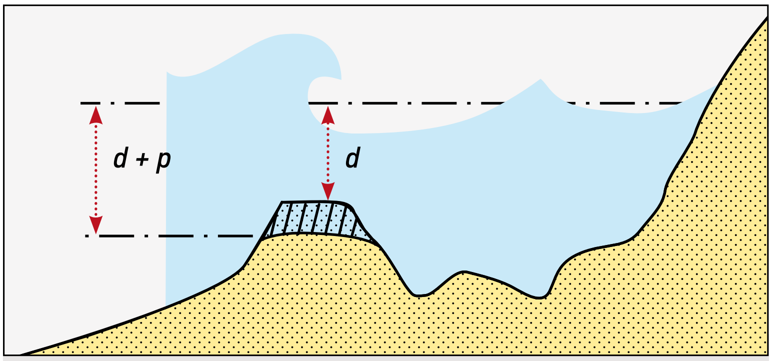


Figure 27 – ***Effect of extraction on a sand bank*** *(according to Cayocca et Béryl du Gardin, 2003)*

3.3. SUMMARY OF THE STATE OF THE ART IN FRANCE (LATTEUX, 2008)

Following the above research, complemented by the results from the European project SANDPIT (**see below**), in 2008 Ifremer appointed an independent expert, Bernard Latteux, to write a summary entitled "Exploitation de matériaux marins et stabilité du littoral" ("Exploitation of marine materials and coastline stability"), which was published by Éditions QUAE.

- A short introductory chapter summarises marine aggregate extraction activities in France.
- Chapter 2 describes in detail the physical processes and factors involved, including a set of formulae for calculating the intensity of sediment transport under wave and current action.
- Chapter 3 lists the potential impacts on the physical environment (hydrodynamics and sediment beds).
- Chapter 4 lists the tools that exist for assessing the impact of an extraction site, placing the focus on numerical modelling rather than physical scale modelling.
- The last chapter is devoted to selecting an extraction site and performing the impact assessment.

This document is a fairly comprehensive compilation of the research that had been published on this topic at the time, mainly in the field of numerical modelling (case studies are rare), complementing the physical modelling-based approach used by the LCHF. It also extends the topic to sites subject mainly to ocean currents (sand banks in the English Channel and the North Sea). It does not provide any new knowledge on potential impacts for the coastline.

3.4. THE EUROPEAN SANDPIT PROJECT (2002-2005)

The European SANDPIT project brought together 17 European institutes, three of which were French (university of Caen, Cerema (ex-Cetmef) and Artelia (ex-Sogreah)) between 2002 and 2005 with the aim of developing recommendations and forecasting tools to better understand and predict morphodynamic changes at sediment extraction sites in the coastal zone and their area of influence (excluding the upper shoreface and the coastline) with a particular focus on short-term numerical modelling and the measurements required to validate the simulations. This project enabled the French researchers to exchange information and documentation with their European peers and thus gain insight into international research.

It was also an opportunity to compare the different practices applied in each country, especially in terms of criteria for positioning dredging areas as a function of depth. An initial criterion concerning drawdown of the beach and upper shoreface tallies with the French recommendation to position dredging areas beyond -15 mCD to avoid direct impacts on the coastline and preferably create the dredging area parallel to the shore. A second, longer-term impact concerns the possibility of movement from the upper shoreface towards the beach of sediment that could be extracted in the dredging area and removed from the system or even simply intercepted by the dredging area. A limit of -25 mCD is proposed, beyond which this upward movement is considered negligible. The estimated limit of sediment movement under wave action is the same as that calculated by the LCHF, i.e. -30 mCD.

This project also provided opportunities to examine several types of site, including the areas of underwater banks in the English Channel and the North Sea, for which the criteria developed for the Bay of Biscay are not completely suitable.

It also highlighted the variety of reasons for extracting marine aggregates, including the development of beach nourishment as a sustainable method of combatting coastal erosion, especially in the Netherlands. In this particular case, the extracted sand is returned to the system by being placed on the beaches, so there is no net loss and the dredging area positioning criteria defined by the Dutch government are therefore less strict.

3.5. RESEARCH IN THE UNITED KINGDOM

3.5.1. IDENTIFICATION OF IMPACTS AND INITIAL RECOMMENDATIONS

The UK has a long history of marine aggregate extraction, and a large volume of research has been devoted to this topic since the 1960s. Recollections of the destruction of 29 houses in the coastal village of Hallsands in Devon during the storm of 26 January 1917 also feature prominently in the British literature. This disaster was subsequently found to be due to the large-scale removal of shingle and gravel from the foreshore between 1897 and 1917 to meet the requirements of port development works at Devonport[25].

Price *et al.* (1978) were the first to pinpoint the four processes that can influence the coastline, in other words:

- Drawdown of the upper shoreface and beach,
- Interception of landward transport of sediment liable to supply beaches,

25 http://jncc.defra.gov.uk/pdf/gcrdb/GCRsiteaccount1836.pdf

- Lowering of the crest elevations of underwater **bars** and banks acting as natural shore defences against the force of the waves,
- Changes to wave refraction potentially altering the distribution of longshore drift and, hence, changing the coastline.

These reflect the main points developed in France, coupled with the issue of preserving underwater sources supplying beaches with sediment (sand and gravel).

The criteria and recommendations developed in this article to avoid these impacts are the following:

- Position the dredging area beyond the closure depth, estimated here at -10 mCD to avoid any risk of drawdown,
- Position the dredging area beyond the depth at which sediments potentially involved in beach nourishment start to move; a limit of -18 mCD is provisionally recommended for sites with weak currents, possibility extended to -22m CD if the currents exceed 1 m/s,
- Prohibit the dredging of bars and banks that protect the shore, other than in exceptional cases,
- It is recommended to perform a numerical model study to estimate impacts on wave refraction and longshore drift. Initial calculations on a specific site indicated a limit of -14 mCD beyond which this effect became negligible..

3.5.2. BRITISH REFERENCE GUIDESS

In 2002 the UK government introduced a new Aggregates Levy in order to promote sustainable exploitation. Part of this levy is devoted to marine aggregates via the Marine Aggregate Levy Sustainability Fund (MALSF), which financed research into the environmental impacts of this activity between 2002 and 2011[26] . This research notably included exhaustive regional seabed surveys. In this context, a 357-page guide defining best practices in environmental impact assessment was published in 2004 (Posford Haskoning, 2004). It draws on the four potential impacts defined above and gives practical recommendations for assessing their scale and then mitigating them.

More recently, a specific guide to the impact of extraction on coastlines was published jointly in 2013 by The Crown Estate (the organisation that owns and manages the foreshore and territorial seabed of the UK and issues licences for extraction) and the British Marine Aggregate Producers Association (BMAPA).

3.5.3. REGIONAL IMPACT ASSESSMENTS

In 2008, a series of four regional hydrosedimentary impact assessments was conducted by aggregate producers associations, to examine the cumulative impacts of past, present and future extraction in preparation for licence renewal studies. A handbook of recommendations concerning the method to be used for these regional studies was first drawn up, and they were then performed by various design offices (including HR Wallingford, 2011).

None of these studies found impacts on the coast from past or present extraction activities. However, some of their conclusions have been contested by associations. A typical example concerns erosion of the Great Yarmouth coast, which the Marinet association[27] claims is due to offshore aggregate dredging. A detailed feedback review was hence conducted on this site (**see section 3.6.2 below**).

26 https://tethys.pnnl.gov/publications/marine-aggregate-levy-sustainability-fund-malsf-achievements-and-challenges-future

27 http://www.marinet.org.uk/further-evidence-of-dredging-induced-coastal-erosion.html

3.6. FEEDBACK FROM EXTRACTION SITES

3.6.1. GERMAN COAST OF THE BALTIC SEA

This feedback review was performed in the context of the European Eumarsand project which brought together nine institutes, mainly from Northern Europe, and focused on two study areas: one involving extraction from an underwater sand bank off the coast of Belgium without any direct impacts on the coastline, and the other involving two extraction sites in the Baltic Sea located very close to the German coast..

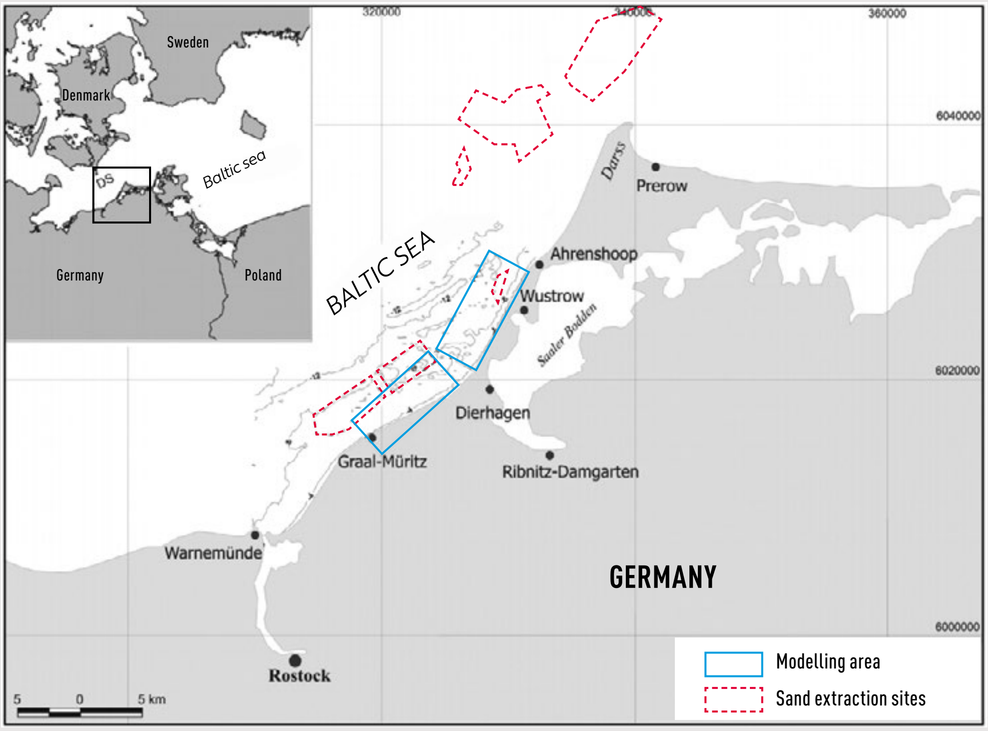


Figure 28 – *Locations of the extraction sites indicated by dotted lines (according to Kortekass et al, 2010).*

The German coast of the Baltic Sea between Warnemünde and Ahrenshoop has been subject to chronic erosion in the order of 0.3 to 0.7m/yr for more than a century. This has led to the construction of many coastal defences, complemented by beach nourishment using sand extracted from offshore sites. The two main sites are located off the town of Graäl-Muritz, between 2.5 and 5.5 km from the coast, at depths of 8 to 12m. Materials are extracted at a depth of about a metre, because the sediment cover is thin. This area is dominated by currents and includes mobile sand banks. Local wave motion is light (the five-year storm has a significant wave height of 1.5m and a mean period of 6 seconds), but waves reach the coast at a very steep angle, generating north-easterly longshore transport driving the formation of a sand spit. The estimated closure depth is 4m.

Comparisons of the bathymetric data (1979 and 2002) and the historical positions of the coastline between 1953 and 2002, and model studies of the wave fields and longshore drift, failed to find any relationship between the sand dredging areas and the zones subject to erosion along the coast. On the other hand, strong correlations were found between these erosion processes and the construction of hard sea defences, two detached breakwaters in particular (Kortekaas *et al.*, 2010).

3.6.2. THE COAST OF GREAT YARMOUTH, UK

This stretch of coastline, in east Norfolk on the east coast of England, is changing in a particularly complex manner because of a series of mobile underwater sand banks that run parallel to the coast. Aggregate extraction firms have been granted a series of licences to dredge on the seaward side of the sand banks closest to the shore. It is these dredging activities which are currently accused of causing coastal erosion, especially in the Hemsby sector.

Figure 29 presents an overview of the sector including all the licence areas and their various statuses (5 in total) with different colours to indicate their boundaries. The black dotted line indicates the area covered by the detailed bathymetric map of the sand banks in **Figure 30**. The locality of Hemsby is situated at the north edge of this area.

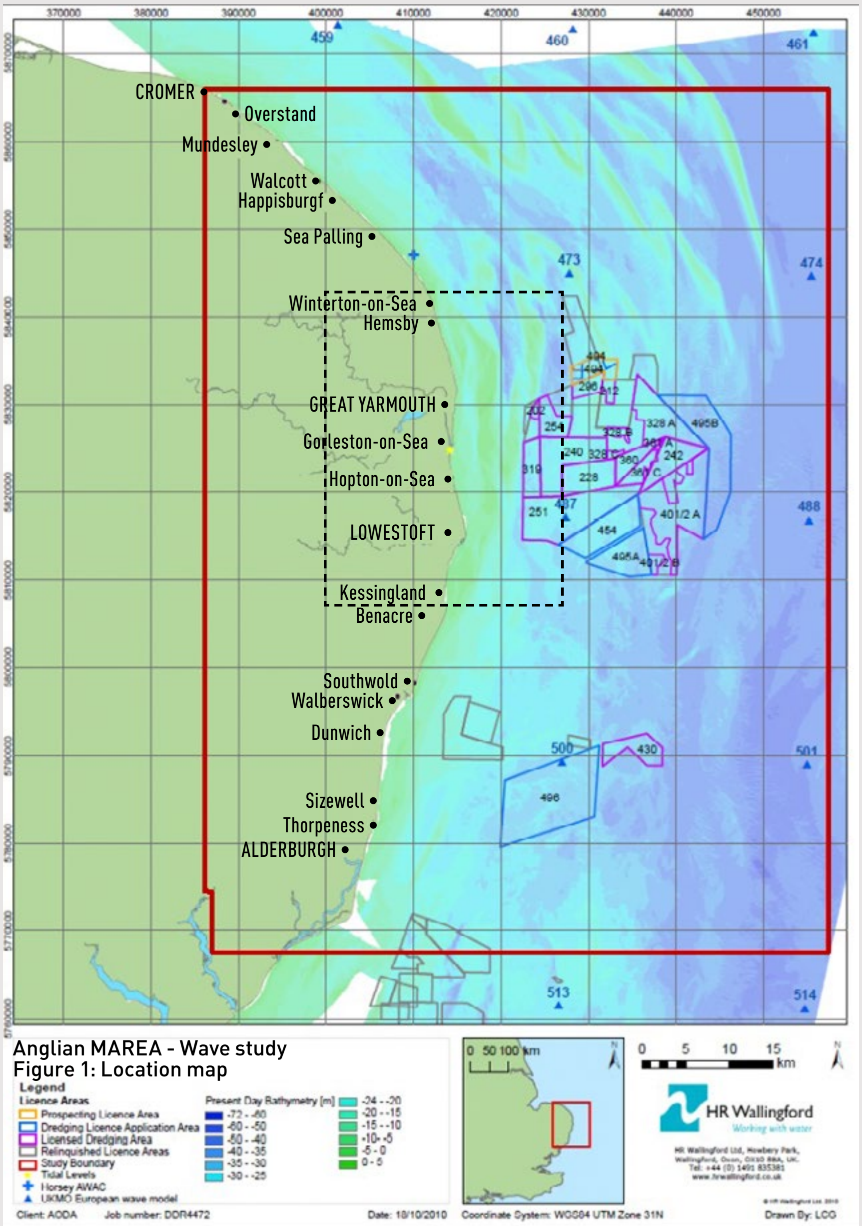


Figure 29 – Great Yarmouth: General bathymetry and aggregate extraction sites (according to HR Wallingford, 2011)

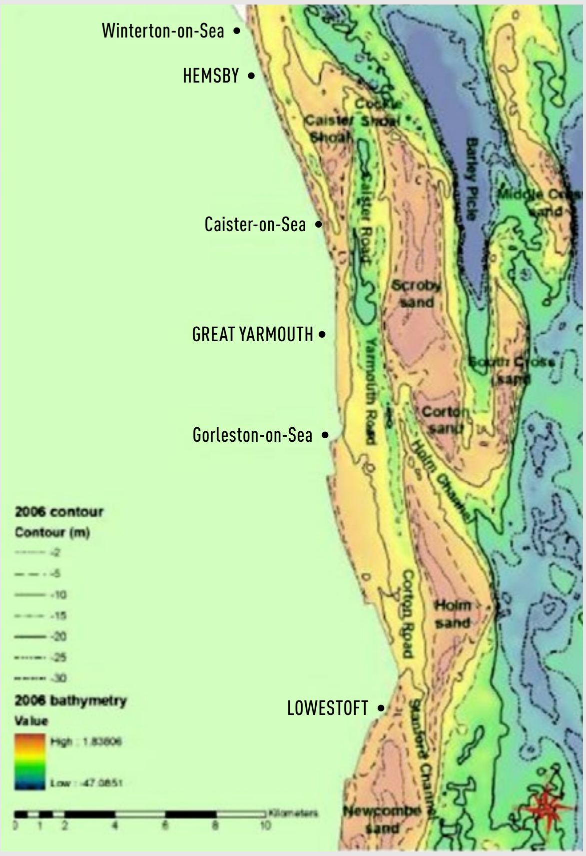


Figure 30 – *Great Yarmouth. Detailed map of sand banks, 2006 bathymetry*
(according to Jacobs, 2018)

The calculations performed to establish the impacts of the licence areas on wave transformation did not find any impacts for the coast (HR Wallingford, 2011). Detailed studies have also been performed on past changes to these sand banks (Jacobs, 2018 provides a summary). They revealed net accretion in volume between 1974 and 2014 causing them to expand width-wise towards the coast, thus shifting the coastal channel landwards by reducing its section (**Figure 31**). It is this displacement which is leading to beach erosion.

