Chapter 2
River Mouths and Coastal Lagoons in Central Chile

Rodrigo Cienfuegos, José Rafael Campino, Jorge Gironás, Rafael Almar, and Mauricio Villagrán

Abstract River mouths and coastal lagoons in central Chile are some of the most dynamic ecosystems in the country. They are controlled by a great variety of natural and anthropic factors, which have confer these ecosystems a high environmental and human value. The diversity of these ecosystems is mainly due to a complex set of parameters that define them: from the hydrological and climatic variability, the heterogeneity of the river mouths, the high energy of the coasts, to different annual sediment availability, etc. These parameters, as well as meteorological and hydro-morphodynamics, all create a very unique combination, even at a global scale, being similar only to some sectors of South Africa, Australia and New Zealand.

Additionally, the seismic characteristics of Chile commonly cause morphological alterations in coastal areas, and these changes range from subsidence or uplifts to dramatic sedimentary changes caused by tsunamis that hit the central coast every 50–100 years. This uniqueness of the river systems of central Chile, enhances its scientific interest within the international community. Moreover, the predominant dynamics of central Chile are quite different than those traditionally studied in the northern hemisphere.

R. Cienfuegos (✉) • J.R. Campino • J. Gironás
Department of Hydraulic and Environmental Engineering, School of Engineering (Departamento de Ingeniería Hidráulica y Ambiental, Escuela de Ingeniería), Pontificia Universidad Católica de Chile, Santiago, Chile

Centro de Investigación para la Gestión Integrada del Riesgo de Desastres (CIGIDEN - Fondap 15110017)
e-mail: racienfu@ing.puc.cl

R. Almar
UMR LEGOS, University of Toulouse/CNRS/IRD/CNES, Toulouse, France

M. Villagrán
Department of Hydraulic and Environmental Engineering, School of Engineering (Departamento de Ingeniería Hidráulica y Ambiental, Escuela de Ingeniería), Pontificia Universidad Católica de Chile, Santiago, Chile

Departamento de Ingeniería Civil, Universidad Católica de la Santísima Concepción, Chile

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This chapter presents the general characteristics that govern the geomorphological processes of the central coast of Chile, such as hydrology, climate, prevailing rise, geographic characteristics and impacts caused by the tsunamis. Additionally, a description and classification of some of these phenomena is presented for different basins in Chile, paying attention to some particular cases used as examples for the description of the coastal processes that govern coastal morphodynamics. Finally, it is concluded that the coastal formations in central Chile are strongly controlled by hydrology and typology of their river mouths, with emphasis on the size of the basin, as well as on the seasonal precipitations. These last two variables are fundamental in explaining and characterizing the coastal geomorphology of central Chile.

Keywords Hydrodynamics • Basin • Geomorphology

Introduction

The morphodynamic evolution of the Chilean coast is determined by complex interactions between waves, tides and wind, on one hand, and the geomorphological and hydro-sedimentary basins that provide overflow and solid material being transported to the Pacific Ocean, on the other. (Araya-Vergara 1971; Benítez 1994). In addition, the highly active tectonic movements of the Nazca and South American plates, can cause significant changes in coastal systems due to overflows and turbulences (Weischet 1963; Farías et al. 2010).

River mouths are complex and fragile systems where a dynamic interplay between physical, chemical and biological variables (Kennish and Paerl 2010) occur. They also represent very active areas from the hydro-sedimentary point of view, where the sediment pattern depends on the relative influence of the ebbs and flows of the tidal currents, the flow and the runoff, the waves and the wind, and the physical characteristics of sediments. Generally, these systems can differentiate between estuaries and coastal lagoons. According to Bird (2007), estuaries are influenced by the dynamic fluvial and marine actions, while coastal lagoons are seawater bodies generally separated by sedimentary barriers that can be connected to the sea intermittently.

Deltas can be classified according to the degree of tidal influences in their dynamics (Davies 1964).

A microtidal estuary (tidal range less than 2 m) is generally dominated by the waves and river currents.

A mesotidal estuary (tidal range of 2 and 4 m) has more intense tidal currents, with a wider intertidal zone and multiple winding canals. A macrotidal or megatidal estuary (tidal range greater than 4 m and 6 m respectively) has dominant tidal currents, shaped like a funnel and a wide mouth. In wide mouth deltas, the effect of the tides favors marine sediment deposits forming banks and dunes, sometimes shaping deltas which are submerged at high tide with divergent channels, upstream and downstream (Davies 1964; French 1997).

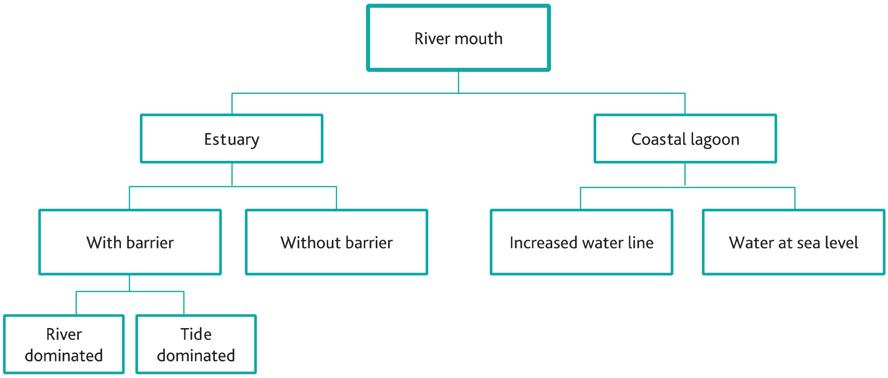

Fig. 2.1 Classification of estuaries in microtidal coasts (Adapted from Cooper 2001)

Cooper (2001) studies the microtidal estuaries of the South African coast, very similar to the systems present in central Chile. Like the South African coast, the Chilean coast is mostly microtidal with the exception of estuaries located south of Puerto Montt, Chiloe and the Chacao channel, which highlights the Reloncavi estuary that is dominated by the tides. Given these similarities, the classification of Cooper (2001) will be used to describe the river mouths located in central Chile. In the Fig. 2.1 this classification that distinguishes between estuaries (whose mouth is open more than 70% of the time) and coastal lagoons (with open mouths less than 30% of the time), is presented.

In turn, river mouths can be divided into those with a bar or sedimentary barrier mouth and those without. Estuaries with a barrier may be dominated by runoffs from either the rivers or the ebb and flow of the tidal currents. On the other hand, coastal lagoons, usually separated from the sea, may present a stilted/heavily banked water levels (above sea level) or be at sea level.

In Chile, studies on configuration of the river mouths in central area are relatively few and recent. The highlighted contributions are those of Araya-Vergara (1971, 1981, 1982, 1996), Stuardo and Valdovinos (1989) and Andrade and Grau (2005). Araya-Vergara (1981, 1982) proposes a zoning of the delta systems according to morphoclimatic characteristics, distinguishing the area of the distal deltas of the desert, the area of the Norte Chico prograded rivers (from the Copiapo River to Maipo), the area of the estuarine deltas in the transition zone between semi-arid and humid climate (from the Rapel river to the Biobio river), and the area of the estuaries of humid and very humid climate in the Lakes Region. Meanwhile, Stuardo and Valdovinos (1989) and Andrade and Grau (2005) distinguish between estuaries and coastal lagoons, incorporating in their classification the seasonal nature of the hydrological regimen forming the fresh water courses. All of these works provide valuable information, which, once consolidated, can serve as a starting point and reference for future studies of river mouths and coastal lagoons of central Chile.

In this chapter, the basic background for understanding of the processes that govern hydro-sedimentary dynamics of the river mouths in the central zone of Chile is exhibited, in order to establish common elements to classify the different morphological configurations observed.

River Mouth Configuration in the Central Zone – Geomorphological Characteristics

The western edge of the South American continent is characterized by a narrow steep continental shelf (Araya-Vergara 1971). This feature is the result of active tectonic processes taking place in the vicinity of the submarine pit that borders the meeting point between the Nazca and South American plates. From Arica to Chacao channel, there are four main distinguished geomorphological units: the Coastal Plains (las Planicies Litorales), the Coastal Range (Cordillera de la Costa), Intermediate Depression (Depresion Intermedia) and the Andes (Benítez 1994). Hydrographic features described below are largely determined by this geomorphological configuration.

The sediments that form the coastal systems of Chile have several features that can largely be explained by their geological origin and form (Paskoff and Manríquez 2004). They are distinguished by sediments example of continental origin transported by surface runoff and winds, where sediments dunes or beaches can be moved by the wind, and those that originate in situ, under the erosive action of waves on cliffs or rocky edges (Bird 2007).

In central Chile, Paskoff and Manríquez (2004) highlight the high sediment of fluvial origin that occurs at the river basins due to erosion caused by rain. Apparently, these contributions have grown over the last century by the gradual decline of vegetation, increasing deforestation and intensification of long, dry summers that favor the removal of solid material. To the south of the Imperial River (Araucanía Region), the dominance of large rivers linked to the disappearance of the Coastal Range (Cordillera de la Costa) and increasing tidal scope inhibits the development of dunes and promotes the formation of estuaries (Araya-Vergara 1981).

