The rise and fall of the tide mill

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Abstract

Tide mills played an important role in the industrial and port development of Europe, particularly in the West. They were often sited on the coast, but also on estuaries. The technique of tide mill building and utilization was exported to the Atlantic coasts of North America. These mills were gradually supplanted by the advent of newer technologies, though several remained functional, and at work, well after the end of the Second World War. They may be justly considered the forerunners of modern tidal power plants. A renewed interest in tide mills has been generated by maritime and industrial heritage historians, and praiseworthy efforts at safeguarding and rehabilitation have blossomed, particularly in France and the United Kingdom. But is only history at stake?

Key words

tide mills, maritime heritage, cultural tourism, conservation and restoration, tidal energy

Introduction

Mankind has been awed by the sea, but not enough to refrain from trying to harness its forces. Since the latter half of the first millennium, people have put to work the energy of the tides. The industrial revolution introduced new sources of energy (e.g. steam, using coal) while the 20th century brought increasing dependence on oil, gas and electricity, even nuclear power. The excesses of 'progress' have also led people to reassess the past and to take a new look at tide mills. For some, they are part of the valuable maritime heritage that must be saved, for others a source of inspiration in the search for an environmentally benign source of energy.

The tide mill (also known as the sea mill) of the past has inspired engineers' dreams and, after lengthy and varied tribulations, became a genitor of tidal power plants. There are many suitable sites to build what the French (the first [1] to construct one) call 'centrales marémotrices', but such plants are still rare, except in China. Perhaps the Chinese have a better, certainly more realistic approach: instead of thinking 'big', as with the Chausey Islands scheme in Normandy (France) or the multiple-basins projects of Passamaquoddy (USA/Canada), they have thought of local needs which could be satisfied by small plants. Catering to local demands for power was the idea behind the tide mills that once dotted the coasts of England, Wales, France, Portugal, Spain, Canada and the United States.

The Persian Gulf was long regarded as the probable site of the first tide mills (Boithias and de la Vernhe, 1988). The Arab geographer, Al-Muqadassi describes the mills found at Basra in the Tigris-Euphrates delta (Iraq) and how water turned the wheels as it flowed back to the sea (Al-Muqadassi, 10th century). In Europe, the earliest recorded mill, mentioned in the *Domesday Book*, built (1066-86) at the entrance to the port of Dover on the English Channel (Wailes, 1941), was also frequently cited as the oldest in Europe. All that has changed since the discovery of a tide mill at the Nendrum Monastic site on Stanford Lough on the east coast of Northern Ireland. In 1999, archaeologists investigating what was thought to be a fishpond discovered millstones and indisputable traces of a tide mill. The dendrochronological study of the timbers first dated the mill to 787 AD, though later work suggests that it could have been built as early as 619 AD and twice rebuilt over the next 200 years. The Christian community at Nendrum flourished between the 7th and 10th centuries.

This paper provides an overview of tide mills throughout the world with emphasis, however, on recent research in the Iberian Peninsula, from the Basque Country in the North to the Gulf of Cadiz in the South, and the restoration of several mills in Brittany (France) over the last decade or so. Today, some are derelict (Fig. 1), many have disappeared without leaving a trace and efforts to save this industrial archaeological heritage are, on the whole, still timid. Until recently there were no molinological societies (González et al., 1997) endeavouring to preserve and restore tide mills, such as those that have long existed for the far more numerous wind- and water mills. In Brittany (France) there were a mere 90 tide mills compared to 3000 water mills and 5000 wind mills (Le Nail, 1982), and in Asturias (northern Spain), in the 18th century, there were 4529 water mills and just a handful of tide mills (Graña García and López Alvarez, 1987).

Tide mills: past and present

The ideal location of tide mills obviously is on coasts with a wide tidal range. Nevertheless, tidal range does not appear to be the sole determining factor, even if considered a major one by Gibrat, the 'father' of the Rance Plant. The Iberian Peninsula had the highest concentrations of tide mills in the world (some 100 mills in both Cantabria and in the Tagus Estuary) despite a limited tidal range not exceeding four metres for the northern, Cantabrian, coast and a mere three to four metres for the rest of the Peninsula during an average equinoctial spring tide. Indeed, in the Gulf of Cadiz, both in the Algarve and in Andalusia, the range is often below 3.5 metres (Ménanteau, 1997). Along the North Sea littoral, where some of the

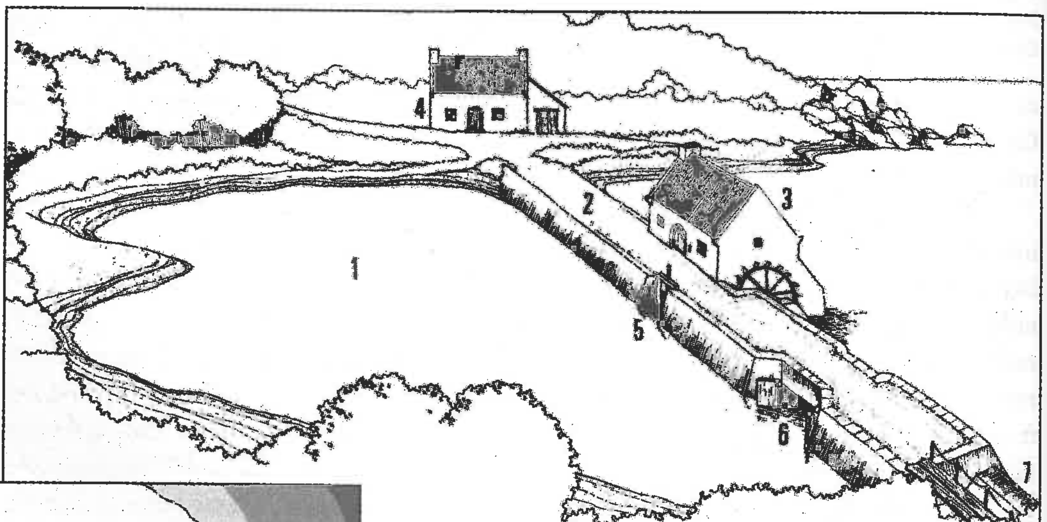
Fig. 1. Vestiges of the upper floor of the Beltrán Mill at Ayamonte, built where a tidal creek, the Estero de la Nao, joins the Guadiana River (Atlantic Andalusia, Spain). Note the outline of the international bridge over the Guadiana in the background. *(Photo: Loïc Ménanteau, March 1996)*

earliest European mills were built, in Guyana, or on the Caribbean, the range is under three metres.

Mills also need indented coastlines with inlets and small estuaries which can easily be blocked off by a dyke or causeway or with marshes drained by numerous channels. This means that rectilinear coastlines, whether rocky or alluvial, even if the tidal range is favourable, are not ideal places for the implantation of tidal mills (e.g. the coast of the Landes area in France). Some, known as mixed mills, have been placed on rivers, capturing both the flow of the river and tidal energy (Fig. 2, next page), others in bays, using tidal currents or on estuaries using the tidal flow.