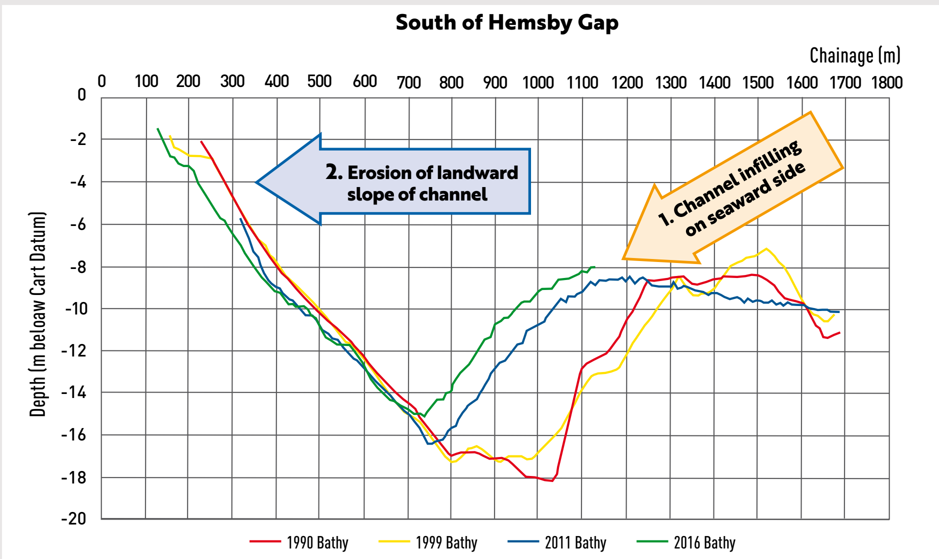


Figure 31 – *Great Yarmouth. Changes to the beach profile in front of Hemsby*
(according to Jacobs, 2018)

3.6.3. PAKIRI BEACH, NEW ZEALAND

Pakiri beach is located on the east coast of the North Island of New Zealand. It is subject to local swell (significant wave heights of less than 3 m), but is also exposed exceptionally to tropical storms such as that of 1978, when estimated offshore significant wave heights reached 8 m combined with a period of 12 s, for an estimated event return period of 10-30 years.

This storm caused widespread coastal erosion and a programme of beach profile monitoring was undertaken to find out, in particular, whether sand dredging operations in the upper shoreface (at depths less than 10m) could be inducing part or all of this erosion. The study by Hilton and Hesp (1996) analyses 15 years of topographical monitoring data from this beach, a task made more complicated by the fact that the beach had undergone maintenance and nourishment works. This study shows that the beach is slowly re-forming, after the shock of the 1978 storm. The profile is slowly being rebuilt by cross-shore sediment transported from the upper shoreface under the effect of the usual wave motion occurring at this site.

Sand has been dredged from this upper shoreface since 1940 under the terms of licences that are updated regularly for a volume of around 100,000 m^3/yr. The dredging takes place 300 m from the shore at depths of 3 to 8 m over a length of 9.5 km. Each campaign involves digging an area two metres deep over a few tens of square metres, which then infills quickly under wave action.

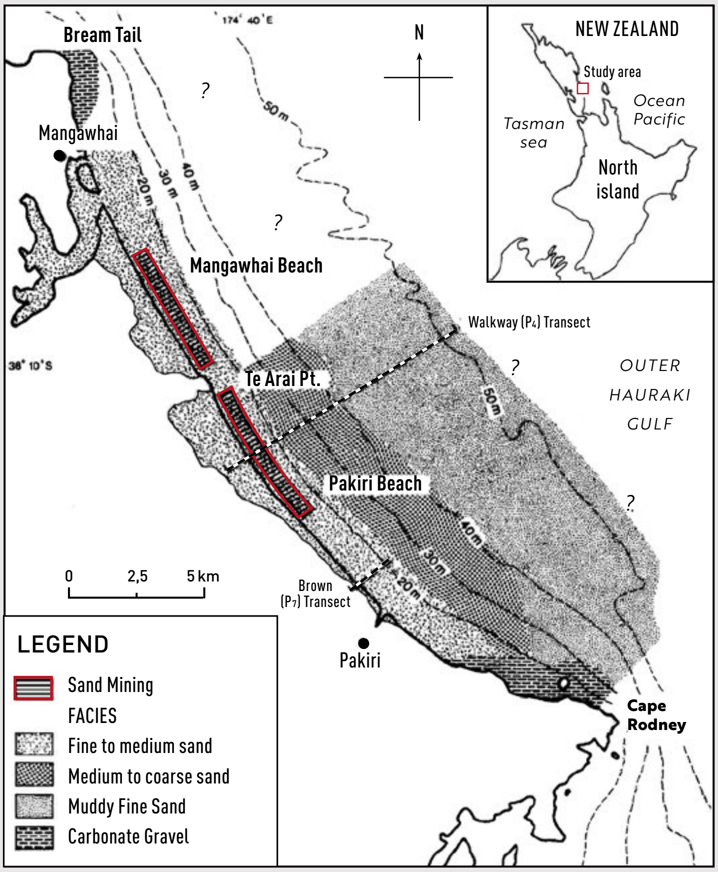


Figure 32 – *Pakiri beach* (according to Hiltonand Heps, 1996)

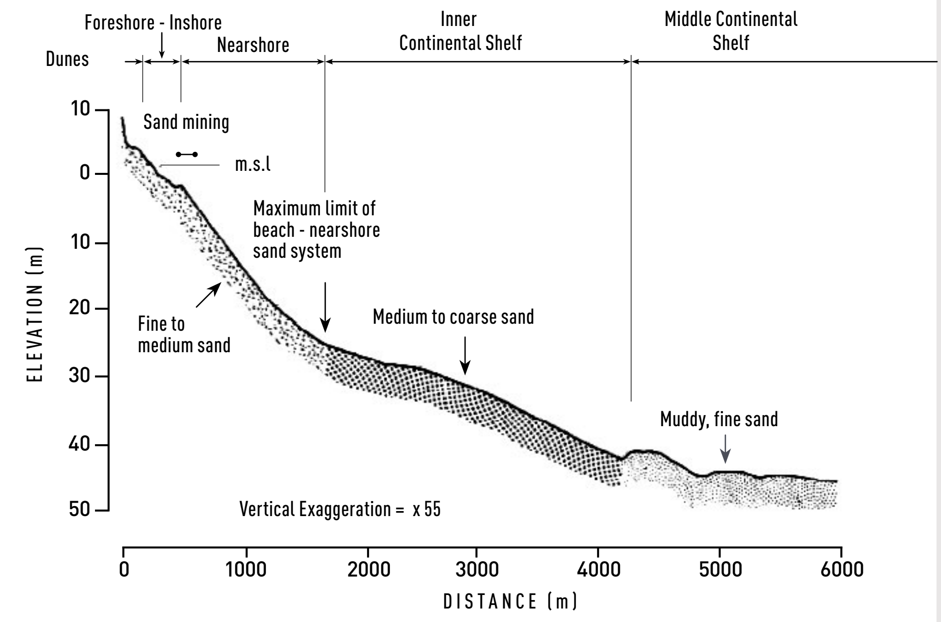


Figure 33 – ***Representative profile of Pakiri beach*** *(according to Hilton and Heps, 1996)*

The licences are renewed following environmental impact assessments indicating that the impact of this dredging is nil, since the coastline has been accreting since 1978, the volumes extracted are small and the dredging areas are infilled with sand carried up from the continental shelf.

The Hilton and Heps study focuses on this last aspect, by investigating the limit of interaction between the continental shelf and the coastal zone.

A literature review carried out to this end highlights seven criteria that can be used to estimate the limit of interaction:

- An analysis of the beach and shoreface profiles between the dune and the continental shelf,
- Estimates of the closure depth,
- The maximum seaward extent of rip currents,
- The bedforms present (ripples, dunes),
- The grain size distribution of the bed,
- Distribution of benthic fauna along the profile.

These criteria are then reviewed. They converge around a limit of -25m, 1500 m from the coast, beyond which there is no sandy sediment movement. This depth also marks a change in the profile slope, which becomes significantly milder. The theoretical calculations of critical stresses for initiation of sediment motion confirm this estimate. The closure depth is estimated at -12/-14m by comparing the bathymetric surveys, while Hallermeier's formula (1978) gives a depth of -10.1m.

In these conditions, the authors conclude that the limited period of observations (15 years between 1978 and 1993) and the absence of baseline bathymetric data prior to the start of sand dredging make it impossible to confirm the impact of the dredging on the position of the coastline. However, they believe they have demonstrated that the stock of sand is limited between the coast and a depth of -25m and that, therefore, the continued dredging of even small quantities of sand in the active zone (on the landward side of the closure depth) is contributing to depleting the stock, thus reducing the resilience of the coast following a rare tropical storm. This reduced resilience is, moreover, demonstrated at the site by comparison with neighbouring sites.

3.7. CONSIDERATION OF CLIMATE CHANGE

Coastal studies performed nowadays in France and around the world address changes to forcing factors related to climate change, especially rising sea levels. This issue is becoming crucial in studies of erosion and coastal flooding risks and measures to improve the resilience of exposed areas. Historical research into the formation of present-day sedimentary shores is now being developed, as it provide insight into how these shores are likely to change in the future.

This section summarises the key results from this research in relation to the possible impacts of marine aggregate licence areas with potential for intercepting offshore-onshore sediment transport.

3.7.1. ORIGINS OF PRESENT-DAY COASTS

The present-day coasts were shaped largely by the rapid 120-metre rise in sea level (at about 10 mm/yr) which took place between -20 000 BP and -6 500 BP[28] during the Flandrian marine transgression. This sea level rise brought about landward sediment transport, shaping shorelines and coastal dunes as it also interacted with sediment inputs from rivers.

Sea levels continued to rise at a much slower rate between -6500 and -2000 BP (0.6 mm/yr), and then stabilised. However, they then began to rise again at the start of the industrial age, and the rate is accelerating (1.5 mm/yr in the twentieth century and 3 mm/yr over the past 20 years).

3.7.2. SHORT-TERM OFFSHORE-ONSHORE SEDIMENT TRANSPORT

Sediment transport from the continental shelf to the shore results from a set of physical processes that remain largely unexplored by research, which has - rightly - instead focused on sudden onshore-offshore losses of sediment during storm episodes. These can be catastrophic, as were those which struck the Atlantic coast of France during the winter of 2013-2014 (Bulteau et al., 2014; Castelle et al., 2015)

Moreover, the first studies on the consequences for coasts of a sea level rise (Bruun, 1962) concluded with an assumption that the distance of coastline retreat would be proportional to this rise. This assumption has been taken up and broadly discussed for more than 50 years, with various refinements. However, the very slow rate of sea level rise over the past 2000 years does not provide sufficient proof to validate this assumption in a quantitative manner (Le Cozannet et al., 2019).

Nevertheless, several studies have shown that these erosion processes are counteracted in the short term by sand being returned to the shore, either partially or completely and on relatively rapid time scales. Generally speaking a process of beach "breathing" can be observed on our coasts, with depletion during the winter under the effects of storms and replenishment during the summer. One study of the resilience of sandy coasts in England showed a wide variety of cases during exceptional storm events, from almost no sand being returned to the beach to rapid beach reconstruction (Brooks *et al.*, 2017).

28 BP = "Before Present". Used for dating events relative to the present day.

3.7.3. LONG-TERM RESIDUAL SEDIMENT TRANSPORT

Several studies in the Netherlands, Australia and the United States have provided insight into the long-term processes. Cowell et *al.*(2000) reviewed onshore transport of marine sand: this is a form of low-intensity residual transport which is often hidden by the widely varying upward and downward sediment transport induced by tidal currents and waves. Geologists have hence developed specific analysis methods to deduce these sand transport movements on the basis of coastal plain stratigraphy monitoring over periods of several millennia.

An example is given below for Moruya Beach, south of Sydney in Australia (Cowell et al., 2000), which has developed over 6500 years, advancing by about 2 km while maintaining a relatively constant sea level. **Figure 34** illustrates the successive layers of sedimentary land that have formed the coast as it exists today. This accretion is explained by the seabed being too high after the Flandrian marine transgression. This led to erosion and offshore-onshore transport of sand at an estimated rate of 7 m^3/m/year 6000 years ago, which has decreased to 3.3 m^3/m/yr today (**Figure 35**).

An important point to note here is the very long time scale required for the coastal system to adapt to a sea level rise that stabilised more than 6000 years ago. Another important point illustrated on **Figure 35** is the presence of seabed armouring, which is probably limiting transport of sand to the shore. Lastly, it can be seen that the seabed is eroding at an almost imperceptible rate of around 1.3 mm/yr on average and 0.5 mm/yr at present. Such thicknesses cannot be measured on a human scale.

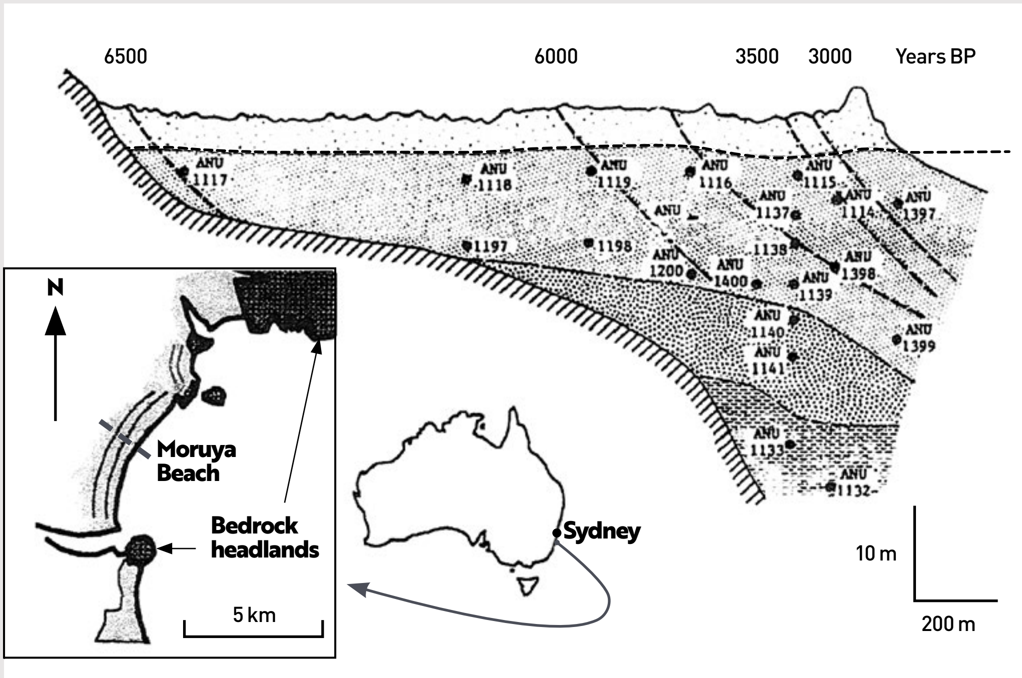


Figure 34 – *Surveys and carbon dating of the stratigraphy of Moruya Beach (Cowell et al., 2000)*

