# Chapter 1
# INTRODUCTION

## 1.1. PRESENTATION

A tidal bore is a series of waves propagating upstream as the tidal flow turns to rising. It forms during spring tide conditions when the tidal range exceeds 4–6 m and the flood tide is confined to a narrow funnelled estuary. The estuarine zone is defined herein as a water body where the tide meets the river flow. It corresponds to the river section where the mixing of freshwater and seawater occurs. Figure 1.1 illustrates several tidal bores in France. Figure 1.1A shows a tidal bore in the Baie du Mont Saint Michel (France). The tidal bore advances in the riverbed and on the surrounding sand flats and sandbanks. Figure 1.1B presents the tidal bore of the Garonne River about 30 km upstream of Bordeaux (France). The surfers give the scale of the bore front. Figure 1.1C illustrates the formation of a tidal bore at the upstream end of a funnel-shaped bay during the early flood tide, while Fig. 1.1D shows a tidal bore propagating upstream into a small creek.

The origin of the word 'bore' is believed to derive from the Icelandic 'bara' ('billow', 'wave') indicating a potentially dangerous phenomenon, i.e. a breaking tidal bore (Coates 2007). During the 19th century, the Severn tidal bore was referred to as a 'bore', although it was also called 'Hygra' (Rowbotham 1983). An older name was 'eagre', used today for the tidal bore of the Trent River (UK). It derives from the Latin word 'augurium' or 'augurum' for 'fruit of the act of divination; omen, prophecy' meaning flood. The Trent River tidal bore was also known as 'Nennius' during the 9th century AD (Coates 2007).

The French name is 'mascaret' that is said to derive from the Gascony word 'masquaret' meaning a 'galloping ox' (Petit Robert 1996). In Japan, a tidal bore is called 'shio-tsunami' but a tsunami-induced bore is called 'kaisho' or simply 'tsunami' (tidal wave). In China, the 'Silver Dragon' is the name of the Qiantang River tidal bore. Other local names of tidal bores include 'le montant' (Garonne River, France), 'la barre' (Seine River, France), 'le mascarin' (Vilaine, France), the 'pororoca' (Amazon River, Brazil), the 'burro' (Colorado River, Mexico) and the 'bono' (Rokan River, Indonesia).

A tidal bore is almost a mythical phenomenon. It occurs only during the flood tide under spring tidal ranges and low freshwater flow conditions. Its passage is very rapid, e.g. from a few seconds to a few minutes at most. And it is so easy to miss … A classical example is the Qiantang River tidal bore that has been documented for nearly 3000 years; yet Marco Polo who visited the city of Hangzhou on the Qiantang River estuary never mentioned the ‘Silver Dragon’. Another is the drowning of Victor Hugo’s daughter Léopoldine and her husband in the Seine River that was related in the memorable poem ‘*A Villequier*’. Léopoldine and her husband drowned when their boast capsized, but not by a tidal bore because the day of the accident was during neap tides and there was no tidal bore at the time of the accident. More her husband was from a family of ship pilots who knew well the tidal bore phenomenon. A tidal bore may further disappear for several years to re-appear stronger as the result of change in estuarine bathymetry and

(A) Tidal bore of the Sée River (foreground) in the Baie du Mont Saint Michel (France) at the Pointe du Grouin du Sud on 19 October 2008 at 09:31 — Note the Mont Saint Michel in the background, and the interactions between the tidal bore flow and the rocks in the foreground — Shutter speed: 1/1000 s.

Fig. 1.1. Photographs of tidal bores in France.

(B) Tidal bore of the Garonne River (France) upstream of Port de Podensac on 28 September 2008 at 17:34 — Note some breaking next to the left bank (on the left of the photograph) while the bore was undular in the main channel — Shutter speed: 1/1000 s.

(C) Incoming tidal bore of the Arguenon River (France) at Les Pierres Sonnantes on 15 October 2008 at 17:25:30, with the Baie de l'Arguenon in background — Shutter speed: 1/320 s.

Fig. 1.1. (*Continued*)

(D) Tidal bore in the Frémur Creek, Baie de la Frênaye (France) on 16 October 2008 at 19:13:43 at sunset — The bore celerity was about 1.5 m/s — Note the bridge of Port-à-la Duc in background — Shutter speed: 1/30 s.

Fig. 1.1. (*Continued*)

man-made works. A classical example is the tidal bore of the Seine River whose tidal bore disappeared in the 1850s following river training, but re-appeared even stronger from 1858. Even small changes in freshwater flow conditions can change the shape of the tidal bore, e.g. the Sélune River tidal bore at Pontaubault was a strong, breaking bore in 2006 during a long dry season associated with very low water levels, but the bore was a weak ripple at the same place in 2008 under similar spring tidal conditions.

## 1.2. RELATED PROCESSES

A tidal bore occurs during the flood tide under appropriate tidal, bathymetric and riverine conditions. There are some related geophysical, as well as man-made, processes. These include the storm-surge-induced bores in the Bay of Bengal, the tsunami-induced bores and the positive surges in canals.