In some rare cases, a cove is cut off from the sea by a dam or a dyke thus creating a retaining basin (Fig. 3a and 3b, next page). It is much more common to find mills on estuaries or 'rías' (submerged coastal valleys or estuaries resulting from a rise of sea level) and the 'cove' or tidal channel can be several kilometres from the coast, though necessarily subject to tidal influence. During the flood tide, water flows into the pond or basin through sluices (water- or floodgates). With the ebb tide, the water flows out of the pond thus activating one or more wheels (Fig. 4, next page), the blades of which produce the mechanical force required, e.g. to grind cereals. These traditional tide mills produce energy once in a tidal cycle, though some (double-effect mills) could provide mechanical power with both ebb and flood tides. The Rance power station could be seen as an heir to the latter.

Fig. 2. The sea-facing façade of the mixed mill of La Venera (on the Ría de La Venera in Armuero, Cantabria) at low tide. The mill building, now a private residence, was restored in the late 1990s *(Photo. Estuarium, 2/02/2003).*



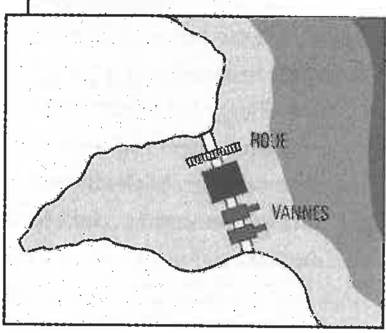


Fig. 3a. (top) Drawing of a traditional tide mill and its surroundings. *Legend:* 1. pond; 2. causeway; 3. mill; 4. miller's dwelling; 5. exit sluice and hydraulic wheel; 6. entrance sluice gate; 7. bridge. *(Drawing by A. de La Vernhe. In Boithias and de La Vernhe, 1988)*

Fig. 3b. (left) Simplified schematic presentation of a traditional tide mill. Roue = wheel; vannes = sluice gates. *(Source: EDF, France).*

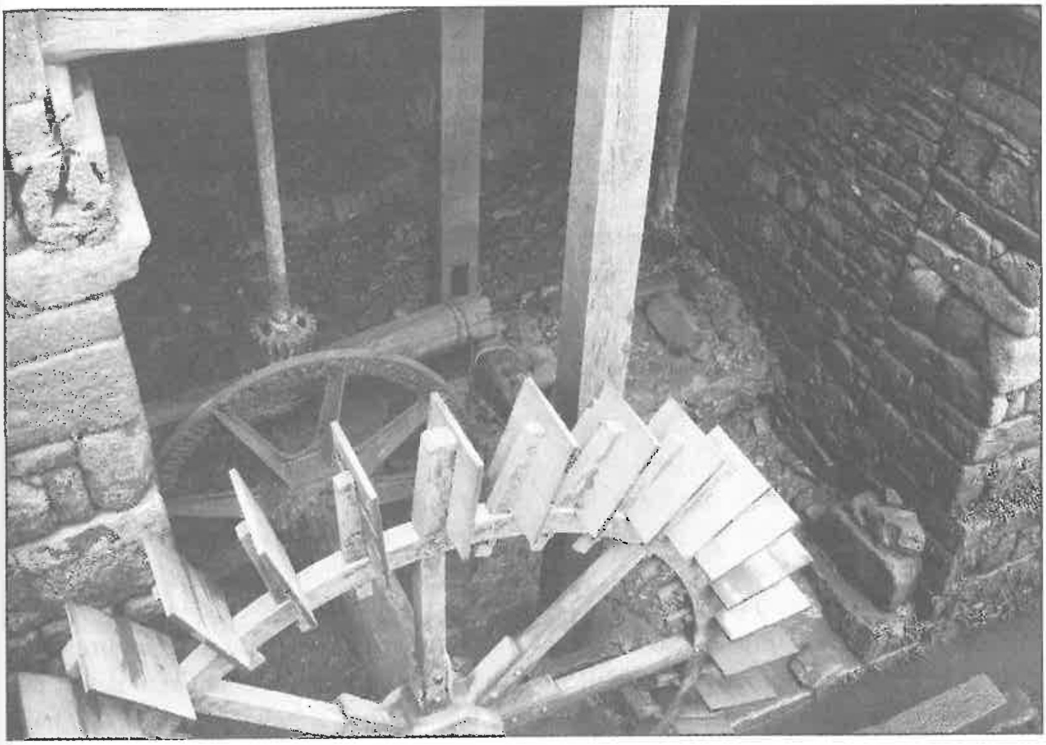


Fig. 4. The hydraulic system of the Traou Meur Mill at Pleudaniel (Côtes d'Armor, France). In the foreground, the vertical paddle wheel and, in the background, the mechanisms for transmitting power to and regulating the grinding stones *(Photo: Loïc Ménanteau, 11.08.1993).*

For reasons that go beyond the scope of this paper, natural conditions, though necessary, have not proved sufficient to encourage men to establish tide mills. Thus, the authors were unable to get information on whether tide mills ever worked on the coast of Korea, a region which, given its wide tidal range, is ideal for tidal power plants. Similarly, no tide mills were built in Northeast China, although information gathered at the Sixth International Congress on the History of Oceanography (ICHO VI, Qingdao, China, August 1998) places numerous such mills on the estuaries and coasts of Southeast China (personal communication to R. Charlier at ICHO-VI).

Indeed, apart from the mills described by Al-Muqadassi in the Tigris-Euphrates delta, so far tide mills appear to be very much a European, Atlantic basin technology. Their establishment by European settlers in North and South America has been well documented. Recent research has revealed that this technology was also exported to Australia. Two tide mills (a saw mill and a flour mill) operated in Spreyton, near Latrobe on the North coast of Tasmania between 1855 and 1890. They were established on land bought by Stephen Kelcey, a native of Kent, in 1852 (Preston, 2001).

Northern Europe

Little is known about northern Europe, nor does it seem that in-depth studies have been conducted in the Low Countries. In The Netherlands, where the earliest known mill dates from 1220, some twenty mills have been reported (Tuttel, 1978). A mill functioned in the thirteenth century in Zeeland and another in South Beveland. There were mills at Goes and in the canals on Walcheren Island's Flushings (Vlissingen, in Dutch; Flessingue on French maps). The last Dutch tide mills, according to a letter received from the late Jacob De Waart of the [Dutch] Molinological Society, disappeared during the 'Golden Age of the XIX Provinces' (16th and 17th centuries). Belgian tide mills were river-sited (on the Scheldt, off Rupelmonde and Zwijndrecht). The former probably dates from the early 16th century and was altered in 1567. Today it is well within the town of Rupelmonde and is regarded as one of its main tourist attractions.