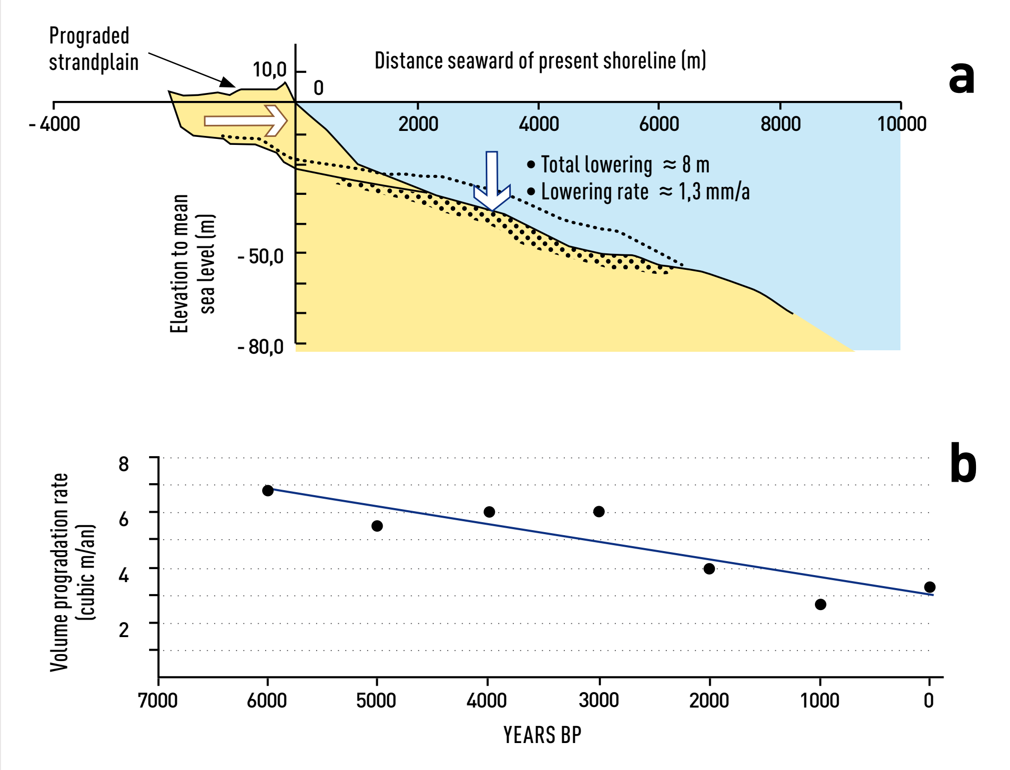


Figure 35 – *a) Process of Moruya Beach construction through seabed erosion and offshore-onshore transport of sand (according to Cowell et al., 2000) and b) rate of beach sedimentation in m³/m/yr*

Processes such as these have also been identified in other regions such as the Netherlands and the United States (Cowell et al., 2000). More recently, Houston and Dean (2014) studied changes along a 575 km long stretch of the east Florida coastline over a period of 150 years between 1860 and 2008. They established that the coastline advanced by 48 m on average, 25 m of which over the recent period between 1972 and 2008, during which intensive beach nourishment operations were carried out. They then sought to quantify the various sources of erosion and sedimentation and concluded that inputs of sand from offshore were a predominant source, offsetting the effects of sea level rise and losses at the mouths of lagoons.

A similar study which reached the same conclusion was performed on the south-west coast of Florida, providing a means of predicting the impact of various climate change scenarios on average coastline changes (Dean and Houston, 2016).

3.7.4. THE ROLE OF LOCAL GEOLOGY AND HUMAN ACTIVITIES

This predominance is not the norm on all coasts, however, and the most recent research (Cooper et al., 2018) indicates that local geological constraints dating back to the Flandrian marine transgression play a major role in these long-term processes.

Thus, Menier et al. (2019) investigated the possibility that Holocene relict sands in Etel bay (Morbihan, France) at depths between -25 and -50m were supplying the coast. Their analysis shows that, in this case, these sands are trapped in bedrock at a depth that prevents them from being carried onshore, with the rocky upper shoreface acting as a barrier (**Figure 36**).

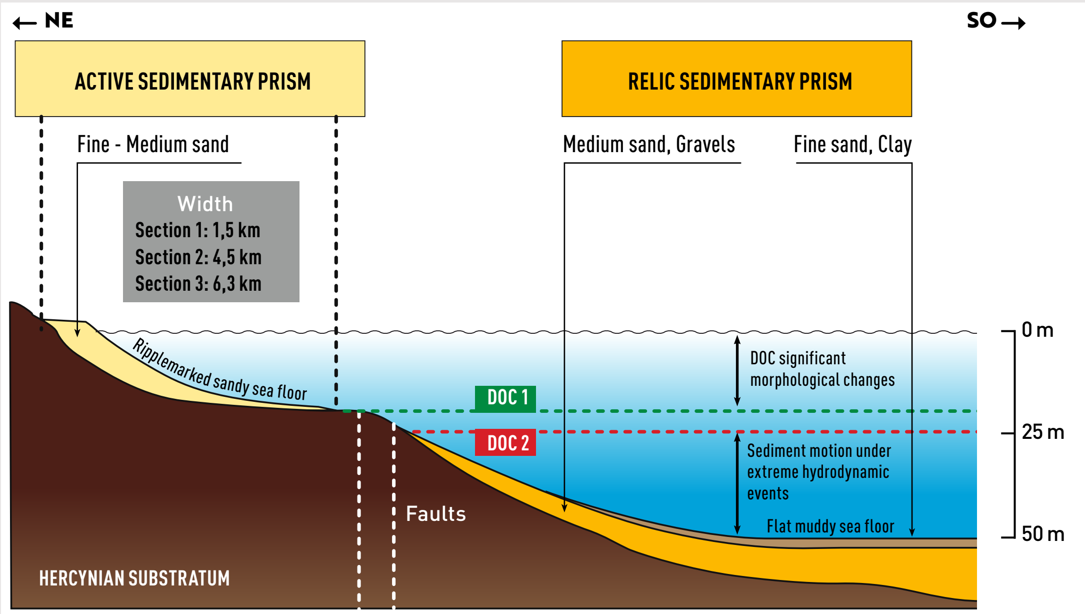


Figure 36 – *Disconnect between the active and relict sedimentary prisms in Etel bay (according to Menier et al., 2019).*

The overall impact of human activity has become so profound since the 1950s that a new geological epoch called the "anthropocene" can be defined (Waters et al., 2016).

Two major anthropogenic processes are shaping present-day coasts. The first of these is the construction of dams on rivers, leading to the retention of sediment and preventing coasts from being supplied naturally with sand (Syvitski and Kettner, 2011). Secondly, large numbers of structures have been built to hold coastlines in position (starting in the tenth century with dykes to reclaim land, followed subsequently by rockfill revetments, groynes and breakwaters), preventing them from adapting to meteorological and oceanic forcing.

These two human actions, combined with sea level rise, are liable to lead to "coastal squeeze" (also referred to as "coastal narrowing", Pontee, 2013), in other words the reduction of foreshore areas, erosion of dunes, steepening of beach profiles, and even the disappearance of beaches altogether. In parts of western Europe this is prompting managed realignment operations with the aim of reducing coastal risks (coastal flooding, coastline erosion) and restoring coastal ecosystems (Goeldner-Gianella, 2013)

A wide variety of cases have hence been studied and published, with some widely contrasting results. Cooper et al. (2018) conclude their study by stating that it thus seems quite difficult to formulate simple, consistent conclusions at an overall scale.

FEEDBACK FROM FRANCE

This chapter summarises the experience gained on a historical licence area at Le Pilier and three licence areas granted recently at Cairnstrath and Le Havre, with a view to pinpointing best practices to be adopted and disseminated. It explains how the approaches to the topic in impact assessments for aggregate extraction licence applications have evolved in line with developments in scientific knowledge.

4.1. LE PILIER (LOIRE ATLANTIQUE)

4.1.1. CONTEXT

The site of Le Pilier lies at the boundary between the outer Loire estuary and the entrance to Bourgneuf bay at the location of a palaeo-bed at depths of -16 to -18 mCD on its eastern side. It is 8 km from the nearest coasts (Pointe de Saint-Gildas on the mainland and Pointe de l'Herbaudière on Noirmoutier island) beyond the 3 nautical mile zone. It consists of medium to coarse sands (median diameter of 0.6 mm).

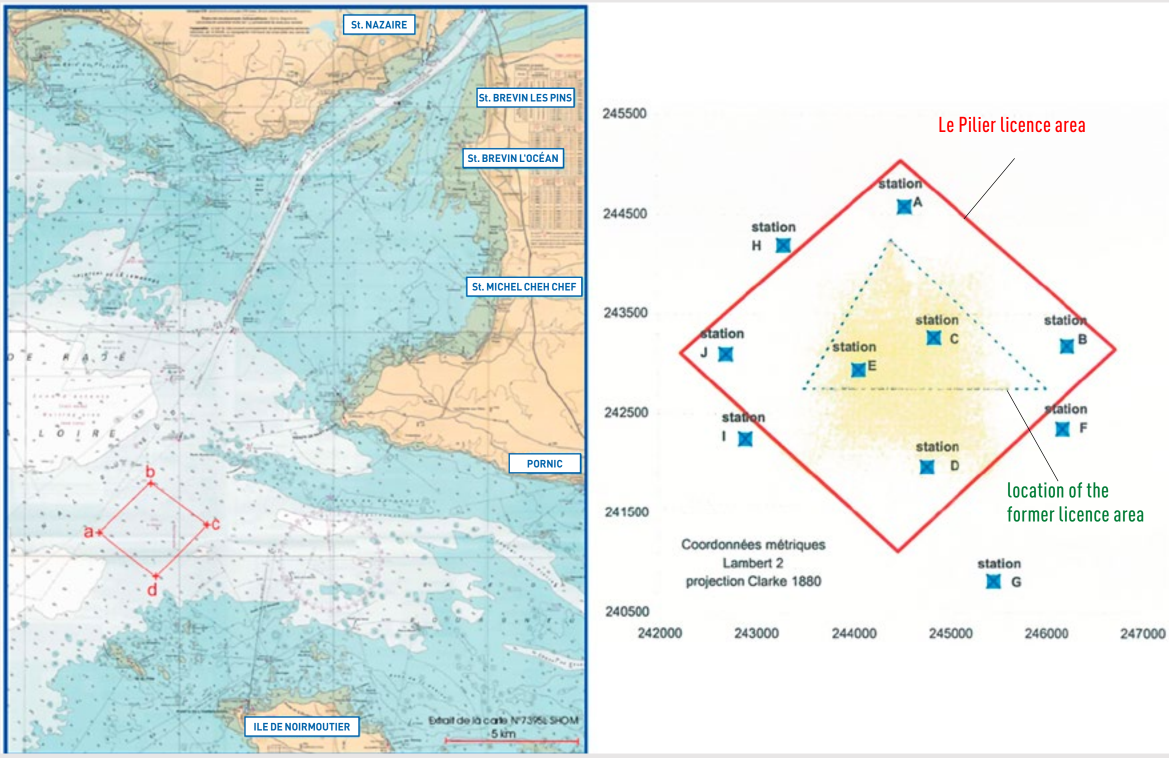


Figure 37 – *Locations of the present and former licence areas of Le Pilier* (Artelia, 2014)

4.1.2. PRELIMINARY IMPACT ASSESSMENTS

Extraction from the site began in 1986 on a small triangular licence area and continued for 13 years, during which 7.2 billion m^3 were removed. An impact assessment was performed by the university of Nantes in 1983 to back up the licence application. The position of the dredging area at a depth of -16 mCD complied with the LCHF's criteria and the results from the relevant formulae indicated that very little of this sand - of a median diameter twice that of the sand tested for the Aquitaine coast - would be put in motion. The dredging area depth was limited to 5m.

The licence area was subsequently extended in 1998 to cover an 8.2 km^2 square. The maximum authorised volume was increased to 2,260,000 m^3/yr and it was deepened to -26 mCD. A second impact assessment was carried out in 1994. It did not provide any new knowledge on impacts for the coastline. On the other hand, baseline studies performed in 1998-1999 provided important additional information for the production of a regional diagram of sediment transport, taking into consideration the complex nature of the bed on the basis of a side-scan sonar survey performed to complement a bathymetric survey. The licence area is separated from the north coast of Noirmoutier by a series of banks, channels and emerging rocks:

- North channel, continuing south-eastwards, at depths of -15 / -20 m CD;
- "Banc de la Blanche" bank culminating between -3 and -6 m CD, constituting a sediment stock in the order of 4 million m^3 above a depth of -6 m CD;
- "Chenal de la Grise" channel, with a thalweg at depths between -5 / -15 m CD, joining the north channel.

However, this study does not reach as far as the north coast of Noirmoutier. Calculations of the impact of the dredging area on wave transformation were also performed, although the results supplied do not go right to the coast.

4.1.3. FIVE-YEAR REVIEWS

Following presentation of the first five-year review (1999-2004) to the local information and monitoring committee (CLIS) in 2006, elected representatives on the island of Noirmoutier expressed concerns. They were worried about the impacts of extraction for erosion of the north coast of the island. The Prefect had an expert appraisal performed by the BRGM, and it was published at the end of 2008. The appraisal considered that the studies produced up to then were not sufficient to allay the elected representatives' concerns. It recommended performing a comprehensive hydrosedimentary modelling study covering a large area to assess the changes induced by digging the dredging area.

The consortium of extraction firms integrated these recommendations in preparing the second five-year review (2005-2009). A literature review, complemented by a comprehensive hydrosedimentary modelling study, was performed by Artelia (ex-Sogreah) and submitted to the authorities, which appointed experts from three public institutions (BRGM, CEREMA and Ifremer) to validate its conclusions. A discussion was held with each of these institutions in order to finalise the study in an executive summary, the conclusions of which were carried over to the updated version of the regional map representing sediment transport (**Figure 38**).

This map shows the three independent sediment pathways in the north channel, over La Blanche bank and along the north coast. A notable finding of the literature review was that the erosion of the north coast was caused by construction of l'Herbaudière harbour, which blocks the incoming sediments from the upper shoreface to the west..

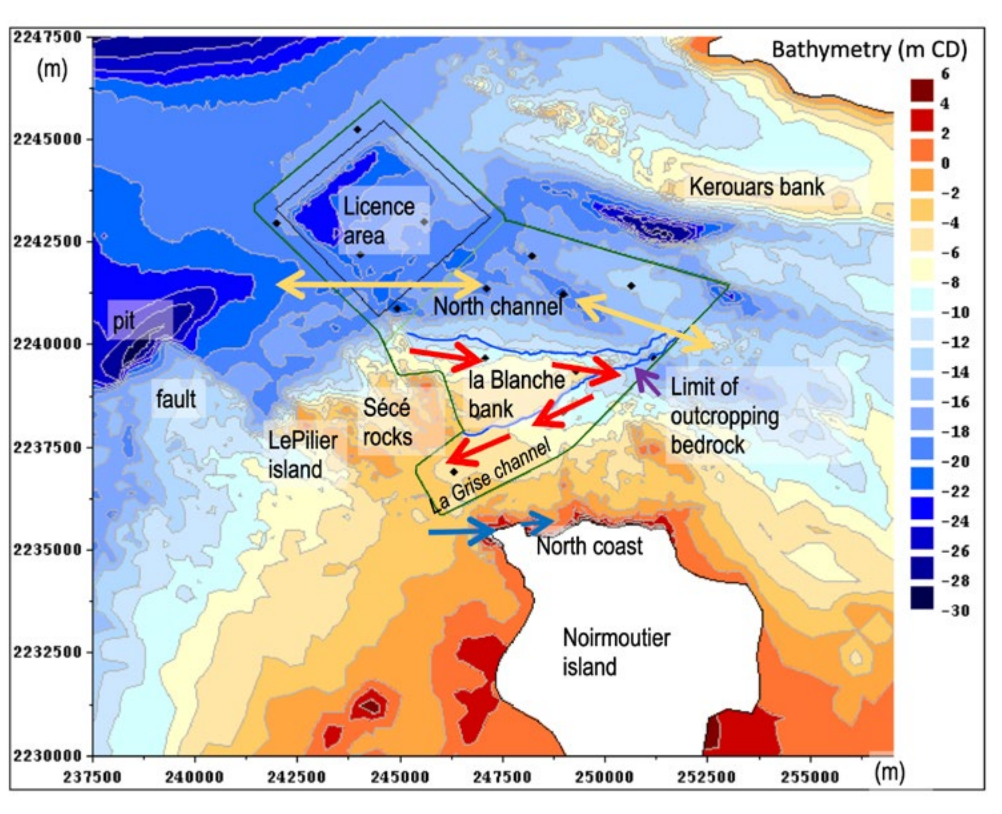


Figure 38 – *Le Pilier: Regional representation of sediment transport* (Sogreah, 2012)

4.1.4. MODELLING OF IMPACTS ON LONGSHORE TRANSPORT

In 2013, in light of information contained in the 2012 annual review, the authority noted that the maximum authorised depth for extraction, set at -26 mCD, had been locally exceeded in the western part of the licence area, down to -28 mCD. The Prefect hence ordered an assessment of the hydrosedimentary impacts of this over-deepening. The study was performed by Artelia following the recommendations of Latteux (2008), especially the chapter devoted to sites in the open sea with moderate currents and dominant wave action. For this type of site, Latteux (p. 122) [29] states that particular attention must be paid to nearshore wave transformation and the longshore drift that it generates.