Furthermore, the sediments of continental origin carried by water are subjected to the action of coastal drift currents when they reach the Pacific Ocean. In the south-central coast of Chile, this coastal current transports sediments from river mouths or estuaries towards north as a product of reigning South-West waves (Araya-Vergara 1971). This is the case of the El Yali wetland (Valparaiso Region), whose sands are not coming from the neighboring beaches and boulders, but from the deflation of ancient marine deposits of the Punta Torro terraces (Paskoff and Manríquez 2004). Similarly, the Ritoque dune field (Valparaiso Region) is supplied by sands of the Aconcagua River, which flows into the sea a few kilometers further south. The sediments are transported by a coastal drift, and unloaded in the northern sector of this dune field, as the Quintero elevation puts obstacle to this action. The Concon sand dunes (Valparaíso Region) have their origin in the marshlands of Vina del Mar (Marga-marga) and Renaca, transported north along the littoral drift (Paskoff and Manríquez 2004).

The Santo Domingo dune ridges (Valparaiso Region) have a clear relationship with sediments carried by the Maipo River, which are also transported over 35 km to the north by the coastal current. Moreover, the Putu dune ridges located north of Constitucion (Maule) converge towards the mouth of the Maule River, demonstrating that its sediments have been supplied by the river and aligned by the littoral drift on the proximal convex part (Araya-Vergara 1981); the large volume of sediment shows considerable force of the river. Further south, the Itata River (Biobio Region) is an important source of sediment and sand for the dunes, marshes and beaches. According to Paskoff and Manríquez (2004), the Chanco dunes have their origin in the solid material carried by the river.

The above mentioned examples demonstrate the role of littoral drift and river sediments in the dynamic, and source of sand for littoral coastal systems of the central zone. However, although the material carried out by the rivers is one of the most important sources of beach and dune sediment on the central coast of Chile, there are also structures of different origins. For example, the Gulf of Arauco dunes in the Bio-Bio Region – the largest dune complex in the country (30,000 hectares approximately) - is not located north of any major delta that could explain its origin. In this case, it is thought that the continental shelf, due to its low slope and large width, could be an important source of sediments (Araya-Vergara 1985). These sediments have accumulated during glacial periods of low sea level. Tavares-Correa (1996a, b) has noted that the average diameter of the sand grows despite the dominant coastal current coming from the south. According to him, this increase in size is due to a process of selective removal of the finer grains through the wave action. However, the detour to the south of most of the stream and river mouths that cross this dune field, remains to be explained (Paskoff and Manríquez 2004). Araya-Vergara (1985) also considers that the tectonic rising trend in this area can promote the formation of the dunes. The phenomenon was confirmed during strong earthquakes in 1835, 1960 and 2010 (Darwin 1846; Weischet 1963; Farías et al. 2010). The positive co-seismic movements have the effect of reducing coastal depths, and thus facilitating the transfer of submerged sediments to the coast by the sheer power of waves. Those were probably accumulated by the estuaries on the emerged continental shelf during the last glacial period. Proof of this is in the remarkable presence of characteristic metamorphic rock minerals around regional neighborhood of the Coastal Range Mountains and in the dune sands of the Arauco coast (Tavares-Correa 1996a, b). According to Paskoff and Manríquez (2004), the sand forming dunes, beaches and marshes near the Gulf of Arauco range from fine grain with good selection and light color in the south, to medium grain, well selected and with yellow to brown tones in the north. The origin of the sediments ranges from metamorphic rocks basseting of the Coastal Range Mountain range (quartz, feldspar, and magnetite), to volcanic rocks of the Andes (olivine, pyroxene, and amphibole).

Even though there is not much information on the temporal variability of sediments in estuarine systems in Chile, this seems not to be very significant. Bertrán et al. (2001) have shown that the variability of sediment at the Biobio River (Biobio Region) between winter and summer is not significant, having the particle size a termporal variability greater at the mouth. The greater temporal variability was detected in the area nearest to the mouth, probably because of the greater relative influence of waves and tides with respect to the runoff of the river. Sediments observed in all monitoring stations (up to 5 kilometers upstream of the mouth) correspond to coarse sands.

In the estuaries throughout the country, the average size of sediments typically ranges from 0.1 mm (fine sand) to 2 mm (very coarse sand). An exception are the sediments of the Elqui River mouth, which can be classified as rocks, with a representative diameter of 13.5 mm. Table 2.1 summarizes the size of sand located in the mouths of different rivers along the area of central Chile. In the case of Longotoma and Ligua Rivers, Vina del Mar estuary and Rapel River (Valparaiso Region), these sands have been found in dunes north of their mouths. For coastal rivers of Arauco (Lebu, Paicavi, Lleulleu and Tirua, located in the Biobio Region), it is assumed that the sands have been created by the continental shelf, and are equivalent to those that form the dunes of Arauco. For coastal rivers Lenga, Tubul and Raqui (Biobio Region) it can be assumed that the sands located at their mouths must be of the same origin as those of other coastal rivers in the Gulf of Arauco.

Table 2.1 Granulometric characteristics of sands in estuaries

River mouth (Delta, Estuary)	Average diameter (mm)	Average river gradient (%)	Sediment type
Copiapo River	0.4	1.5	Medium Sand
Elqui River	13.6		Boulders
Ligua and Longotoma Rivers	0.1	1.1	Fine Sand
Viña del Mar Tideland	0.1	1.1	Fine Sand
Rapel River	0.2	1.2	Medium Fine Sand
Cahuil			Medium Fine Sand
Mataquito	0.1		Fine Sand
Maule	0.5	1.2	Medium Coarse Sand
Itata	1.8		Very Coarse Sand
Lenga			Fine Sand
Tubul-Raqui			Medium Fine Sand
Biobio	0.8		Medium Coarse Sand
Ríos costeros de Arauco			Arena media-fina

Fuente: Paskoff and Manríquez (2004), Stuardo et al. (1993), Bertrán et al. (2001), Niño (2002)

Hydrology

Weather and Rainfall

The mainland of Chile stretches over 4000 km with an average width between 150 and 200 km. Throughout the country there is a variety of climates, morphological and lithological features, which affect different behaviors regarding its hydrology. In particular, the range of climates observed in the country ranges from the desert climates with warm anticyclone influences in the north to the oceanic climates with cold cyclone influences in the south (Fig. 2.2). This climate variability translates into large differences in annual rainfall and average annual temperature (Fig. 2.3).

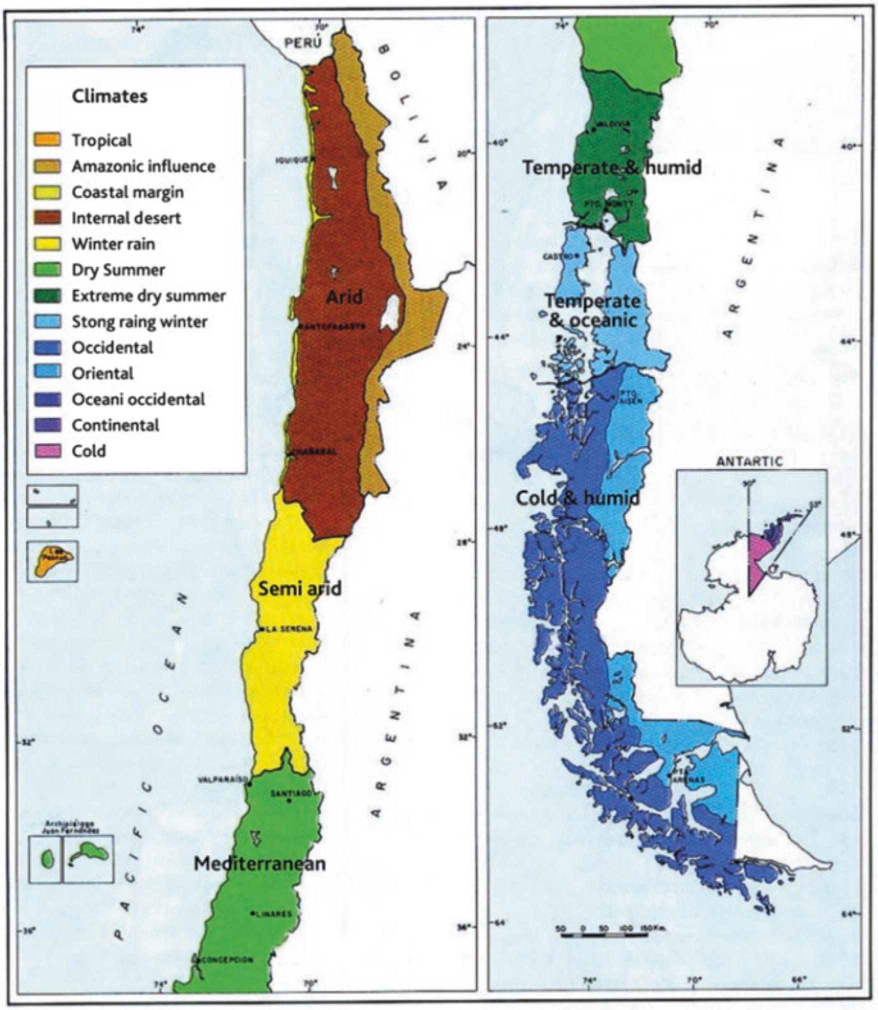

Fig. 2.2 Classification of climates in Chile (Taken from Toledo and Zapater 1989). To be compared with hydrologic characteristics presented in Tables 2.10 and 2.11