In Germany there were no tide mills along the North Sea coast, but some were built in the Hansa City-State of Hamburg in the 16th century. The tidal range was ingeniously increased by damming some of the branches of the river. Canals were improved and by deepening some sections it became possible to establish tide mills using the canals as reservoirs (Minchinton, 2002).

British Isles

Tide mills operated mainly in England (including the Isle of Wight) and Wales, though some were located in Scotland. One, as noted above, is known to have existed already in the 11th century at the entrance to the port of Dover. Most mills, apart from the undated traces in Northwest Scotland, provided power to various 'industries' and businesses in Suffolk, Essex, Sussex, Hampshire, Pembrokeshire and London. The best sites are, of course, on the North Sea coast and on the Severn and Mersey Estuaries, sites frequently proposed for a tidal power plant. Nevertheless, there were more mills built on the southern coast, mostly for economic and political reasons: this is where the great ports Portsmouth, Plymouth, and Southampton are located (Fig. 5).

Among the earliest mills are: Bromley-by-Bow, built in 1135 and restored in the 14th century; Woodbridge (Suffolk), built in 1170; and Baynard's Castle near London (1180). According to Holt (1988), by 1300 there were 37 sea mills, as they were then known, in England. Thereafter, wind mills were often preferred because tide mills were damaged, even destroyed, by storms. In 1299 the Milton Hall mill (Essex) was replaced by a windmill and one of England's earliest tide mills, Walton Mill, (reputedly in existence in 1086), was abandoned in 1300. Lynn Mill, on the Ouse, was wrecked by the sea in 1369, as had already happened to Gulpelar and Lestanton mills, both on the Deben Estuary. The construction of tide mills, particularly from the fifteenth century onwards, encouraged better protection against severe storms. Millers protected their seaside structures with abutments, which constituted strong breakwaters and indirectly

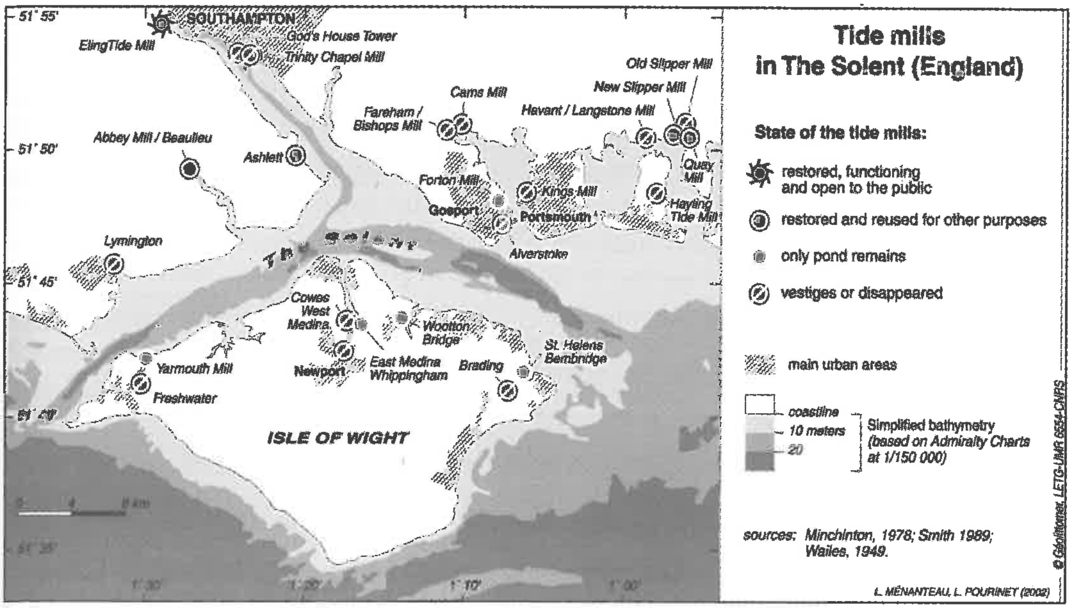


Fig. 5.

benefited neighbouring areas as well. Some of these structures have been conserved. Plymouth and Southampton had sea mills in the fourteenth and fifteenth centuries. Those of Southampton developed further in the seventeenth and eighteenth centuries; Eling Mill, built on a toll bridge in Southampton Water, is currently a working museum producing wholemeal flour. Plymouth had a mill in the eighteenth century. Background information on these mills has been provided in papers, amongst others, by Wailes (1941, 1961), Minchinton (1972-1982), Holt (1988), Triggs (1989) and Charlier and Ménanteau (1997).

France

Brittany has some 90 of the 150 mills thus far catalogued on the country's Atlantic coast. In France, as elsewhere, the architecture of many of these mills has been distorted by transformation into private residences (Loix Mill, Île de Ré in the Charente Maritime Department or Mériadec [Fig. 6, next page]), antique shops (Pomper, Morbihan), restaurants (Pencastel, on the Gulf of Morbihan, housed a famous restaurant in the 1960s) and crêpe-snack bars.

Some mills, however, have been fully restored. The Traou-Meur mill in Pleudaniel, on the Trieux (Côtes d'Armor) bought by the Page family in 1979, was one of the first to be fully restored and opened to the public as a working mill. Local and regional authorities have also contributed to safeguarding this Breton heritage. In 1964 the municipality of Perros-Guirec (also in the Côtes d'Armor) acquired the Petit Traouieros mill in Ploumanac'h and recently the regional authorities of Brittany have contributed to the cost of restoring the nearby Grand Traouiéros mill in Trégastel, where exhibitions on its history are set up during the summer. Although the site of the latter has had a mill since 1375, the present building dates from the 18th century. The relatively recent Petit Traouiéros mill was used for crushing ice for the fishing trade.