For this purpose a large-area model of wave transformation was implemented, for various conditions of site operation and with boundary conditions representing the mainly westerly incident wave climate. Theoretical calculations of longshore drift along the north and north-east coast of Noirmoutier were then carried out.

The baseline situation (compliance with the maximum depth of -26 mCD over the entire licence area) was compared with a situation involving maximised over-deepening of the north-western half of the licence area (scenario 2). The following maps illustrate the transformation of a westerly wave with a 15-second period for the baseline scenario and the impact of scenario 2.

29 Latteux, B., 2008. Exploitation de matériaux marins et stabilité du littoral. Ed. QUAE, 162 p.

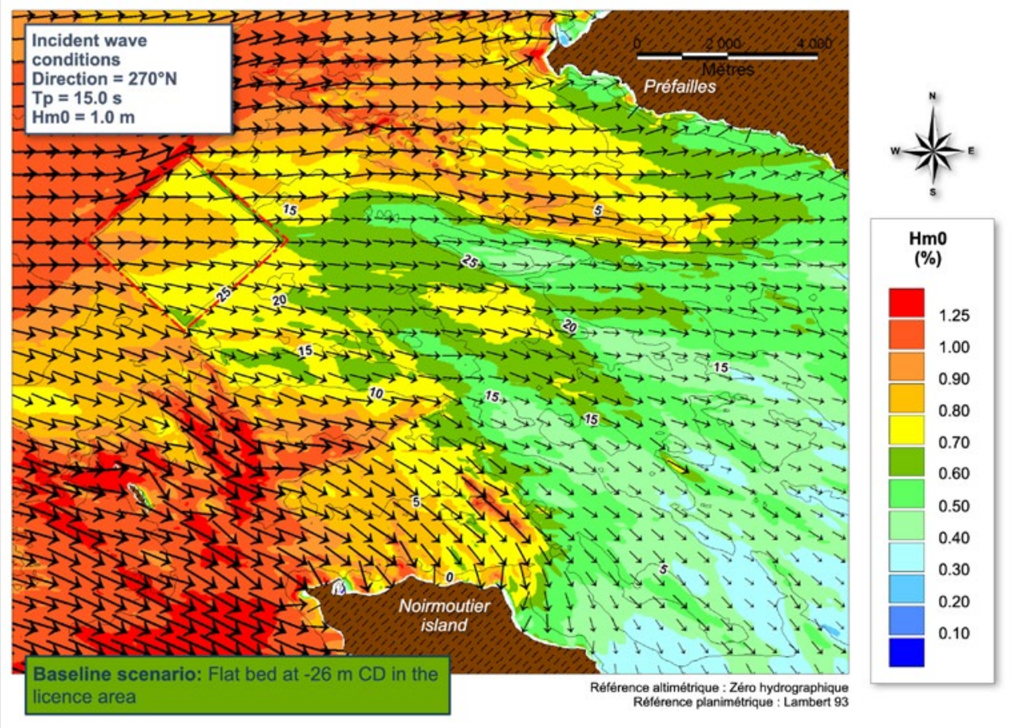


Figure 39 – *Le Pilier: transformation of a westerly wave - baseline scenario* (Artelia, 2014)

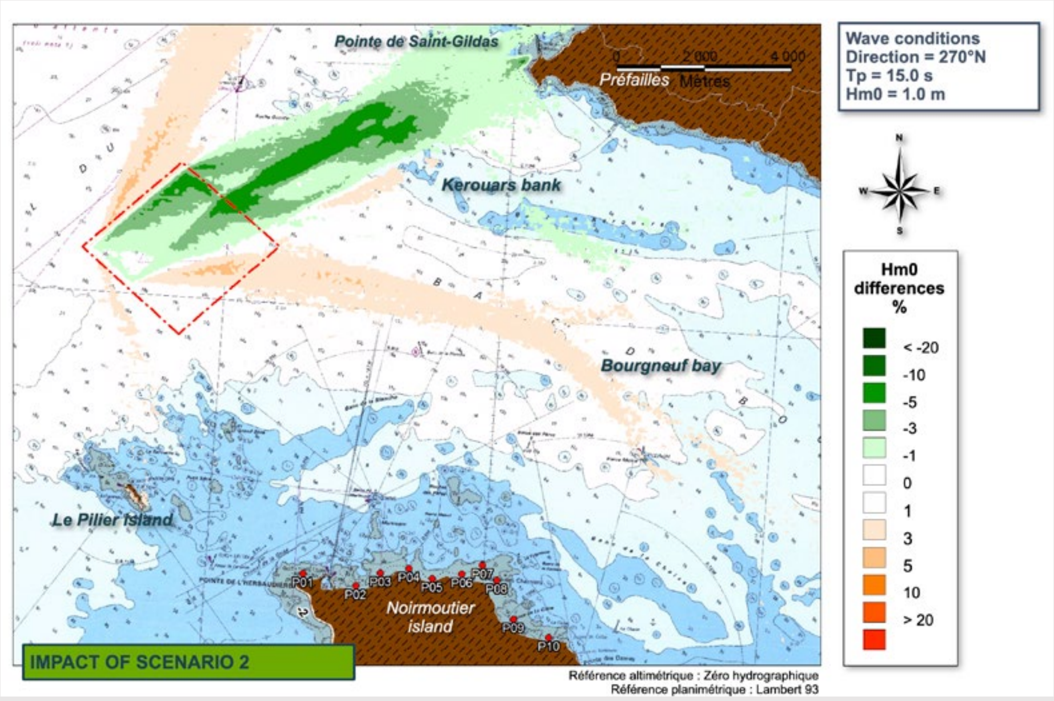


Figure 40 – *Le Pilier: transformation of a westerly wave - impact of scenario 2 on significant wave height* (Artelia, 2014)

For these unfavourable conditions, the significant wave height can be reduced by up to 10% at Pointe de Saint-Gildas, which is relatively favourable for this non-sedimentary coast (undermined cliffs).

On the Noirmoutier side, the differences are smaller than 1% along the north coast. The rationale behind Latteux's recommendations was retained nevertheless, by calculating longshore drift at 10 representative points based on a complete set of annual wave statistics for the various scenarios

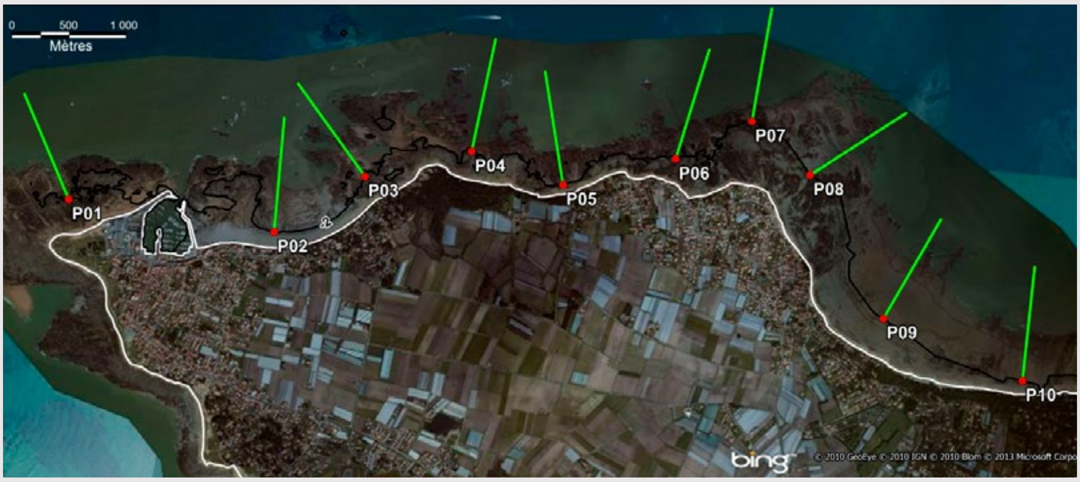


Figure 41 – *Le Pilier: positions of longshore drift calculation points* (Artelia, 2014)

The calculation shows a difference of a few tens of m3/yr for scenario 2, a result which is so small as to be insignificant (differing with the baseline scenario by less than 1%).

	ANNUAL LONGSHORE DRIFT (m³/yr)									
	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10
Baseline Scenario «2019»	5 245	7 320	3 105	5 492	2 186	4 750	6 839	9 536	10 982	8 121
Scenario 1	5 246	7 326	3 109	5 481	2 179	4 746	6 842	9 550	10 993	8 124
Scenario 2	5 249	7 345	3 113	5 496	2 187	4 770	6 862	9 574	11 044	8 149

Table 8 – *Calculation of sediment transport capacity at the results points* (CERC formula)

	ANNUAL LONGSHORE DRIFT: DIFFERENCES WITH THE BASELINE / SCÉNARIO «2019» (%)									
	P01	P02	P03	P04	P05	P06	P07	P08	P09	P10
Scenario 1	0,0%	0,1%	0,1%	-0,2%	-0,3%	-0,1%	0,0%	0,1%	0,1%	0,0%
Scenario 2	0,1%	0,3%	0,2%	0,1%	0,1%	0,4%	0,3%	0,4%	0,6%	0,3%

Table 9 – *Difference in longshore drift between scenarios at the results points*

These results were submitted by the authority to the BRGM and Cerema and a discussion meeting was held in order to compare the various points of view, especially regarding the limit values given in Latteux's guidelines (2008), and to validate the conclusions of the study.

4.1.5. SITE CLOSURE ASSESSMENT

Extraction at the Pilier site stopped at the end of 2017. A closure assessment was drawn up in July 2018 and submitted to the authorities. It includes the bathymetric and morpho-sedimentary surveys (side-scan sonar and sediment sampling for grain size analysis) required to terminate operations, following on from the 1999 initial survey and the three five-year surveys from 2005, 2010 and 2014. For this assessment the applicants called on the expertise of the SHOM, which analysed all of this data and commended its high quality, emphasising in particular the contribution of multibeam echosounder technology, which is the only means of obtaining a much more precise map of the submarine bedforms (sand dunes and banks). It is important to monitor these in order to quantify and gain a deeper understanding of the sedimentary transport processes. Indeed, the SHOM insisted in particular on the importance of measuring more precisely the velocities of sand dune and bank displacement in order to deduce the annual bedload rates all the way round the licence area, calling into question the limits imposed for the five-year survey, which were biased towards the south in the direction of Noirmoutier island. it is important to bear this conclusion in mind, as it is applicable to other sites.

This site closure assessment was then appraised by Cerema, which delivered its conclusions in February 2020. Cerema validated the entire assessment, notably the SHOM's conclusions, stressing that the next survey five years later would provide additional knowledge over a period free of any extraction, making the Pilier site a somewhat unique laboratory area in France.

The BRGM also delivered its opinion in March 2020, with a number of recommendations focusing mainly on calls for a better assessment of the local hydrosedimentary impact in and around the licence area.

4.1.6. CONCLUSIONS REGARDING THE PILIER SITE

Extraction at Le Pilier stopped at the end of 2017. The studies performed, from the preliminary impact assessments to the five-year monitoring reports and the closure assessment, form a coherent set, in phase with improvements in scientific knowledge and developments in field measurement and numerical simulation techniques between 1983 and 2017. These studies were submitted for appraisal to the main public institutions in charge of checking studies of this type. The in-depth discussions held with the BRGM, Cerema and also the stakeholders along the coast of Noirmoutier made it possible to clarify the methodologies and provided insight into the potential impacts of a dredging area of this type on the coast. They also provided an understanding of the blockage of longshore transport brought about by construction of l'Herbaudière harbour.

4.2. CAIRNSTRATH A AND SN2

4.2.1. CONTEXT

The Cairnstrath site is located about 16 km south-west of the Pilier site (**Figure 42**) at a depth of 30m. The first hydrosedimentary studies were performed by Sogreah and Creocean in 2008 on the basis of two initial licence area projects. These were revised in 2011 under the names Cairnstrath A and SN2 with a footprint reduced from 14 to 9.2 km² and a maximum deepening of 5m. The assessments from 2008 and 2011 were appraised by the CETMEF and the BRGM, leading to requests for additional studies the content of which was discussed and finalised during a meeting at the Pays de Loire Regional Directorate for the Environment, Planning and Housing (DREAL) in March 2015.

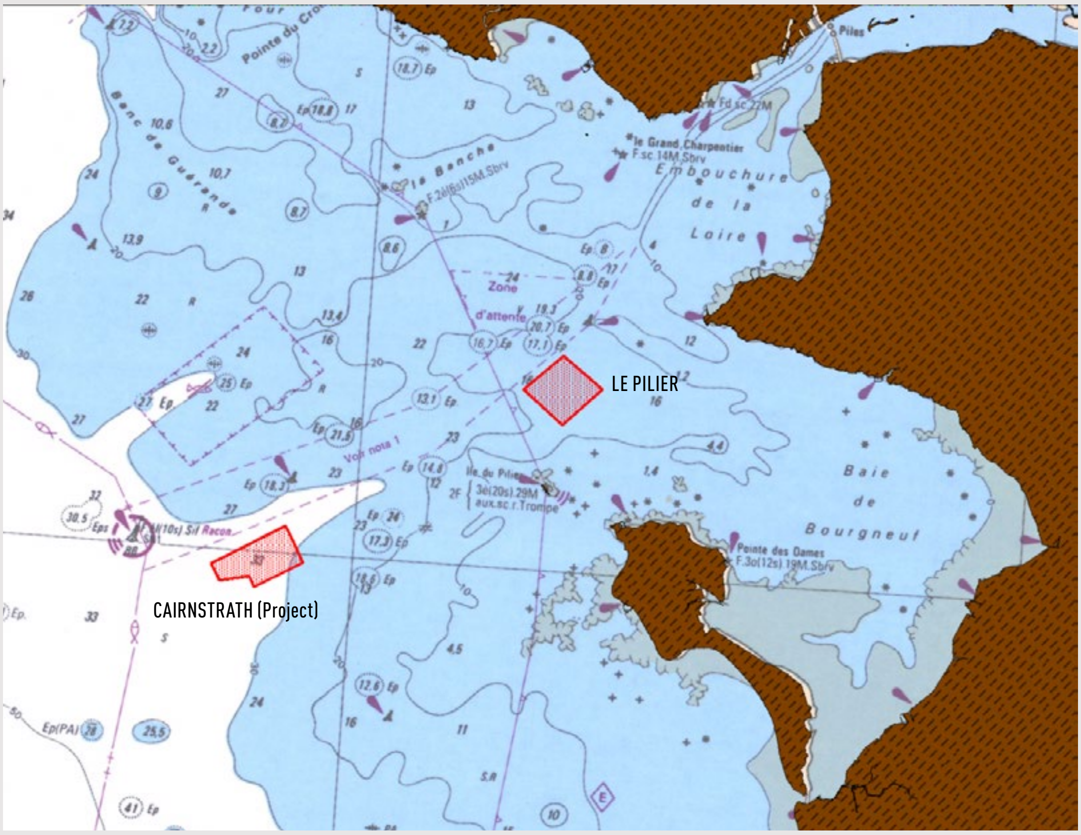


Figure 42 – ***Location of the Cairnstrath dredging area*** *(Artelia, 2015a)*

After these discussions, Artelia (ex-Sogreah) performed two additional studies to answer the following questions:

- Impact of extraction on wave motion and coastline stability,
- Impact of extraction on currents and sediment transport in the area of influence.

For these studies, an analysis of the cumulative impact of the Cairnstrath project and the Pilier licence area based on March 2015 baseline conditions was requested.

4.2.2. STUDY OF WAVE MOTION AND ITS IMPACT ON THE COASTLINE

The methodology adopted is based on the one used for the studies of Le Pilier with the improvements drawn from the conclusions of the Cairnstrath meeting in March 2015.