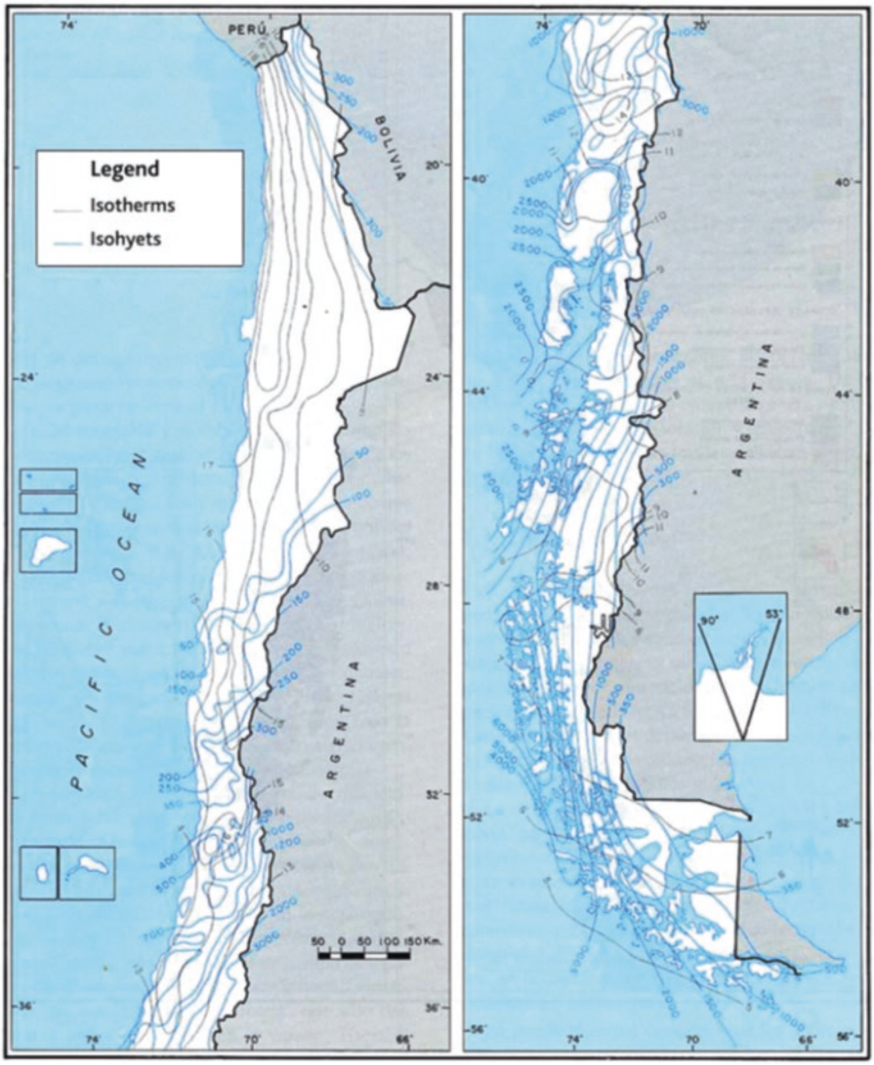

Fig. 2.3 Average annual temperature and precipitation distribution in Chile (Toledo and Zapater 1989)

The area of Norte Arido (Arid North) includes the regions of Arica and Parinacota, Tarapaca, Antofagasta and the eastern part of the Region of Atacama. This area is characterized by the extreme aridity, particularly in the coastal area and in the interior below (the altitude) 2000 m, where annual rainfall does not reach 10 mm (Sánchez and Morales 2004). It is in this area where we find the Atacama Desert, one of the driest in the world, with annual rainfall of less than 1 mm. Only in the Altiplano (Highlands) there is a significant rainfall, which generates small and sporadic runoff throughout the year, and significant flooding in summer. To the south of Norte Arido area is a semiarid climate, with rainfall ranging from 25 mm per year in the Atacama region, to 250 mm in the Valparaiso Region. These precipitations fall mostly in the winter months, when it rains up to 2500–3000 msnm. Above this elevation there is a significant nival precipitation significant for the annual hydrological regimen.

The central region is divided into a north-central area between the mountain range of Chacabuco to the Biobio River basin, and the south-central area from the Basin to the Chacao Channel and within Reloncavi. The first area has a Mediterranean climate, with rainfall concentrated in the winter months, while the south-central area is temperate, with annual rainfall of greater magnitude and distributed throughout the year.

To the south is the southern zone or Chilean Patagonia, which has an oceanic humid climate. This sector of archipelagos and fjord networks of the Pacific coast has one of the highest rainfalls in the world, and there are areas with annual rainfall greater than 6000 mm, while in the continental sector they decrease. An example of the magnitude of rainfall in this region is the annual rainfall of 4266 mm on the Island of San Pedro in the Gulf of Penas (Sánchez and Morales 2004).

The water balance in Chile (DGA 1987) shows the remarkable increase in rainfall with latitude, with the precipitation in southern Chile nearly 40 times higher than in the north of the country (Table 2.2[1]). In its entirety, Chile presents precipitations equivalent to South America, but it almost doubles the precipitations on a global level (Table 2.3).

Table 2.2 Annual water balance in Chile per administrative region

Region	Precipitation	
	m3/s	mm
I	157	93.6
II	182	44.5
III	205	82.4
IV	281	222
V	211	434
RM	335	650
VI	508	898
VII	1347	1377
VIII	2467	1766
IX	1451	2058
X	6319	2970
XI	11,763	3263
XII	11,748	2713

Source: DGA (1987)

[1] The 1st región, in 1987, was considering the actual I and XV Regions. On the other hand, the Region X was considering the actual regions X and XIV. This is also valid for the Figure 2.4.

Table 2.3 Annual water balance per macro-zone in Chile, and comparison with other global balances

	Precipitation	
Macro zone	m3/s	mm
I, II y XV Region	340	59
III a X, y XIV Region	13,120	1246
XI a XII Region	23,490	2363
Continental Chile	36,950	1522
South America	888•103	1564
Global	3522•103	746

Source: DGA (1987)

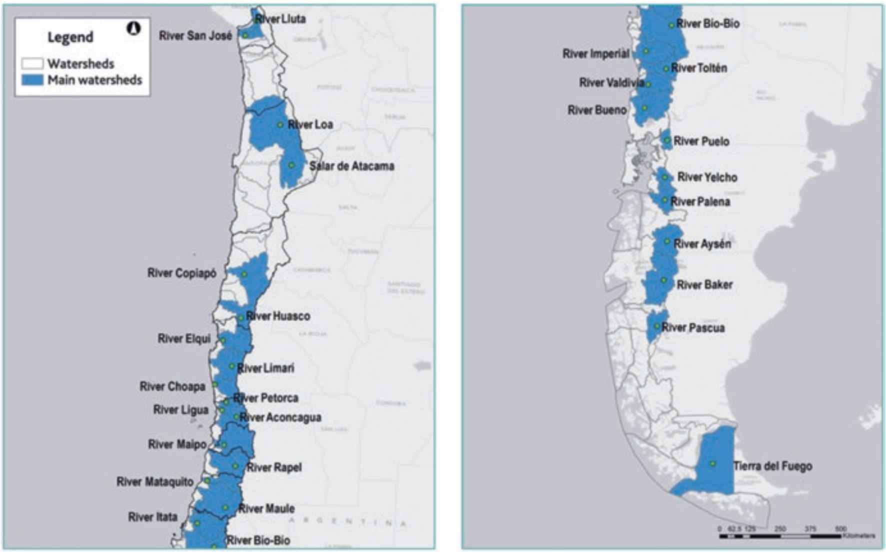

Fig. 2.4 Main rivers and watersheds in Chile (Taken from Niemeyer and Cereceda 1984)

Runoff (Overflow, Surplus)

Water basins and their respective hydrological regimens throughout the country exhibit significant variability due to spatial diversity of climate, morphological and lithological features, vegetation, topography and other relevant factors. Within the national territory there is a number of basins contributing to the major rivers in the country (Fig. 2.4). In Chile, it is possible to identify the following macro-areas with similar hydrographic and fluvial characteristics (Niemeyer and Cereceda 1984): northern arid, semi-arid, central Mediterranean, central temperate and southern zone.