Brittany boasts the only two fully restored island-sited tide mills in France: Birlot, on the Île de Bréhat (Côtes d'Armor) and Berno, on the Île d'Arz (Morbihan), as well as the only inter-island mill, Buguelès (Fig. 7). Built between 1633 and 1638, the Birlot mill underwent considerable restoration in 1744. As flour was imported from the mainland, the mill was abandoned in 1916 and by the early 1980s was in a very sad state (Le Nail, 1982; Homualk de Lille, 1987). The municipality of Bréhat bought the site in 1990 and thanks to the devoted labour of volunteers the mill is now again in perfect working order; the large external wheel was put in place in 1997 and flour was ground, for the first time in more than 80 years, in May 2000. On the Île d'Arz, the mid-16th century mill was also abandoned in the early 20th century and was a mere ruin by 1980 (Le Nail, 1982). Local volunteers began work on restoring the 350-metre long dyke in the early 1990s, but it was in 1995, when the association created for its restoration signed a 99-year lease with the owners, that work began in earnest: the mill wheel was installed in 1998, and, after the brand new millstones were put in place, flour was ground for the first time in June

Fig. 6. The 17th century Mériadec Mill in Baden (Gulf of Morbihan, France) with dyke and two sluice gates with trap door. The mill stopped working in 1965. The 12.8 hectare pond, here seen at low tide, was used for aquaculture *(Photo Loïc Ménanteau, 21/08/1993).*

Fig. 7. The inter-island Buguelès Mill at Penvénan (Côtes d'Armor). This unique mill is built on a dyke between the Île Baëlenec and the Île des Oies. The funnel effect between the two small islands concentrates tidal energy and dispenses with the need for a mill pond. The mill building has become a private residence *(Photo Loïc Ménanteau, 11/08/1993).*

2000 (personal communication, Mr Demars). Here too subsidies, sponsorship and thousands of man-hours from volunteers proved crucial.

The Pencastel mill, the origins of which go back to 1186, stands on a 'listed' site (1933). The present mill, a fine early 16th century building, was bought by the General Council (Conseil Général) of Morbihan in 1995. The pond has been cleaned, the water flow restored, and the mill should be open to the public in 2004, when work on the building is due to be completed. There are, however, no plans to make this a working mill (information provided by: Services Techniques, Mairie d'Arzon, August 2003). In Vannes, the 'Musée des Beaux-Arts de la Cohue', displays the scale model of a tide mill and offers visitors a video programme dealing with those of the Gulf of Morbihan. In Finistère, the building of the Hénan Mill in Névez has been restored and a scale model can be seen at the local Tourist Office.

Though most mills were built in Brittany (Guillet, 1982; Le Nail, 1982; Boithias, 1988), others were sited in Normandy, in Charente Maritime, and in the French part of the Basque Country, the department of Pyrénées-Atlantiques (Rivals, 1973). No traces are left of the two tide mills constructed at the entrance to the Bay of La Rochelle, near the 'Tour à la Chaîne' (or Chain Tower), under an 1139 grant to the Knights Templar by Eleanor of Aquitaine. By 1300, seven mills were at work, along the Maubec Canal, inside the fortifications of the Protestant stronghold of La Rochelle. Eleanor's son, Richard I (or Richard the Lion-hearted as he is better known) donated a mill in the Bay of Mont Saint-Michel to the Abbey of the same name when he was Duke of Normandy (1189-1199). Of the seven mills once found on the Île de Ré in Charente Maritime (Tardy, 1984), the only survivor, in Loix, was abandoned some time after the Second World War and is now a private residence. In this department the Loges Mill (Pinard, 1983), in Saint Just Luzac in the Seudre basin, was bought by the Conservatoire du Littoral and now houses a museum.

In the Basque Country (Pyrénées-Atlantiques), where some 30 mills have been recorded, the earliest go back to the first quarter of the 12th century: Bayonne (1120- 1125) and La Mufale (1123-1133) (Veyrin, 1936; Aguirre Sorondo, 1982). Most mills were built along the estuaries of the Nive and the Adour Rivers and two were established at the confluence of the two rivers. In Bayonne six mills were still functioning in the Saint-Esprit quarter in the early 19th century, but also in Ascain, Sopite and Saint Jean de Luz.

The Perse Mill, a lone mill in Dunkirk (Dunkerque in French, Duinkerke on Flemish documents) built at the end of the 17th century, was connected to a windmill and used both the ebb and flood currents, a forerunner of sorts of the double-effect tidal power plant. (Forest de Bélidor, 1737-53). The Indret mill, situated at Basse-Indre (Loire-Atlantique) on an island in the Loire, housed an iron foundry functioning entirely on tidal power between 1778 and 1786. William Wilkinson, the English engineer entrusted with the project by the French Navy, decided to use tidal power for the melting and boring of cannon (Ménanteau, 1999). Even more spectacular was the industrial flour mill, built (1787-88) on the present Bacalan quay in Bordeaux. This monument of industrial architecture was described by numerous travellers who were much impressed by the sheer size of the construction (65 x 29 metres) and of the installations (4.8 hectares). Like the Perse Mill, it had a two-way function. (Charlier and Ménanteau, 1997).

Thus, Brittany, which had the largest number of mills in the past, is today the only region with several fully functioning mills and endeavours actively on restoring others (e.g. Kervilio, in Bono in the Gulf of Morbihan). This should change in 2004: the Loges mill in the Seudre salt flats (Charente Maritime) is due to join this very exclusive club.

Iberian Peninsula

Here, three major geographic regions can be distinguished: the coast of the Cantabrian Sea (from the Basque Country on the border with France to Galicia in the Northwest), the Atlantic façade (western Galicia and Portugal) and finally, the Gulf of Cadiz (the Algarve in Portugal and Atlantic Andalusia in southern Spain). In Spain, and particularly in the northern region of Cantabria, where several mills go back to the 16th century (Joyel, Fontorilla, Victoria or Barbijo) the real change is in the domain of research. Luis Azurmendi reported fifteen mills some twenty years ago (Azurmendi, 1985 and 1988) whereas now the figure stands at about 100 for the region of Cantabria alone. Vestiges of some 50 mills have been found and some 50 others have been traced in archives (personal communication by L. Azurmendi, August 2003).

In the Basque Country, the highest concentration of mills seems to have been around the Port of San Sebastián in the province of Guipuzcoa (Cordón, 1975), which had seven in all and three in Arteaga (Guernica Estuary, Vizcaya). In this Basque province, local authorities set out detailed rules on the construction of tide mills as early as 1528 and the earliest documented mill, in Leiqueitio, dates from 1555. In Guipuzcoa, there are references to what was probably a tide mill in Irún in 1527 and the deeds of the Santa Engracia (Fuenterrabía) go back to 1576. This mill continued to work until the late 18th century (Aguirre Sorondo, 1982 and 1997). One of the last mills to be built (1796) in the Basque Country was the Maiukitza Mill in Murueta. This was a standard flour mill, but also ground kaolin for the nearby Busturia ceramics factory. By the late 16th century tide mills were a common sight in the Spanish Basque Country. It is interesting to note that early Spanish documents frequently refer to French master mill builders ('maestros de fazer molinos franceses'); as has been said the Mufale Mill in Bayonne (French Basque country) was built between 1125 and 1133.

Today, there is no trace of the mills of San Sebastián (Donostia, in Basque): the last vestiges of the Naza-errota or Santander-errota, as it was also known, were destroyed in 1996 and only part of the mill in the nearby fishing port of Orio remains. In Vizcaya, one of the finest Basque mills, Plentzia, was torn down in the late 1980s to make room for a bridge. Under the circumstances, the fate of Portu Errota, the only Basque working mill, is all the more wonderful.