The area covered by the wave transformation model was extended to cover all the zones potentially affected. The boundary conditions were improved; they were taken from the HOMERE database constructed and disseminated by Ifremer. This database reconstitutes the sea states along the North Sea, English Channel and Atlantic coasts starting in 1994, and is updated annually. More specifically, the boundary conditions were extracted from the spectral database, which provides the most precise information on incident wave motion in terms of frequency and direction, as opposed to the reduced database of parameters, which only provides significant height, peak period and peak direction. Water level variations and the effect of wind on wave motion were also included in the model.

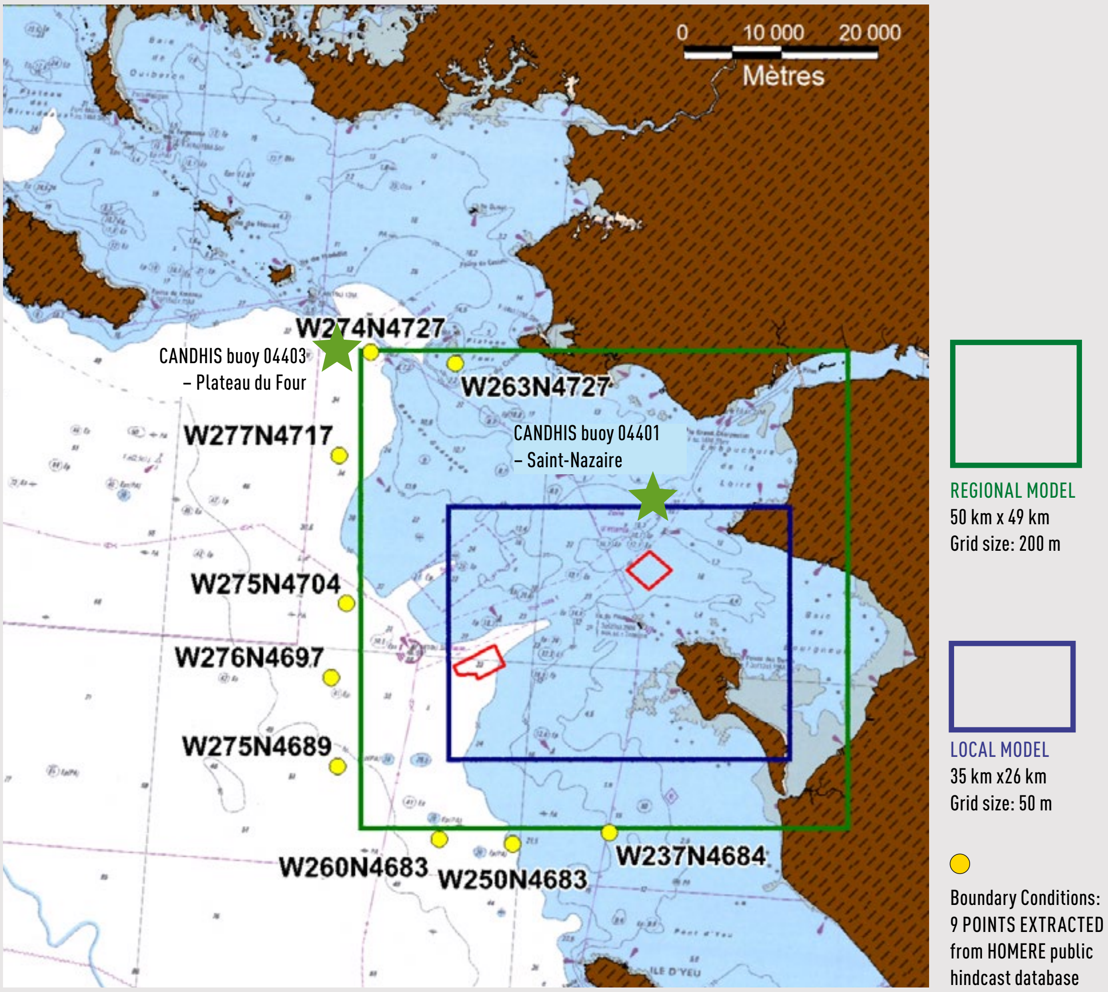


Figure 43 – ***Area covered by the wave transformation model*** *(Artelia, 2015a)*

The wave transformation model hence uses the nine-point incident wave conditions from HOMERE and simulates their nearshore transformation. It was validated through a comparison with the field measurements taken at the Saint-Nazaire and Plateau du Four buoys, which are archived in Cerema's CANDHIS database.

Figure 44 illustrates the comparison between the measurements and the simulation at the Saint-Nazaire buoy for the month of October 2006. The model accurately reproduces the succession of sea states, including the storm of 24 October.

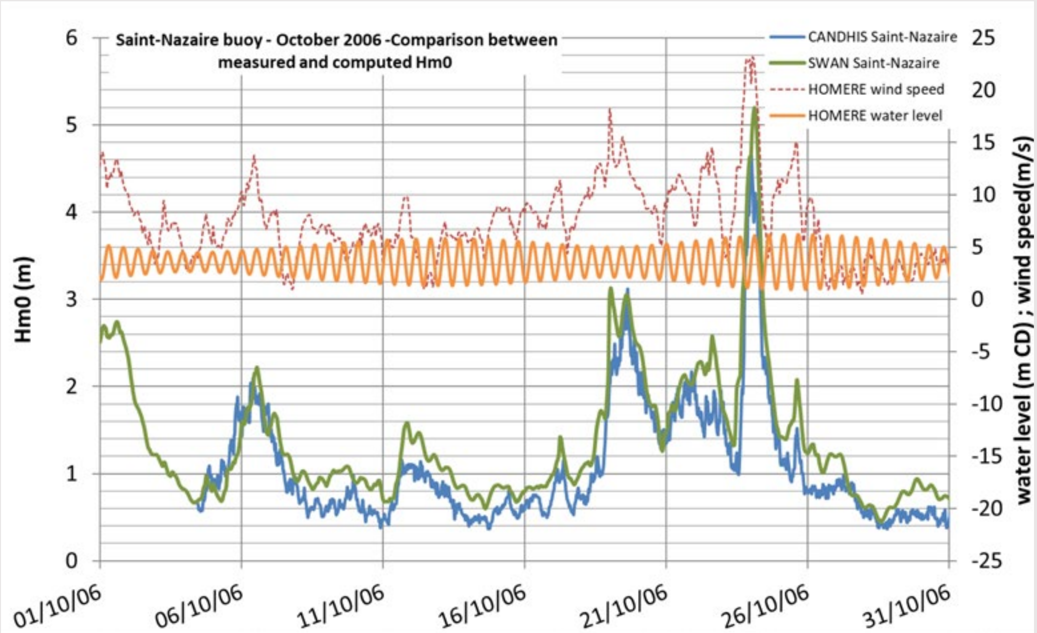


Figure 44 – *Comparison of significant wave height data calculated and measured at the Saint-Nazaire buoy* (Artelia, 2015a)

Secondly, we studied the wave climate over the period available in HOMERE (1994-2012) in order to select a representative winter period. To do this, we calculated the distribution of the incident wave motion energy flux for each direction and for different periods at a point located in the middle of the Cairnstrath licence area (**Figure 45**). The winter of 2011-2012 proved to be the most representative in terms of both energy flux and directional distribution.

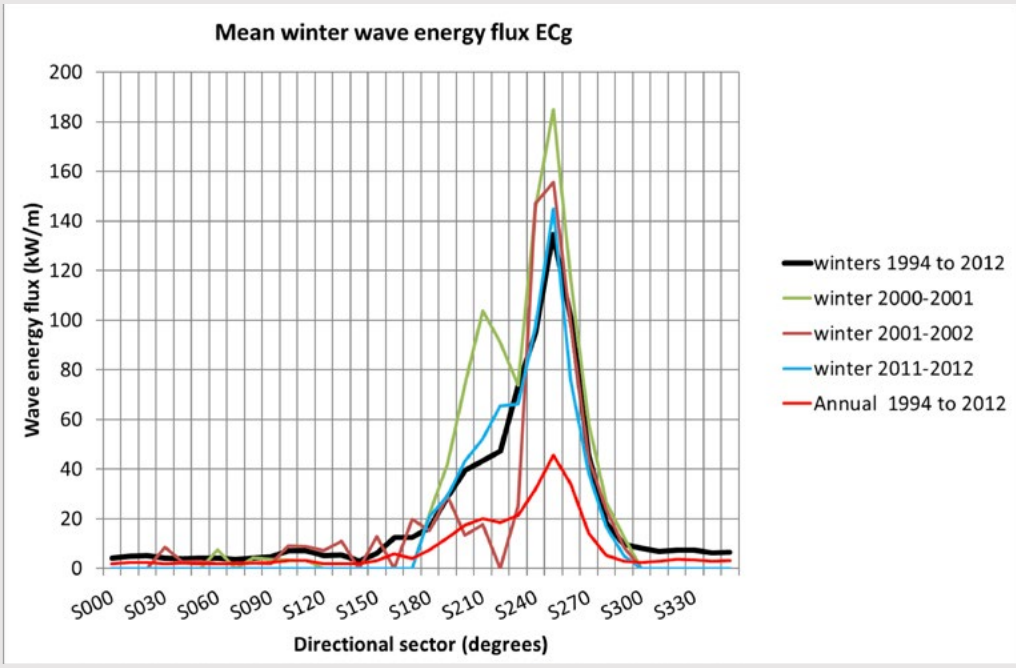


Figure 45 – *Mean wave motion energy flux at Cairnstrath* (Artelia, 2015a)

An analysis of extreme storms over the 1994-2012 period also demonstrated that the storm of 16/12/2011, which saw a significant wave height of 8.25 m at the extraction site, corresponded to a return period of five years. The characteristic winter adopted hence contains a five-year extreme storm, as required by the BRGM.

The impact of the planned licence area is hence similar to that already observed at Le Pilier: a reduction in wave motion is observed downstream of the licence area, along with an increase on its north and south sides, accompanied by variations in wave direction.

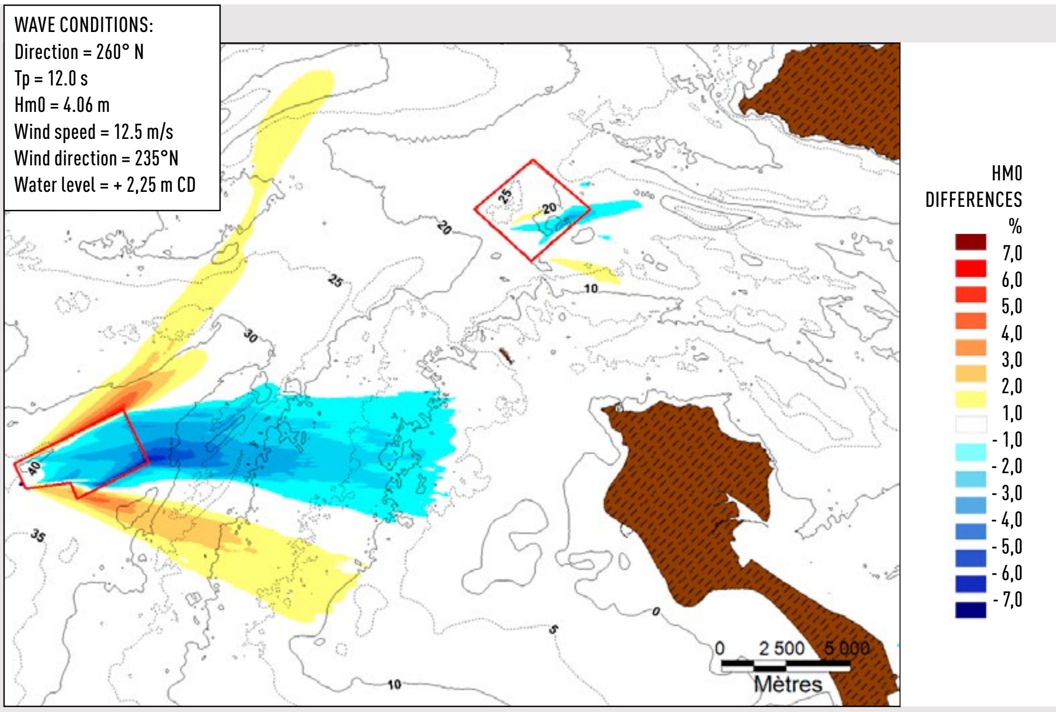


Figure 46 – *Example of impacts on N260° significant wave height at Cairnstrath* (Artelia, 2015a)

Along the coast, variations in significant wave height are on average almost nil (smaller than 1%) with a maximum in the order of +- 5 cm.

The impact on longshore drift along the north and west coasts of Noirmoutier was quantified by estimating this transport of sand using a bulk empirical formula (the **CERC** formula), which was adjusted using the available estimates.

The accumulations of sand along jetties in the harbours of l'Herbaudière on the north coast of Noirmoutier and Le Morin on its west coast were used in particular to check that the orders of magnitude of transport were correct and that the wave data used were representative:

- On the deposition area at the north jetty in Le Morin harbour it was confirmed that the shift in orientation of the coastline from N213° to N226° (**Figure 47**) does indeed correspond to the establishment of a new equilibrium state with zero longshore drift induced by the blockage caused by the jetty.
- In l'Herbaudière, the west beach is saturated and the sand flows round the jetty to settle in the harbour and its approaches, making regular maintenance dredging necessary. Moreover, this interruption in longshore drift caused by the jetty is a major contributor to erosion of La Linière beach to the east of the harbour. Operations to transfer sand between the harbour and the beach are hence organised on a regular basis. The latest one started at the beginning of February 2020 and involved a volume of 23,000 m^3.

Photos june 2013

Figure 47 – ***Longshore drift calculation points in Noirmoutier*** *(Artelia, 2015a)*

This made it possible to carry out comparative calculations, which were used subsequently to estimate the impact of the licence areas with a higher level of confidence in the results obtained:

- On the north coast, longshore drift is in the order of 6,000 m^3/yr. A very small reduction in the order of 1.1% is observed at Pointe de l'Herbaudière with the presence of the Cairnstrath dredging area. Further east, the differences become smaller than 1%.
- On the west coast, the intensity and direction of longshore drift vary more widely. The impact is very small from south of Pointe de l'Herbaudière to Luzéronde and indicates a decrease of 1 to 3%, reducing the tendency of this stretch of coastline to erode. Further south, the differences also become smaller than 1%.

4.2.3. STUDY OF CURRENTS AND SEDIMENT TRANSPORT

A model of sediment transport under wave and current action was set up. It was based on a 3D hydrodynamic model validated on field measurements of water levels, currents and wave motion at the Lambarde site. It was complemented by a model of sandy sediment transport under the combined action of wave motion and currents (Soulsby bulk formula).

The calculations covered a complete representative hydrological year, from October 1998 to September 1999. First of all, they revealed the complex circuit of sand fluxes in the area (**Figure 48**). The two main fluxes (oceanic and fluvial) are hence shown to subdivide in the outer Loire estuary.

The south-westerly incoming oceanic flux splits into three branches:

- The southernmost flux meets the island of Noirmoutier and continues down its west coast,
- The flux moving up the palaeo-valley meets the one discharged by the river Loire and part of it is diverted northwards,
- Lastly, a central flux is directed towards Bourgneuf bay across the Cairnstrath and Le Pilier licence areas.

The Loire fluvial flux also splits into two parts: one directed southwards towards Bourgneuf bay and the other towards the outer estuary, where it meets the oceanic flux and is forced into a rotating movement.