In the Bay of Bengal, the development of a storm surge during the early flood tide with spring tidal conditions may yield a rapid rise in water level generating a bore front. The wind shear amplifies the tidal range and the phenomenon has been observed in Bangladesh where the storm events are called locally 'tidal bores' (Sommer and Mosley 1972, Delwar 2001). For example, on the night of 12–13 November 1970, a cyclone and tidal bore hit the southern coastal region of East Bengal, then East Pakistan. More than 224,000 people died, possibly as many as 550,000 lives lost (Sommer and Mosley 1972). The Great Cyclone landed ashore between the mouths of the Haringhata and Meghna Rivers. The wind speeds were up to 222 km/h and the storm surge was estimated to be about 4.5–6 m high (Longshore 1998). Some simple calculations based upon the Saint–Venant equations predicted a 2 m high storm-surge-induced bore. The surging waters flooded the low-lying country in the first few hours of the day. The severity of the catastrophe was unrecognised by the Government at the time and the event contributed to local resentment against the Pakistan Government, the break-out of civil war in 1970, and ultimately the secession of Bangladesh in 1971.

Another related process is the tsunami-induced bore. After breaking, a tsunami wave propagating in shallow-water regions is led by a positive surge. In shallow rivers, the process is somehow similar to a tidal bore and the tsunami-induced bore may propagate far upstream. Some tsunami-induced river bores were observed in Hawaii in 1946 and in Japan in 1983, 2001 and 2003 (Shuto 1985, Oshiki *et al.* 2008). During the 26 December 2004 tsunami catastrophe, tsunami-induced bores were observed in shallow-water bays and river mouths in Malaysia, Thailand and Sri Lanka. Figures 1.2A and 1.2B show two examples of tsunami-induced bores in shallow-water bays on 26 December 2004. In rivers and shallow-water bays, the propagation of the bores is associated with sediment scour, strong mixing and suspended sediment advection upstream.

Positive surges and bores may be observed in irrigation channels and water power canals during gate operation. Ponsy and Carbonnell (1966) and Treske (1994) presented some photographic illustrations while Benet and Cunge (1971) conducted some field measurements in prototype hydropower canals. Bores are also observed at the leading edge of violent flash floods propagating downstream narrow canyons. Cornish (1907) documented a number of such 'downstream bores'. Another form of bore is a dam break wave propagating downstream in a valley with a volume of liquid at rest or in motion (Liggett 1994, Montes 1998).

At a smaller scale, some swash-induced bores may be observed on beaches when the wave runup enters into a small creek or channel. Figure 1.3 presents a series of four photographs of a single event. The bore was generated by the swash runup of long waves on the beach slope during the mid-flood tide, and the photographs illustrate the evolution of the bore shape over a 10 s period.

Lastly, some water parks generate large artificial waves somehow similar a sudden dam break wave led by a man-made bore, e.g. the Typhoon Lagoon at Disneyworld, the Wave Lagoon in Darwin (Australia).

(A) Looking at the incoming tsunami-induced bore on 26 December 2004 at Phi Phi Don (Thailand) (Photograph by Lou Evans on yacht Gaultine III) — The camera was about 3.5 m above the water surface (Aragorn eyewitness {http://www.yachtaragorn.com/Thailand.htm}).

(B) Tsunami-induced bore on 26 December 2004 at Penang (Malaysia) during the second series of tsunami waves (Courtesy of Angela Egold and Sonja Prein) — Note the breaking bore in the foreground while the bore was undular in deeper waters (background).

Fig. 1.2. Tsunami-induced bores.

Fig. 1.3. Generation of a bore by the long-wave-induced swash in a freshwater inlet on Takatoyo Beach, Toyohashi (Japan) on 14 November 2008 — Sequence of four photographs: $t = t_o$, $t = t_o + 8$ s, $t = t_o + 9$ s, $t = t_o + 10$ s (from left to right, top to bottom).

## 1.3. STRUCTURE OF THE BOOK

In this book, the author aims to share his enthusiasm and passion for tidal bores. He has investigated this topic as well as experienced first hand the tidal bore processes for over a decade. He surfed in kayak the Garonne River tidal bore on 3 September 2008 (Fig. 1.4). In dinghy, he followed the tidal bores of the Garonne and Dordogne Rivers for 40 and 27 km, respectively, on 28 and 30 September 2008.

The book is designed to bridge the gap between general knowledge and scientific expertise on tidal bores. Anybody interested in geography and the landscape of river mouths should be encouraged to read first Secs. 3, 4 and 6 dealing respectively with some tidal bore observations, the rumble noise of tidal bores, and the interactions between tidal bores and Mankind. Sections 2 and 5 would provide these readers with more scientific data. The scientific readers would read first Secs. 2, 4 and 5 on the tidal bore theory, the rumble noises of tidal bores, the turbulence and turbulent mixing in bores respectively. These advanced readers would find some relevant illustrations in Sec. 3 and some discussion in Sec. 6.

The book is documented with photographic observations of many tidal bores in Europe, Asia, America and Australia (Sec. 3) after a series of simple theoretical considerations (Sec. 2). Later the rumble noise of a tidal bore is discussed (Sec. 4), the turbulence induced by a tidal bore is detailed (Sec. 5) and the interactions between tidal bores, the environment and mankind are developed (Sec. 6). The book is supported by several appendices, including a reliable reference list of tidal bores in which all the information on each tidal bore was double-checked by independent, reliable reports (App. A), a technical appendix on undular tidal bores (App. B), some comments of tidal bore surfers (App. C) and a glossary of technical terms (App. D).

Fig. 1.4. Surfing the Garonne River tidal bore at Baurech (France) on 3 September 2008 — Looking downstream at the incoming tidal bore (Photograph by Michel Deyrich) — Hubert Chanson was on the second kayak from the left.