Of the three mills once found in the Guernica Estuary, one of the oldest, Portu Errota (1683), was bought by the Iturribarria family in 1965 and has since been perfectly restored. The mill was built some five kilometres from the coast, in a tidal zone where the exceptionally long low tides (nine hours) and the very rapid rise of the incoming tide (three hours) allowed the miller to operate the mill for seven hours twice a day. During neap tides, thanks to the channelling of the Koba, a mountain stream, the miller could, and still does, extend his working day. For this is a working mill, which grinds maize just as it did when it was built, nearly 300 years ago (www.arrakis.es/~errota/indexe.htm).

In the neighbouring region of Cantabria in the 17th century, the widespread use of maize as the staple crop explains both the remarkable population growth and, to a lesser extent, the spectacular increase in the number of tide mills. Research here progresses well and, like the Nendrum mill, is likely to upset a few established 'apple carts'. The highest concentration of tide mills was to be found in the Trasmiera area and was due to the export of flour to the American colonies through the port of Santander (Escaleza and Villegas, 1985).

Fig. 8. Santa Olaja Mill built in the early 18th century at Armuero in the marshes of the Ría de Quejo (Cantabria, Spain). Detail of one of the two rooms of the restored mill. Here (from left to right) Nicasio Perera, Loïc Ménanteau and Luis Azurmendi (who drew up the plans for the restoration of the mill) watch, through the glass plaque at right, some of the nine horizontal mill wheels turning. The project was financed by the Municipality of Armuero and the Spanish Ministry for the Environment (Dirección General de Costas) *(Photo Estuarium, 2/02/2003).*

Existing tide mills, mostly found in small 'rías' (Castellano, Quejo etc.) and in the wetlands surrounding them (e.g. Marismas de Joyel-Noja-Isla, de la Victoria) as well as in the Ría de Santoña at Escalante are also being salvaged and restored. Thus, La Venera (1753), now a private residence (Fig. 2), was restored by Luis Azurmendi who also drew up the plans for the restoration of Santa Olaja. This is a working mill open to the public with exhibitions on milling techniques and an excellent video presentation on the lunar influence on tides (Fig. 8).

Along the Cantabrian Sea coast, the earliest documented mill stood in Avilés (Asturias) in the municipality of Villaviciosa. On 12 June 1232, Ferdinand III (Saint Ferdinand) confirmed a grant made by his father, Alfonso IX on 31 July 1229. A few years later the mill was sold to the neighbouring Cistercian monastery of Valdediós (Graña García and López Álvarez, 1987). Of the ten tide mills located in the Principality of Asturias, four are still in fairly good condition and could be restored. In Llanes, the municipal authorities are restoring the Mari Muerto Mill (López Alvarez, 1997).

Several mills have been traced and studied in Galicia (Bas López, 1991) where the deep wide rías of the western coast are particularly suited for harnessing tidal power. The Ría de Arousa had the largest number of mills. Many were built in the 17th century (e.g. A Seca mill, 1622) and several large industrial mills were built in the 18th and 19th centuries. Some have been restored and now house various exhibitions on milling and other aspects of local history. The das Acenas or Aceas mill on the Isla de Arousa, in the ría of the same name, became one of the main flour mills in Galicia in the 19th century when grain arrived from the Ukraine and America. The Muiño da Cura, at the mouth of the Catoira is currently being restored. Another vast 19th century structure, the Pozo de Cachón Mill in Serres, was also restored in the 1990s, as was Galicia's best known mill, the Molino das Mareas in Muros (Bas López, 1997). Galicia also boasts the very last tide mill to have been built in Europe (1905-1910): known simply as Muiño do Mar (tide mill) it was built in the Ría de Ortigueira. The new interest in tide mills is reflected by these official restoration projects (Llano, no date) and the fact that they are increasingly included on tourist routes even if only vestiges remain.

Along the Atlantic façade of Portugal, the earliest recorded mills were found at Alcantara (Lisbon) in 1313 and at Montijo (1386). Most of the Portuguese estuaries had tide mills but there were exceptional concentrations in the Tagus Estuary: in the Seixal area, on the South bank and across the river from Lisbon. By the 16th century some 60 mills were recorded between Almada and Montijo. In the Vale-do-Zebro, opposite Lisbon, 27 mills supplied an equal number of ovens producing ship's biscuits for the Portuguese Navy. At the height of activity of the port of Lisbon there were about a hundred mills in the Tagus Estuary alone. (Veiga de Oliveira et al.,1983; Branco, 1990; Maia Nabais, 1997).

In 1755, the so-called 'Lisbon earthquake' (the repercussions of which were felt even in Atlantic Andalusia) destroyed many tide mills. Some were restored, others completely rebuilt and, of these – perhaps due to the economic conditions in Portugal – some survived well into the 20th century. Most continued to produce flour, others were used for grinding fishmeal, or husking rice.

The Corroios Mill closed in 1970 only to be bought by the municipality of Seixal in 1979. In 1986 it was opened to the public, in perfect working order, as an eco-museum and part of an industrial heritage centre (Montalverne, 1991). The ten mills, many of them mere ruins, which survive in the Seixal were all 'listed' by the Portuguese authorities in 1984.

Nearly ninety mills have been recorded in the Gulf of Cadiz, more than half of them in the Algarve (Portugal) and the remaining 40 in Atlantic Andalusia (Spain) (Vanney and Ménanteau, 2003). There were some twenty mills in the western Algarve along the Rio Arade between Silves and Portimão and 29 in the Eastern Algrave near Faro and in Olhão, Tavira, and Castro Marim (Rosa Santos, 1992). The earliest representations of tide mills in the Iberian Peninsula depict two mills in the Gulf of Cadiz: Castro Marim in 1290 (Fig. 9, next page) and the Trocadero Mill (later known as the Guerra Mill) in Puerto Real, by the Castillian artist, Francisco Lobato in the 16th century.