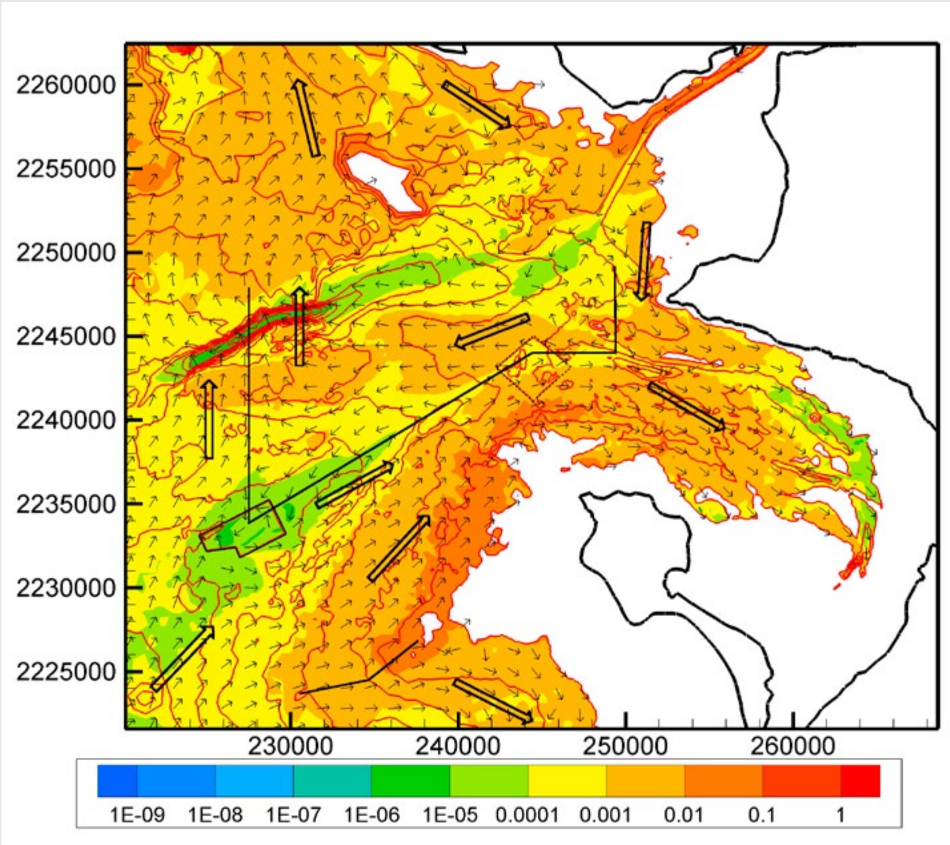


Figure 48 – *Cairnstrath – residual sediment transport (in kg/ms) for a 0.7 mm sand in present-day conditions* (Artelia, 2015a)

The impact of the planned licence area on sand transport was then mapped. It is consistent with the impact on wave motion, in other words a reduction within the shadow areas of the licence areas and an increase on either side.

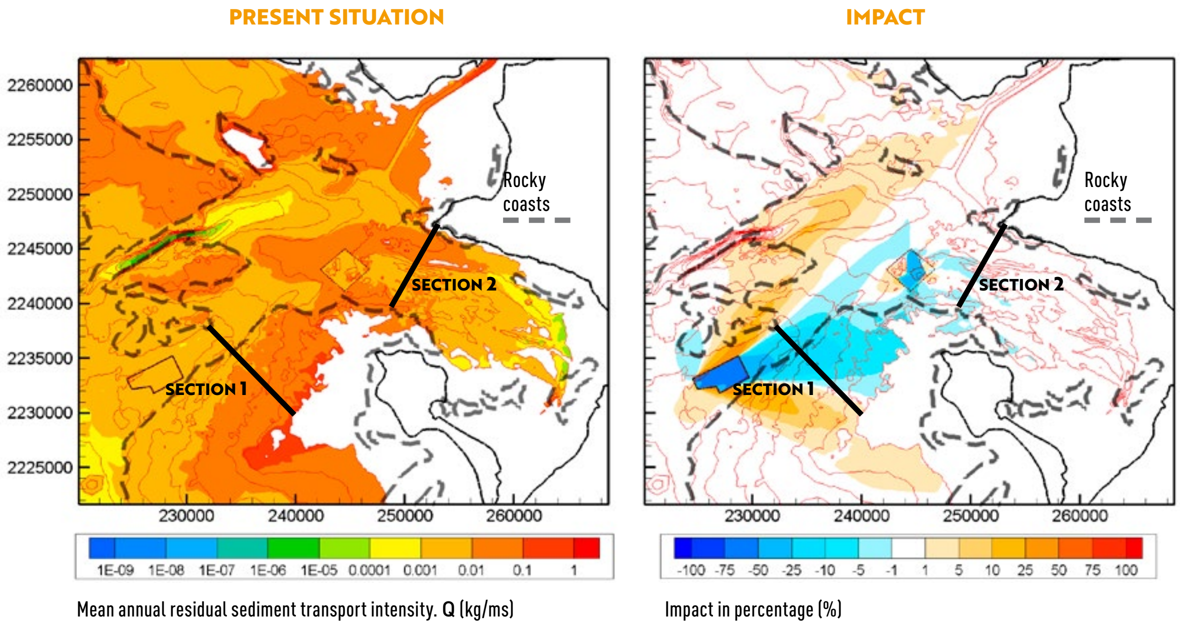


Figure 49 – *Cairnstrath – Mean annual sediment transport for the 0.7 mm diameter in present conditions, and Impact* (Artelia, 2015a)

The residual **offshore-onshore** sand transport flux (**Figure 48**) across the licence area was assessed in two sections (**Figure 49**, section 1 and section 2).

From a methodological point of view, these fluxes do not take longshore drift into account as the sections end at a depth of -5 mCD. The volumes are maximum capacities that the flows can transport; they obviously depend on the available sediment sources. In addition, these fluxes are calculated for a single grain size and must hence not be added together. If the nature of the bed is a mixture, the fluxes will be in proportion to the percentage of sediment available on the bed for each class. The results are given in **Table 11**.

On section 1, the impact is positive, with an increase between 1.6 and 2.8% depending on the sediment type (excluding 4mm, which is unrepresentative). One might have expected sediment transport to decrease, since the position of section 1 mainly covers an area in which this is happening, as shown on F**igure 49**. This figure indeed indicates that sediment transport at the dredging area is about 1000 times lower than at a depth of -5 mCD. Yet the impact is positive around -5 mCD, ultimately inducing an increase.

diameter (mm)	SECTION 1 (Millions of m³) PRESENT SITUATION	SECTION 2 (Millions of m³) PRESENT SITUATION
0.25	2.70	2.14
0.5	1.56	1.16
0.7	0.97	0.54
1	0.57	0.18
4	0.03	0.00

diameter (mm)	SECTION 1 (Millions of m³) FUTURE SITUATION	SECTION 1 (Millions of m³) FUTURE SITUATION
0.25	2.74	2.13
0.5	1.59	1.15
0.7	0.99	0.54
1	0.59	0.18
4	0.03	0.00

diameter (mm)	SECTION 1 (M³) IMPACT	SECTION 2 (M³) IMPACT
0.25	43401	-9163
0.5	27336	-5121
0.7	21475	-2762
1	15867	-1164
4	2198	9

diameter (mm)	SECTION 1 (%) IMPACT	SECTION 2 (%) IMPACT
0.25	1.6	-0.4
0.5	1.8	-0.4
0.7	2.2	-0.5
1	2.8	-0.6
4	6.7	-2.7

Table 11 – *Annual volume of sediment (of a single diameter) passing through sections 1 and 2 according to the residual fluxes for 5 sediment classes, for present conditions, future conditions, and impact* (Artelia, 2015a)

In Bourgneuf bay (section 2, located between two rocky zones), mean annual transport decreases slightly, by between 0.4 and 0.6% (excluding 4mm, which is unrepresentative). The order of magnitude of induced sedimentation on the mean depth beyond -5 mCD (surface area of about 105 km²) was then estimated (see **Table 12**).

Mean sedimentation rate (mm)	Mean sedimentation rate (mm/ 100 years) for an estimated area of 105 km² PRESENT SITUATION	Mean sedimentation rate (mm/ 100 years) for an estimated area of 105 km² FUTURE SITUATION	Mean sedimentation rate (mm/ 100 years) for an estimated area of 105 km² IMPACT
0.25	20.4	20.3	-0.087
0.5	11.0	11.0	-0.049
0.7	5.2	5.1	-0.026
1	1.7	1.7	-0.011
4	0.0	0.0	0.000

Table 12 – ***Estimation of 100-year sedimentation rates in Bourgneuf bay on the basis of residual fluxes by type of sediment: present conditions, future conditions, and impact*** *(Artelia, 2015a)*

The impact on Bourgneuf bay (excluding longshore transport) for depths of less than -5 mCD is a decrease in the mean sedimentation rate over 100 years which, according to the calculations, is less than a tenth of a millimetre.

4.2.3. CONCLUSION REGARDING THE CAIRNSTRATH STUDIES

The discussions with the BRGM and CEREMA enabled the joint construction, by iteration, of a methodology for assessing impacts on the coastline on the basis of mathematical models of wave motion and sediment transport.

4.3. GRANULATS MARINS HAVRAIS (GMH) LICENCE AREA

4.3.1. CONTEXT

The GMH licence application, filed by the LGE (Les Gravières de l'estuaire) and MBS (Matériaux Baie de Seine) companies in July 2015, follows on from the "Granulats Marins Havrais – PER GMH" exclusive exploration permit. It includes 7 sub-zones, covering a total surface area of 10.3 km² for an average deepening of 2.5m.

The licence application includes an impact assessment comprising, in particular, impacts of extraction on wave motion and the coast, which was conducted by Artelia in June 2015.

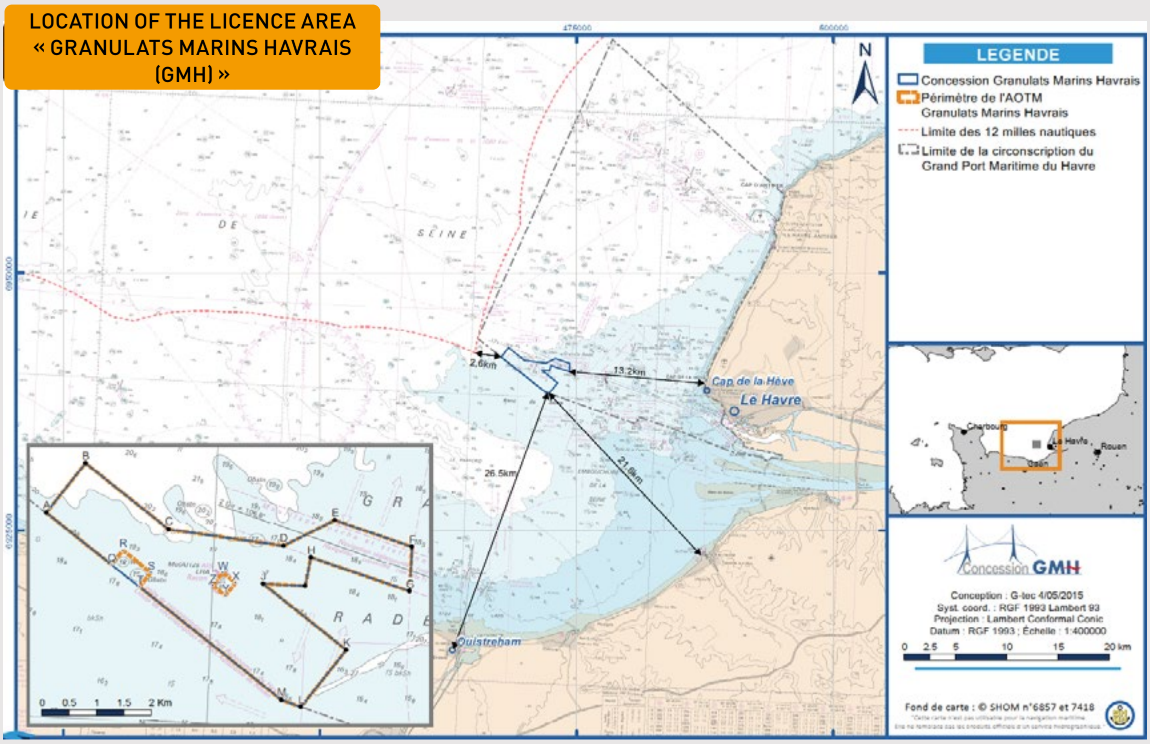


Figure 50 – ***Location of the GMH licence area*** *(Artelia, 2015b)*

4.3.2. ASSESSMENT OF IMPACTS ON WAVE MOTION AND THE COAST

This assessment draws on the above-mentioned methodology constructed jointly with the BRGM and Cerema during the assessments of the Pilier and Cairnstrath licence areas, in other words:

- A study of the wave climate at the site, based on a selected point within the licence area footprint in the Ifremer HOMERE database,
- A study of extreme storms at this same point, to estimate the return period of various historical storms,
- Establishment of a regional and then local model of wave transformation, forced at its boundaries by variable spectro-angular data and with levels and wind values taken from the HOMERE database,
- Validation of these simulations by comparison with field measurements from the Metzinger buoy supplied by the CANDHIS network (buoy 07606) over two periods,
- Selection of a representative year (2012), complemented in this case with the 10-year storm of 27 October 2002.
- Calculation of longshore drift using the CERC bulk formula at a number of control points along the potentially affected coast
- Comparison of the results obtained on a baseline configuration and then a with-project configuration.

The obligation to study the cumulative impact was also respected, by considering all the other sites subject to human intervention as indicated in **Figure 51**.

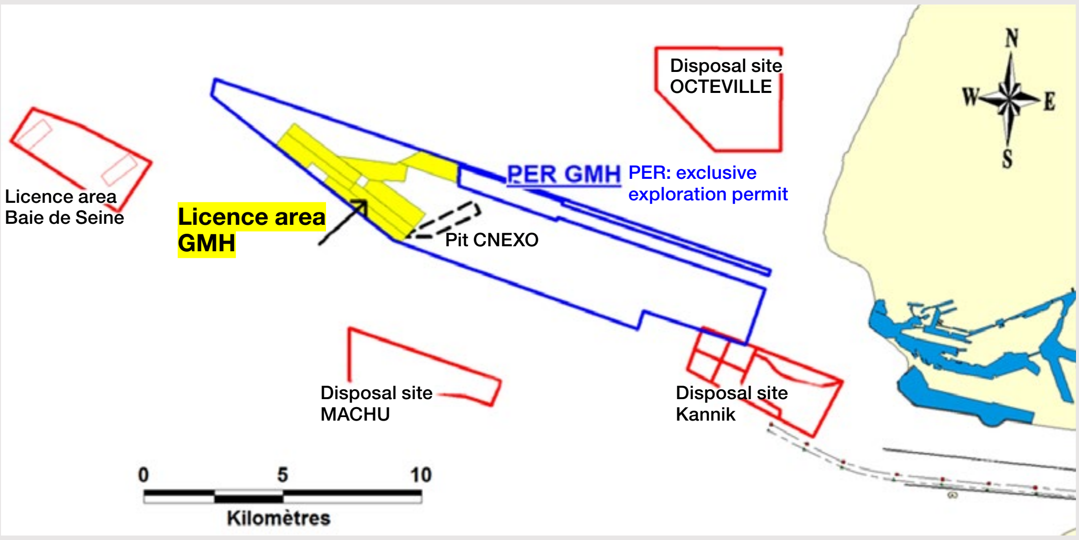


Figure 51 – ***Location of the GMH licence area and other sites of human intervention*** *(Artelia, 2015b)*

The area covered by the wave transformation model and the positions of the Metzinger buoy and the HOMERE points used are mapped on **Figure 52**.

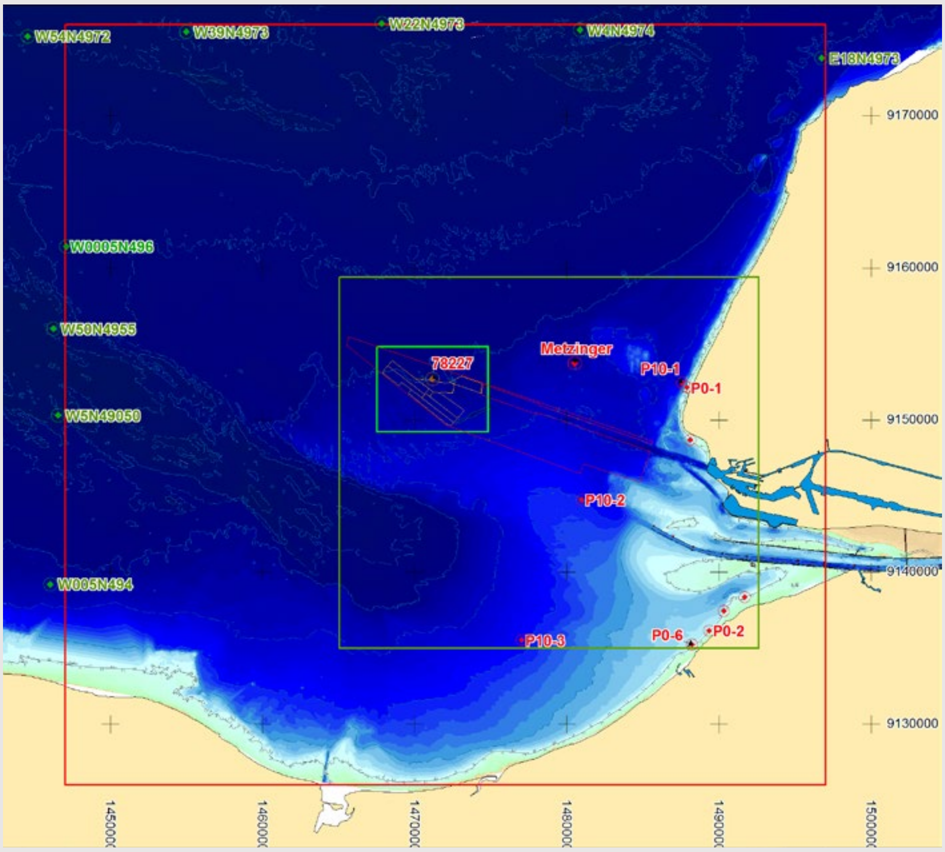


Figure 52 – *GMH: boundaries of the regional model (red line) and local model (green line) of wave transformation and positions of the HOMERE points and the Metzinger buoy* (Artelia, 2015b)

An example of a comparison between the calculations and the buoy measurements is given in **Figure 53** and **Figure 54**. A good match can be seen between the measured and calculated values, in terms of significant wave heights as well as periods and directions.