Most of the basins of the northern arid zone (Regions I, XV and II) are the endorheic type, and rivers Lluta, San Jose and Loa with their major surface water-courses drain into the sea. However, as it is shown in Table 2.4, the average flow

Table 2.4 Flows in the main hydraulic systems in Chile (Modified from Peña and Salazar 1993)

Region	Basin	Medium entrance flow rate (m^3/s)	Medium flow rate exit (m^3/s)	Minimum flow rate exit (m^3/s)
I	LLuta River	2.3	1.4	0.09
I	San Jose River	1.5	0.0	0.0
I	Tamarugal Pampas	1.0	0.0	0.0
II	Loa River	2.8	0.6	0.04
III	Copiapo River	2.9	0.1	0.04
III	Huasco River	3.5	1.7	0.3
IV	Elqui River	8.1	1.0	0.15
IV	Limarí River	15.1	7.5	0.0
IV	Choapa River	13.2	12.8	0.0
IV	Aconcagua River	38.0	30.0	0.0
RM	Maipo River	116.0	100.0	1.0
VI	Rapel River	130.0	174.0	1.0
VII	Maule River	257.0	569.0	58.0
VIII	Bio Bio River	639.0	1000.0	120.0

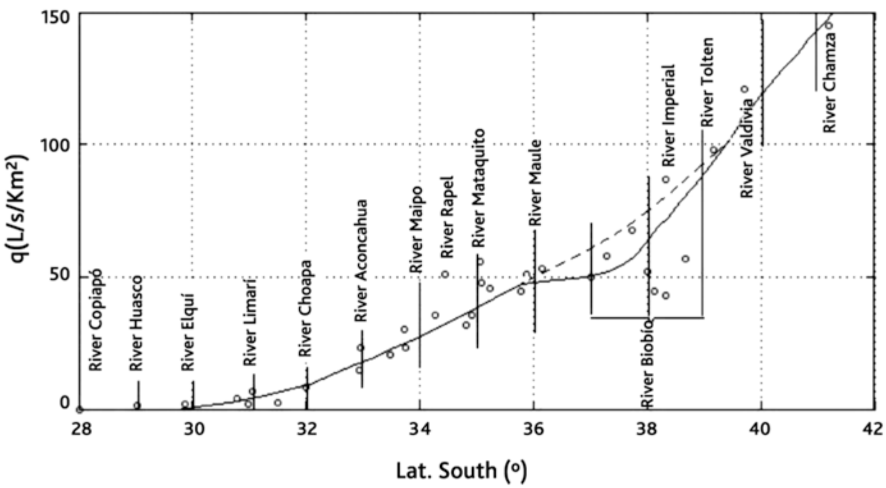

Fig. 2.5 Variation of the mean flow as a function of latitude (Peña and Salazar 1993)

rates in the areas close to the river mouth (river mouth exit flow) are very low or nonexistent.

Figure 2.5 show the variations of average annual flow rate for the semiarid, central mediterranean, temperate central and the southern areas, depending on the latitude. The semiarid zone located from the Copiapo River to the Chacabuco Ridge (regions III, IV and V) is characterized by torrential rivers, with steep slopes on the east-west conditioned by local tectonics. A direct relationship between the volumes of the runoff surface and annual rainfall, which tends to increase with latitude, is observed. The rivers in this area have a mixed system, where the importance of regimen component depends on the proportion of the basin located at higher elevations. They originate in the Highlands and manifest runoff throughout the year. The main watercourses are, from north to south: Copiapo, Huasco, Elqui, Petorca, La Ligua and Aconcagua.

Central mediterranean area (from Chacabuco Ridge to the Biobio River) presents river regimen and/or mixed, thanks to the seasonal variability of rainfall and temperatures, which favors overflows throughout the whole year. The main courses in this area are the rivers Maipo, Rapel, Mataquito, Maule, Itata and Biobio. Just as is in the case of water courses in the north, most of the rivers in the central area have hydraulic torrent regime relating to speed-altitude of the fairly high runoffs. This type of system is caused by the high slopes of its basins and whose origins are in the high mountains of the Andes.

On the other hand, the temperate central zone (from the Biobio to the Reloncavi River mouth) contains calm rivers with lake system, which presents a more stable runoff, with peak flows during the winter time. Majority of waterways of this area have a hydraulic river regime (i.e. speed vs. height reasons rather than low runoff), due to the smaller gap between the lakes that gives birth to these rivers and their balance base, as well as to the greater paths of these (Niemeyer and Cereceda 1984). The highlighted ones are the Imperial, Tolten, Valdivia, Well, and Maullin Rivers and their tributaries.

Coastal and Mountain Rivers

For the study of the central zone estuaries, it is useful to consider the work of Stuardo et al. (1993), who differentiate the behavior of the river mouths of the Mediterranean and temperate central area of Chile according to their origin and type of basin. On one side, they consider the rivers of Andean origin, which flow into the estuaries that remain open all year and, depending on the degree of silting at the mouth, can present an estuarine behavior. The Biobio River is a clear example of this type of course. On the other side, coastal rivers have smaller water basins and flow rate, and to disembogue against the strong energy of waves they favor the formation of barriers, particularly in summer. This typically generates a narrow channel and, in some cases, complete closure, with the consequent formation of coastal lagoons. Only in those channels where the mouth is partially protected from the littoral drift and wave energy, the mouths are kept open. Examples of the rivers like that are Carampangue, Lebu and Tirua.

Similar phenomena occur in estuaries linked to Coastal Plains with large areas of marshland, as in the estuaries of Tubul-Raqui and Lenga. However, the deltas of coastal rivers generally remain closed most of the year.

The above classification may be extended to certain rivers of Andean origin of the semiarid area to. In the case of the Copiapo River, for example, the average monthly flow ranges from 0.63 m^3/s in January, and 0.26 m^3/s in October, which would explain how this river mouth can be closed in spring, even more so if its waters are removed for productive activities. Moreover, the Elqui and Choapa Rivers have minimum average flow rate of 3.11 m^3/s in October, and 4.65 m^3/s in April respectively (DGA 1987), which would explain their deltas remaining open most of the year. The distinction between rivers of the coastal and Andean origin is therefore relevant for understanding the dynamics of the river mouths.

Seasonality

The evolution and temporal stability of an estuary are strongly conditioned by the annual variability of the hydrologic regime, which influences the coastal morphology and determines whether the mouth of an estuary is open or closed. Then we quantify this variability by seasonality of monthly flows around the annual average flow (Qanual), characterized by the coefficient of variation CV = /Qanual where corresponds to the standard deviation of monthly average flows with respect the Qanual. Table 2.5 shows these values calculated for a number of rivers in the central area with fluviometric records that have been updated at the river mouth.

Being that the coefficient variant is the measure of the uscaled invariant dispersion, the seasonality in various waterways can be directly compared. It is observed that there is a high variability for coastal rivers in the central area, such as Nilahue and Loanco, with variation coefficients greater than unity.

Moreover, the Itata River, of Andean origin, has a lower variability (CV = 0.84), despite the mainly rainfall regime. Without a doubt its mouth remains open even in the summer months due to its high discharge. The Lleulleu River, of coastal origin, does not present a very high seasonality, because it is located further south, where rainfall is more uniform throughout the year.

The hydrograph of monthly flows normalized by the average annual flow allows for comparing of the hydrological regimes of each river. Figures 2.6 and 2.7 show the comparison for Andean rivers and coastal rivers respectively. Andean rivers of

Table 2.5 Statistics of mean monthly flows in central Chile (by the authors, based on information from DGA 1987)

River	Station			*Qanual* (m3/s)	σ (m3/s)	σ/Qanual
	latitude S	longitude W	Altitude			
Nilahue	034° 34′ 08	071° 47′ 27	50	10.9	14.6	1.3
Mataquito	034° 59′ 04	072° 00′ 36	20	130.2	78.8	0.6
Maule	035° 24′ 25	072° 12′ 30	20	505.5	309.2	0.6
Loanco	035° 34′ 08	072° 35′ 00	20	4.5	4.5	1.0
Itata	036° 28′ 05	072° 45′ 05	10	352.7	295.4	0.8
Biobio	036° 50′ 14	073° 05′ 11	5	982.0	633.9	0.7
Lleu-Lleu	038° 07′ 00	073° 24′ 00	10	20.1	15.3	0.8

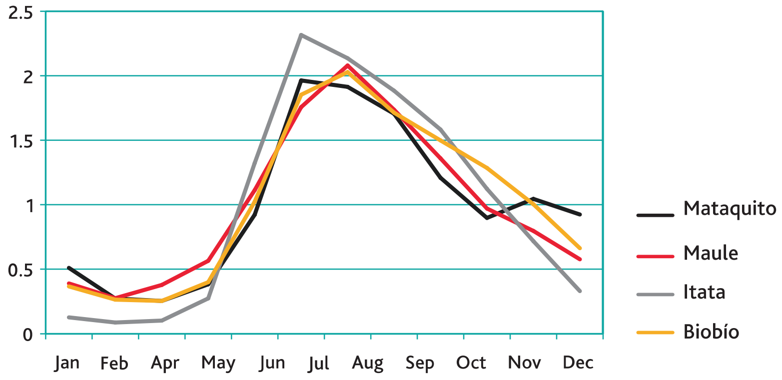

Fig. 2.6 Monthly normalized flows for Andean rivers (by the authors, based on information from DGA 2009)

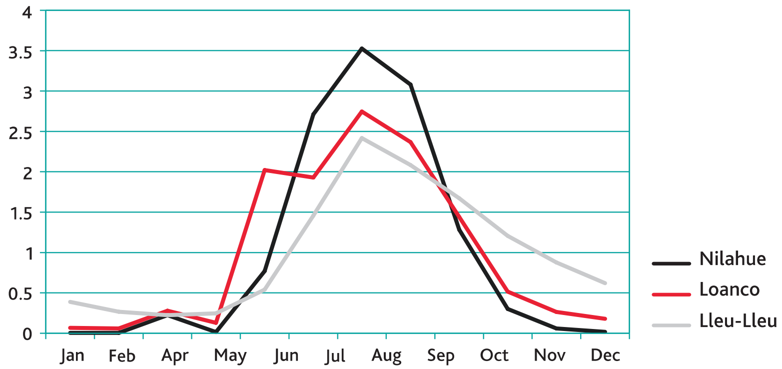

Fig. 2.7 Monthly normalized flows for coastal rivers (by the authors, based on information from DGA 2009)

central and south Maule Region have a very similar seasonal behavior reflected in the essentially pluvial character of these watercourses. However, coastal rivers Loanco and Nilahue have a marked seasonality, but with a superficial overflow only during the winter months. The Lleulleu River, located further south, has a similar seasonality, but with a permanent flow throughout the year, as rainfall it receives its basin is a more frequent contributor.