The Bay of Cadiz (Ménanteau et al., 1989; Molina Font, 2002), with the ports of Cadiz and Puerto Real had a total of 21

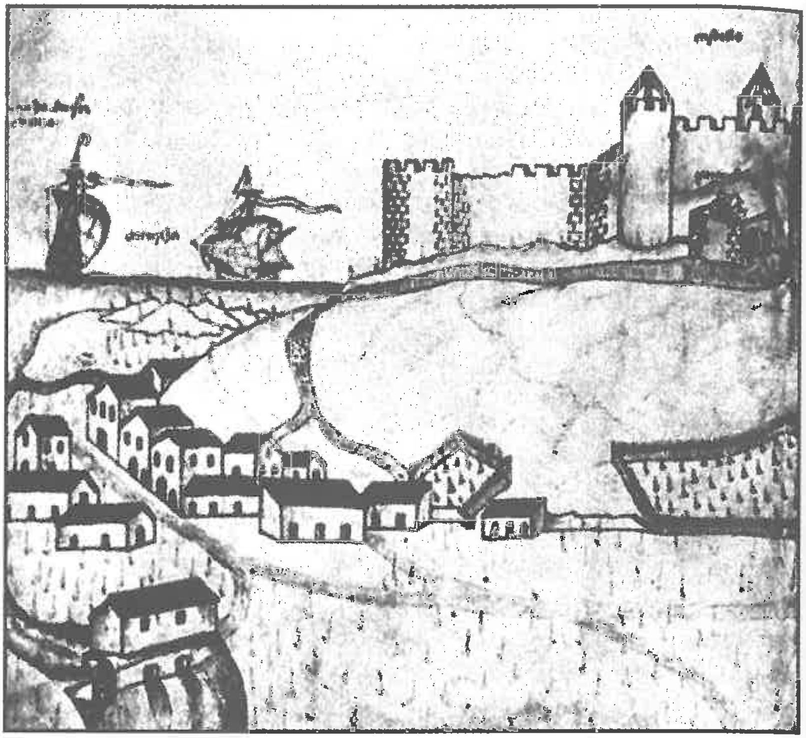


Fig. 9. The tide mill at Castro Marim (Algarve, Portugal) on the right bank of the mouth of the Guadiana. This is the earliest known representation of a tide mill in the Iberian Peninsula (taken from *Livro das Fortalezas* by Duarte Larmas, 1290, courtesy of L. Ménanteau). The mill, bottom left hand corner, stood at the exit of a tidal channel. Note the larger, entrance sluice gate (to the left) and the two exit sluices, the water of which set the horizontal mill-wheels in motion.

mills: seven around the Isla de León and six on the inner border of the bay in Chiclana, Puerto Real and Puerto de Santa María (Fig. 10). In Atlantic Andalusia mills were also found in the estuaries of the Guadiana and Río Piedras, in the Ría de Huelva (Vanney and Ménanteau, 1985), in the Tinto-Odiel wetlands, and in what is today the National Park of Doñana in the wetlands of the Guadalquivir (Ménanteau, 1991).

The late 19th century Quinta de Marim Mill, at Olhão functioned until 1970, when it was acquired by the Serviço Nacional de Parques. Today it is a reception and exhibition centre for visitors to the Nature Park of Ria Formosa. The rest of the Algarve mills are mostly in poor condition with the exception of the Estombar mill on the banks of the Arade River that, thanks to the efforts of the Lagoa municipal authorities, is a working mill and produces flour for the local baker. It is the only Portuguese mill with a dwelling and a current resident miller (Vanney and Ménanteau, 2003).

Andalusia, which played such a key role in the maritime history of Spain, has so far neglected this and other aspects of its maritime heritage (Ménanteau, 1993). Nevertheless, it seems that plans to restore several tide mills such as El Arillo (Fig. 11), Caño Herrera and Santibañez in the Bay of Cadiz, or the El Pintao Mill in Ayamonte, close to the Portuguese border (González et al., 1997), are finally getting off the ground.

In the Bay of Cadiz, where salt-pan reservoirs often doubled as mill ponds and tide mills were used for grinding salt

Fig. 10.