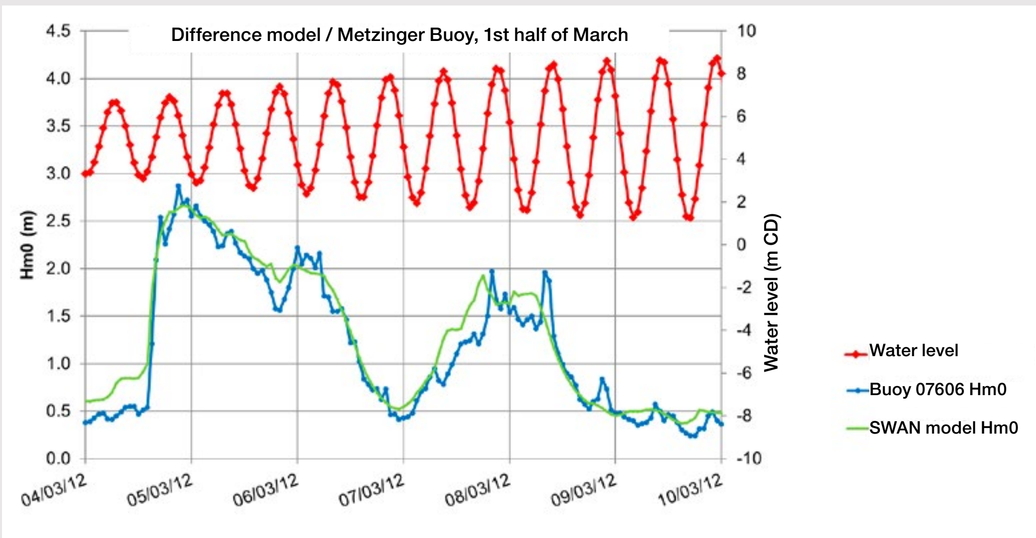


Figure 53 – *GMH: Validation of the model (significant wave height) at the Metzinger buoy, March 2012* (Artelia, 2015b)

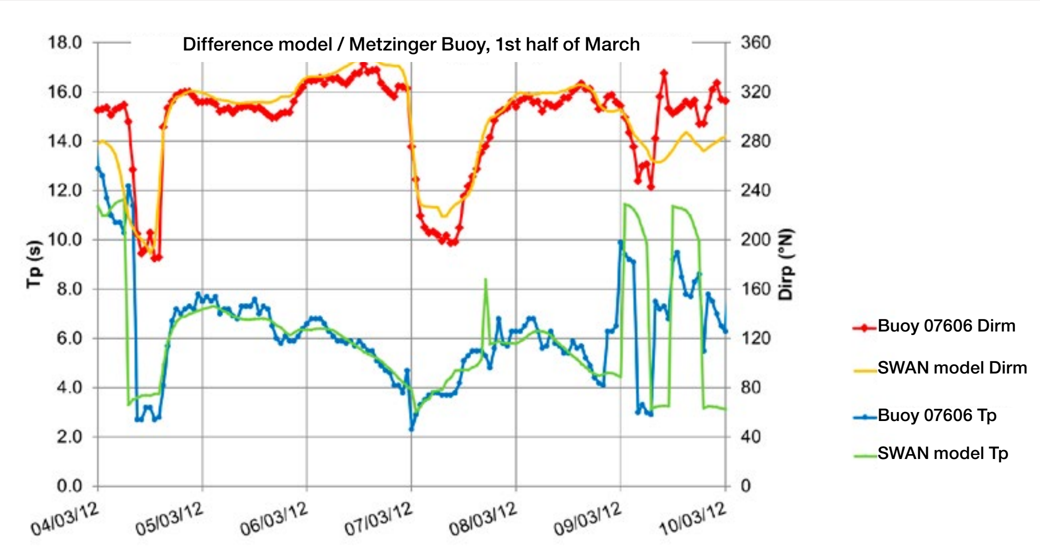


Figure 54 – *GMH: Validation of the model (period and direction) at the Metzinger buoy, March 2012* (Artelia, 2015b)

Following this validation, the impact on wave motion was estimated for various wave conditions. **Figure 55** shows an example of wave transformation at the site for the 10-year storm and the differential map of the impact (in %) on significant wave height. Here again, wave motion decreases in the shadow area of the dredging area and the wider area on either side.

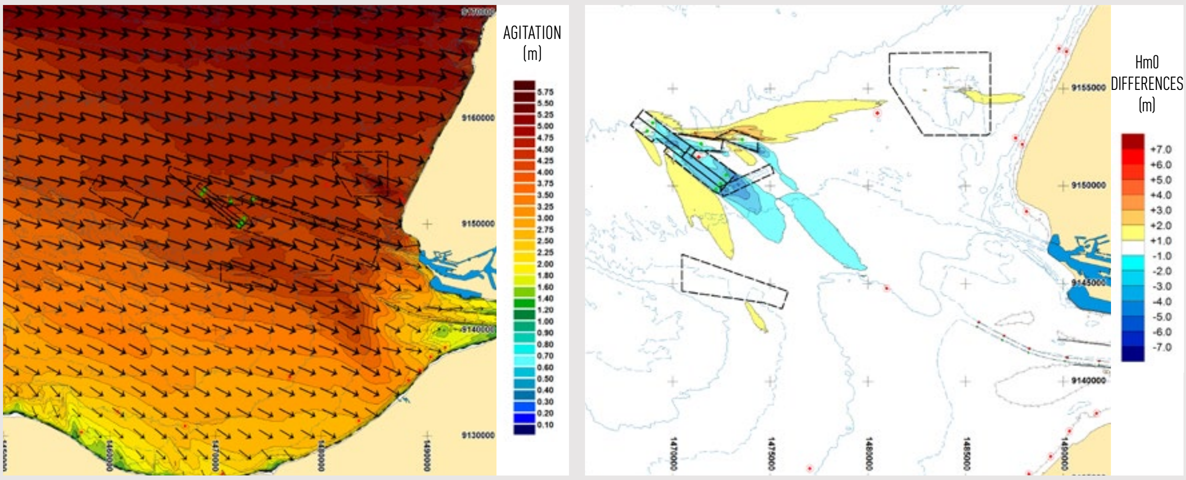


Figure 55 – *GMH: Impact of the licence area on the 10-year storm* (Artelia, 2015b)

The study of longshore drift was then performed, first selecting a representative year for local wave motion. 2012 was adopted, following a comparison with the multi-year average (**Figure 56**). Wave motion was then studied at several control points along the coast (**Figure 57**) for the two sets of conditions (baseline and with-project). The calculation results indicate that the impact on longshore drift is negligible (**Table 13** and **Table 14**).

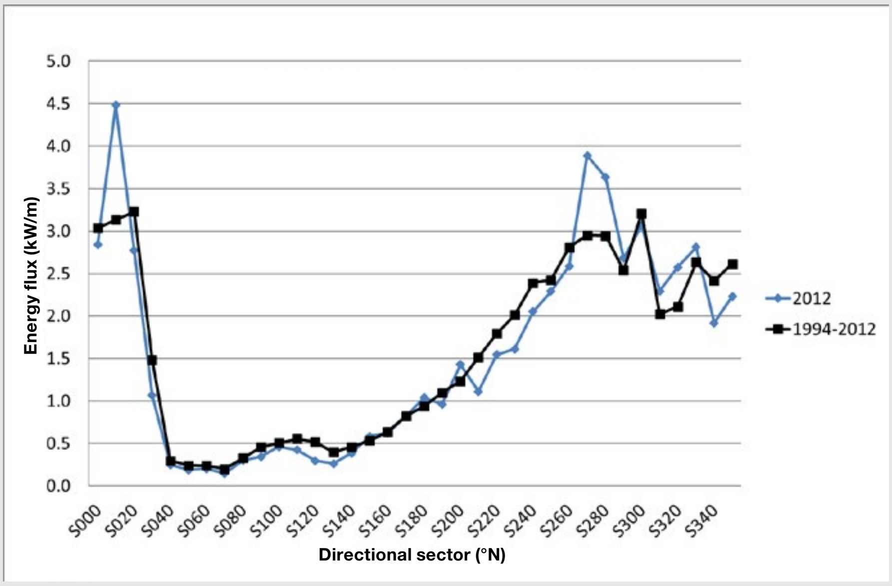


Figure 56 – ***GMH: mean wave energy flux*** *(Artelia, 2015b)*

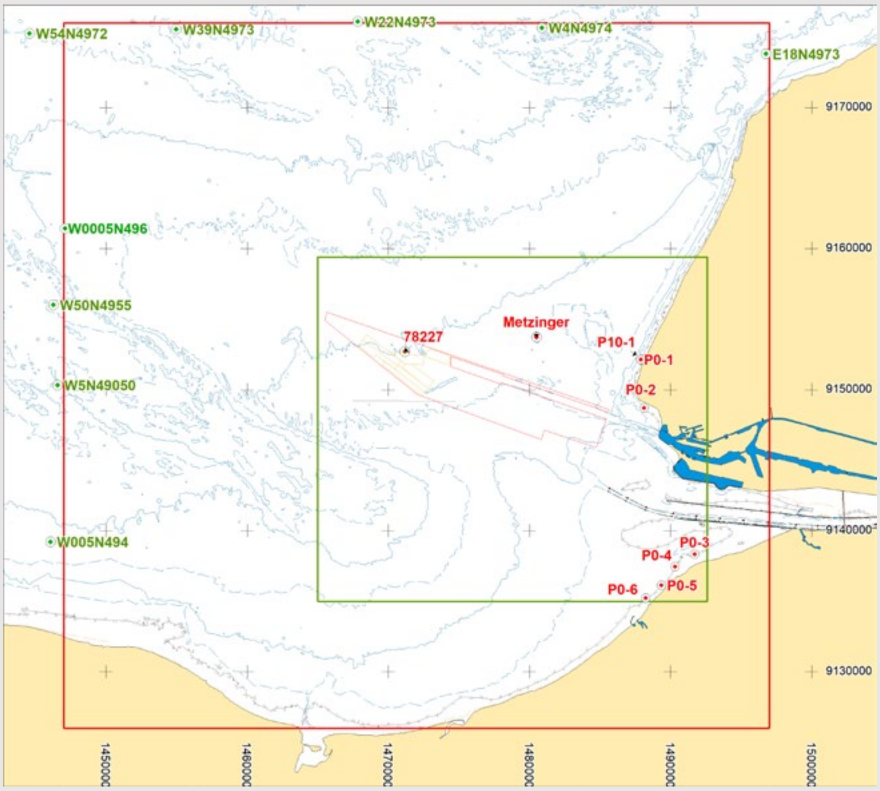


Figure 57 – ***GMH: Wave motion control points along the coast*** *(Artelia, 2015b)*

Point	Net drift, present conditionsl	Net drift, with-project conditions	Net difference	Relative difference
P0-1 shingle + sand	-89,672 m³/yr	-89,379 m³/yr	293 m³/yr	-0,33%
P0-2 shingle + sande	-91,313 m³/yr	-91,655 m³/yr	-342 m³/yr	0,37%
P-03 sand	63,345 m³/yr	63,139 m³/yr	-206 m³/yr	-0,33%
P-04 sand	50,580 m³/yr	50,983 m³/yr	403 m³/yr	0,80%
P-05 sand	70,990 m³/yr	71,193 m³/yr	203 m³/yr	0,29%
P-06 sand	88,501 m³/yr	88,316 m³/yr	-185 m³/yr	-0,21%

Table 13 – *Capacity of longshore drift over representative year 2012* (Artelia, 2015b)

Point	Net drift, present conditionsl	Net drift, with-project conditions	Net difference	Relative difference
P0-1 shingle + sand	-4010 m³	-4087 m³	-77 m³	1,90%
P0-2 shingle + sande	-3486 m³	-3476 m³	10 m³	-0,30%
P-03 sand	1479 m³	1477 m³	-2 m³	-0,10%
P-04 sand	2371 m³	2372 m³	1 m³	0,00%
P-05 sand	3273 m³	3274 m³	1 m³	0,00%
P-06 sand	3727 m³	3781 m³	55 m³	1,50%

Table 14 – *Capacity of longshore drift over a 10-year storm* (Artelia, 2015b)

4.3.3. CONCLUSIONS CONCERNING THE GMH LICENCE AREA

The methodology used to assess the impact of the GMH licence area on the coast draws on the one developed during the studies of Le Pilier and Cairnstrath. It is based on the scientific knowledge of that time and was successfully transposed to another hydrographic context; this methodology is therefore transposable.

4.4. SUMMARY

Chapter 3 Chapter 3 demonstrated that the studies performed in the 1970s and 80s in France and the UK on the various hydrosedimentary processes that could result in aggregate extraction having impacts on the coastline correctly identified the main physical processes potentially involved, which include:

- 1/ Wave-induced sediment transport being trapped by the dredging area
  - through direct interception of longshore drift in the upper shoreface
  - through drawdown of the upper shoreface and beach (transport from the shore into deeper water)
  - through sediment transport being trapped outside the upper shoreface in the direction of offshore-onshore transport.
- 2/ An alteration of nearshore wave transformation capable of changing the regime and intensity of longshore drift and hence influencing coastline changes:
  - through refraction with a modulation of wave heights and directions,
  - through decreased wave breaking (due to the lowering of sand banks and bars),
- 3/ An alteration of site morphodynamics in cases where currents play a major role.

Some simple criteria in terms of depth, distance to the coast and dredging area geometry have hence been established to prevent these impacts. Thanks to these, the aggregate licence areas operated in France over the past thirty years have been positioned correctly, and it has been concluded that the existing sites have no proven impacts on the coast.

In more recent times, increasing awareness of the effects of climate change has prompted some long-term studies that have pinpointed the important role played by offshore-onshore residual sediment transport in supplying some coasts with sand. This process is now taken into consideration in impact assessments.

More recently, the progress made in field measurements (wave motion, bathymetry, geomorphology) and in mathematical modelling (currents, wave motion, sediment transport) over the past 20 years has made it possible to fine-tune impact assessments for new licence applications on a case-by-case basis, using numerical hydrosedimentary simulations calibrated with field measurements.

This chapter presented the results obtained with a methodology constructed jointly by iteration with the BRGM and CEREMA, developed in the département of Loire-Atlantique and applied successfully in another regional context (the English Channel). This methodology is state-of-the-art, robust, transposable, and satisfies the requirements laid down by technical inspection bodies.

The feedback from existing licence areas in France and other countries (**chapters 3 and 5**) demonstrate the complex studies that must be performed to make a connection between aggregate extraction and coastline change driven by both natural sedimentary dynamics and onshore coastal developments implemented at the same time as the extraction operations. Nowadays, these studies are made even more complex by the effects of climate change. The scientific literature review on the topic found that the cases encountered vary very widely, making it quite difficult to reach a simple overall conclusion (**see section 3.6**). A local analysis must hence be performed for each project - looking beyond marine aggregate extraction alone - based not just on a short-term historical analysis but also a long-term perspective (geological constitution of the current coast), in order to identify the dominant past, present and future processes playing the greatest roles in the changes taking place along a coast.

APPENDIX A

A1. BIBLIOGRAPHY RELATING TO CHAPTERS 1 AND 2

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APPENDIX B: FRENCH LEGISLATION CONCERNING MARINE AGGREGATE EXTRACTION (UPDATED IN 2018)

B1. DÉFINITIONS

The term "aggregates" covers all products composed of "a set of particles with dimensions between 0 and 125 mm" (standard NF P 18 540 published in 1997). In France, the exploration and exploitation of sand and gravel is governed by a number of regimes depending on their use or their place of extraction.