The coefficient of variation can adequately characterize the seasonality of the monthly flows of the rivers in the central area. Therefore, the behavior of the river mouth will depend on this parameter and the average annual flow. For rivers with high seasonality and relatively low average annual flow, it is very likely that their river mouths are closed during dry seasons. Similarly, river mouths with low seasonality and high average annual flow tend to have their mouths open all year, although there could be ravines forming in its mouth.

Tides

Tides play an important role in the morphology of river mouths since the sea level restricts the area where the energy of waves and coastal currents are present. Besides the ebb and flow of the tidal currents within the estuary, tides may also have an impact on erosion, sediment deposition and the degree of saline intrusion into the estuary (Prandle 2009).

The tidal wave that travels the coast of Chile spreads in the north-south direction. The tide observed is of mixed semidiurnal-type with two low tides and two high ones every day, and considerable differences of water levels reached in the tides every morning and afternoon.

Maximun amplitudes of the syzygy tides are variable along the coast, ranging between 1.5 and 1.9 m between Arica and Cape Quedal (Lake Region). Further south, in the bosom of Reloncavi and the gulfs of Ancud and Corcovado, the amplitudes have a significant increase, ranging between 5 and 8 m, due to the lower depths of the fjords areas that favor the establishment of resonant conditions. Table 2.6 presents a summary of typical tidal ranges in some ports.

Based on the information gathered it can be established that a large coastal area of Chile between Arica in the north, and Puerto Saavedra in the south, is subject to a microtidal regime according to the classification proposed by Davies (1964). In microtidal environments (ranges less than 2 m tide), it is often observed the formation of sand ravines at the river mouths under the effect of waves, as energy dissipation and the contribution of river sediments are concentrated in this sector. It is interesting to note that this type of tidal regime, coupled with a high seasonal variability in river hydrology, has helped explain the dynamics of closing and opening of some coastal lagoons in India (Bruun 1986), Australia (Ranasinghe and Pattiaratchi 1999), South Africa (Cooper 1990; Largier et al. 1992), United States (Elwany et al. 1998), and Brazil (Moller et al. 1996), among others.

From ecological and environmental point of view, the influence of the tides in upstream rivers coming from their mouths can be very relevant. This situation affects the development of a salt wedge modulated by the river runoff and fluctuations at sea level.

Table 2.6 Typical tidal ranges in some ports of chile (SHOA 2010)

Port	Latitude	Average sea level (m)
Coquimbo	29° 56′	0.9
Valparaiso	33° 02′	0.8
San Antonio	33° 35′	1.4
Talcahuano	36° 41′	1.1
Corral	39° 52′	1.1
Puerto Montt	41° 29′	4.7
Ancud	41° 52′	2.1
Chacabuco	45° 28′	2.8

The river mouths that have a lower slope generally have a greater influence on the tides penetration. Table 2.7 shows the penetration level for some rivers on the central coast of Chile, according to the studies of Araya-Vergara (1981).

Surf (Swell, Breaking Waves)

The Chilean coast is affected by the waves of local origin (wind sea) and remote origin (swell). Typical periods depend on the type of generation, distinguishing themselves in general to periods between 4 to 8 s to wind sea and between 8 and 20s to swell (Scott et al. 2002).

The surf waves reaching the coast of Chile originate in distant storms in the Pacific Ocean and therefore correspond to swell. Dominating surf is of south-west direction, with low seasonal variability, energy conditions and relatively long periods (Acuña and Monárdez 2008). During the winter, in front of the coast of Chile may occur intense storms of cyclonic origin. These conditions are often accompanied by strong winds and affect the wave occurrence of great intensity that reaches the central southern coast in the north-west direction.

The statistics on surf climates on the Chilean coast is generally scarce. There is little information by direct observations, so it is necessary to use global statistical data generated by numerical models as WaveWatch III (Tolman 1991) or WAM (Hasselmann et al. 1988).

Table 2.7 Average slope of inferior courses of rivers in central chile (Araya-Vergara 1981)

River	Latitude river mouth	Secant slopes (%)	Average penetration distance (km)	Average tide penetration level starting at low water level (m)
Maipo	33° 37´	4	20	1.2
Rapel	33° 54´	2	41	2.5
Mataquito	34° 58´	2	52	3.1
Maule	35° 19´	1 a 2	62	3.7
Itata	36° 23´	1 a 2	60	3.5

Table 2.8 Climate summary statistics for the annual medium wave climate in the south central coast of chile (CEPAL 2009)

	Height Hmo (meters)		Period Tm (seconds)		Direction
Coordinates	Average maximum	Maximum	Average 10% exc.	10% exc.	Average
31°S	2.5	5.9	8.9	11.1	226°
33°S	2.5	6.8	9.0	10.5	243°
35°S	2.6	8.0	9.0	11.2	235°
37°S	2.9	8.5	9.2	11.2	237°
39°S	2.8	9.2	9.2	11.1	242°

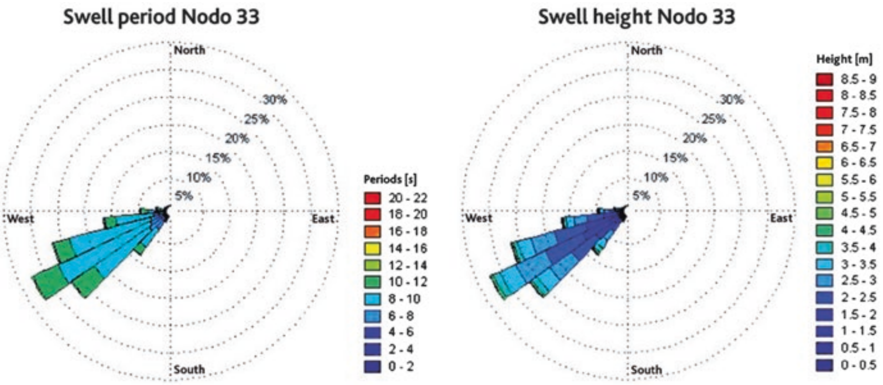

Fig. 2.8 Frequency-direction for swell periods and height in the coastline of parallel 33°S (CEPAL 2009)

The Oceanic Engineering Group of the University of Valparaiso has conducted an analysis of artificial wave during a period of twenty years, generated by these models (Cepal 2009). Table 2.8 shows the direction and two statistical waves parameters presented: the significant wave height (Hmo), corresponding to the average one third of wave heights in a sea (state), and the mean period (Tm), obtained in deep 5 nodes waters located off the south-central coast of Chile, between Los Vilos and Puerto Saavedra. It is noted that the annual significant average heights are between 2.5 and 3.0 m increasing gradually to the south. The maximum heights comfortably exceed 5 m. The average wave direction is south-west, while the average period is close to 9 s. These values confirm the prevailing south-west direction and highly energetic character of the waves reaching the coast of Chile. In Fig. 2.8 it is shown, for example, the wind rose of frequency-direction periods and wave heights at 33 ° S parallel that is in front of Valparaiso.

Tsunamigenic Earthquakes

The confluence of very active tectonic plates against the Chilean coast has historically produced large-scale seismic events that have generated destructive tidal waves. From colonial times until today, historical records (Lagos 2000; Monge 1993; Lomnitz 1970) indicate the occurrence of hundreds of tsunamigenic earthquakes near the area to the north and the central coasts of Chile, out of which at least one third has produced considerable damage. Figure 2.9 shows the main events which are on record. Besides the loss of human lives and enormous direct economic damages, these events can generate changes in ecosystems and in coastal morphology, and alter the dynamics of the coastal processes (Darwin 1846; Weischet 1963).

In the national historical literature, there is a wealth of information on seismic events and tsunamis that have occurred since the time of the Spanish Conquest. The