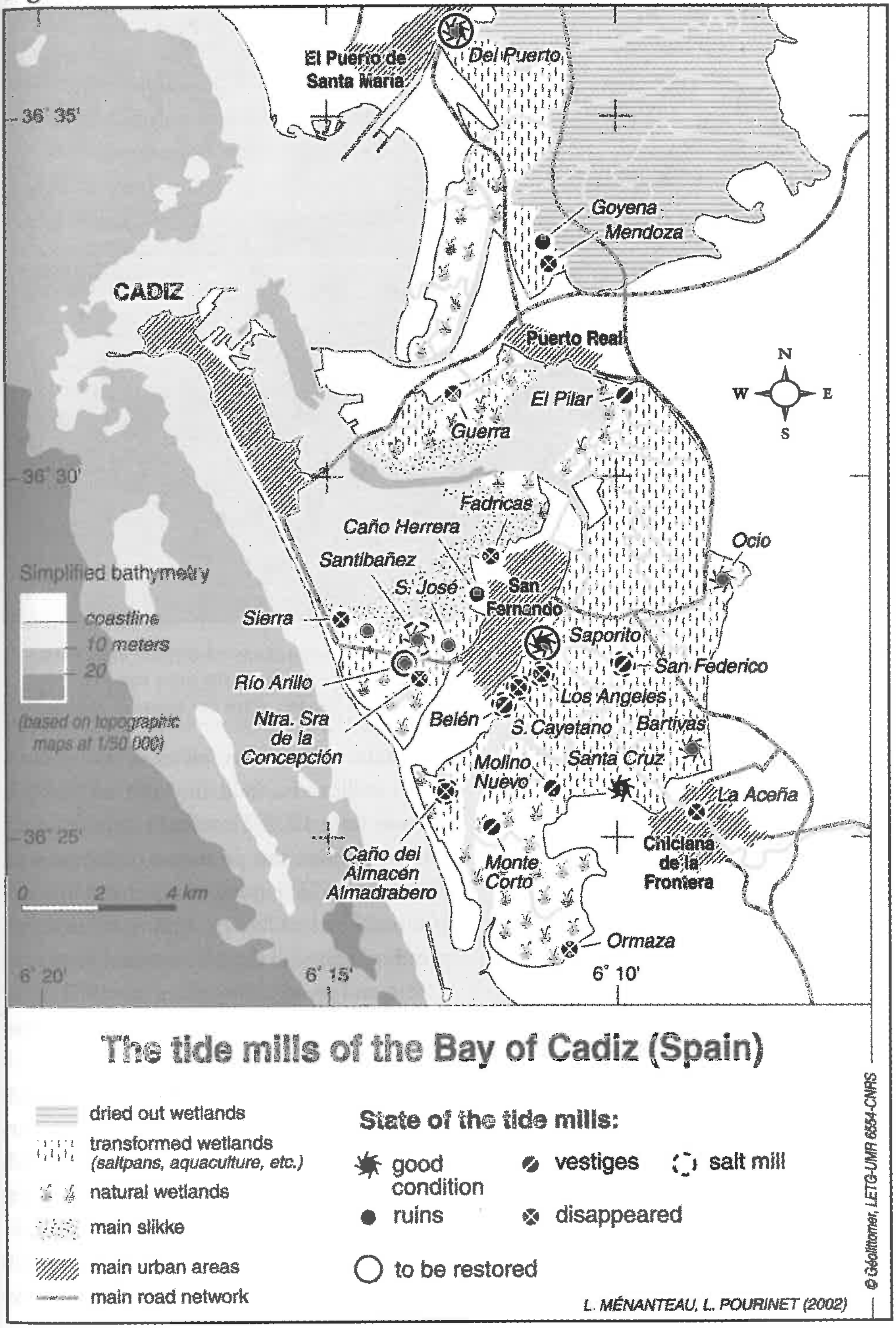

El Puerto de Santa Maria
Del Puerto
36° 35'
Goyena
Mendoza
CADIZ
Puerto Real
N
W
E
S
El Pilar
Guerra
36° 30'
Fadricas
Caño Herrera
Santibañez
Ocio
S. José
San Fernando
Simplified bathymetry
coastline
10 meters
20
(based on topographic maps at 1/50 000)
Sierra
Saporito
San Federico
Río Arillo
Los Angeles
Ntra. Sra de la Concepción
Belén
S. Cayetano
Bartivas
Santa Cruz
Molino Nuevo
La Aceña
36° 25'
Caño del Almacén Almadrabero
Monte Corto
Chiclana de la Frontera
0
2
4 km
Ormaza
6° 20'
6° 15'
6° 10'
The tide mills of the Bay of Cadiz (Spain)
dried out wetlands
transformed wetlands (saltpans, aquaculture, etc.)
natural wetlands
main slikke
main urban areas
main road network
State of the tide mills:
good condition
vestiges
salt mill
ruins
disappeared
to be restored
© Géolittomer, LETG-UMR 6554-CNRS
L. MÉNANTEAU, L. POURINET (2002)

Fig. 11. The main façade of the Arillo Mill (Cadiz, Spain). Water flowed into the pond through eight entrance sluices: four on main façade and four others perpendicular to the mill (not seen here); the most important are behind the two larger central arches. All the exit sluices are on this main façade. *(Photo Loïc Ménanteau, November1991).*

(Ménanteau, 1994), pressure comes as much from conservationists who want to see salt pans restored as those interested in preserving an architectural heritage.

The Americas

British and Dutch settlers took their ideas with them and recreated, on the other side of the Atlantic, working environments that they had known in their country of origin. In all, some 300 to 350 tide mills were built along the Atlantic coast of North America from Canada to Georgia (USA), most of them (some 150) in Maine and Massachusetts (USA). The first tide mill in the United States was built in Salem (Massachusetts) in 1635. That same year, Henry Jackson left England for the United States where he built a tide mill at Fairfield in 1648 or 1649. A century later, 1734, Thomas Pratt built a tide mill at Chelsea; the precursor of the present Slade's Spice Mill, now incorporated in a US National Park. Chelsea Mill was used for grinding grain till the 1820s when snuff was added and eventually spices in 1837. The machinery for harnessing the tide and opening the sluice is still operable.

Dutch colonists also built such mills in and around what is today New York, in the first half of the 17th century. Tide mill construction and utilization took off in earnest, both here and in Massachusetts, in the following century. Of the numerous mills built on Long Island in the eighteenth century, one of the most remarkable is the Van Wyck-Lefferts Tide Mill, built (1793-97) at Mill Cove Pond, near Huntington. (Wickert, 1956; Charlier and Ménanteau, 1997).

French immigrants, however, were the first to import tide mill techniques to the New World. In 1613, with the help of Mi'kmaq Indians, the French built a dual-function tide mill in Port Royal, capital of Acadia (now Annapolis Royal in Nova Scotia) (Cornier, 1990). This rich fishing area was colonized in the early 17th century by settlers from around La Rochelle and Brouage, famous for its salt pans. The early Acadian system of dykes, salt pans and the use of the marshes dates from this period.

On the tropical shores of the Caribbean several mills have been recorded, notably in Surinam (formerly Dutch Guiana) and others undoubtedly existed both in the Lesser and in the Greater Antilles, where they were used for sugar cane processing (Boithias and de la Vernhe, 1988). No tide mill has survived in Surinam, though one can still see the foundations of the tide mill on the Visserszorg estate on the Commewijne River. The last vestiges of the much older mill on the Waterland Estate on the Surinam River were removed a few years ago (www.jodensavanne.sr.org). A tidal power plant is said to have functioned in Surinam (Charlier and Justus, 1993).

Electricity from tidal energy: France's Rance Estuary power station

The Rance lost several tide mills, including Guinard or Beuzais, when the homonymous tidal power station was constructed in the 1960s, thus depriving the estuary of its natural tidal influence. Transformed flour mills, using diesel or electricity, resisted somewhat longer, notably La Cale (1970) and Beauchet. The buildings were often in good condition, but the ponds silted up when the tidal range and the currents within the estuary were reduced. Time and the exposure to nearby sea conditions, however, have taken their toll, and the need for maintenance and restoration of such rare buildings is evident. Figure 12 shows the Beauchet tide mill at Saint-Suliac as it stood in the 1970s. Since the 1990s some have been restored. The Prat Mill, acquired by the municipality of La Vicomté sur Rance in 1994 was officially opened to the public on 29 June 2002. (http://lavicomtesurrance.free.fr).

The Rance Estuary power station [1], designed in 1959 and in operation seven

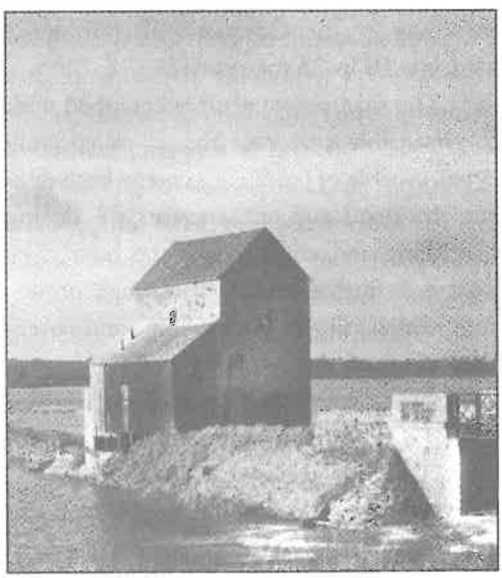


Fig. 12. The tide mill of Saint-Suliac, France *(Source: EDF, France).*

years later, transposed the tide mill principles of tidal energy harnessing into modern technology. Like many traditional tide mills it has a retaining basin closed off from the estuary by a barrage or dam. In other cases a small bay is closed off, as for instance in many Chinese plants. In tidal current schemes, no barrage is required as a part of the estuary flow is diverted and forced to pass through a separate channel.

A causeway was built on top of the dam and a highway crosses the river, shortening the distance between towns on both sides of the Rance River by more than 30 kilometres and putting a ferry out of operation. In traditional mills the width of dykes depended largely on the resistance to be opposed to the sea as well as the shape of the dyke and the methods used in its construction, though most were three to five metres across. This Rance dual carriageway (the D-168) is closer to the exceptional causeway of the Cosquer mill (Finistère,) which is 18 to 23 metres wide.