- **Exploitation of land-won aggregates** is governed by the French Environment Code (Articles L 511-1 et seq.) in accordance with the "ICPE" listing (classified facilities for protection of the environment).
- **Extraction for the purposes of coastline management** is governed by the French Environment Code (articles L 211-7, L 214-1 to -6 [30]) under the French water and aquatic environments law. As regards beach nourishment, French local authorities are allowed to undertake the study, implementation and operation of all works in the general interest and with a view to building sea defences (article L 211-7 of the Environment Code). Extraction related to beach nourishment is subject to declaration or permitting procedures under articles L. 214-1 to 6 of the Environment Code. If the cost of the works exceeds € 1,900,000 or the beach area being replenished is larger than 2,000 m², the works are subject to an impact assessment (article R 122-8 of the Environment Code). Otherwise, only an impact statement is required (article R 122-9 of the Environment Code). The extraction of marine materials to be used for coastline management is not subject to the "redevance domaniale" (State fee for occupation of public land), whether the extraction site is located within the public maritime domain or not.
- **Sandy materials dredged from harbours** are governed by the Environment Code (article L 214-1 to 3). The circular of 4 July 2008 specifies the procedures relating to sediment management. These dredging operations are vital to guarantee safe access to port facilities. A small part of this sediment dredged to maintain harbours and channels is reused in beach nourishment.
- **Marine aggregates**, on the other hand, are governed by the French Mining Code under law no. 97-1051 of 18 November 1997 (including calcareous materials, hitherto considered as "fisheries" products). They are also subject to an environmental assessment (article R 122-1 et seq. of the Environment Code), in particular an impact study the content of which is described in article R 122-5 of the Environment Code. Their extraction is subject to payment of a fee (**see section 7**).

30 Article L 321-8 of the Environment Code stipulates that the extraction of materials not stated in articles L 111-1 and L 111-2 of the French Mining Code is restricted or prohibited when there is a risk of it directly or indirectly compromising the integrity of beaches, coastal dunes, cliffs, marshes, tidal flats, seagrass beds, spawning grounds, natural shellfish beds and fish farms. However, this provision cannot pose an obstruction to dredging works carried out in harbours and their channels or those aiming to preserve or protect outstanding natural areas.

B2. PERMITS REQUIRED TO EXPLORE AND EXTRACT MARINE AGGREGATES UNDER THE FRENCH MINING CODE [31]

Before being able to extract marine aggregates, several phases must be completed:

- **An exploration phase** to search for a potential deposit, estimate its volume and determine the technical and economic conditions of subsequent extraction. This phase can last between 5 and 15 years, by 5-year periods.
- **An extraction phase** corresponding to dredging of the resource and then closure of the licence area. Permit applications generally cover a 30-year period.

Before any marine aggregate exploration or extraction can take place, the Mining Code stipulates that three permits must be granted: a mining title ("titre minier"), a permit to open exploration or extraction works, and a permit to occupy the public maritime domain if applicable.

B.2.1 The mining title

The regulatory provisions relating to the examination of applications for a mining title ("titre minier") are set out in the (new) French Mining Code and decree nos. 71-362, 2006-648, 2006-798 and 2018-62.

As regards exploration, applicants must obtain:

- either a "**permis exclusif de recherches"** (**PER** - exclusive exploration permit), granted by ministerial order for a renewable period of 5 years,
- or an "a**utorisation de prospection préalable**" (**APP** - prior exploration permit), granted by the competent administrative authority without competitive bidding or a public inquiry and without the prior consultation process stipulated in article L. 123-1.

To extract aggregates, applicants must obtain a licence. This is granted by ministerial decree, for a maximum period of 50 years. The licensing decree can be accompanied by specifications that the Prefect must take into consideration in his/her prefectoral order relating to the extraction works. These specifications may, for instance, require specific measures to monitor or supervise the works.

B2.2. Permit to open exploration or extraction works

Since 2006, applications for a mining title and a permit to open works can be filed jointly (decree no. 2006-798 of 6 July 2006). The opening, within the boundary of 12 nautical miles or in inland waters, of works to prospect for, explore or extract mineral or fossil substances mentioned in article L 111-1 is subject to permitting or declaration procedures.

Permits are granted in accordance with the provisions in articles L 162-1 to L 162-12 of the New Mining Code and in decree no. 2006-649 relating to mining works. Decree no. 2014-118 amends the list of mining works subject to declaration or permitting procedures. Mining drilling works that are not likely to pose serious hazards or drawbacks for the environment (drilling to depths of less than 100 metres, geological or geophysical exploratory boreholes, and mineral exploration drilling) are subject to declaration procedures.

The provisions specific to permits for offshore works are described in articles L 162-6 to L 162-9 of the New Mining Code.

Permits to open works are granted by prefectoral order and stipulate the conditions for exploration or extraction, the maximum authorised volumes and the environmental monitoring requirements.

31 The latest versions of the regulations can be found at the websites http://www.mineralinfo.fr/ and www.Sablesetgraviersenmer.fr

B2.3. Permit to occupy the public maritime domain

Within a distance of 12 nautical miles (i.e. about 22 km), an "autorisation d'occupation du domaine public maritime (DPM)" (permit to occupy the public maritime domain), governed by article L 2122-1 of the "Code général de la propriété des personnes publiques" (French General Code of Public Property) is required.

It is issued in the form of an order by the authority managing the public maritime domain: the Prefect of the département or a "Grand port maritime" authority. This permit stipulates, among other things, the amount of the State fee for occupation of public land called the "redevance domaniale" (decree no. 2017-32)[32].

B3. ENVIRONMENTAL ASSESSMENT

B3.1. Consideration of environmental issues

In France, the national legislation is adapted to incorporate the EU "Habitats" directive (92/43/EEC) on the conservation of natural habitats and of wild fauna and flora, in keeping with the OSPAR convention and the modified directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment.

In addition, the regulations of 2006 and 2011 (Ordinance no. 2011-91 of 20 January 2011 on codification of the legislative part of the Mining Code) increased the consideration given to environmental issues. According to article 162-7 of the New Mining Code, if the applicant simultaneously files an application for a licence to dredge marine aggregates on the seabed of the public domain and the continental shelf and an application to open works, the examination process must include an environmental assessment and a public inquiry (in accordance respectively with chapters II and III of title II of book I of the Environment Code) and the implementation of a consultation process.

The guidance documents on the sustainable management of marine aggregates (DOGGM) must tie in with the sea basin strategy documents (DSF) introduced by articles L 219-1 to L 219-6-1 and articles R 219-1-7 to R 219-1-14 of the Environment Code.

According to the technical memo of 17 August 2018, the DSF incorporate the national strategy for the sea and the coast (art. L 219-1), action plans for the marine environment (PAMM) (as per directive 2008/56/EC, the MSFD), and maritime spatial planning (as per directive 2014/89/EU, the MSPD).

As regards marine aggregate extraction, the objectives stated in the DSF mainly revolve around implementing sustainable conditions for extraction, reducing impacts, protecting certain zones such as tidal flats and nursery grounds, and respecting other maritime activities, while factoring in the socio-economic necessities and environmental sensitivities of each coast.

Therefore, in the event that an extraction site would be located:

- within or close to a Natura 2000 site (article R 414-19 of the Environment Code), an impact assessment will have to be performed (decree no. 2010-365 of 9 April 2010 on Natura 2000 impact assessment);
- within a marine natural park, the management board gives an opinion (via an assent procedure) on the appropriateness of authorising a project with a significant impact on the marine environment (art. L 334-5, R 334-33 and R 331-50 of the Environment Code);
- within a national park, provisions of the Environment Code also apply (article L 331-14).

32 As of 2017, this fee is also applicable to licence areas located beyond the 12 NM boundary

B3.2. Environmental impact assessments

The Mining Code requires the submission of a detailed impact assessment (the content of which is defined by article R 122-5 of the Environment Code) with any simultaneous application for an exploration or extraction permit and for the opening of works. This impact assessment must be in keeping with the scale of the planned works and developments and with their foreseeable consequences for the environment. It must contain:

- a description of the project: location, physical characteristics of the entire project, and main characteristics of the operational phase of the project (nature of sediments, volumes, and depth of extraction),
- a description of the relevant aspects of the current environmental conditions, referred to as the "baseline scenario", and of how these will change if the project is implemented, as well as an overview of the probable environmental changes if the project is not implemented,
- a description of the factors mentioned in section III of article L 122-1 of the Environment Code likely to be affected significantly by the project,
- a description of the expected significant environmental impacts of the project (morphology, nature of the seabed, sediment dynamics and hydrodynamics, benthic resources, fish resources, megafauna, physical and chemical water quality, cultural heritage, socio-economic activities, protected sites),
- a description of significant potential impacts of the project on the resulting environment, in particular an accumulation of impacts with those of other existing or approved projects (article R 214–6 of the Environment Code),
- a description of the measures planned by the project owner to avoid, mitigate or compensate for the significant negative project impacts on the environment or human health (AMC approach). The description of these measures must be provided with an estimate of the corresponding expenses, and arrangements for monitoring the measures must be proposed.

In the case of marine aggregate extraction, the main mitigation measures envisaged consist in limiting the depth, not screening materials at sea, not exposing the bedrock, phasing the extraction works to encourage recolonisation, and suspending extraction during certain defined periods (spawning periods of certain species that lay eggs on the seabed, scallop fishing, etc.) The impact assessment is submitted to the competent environmental authority for approval, as specified in article R 122-6 of the Environment Code.

B3.3. Baseline conditions

Before any extraction of marine aggregates can begin, the prefectoral orders authorising the opening of extraction works stipulate a set of baseline conditions including:

- a morpho-bathymetric map
- a morpho-sedimentary map
- a biological (biosedimentary) inventory

B3.4. Monitoring during the extraction period

In accordance with article L 172-1 of the Mining Code and with a view to ensuring oversight during the extraction period, licence holders must send the administrative authority an annual report on the impacts of their activity on land use and the key characteristics of the surrounding environment. The characteristics of this annual extraction report are defined in articles 35 and 36 of decree no. 2006-649. This report, which is forwarded to the services and local authorities concerned, contains all the information required to assess the technical and economic conditions of the extraction activity, implementation of the works programme, and the results of the stipulated monitoring measurements (article 46 of decree no. 2006-798).

The operator also sends an annual declaration of the quantities extracted over the previous year to the "Service des domaines" (land tenure service) and the regional director of the DREAL (Regional Directorate for the Environment, Planning and Housing). In the event that the results do not comply with the targets set, the Prefect can issue an order prohibiting further works, under the stipulated conditions (article 46 of decree no. 2006-798).

The annual report also includes information on the conditions for stopping the works and an estimate of their costs, in application of the provisions of articles L 163-1 to L 163-9 of the Mining Code.

Five-year monitoring, or in some cases monitoring at shorter intervals, depending on the site characteristics, is also defined. It comprises:

- morphosedimentary monitoring,
- monitoring of benthic fauna,
- monitoring of fish stocks (in some cases).

B4. POLICE DES MINES EN MER

Under articles 35, 36 and 42 of decree no. 2006-798, measures taken by the "Police des mines en mer" (the branch of the French national police responsible for overseeing offshore mining activities), as defined by prefectoral order, aim to ensure that extraction is carried out:

- within the boundaries of the licensed area: records of ship movements during the dredging phases are forwarded to the maritime affairs directorate,
- on quantities not exceeding the maximum authorised annual quantities: volumes declared are inspected at the ports,
- in accordance with the provisions of the order authorising opening of the works.

On the continental shelf, the exploration and extraction of mineral or fossil substances are subject to the declarations, inspections and reporting requirements laid down in articles L 411-1 to L 412-2 of the Mining Code.

B5. "REDEVANCES DOMANIALES" AND OTHER FEES

On the basis of the provisions of article L 132-15-1 of the Mining Code, article 19 of decree no. 2006-798 of 6 July 2006, and decree no. 2017-32 of 12 January 2017, a "redevance domaniale" fee called the "State fee for the extraction of non-energy mineral resources on the seabed of the continental shelf or the exclusive economic zone" is due annually for occupation of the public maritime domain for aggregate extraction activities.

It is set taking into account the characteristics of the deposit, especially its depth, distance from unloading points and the quality of the substances intended to be extracted, within a minimum and maximum amount indexed on 1 January of each year in line with variations in the "TP06" index applicable to marine and river dredging published by the French National Institute of Statistics and Economic Studies (INSEE).

Other taxes applicable to these activities pertain to shipping:

- a tax on the ship (articles R 212-2 et seq. of the French Seaports Code),
- pilotage and boatage fees.
- other more specific fees applicable to the extraction, transport and processing of marine aggregates, or to dredging operations:
- a goods tax (articles R 213-15 of the French Seaports Code),
- a port levy on the processing of waste produced by ship operations,
- a fee for occupation of the public port domain (for the use of sand carrier terminals and processing on-land),
- a toll on the transport of goods by ship and for passage through locks (case of sand carrier terminals served by inland waterway),
- the general tax on polluting activities ("TGAP"), applicable to hazardous installations (which include sand carrier terminals). The TGAP includes a component relating to extracted materials of all origins destined for the building construction and public works sectors. It must be paid by the producer or the importer, depending on the net weight of the materials.

B6. LAWS AND REGULATIONS

- The European "Habitats" directive: Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora
- Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy
- Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment
- Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for Community action in the field of marine environmental policy (Marine Strategy Framework Directive)
- Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning
- French ordinance no. 2011-91 of 20 January 2011 on codification of the legislative part of the French Mining Code
- French ordinance no. 2016-1687 of 8 December 2016 on maritime spaces under the sovereignty or jurisdiction of the French Republic
- The French Environment Code
- The French General Code of Public Property
- The New French Mining Code
- French law no. 68-1181 of 30 December 1968 on the exploration of the continental shelf and extraction of its natural resources, repealed by Ordinance no. 2011-91 of 20 January 2011 and by Ordinance no. 2016-1687 of 8 December 2016

- French law no. 76-646 of 16 July 1976 on the prospecting, exploration and extraction of mineral substances not covered by article 2 of the French Mining Code and contained within the seabed of the public domain of mainland France, repealed by Ordinance no. 2011-91 of 20 January 2011
- French decree no. 71-362 of 6 May 1971 on prior exploration permits for mineral or fossil substances in the subsoil of the continental shelf
- French decree no. 95-696 of 9 May 1995 on the opening of mining works and the "Police des mines", repealed on 3 June 2006 by decree no. 2006-649 of 2 June 2006
- French decree no. 2006-648 of 2 June 2006 on mining titles and underground storage titles
- French decree no. 2006-649 of 2 June 2006 on mining works, underground storage works, and the policing of mines and underground storage facilities
- French decree no. 2006-798 of 6 July 2006 on the prospecting, exploration and extraction of mineral or fossil substances contained in the seabed of the public domain and continental shelf of mainland France
- French decree no. 2014-118 of 11 February 2014 amending decree no. 2006-649 of 2 June 2006 on mining works, underground storage works, and the policing of mines and underground storage facilities as well as the appendix to article R 122-2 of the French Environment Code
- French decree no. 2016-1303 of 4 October 2016 on prospecting work involving drilling and extraction of mining substances by means of wells, repealing the appendix entitled 'Title to conduct exploration involving drilling, extract fluids by means of wells, and process these fluids" of decree no. 80-331 of 7 May 1980 on general regulations governing extraction industries
- French decree no. 2017-32 of 12 January 2017 implementing article L. 132-15-1 of the French Mining Code
- French decree no. 2018-62 of 2 February 2018 in application of article L. 611-33 of the French Mining Code
- French government instruction of 17 February 2014 on the interaction between the EU Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD)
- Technical memo of 17 August 2018: sea basin strategy document

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UNPG

UNION NATIONALE DES PRODUCTEURS DE GRANULATS

The Union nationale des producteurs de granulats (UNPG) is the French national trade organisation representing all the companies that extract and produce natural aggregates (sand and gravel), whether land-won, marine, or recycled (from demolition or processing on-site), to supply the building and public works sector (1,800 companies, 2,300 quarries, 400 recycling sites, and 15,000 direct jobs). Most of the UNPG's members have signed up to the French quarry industry's environmental charter and to the 'UNICEM Entreprises Engagées' association (CSR).

To find out more: www.unpg.fr

FOR FURTHER INFORMATION:
www.sablesetgraviersenmer.fr