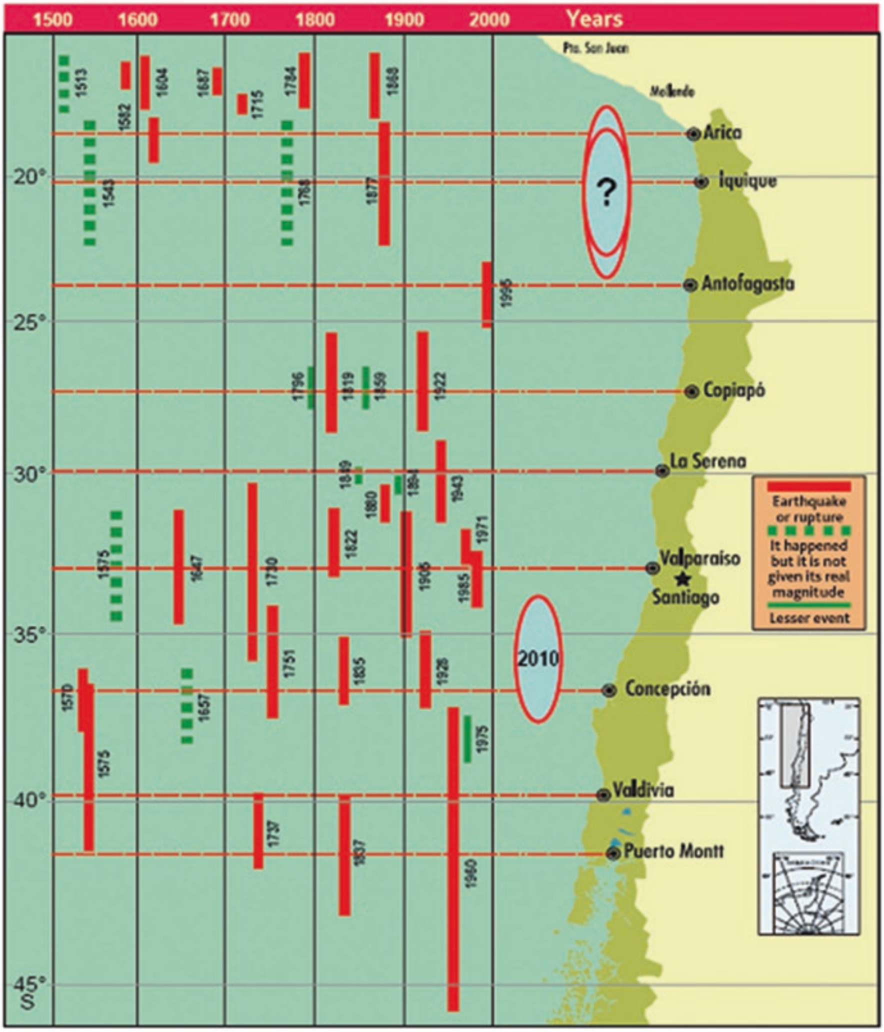

Fig. 2.9 Map with localization and dates of Tsunamigenic seismic events recorded in Chile (Source: Geophysics Department (Departamento de Geofísica), Universidad de Chile)

first historical event which was record corresponds to the earthquake and tsunami of February 8, 1575, that occurred near the city of Concepcion and which has affected greatly much of the city.

Although no deaths were recorded, the city of Concepcion had to be re-founded (Lomnitz 1970). Table 2.9 shows the main tsunamigenic events in the region over the past 500 years.

Similarly, Lagos (2000) classified historical information of tsunamis that have occurred over the past 450 years and produced a graph in which the degree of tsu-

Table 2.9 Summary of tsunamigenic events in Chilean coasts

Date	Hour	Epicenter	Richter scale	Comments
08-02-1570	09:00	Penco	8.5	It's hard to stand. Destruction of property, successive waves devastate the coast of the city of successive waves devastate the coast of the city of Concepcion (three waves). No fatalities were recorded.
16-12-1575	18:00–19:00	Corral	8.5	Great earthquake and tsunami in southern Chile that has affected the areas from the Araucania to Chiloe.
24-11-1604		Arica	8.7	Major disaster in northern Chile and southern Peru. 16 m flood in Arica.
15-03-1657	19:30–20:00	100 km. to the sea from Penco	8.0	Destruction of the city in few seconds. It is impossible to stand. Three successive waves arrive two hours after the devastating earthquake. Forty dead.
08-07-1730	04:45	Valparaiso	7.5	Tsunami destroyed the coast of Valparaiso. There were three consecutive waves which swept the city.
25-05-1751	01:00	Penco	8.0–8.5	Total destruction of the city. The tsunami arrived half an hour after the earthquake. Gap and a collapsed cavern on the coast.
11-05-1819	23:00	Caldera	8.5	4 m flooding of Caldera. Tsunami raged from Huasco to Constitution.
19-11-1822	22:15	Valparaíso	8.3	3.5 m flooding in Valparaiso.
20-02-1835	11:30	30 km. from Concepcion	8.2	Destruction of the city of Concepcion.
17-11-1849	06:00	Coquimbo, La Serena	7.5	5 m flooding in Coquimbo.
05-10-1859	08:00	Copiapo-Caldera	7.0–7.5	6 m flooding in Caldera.
13-08-1868	16:45	Arica	8.8	20 m flooding in Arica and the entire nothernorthernst northern coast of Chile and southern Peru.
09-05-1877	20:30	Mejillones	8.8	Grand Tsunami in the Pacific Rim Basin. 20 m flooding in Mejillones. Iquique y Antofagasta also affected.
10-11-1922	23:53	Copiapo-Coquimbo	8.4	9 m flooding at Chañaral.
22-05-1960	14:55	Valdivia	9.5	It lasted 10 min. Tsunami devastated Chilean coast and caused deaths in Japan.
30-07-1995	01:11	Antofagasta	8.0	It affected the Antofagasta area with 2.8 m flooding and was felt in all of the Pacific.
27-02-2010	03:34	Cobquecura	8.8	The tsunami caused great destruction along the coast of Vl and Vll Regions, Few hundreds dead.

Based on various sources: Lomnitz 1970; Monge 1993; Lagos 2000

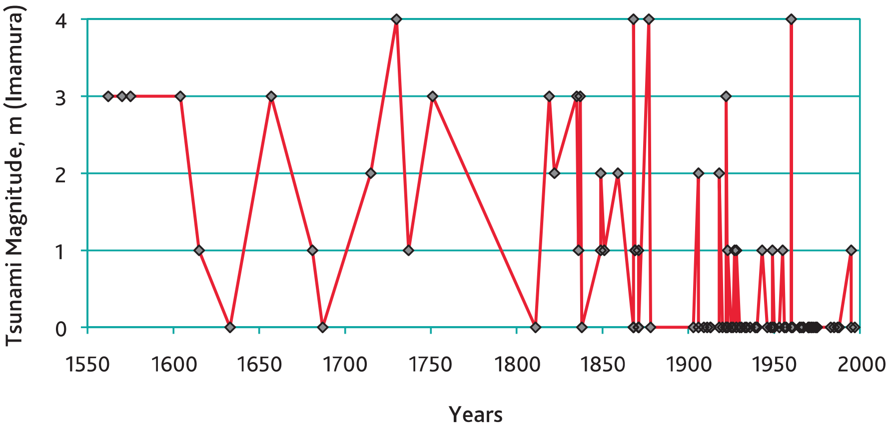

Fig. 2.10 Chronology of Tsunamis that have occurred along the coast of Chile with its associated magnitude (Adapted from Lagos 2000)

nami related to a scale from 0 to 4, where zero is inconsequential and 4 is catastrophic consequences. This classification is presented in Fig. 2.10. It is noted that the events of magnitude m = 0 represent approximately 65% of reported cases. The increase in frequency in the last century is mainly due to the increase and improvement of specialized instruments and a greater occupation of the coast. Additionally it shows that between 2 and 3 events or the tsunamis of great magnitude (about magnitude 3) have occurred in Chile in every century. This suggests that the coastline has been permanently shaped by these phenomena, being affected by at least one major event every 100 years. This fact can make us think that coastal configurations of the Chilean coast, especially sedimentary base, are relatively recent formation, since tidal waves tend to modify coastal morphological conditions.

Classification of the River Mouths of Central Chile

The morphology of the river mouths depends largely on the availability of sediment (geomorphology), wave energy and the direction of dominant attack, the effect of tidal flow and seasonal surface runoff from rivers (hydrology) and the slope (Bird 2007; Cooper 2001). These factors have a major influence on the morphology of coastal systems, both in plan and profile, and can be used to classify the different configurations found along the central Chile. In the previous sections the main features of these factors and a general classification have been summarized for some of the river mouths located in central Chile.

The central zone of Chile has a microtidal tidal regime type, ranging generally at less than 2 m. However, when it comes to surf/wave climate, it is in the south-west direction, with significant heights of waves on highly energetic annual average (over 2 m), which allows us to deduct that the estuaries of this zone are dominated by

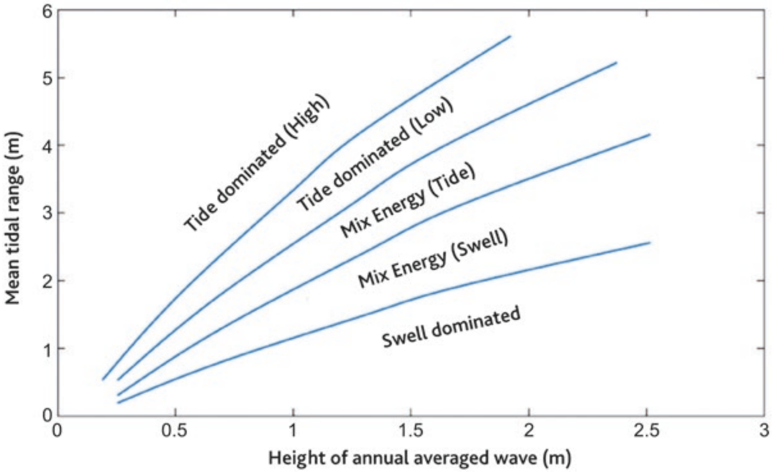

Fig. 2.11 Relationship between the average tidal level and the height of an annual averaged wave, outlining the degree of influence of the tide/swell on the morphology of a beach (Modified from Davis and Hayes 1984)

waves according to characterization proposed by Davis and Hayes (1984) and Bird (2007), presented in Fig. 2.11.