The tidal power plant is equipped with 24 reversible turbines (the so-called bulb type), capable of producing energy both during the flood and ebb currents, i.e. during the filling and emptying of the basin. The system is further enhanced through pumping, which allows 'over-filling' and 'over-emptying' of the retaining basin (Morcos, 1967; Charlier, 1982; Charlier and Justus, 1993). The nine to fourteen-metre range tides can produce close to 550 000 kilowatts. The station is linked to the French National Electricity Grid. Figure 13 gives a perspective of the size of this modern installation.

Tidal power stations could provide valuable co-generation; yet, since the Rance Estuary station, only very modest stations have been built in Russia, Canada and China (Charlier, 2003). Much attention is now given to tapping tidal current energy, which dispenses with a barrage (Charlier, 2003). The talk about putting tide mills – ancient, rebuilt or new – back to work may not be entirely idle, as these 'traditional facilities' could perhaps, in isolated sites, 'refloat' the industries of decaying villages.

Conclusion

Tide mills, the true ancestors of the tidal power plant, could possibly find a new life as small mills serving an immediate community, an idea perhaps reflected in the many small tidal power plants functioning in China (Zu-Tian, 1989). The question may be appropriately raised, it seems, as to whether tide mills, or their remnants, ought to be preserved as a rare heritage, or considered as a technology, which, with refinements, could be usefully resurrected and put back to work.

As can be seen from the various restored mills mentioned above, so far heritage has the upper hand. There are many reasons why in France, it is in Brittany, with its strong cultural identity, that so many mills have been restored. That volunteers should have played, and continue to play, such a key role is also symptomatic. The close collaboration between a tiny community and the local authorities in the restoration of the Prat Mill (Rance Estuary) is a case in point. Here, with the aid of

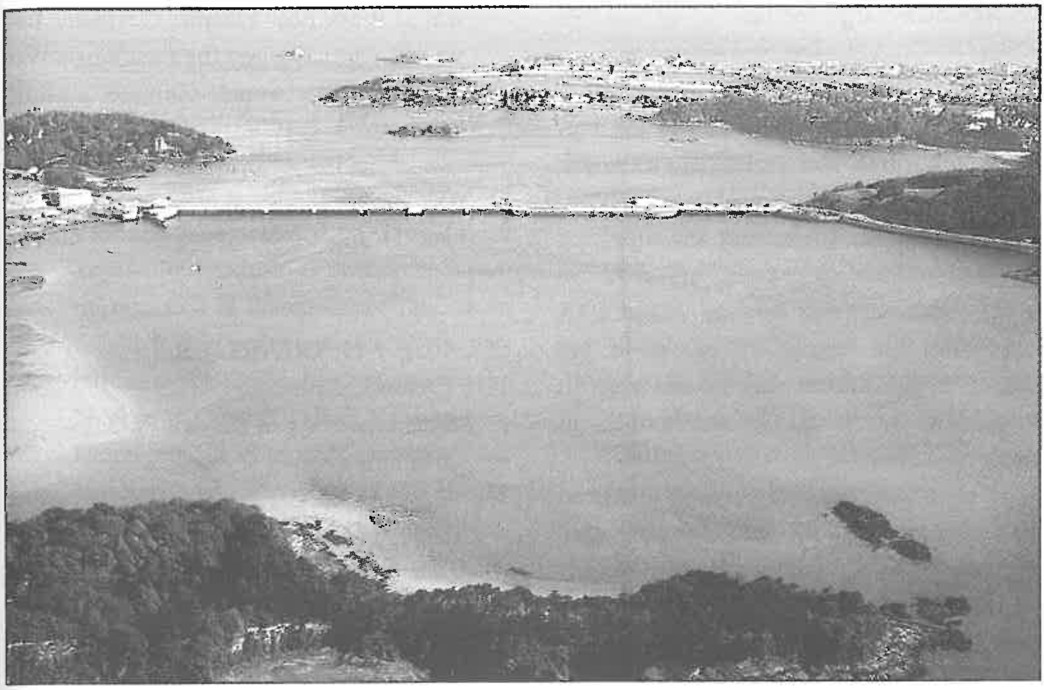


Fig. 13. Rance Estuary tidal power station, France *(Source: EDF, France).*

helpful bankers, the Mayor took out a loan that the local association paid back by a very active fund-raising campaign. If, after a long period of neglect, tide mills are making headlines it is because they are seen as part of a much wider context: the maritime heritage of regions which traditionally turned to the sea for their livelihood. Witness the interest in early sailing craft: thousands come to see the rare beauty of the large sailing vessels which come to Brest or Rouen every two years; in Nantes, the *Bélem* always gathers a crowd when she comes into port; in Portsmouth the Maritime Museum is equally popular. If in Andalusia, and especially in the Cadiz area, it is the conservationists who are putting on the pressure for the restoration of tide mills, it is because they want to see salt pans brought back to life (as has been so successfully done in Guérande, France) and thereby the traditional water flow restored to the tidal channels of the inner Bay.

And then there are the engineers looking for new, renewable sources of energy. Some feel it is not too far-fetched to suggest that tide mills could function parallel to their impressive modern counterparts and provide (in disinherited regions, in developing countries, in forlorn areas not in need of huge blocks of kilowatts) the power needed by modest local industries. Small can be beautiful, it was once said. It can also be useful and adequate. Why should not tide mills, like the Phoenix, rise from their ashes?

Acknowledgements

The authors express their thanks to the colleagues who read the manuscript critically. Special appreciation is expressed to Selim Morcos for reading this manuscript and supplying additional information and illustrations. Above all, they owe a great debt to Marja L.O. Kostrowicka for sharing the results of her research on the present state of tide mills in Europe and her invaluable contribution in editing the article.

The authors also express their thanks to Luis Azurmendi, who provided data on the latest research in Cantabria (Spain); to Mr Dumars of the *Association pour la restauration du moulin de Berno* (Île d'Arz, Brittany) and to all those who provided information on the present state of tide mills in their area. Laurent Pourinet is thanked for his excellent and very professional technical work in preparing several of the images for this article. Finally, special appreciation is also expressed to Gary Wright and Michael Tran for their help and patience during the final stages of preparing the article for publication.

Endnote

1. The claim, sometimes made, that the French Rance River plant was the first such tidal power station is challenged at times, but it certainly was the first one of large dimension and of high production. A tidal power station functioned in the latter part of the 19th century in Boston Harbor (Massachusetts, USA) [cf. H. Creek, 1952, Tide mill near Boston: *Civil Engineering*, **22**:840-841]. Another was at work near Husum, Germany, but was dismantled when the First World War began (1914). Some Chinese authors have stated that a tidal power station existed in China prior to the construction of the Rance River station (Ch'in Hsu-Ts'ung, 1958).

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