Table 2.10 shows the summary of the hydrological characteristics of the semiarid region of Chile. The rivers are differentiated by Andean and coastal origin, and their seasonality has been quantified through the coefficient of variation. It is important to note that in this case the average annual flow is the dominant element. Rivers with the low average annual flow and relatively high coefficient of variation tend to have closed mouths and form coastal lagoons, since sediment transport caused by the dominant waves favors the ravine formation that the river's superficial runoff fails to break. This is the case of the Copiapo River mouth, which despite being a mountain river, has an extremely low average annual flow, causing the landlocked river under normal conditions (Fig. 2.12). As latitude increases, the average flow of the Andean rivers also increase, and their mouths can remain open, despite having major barriers generated under the influence of waves. The Limari and Aconcagua rivers, with extensive basins, are two examples of this type of behavior (Fig. 2.12) and can be classified according to the Cooper conceptual model (Cooper 2001), as open barrier estuaries, dominated by the river.

On the other hand, as a general rule, coastal estuaries tend to form lagoons or wetlands at their mouths, because their surface runoff is low and highly variable. This is the case of Pachingo marshlands, in the vicinity of Tongoy, and Catapilco estuary near Maitencillo (Fig. 2.12). These river mouths are connected to the sea only in exceptional circumstances, under the effect of flash floods generated by heavy rain. They can be classified as coastal lagoons according to the Cooper model (Cooper 2001). It is important to note that the configuration of these systems favors the proliferation of great ecological biodiversity whose value has been widely recognized but poorly studied (Figueroa et al. 1999).

Table 2.10 Summary of hydrologic characteristics for estuaries in the semiarid zone

Zone	Region	Mountain Rivers	Tributaries	Coastal Rivers	Cavity (km^2)	Average annual spending (m3/s)	Coefficient of variation
Semi Arid	III	Copiapo	Varied		18,407	0.4	0.3
		Huasco	Transito y Carmen		9850	6.3	0.5
	IV			Punta Teatinos			
		Elqui	Turbio & Claro		9657	6.8	0.3
				Estuary Culebron			
				Adelaida			
				EstuaryTongoy	233		
				Salinas Grande			
				Salinas Chica			
				Pachingo	487		
		Limari	Hurtado & Grande		11,760	10.1	0.5
		Choapa	Cuncumen & Totoral		8124	13.8	0.6
				Laguna de Conchali			
	V	Petorca	Pedernal & Sobrante		2669	3.8	0.7
		La Ligua	Alicahue & Est. Cajon		1900	5.9	0.7
			Los Angeles				
		Aconcagua	Varied		7163	42.6	0.4

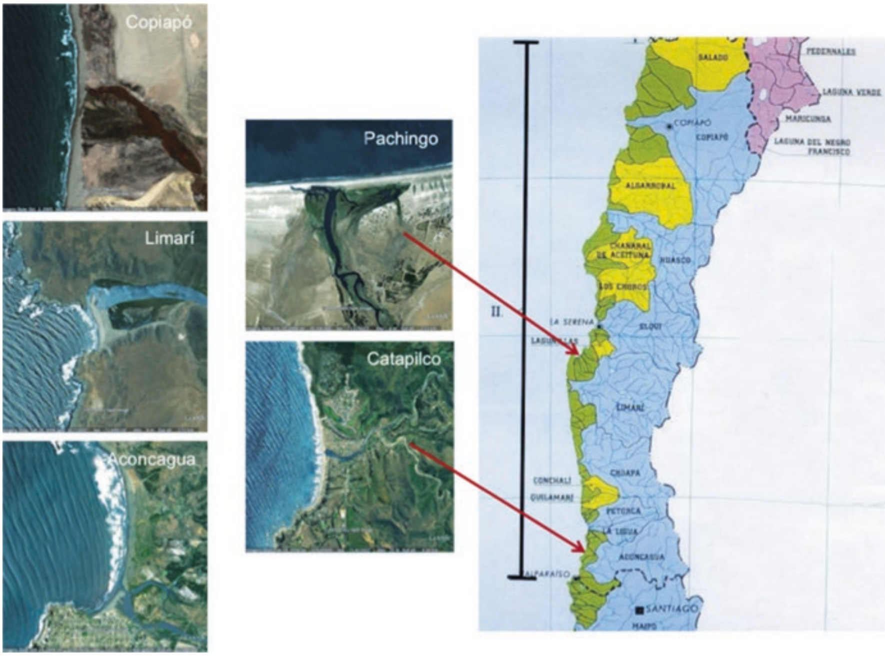

Fig. 2.12 Some examples of estuaries along the semiarid zone of Chile (Google Earth images and map by the Military Geographical Institute {Instituto Geográfico Militar})

Table 2.11 summarizes the main hydrological characteristics of rivers in the Mediterranean and wet temperate zones of Chile. In this area there are marked differences in behavior for the rivers of Andean and coastal origin, mainly associated with the value of average annual waste of its surface runoff.

When it comes to Andean rivers, a rising trend of flow with latitude is observed yet again, although the size of basins also affects this variable. In general, mountain rivers have coefficient variation lower than the coastal rivers, which together with major flows, explains why their mouths stay open permanently. The Rapel and Maule Rivers (Fig. 2.13) are clear examples of this type of morphological configuration. Furthermore, it is possible to see that in these estuaries, sediment transport by coastal currents is less intense because their mouths are protected by the rocky points located towards the south. This creates the less abundant sediment contributions of coastal origin. In these cases, the origin of the sediments is mainly fluvial thus generating a significant source of sediment for the beaches and dune systems located further north of the mouth. According to the Cooper classification (2001), these estuaries enter the way with no barriers, with permanently open mouths and at relatively large depths.

The case of the Imperial River is interesting, since being a mountain river with a relatively constant and high flow, it still presents a barrier at its mouth (Fig. 2.13). This situation is explained by the action of waves and coastal transport, given the

Table 2.11 Summary of hydrologic characteristics for estuaries in Mediterranean and wet temperate zones

Zone	Region	Mountain Rivers	Tributaries	Coastal rivers	Hoya (km^2)	Average annual spending (m3/s)	Coefficient of variation
Mediterranean	V			Margamarga	422		
				Laguna Verde			
		Maipo	Various		15,380	146.9	0.4
				El Yali	765		
	VI	Rapel	Cachapoal &Tinguiririca		14,177	195.5	0.6
				Nilahue	1770	11.1	1.3
				Llico			
	VII	Mataquito	Teno & Lontue		6190	125.9	0.6
		Maule	Various		20,295	495.3	0.6
	VIII	Itata	Various		11,090	351.6	0.8
		Biobio	Various		24,029	982	0.7
Wet template	VIII			Lenga			
				Andalien	780		
				Carampangue	1237	45	
				Tubul – Raqui			
				Lebu	813		
				Paicavi	1133		
				Lleulleu	670	19.4	0.8
				Tirua	400		
	IX	Imperial	Cautin& Cholchol		12,064	240	
				Lake Budi	51		
		Tolten	Various		7886	548.9	0.6
		Petrohue			2644	678	

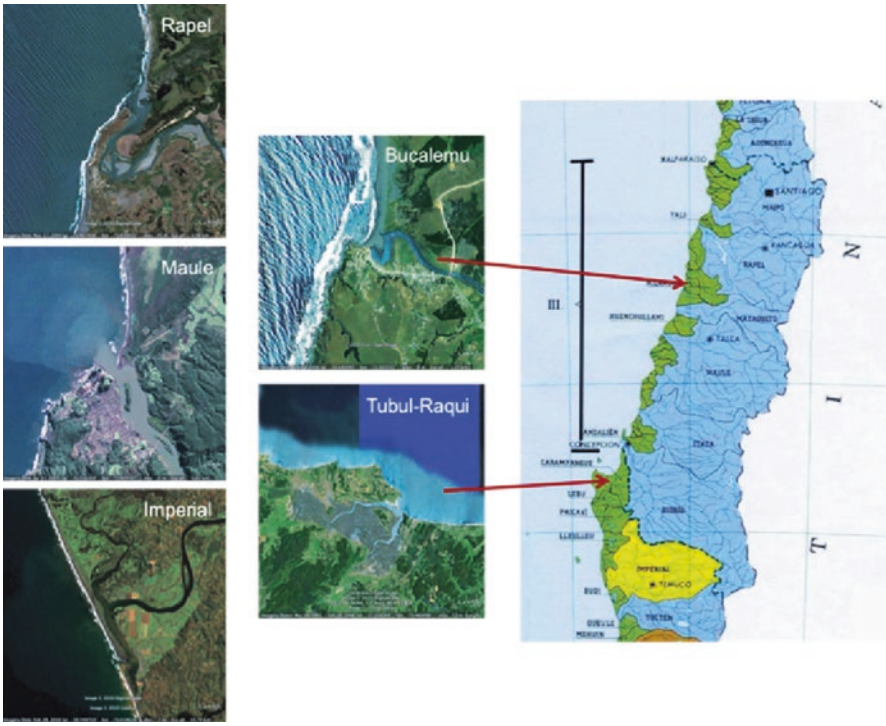

Fig. 2.13 Some examples of estuaries in Mediterranean and wet temperate zones in Chile (Google Earth images and map by the Instituto Geográfico Militar)

south-east orientation of the coastline, it has a predominant south movements. The surf energy together with availability of sediments of marine origin, produces a different morphological configuration of the Rapel and Maule's river mouths. Therefore, the importance of coastal processes, the orientation of the coast and geomorphology resulting in the type of configuration are revealed. According to the conceptual Cooper model (2001), this estuary can be classified as an open estuary with a barrier, mixed regimen, dominated by the river, but with a greater degree of influence over the tidal currents.

Regarding the rivers of coastal origin, with lower annual average flows and increased hydrological variability, it is usual to observe a configuration of coastal lagoons with closed mouths, when there is a high degree of wave exposure. This is the case of the El Yali wetland (Dussaillant et al. 2009) and the Marga-Marga, Nilahue tidelands (Andrade and Grau 2005), Bucalemu (Fig. 2.13) and Llico, among others. These examples can be classified as coastal lagoons following the Cooper model (2001), and being able to function as estuaries with barrier dominated by tides, when connected to the sea during the wet seasons.

The Tubul-Raqui wetlands show different characteristics from the aforementioned coastal rivers, because it has no barriers, and it can permanently stay connected to the sea (Fig. 2.13). This is quite an exceptional situation stemming from the fact that its mouth is protected from the surf action, and having no existing important sediment of coastal origin. On the other hand, the wetland is formed in a low area of slope, and it may be exposed more to the tide influence. This estuary, because of its environmental importance and vast areas of marshland that characterize it, is probably the most important one in the central zone (Stuardo and Valdovinos 1989). According to the Cooper conceptual model (2001), this system can be classified as an estuary without barrier.

The February 27, 2010 Earthquake and Tsunami impact on the Mataquito River Mouth

The February 27, 2010 earthquake was one of the most important in recent history, on a global level. Its intensity was 8.8Mw and its epicenter was located in front of the town of Cauquenes (35,909 ° S, 72.733°W), about 105 kilometers northwest of the city of Concepcion.[2] The rupture zone covered an area of approximately 600 km in the north-south direction, and 300 km in the east-west direction according to estimates by the National Earthquake Information Center (NEIC) of The United States Geological Survey[3] (USGS). The mass movement of the seafloor generated a tsunami of great proportions that then spread in the basin of the Pacific Ocean, causing major damage along 600 kilometers of the coast of Chile, between the Regions V, VI, VII and VIII, and in the archipelago of Juan Fernandez (Fritz et al. 2011).

One of the most dramatic consequences of this event, although little addressed so far, is related to the changes on the affected Chilean coast. The earthquake produced important horizontal and vertical displacements, highlighting the upheaval around the southern edge of the Gulf of Arauco, and subsidence in the Biobio and Mataquito mouths (Farías et al. 2010). This situation reinforces the need to incorporate tectonic variables in the analysis of morphological behavior of the coast of Chile. It is important to highlight that throughout Chilean history, there have been similar changes after each mega-earthquake. The effects on the coast after the 1835 Concepcion earthquake were described by Darwin (1846), while some of the morphological consequences of the earthquake and tsunami of 1960 have been reported by Weischet (1963). It is therefore reasonable to imagine that each of the major seismic events occurred off the coast of Chile has generated significant changes in the configurations of the river mouths located in the affected regions.

As an example of the aforementioned, it is interesting to describe the impact of the February 27, 2010 earthquake and tsunami on the mouth of the Mataquito River, located in the Maule Region (34 ° 58′S, 72 ° 2′W). Before the earthquake, this system was made up of a sedimentary bar several kilometers long, which accounts for

[2] http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/

[3] http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/finite_fault.php

the intense coastal traffic associated with dominant waves, in south-west direction. Coastal currents and winds are responsible for transporting sand brought by the Maule River and Putu dunes, located south of the Mataquito River mouth. The coastal traffic occurs in the south-north direction, with no points or rocky barriers that impede the progress of sediments to the mouth of river Mataquito.

According to hydrological analysis presented in Sect. 2.2, the Mataquito River is of the mountain origin, with an average annual flow rate of close to 126 m^3/s and a relatively low variation coefficient of 0.63, presenting permanent surface runoff throughout the year. Therefore, the surf that affects the river mouth is energetic,

Fig. 2.14 Estuary in Mataquito River and evolution of its bank before and after the earthquake and Tsunami on February 27, 2010 (satellite images obtained from Google Earth)

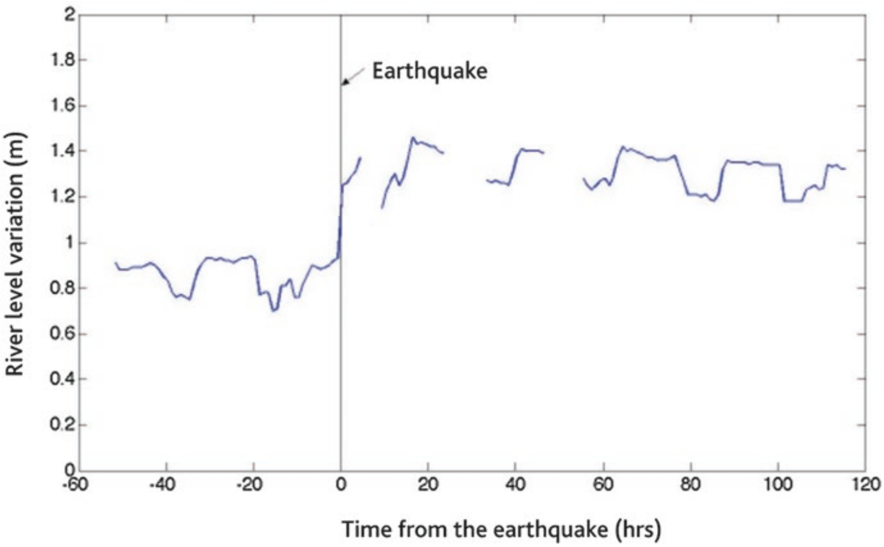

Fig. 2.15 Records from Licanten fluviometric station, part of the Dirección General de Aguas (DGA) de Chile

which together with the wide availability of sediment, generates intense hauling in the south-north direction. This combination of factors explains the formation of the bar at its mouth, which influences the river forcing it to turn north before reaching the ocean, at the proximity of the town of La Pesca. In Fig. 2.14 there are some satellite images that reflect the evolution of the bar before and after the February 27, 2010 earthquake and tsunami. The large size and stability of the bar between 2004 and 2008 is observed, and the impact of the mega-earthquake on it is from March 2010. According to the Cooper classification (2001), the Mataquito river mouth is an estuary with a barrier, dominated by the river.

After the earthquake, there was a subsidence of several tens of centimeters in the area of the river mouth (Farías et al. 2010), a situation that is confirmed by the recorded water level of Mataquito river at the fluviometric station Licanten DGA (Fig. 2.15), located several kilometers upstream from the mouth. So the first effect of the earthquake on the river mouth was to produce a relative increase of the sea level. A few minutes later, the first waves of the tsunami hit the bar, causing a major sediment transport. Several waves reached this sector in the next few hours, contributing to the disappearance of this sedimentary structure.

Despite the February 27 earthquake and tsunami great impact on the morphology of the Mataquito river mouth, during the remaining months of 2010 the river bank has begun to mend quickly. In Fig. 2.16 aerial photographs that were taken in April and September of 2010, it is possible to notice the changes that have occurred. Coastal currents have brought a significant amount of sediment in south-north direction, which explains the progress of the barrier to the north. It is also possible to observe the formation of a beach in the southern heading spike located near the area called La Pesca. Thus, it appears that the great influence of surf/waves, dominating in 2010, has not registered major floods of the river in this period. The prevailing direction of the surf generates currents that have been able to mobilize sediment in significant quantities, so it would be expected for the bar to reach the river mouth during 2011, a similar situation happening before the earthquake too. The seismic

Fig. 2.16 Evolution of the Mataquito river estuary after the earthquake and Tsunami of February 27, 2010 (Photographs courtesy of Arauco taken by natureFilms)

event of February 27, 2010 has therefore allowed to put in evidence the coastal processes responsible for the creation of the Mataquito River bar and to better understand the hydro-sedimentary dynamics of this system. Particularly striking is the great speed with which the morphology of the river mouth has evolved during the months following the earthquake and tsunami.

Conclusions

In this chapter, we have observed and reviewed the basic background information on the processes that govern hydro-sedimentary dynamics of the river mouths of the central zone of Chile, in order to establish common elements to classify the different morphological configurations.

The central coast of Chile is subject to one of the most energetic surf climates in the world, with significant annual average surf/wave heights of over 2 m. The predominant direction of wave attack is south-west, generally resulting in coastal currents carrying sediments from south to north. Additionally, the tidal range in the central area is microtidal, with less than 2 m of amplitudes. The combination of these oceanographic forces allows to conclude that the morphological configuration of the beaches and river mouths will generally be and is dominated by surf (Davis and Hayes 1984).

From the geomorphological point of view, the central-southern Chile has abundant sources of sediments, which are mainly provided by hydrographic basins and waterways that flow into the Pacific Ocean. However, there are some exceptions, such as in the Gulf of Arauco, where the origin of the sediments is rather marine. This situation can be explained by the pronounced tendency of upheaval under the effects of tectonic movements, which combined with a wider and less steep continental shelf, helps produce sediments that can then be carried by coastal currents. In short, the south-central coast of Chile is a subject to a sediment aggradation (rising), but records no events or tendencies towards coastal erosion.

The various morphological configurations observed in river mouths are mainly determined by the hydrological behavior of rivers that form them. Therefore it is possible to distinguish behaviors depending on the size of the basins (of coastal or Andean origin) and the seasonality of the hydrological regime (variability of surface runoff during the year). The average annual flow and the variation coefficient are the most important variables to explain the type of river mouth observed. In rivers and estuaries of coastal origin, or in the Andean rivers with low flow in the semiarid zone, there are often found coastal lagoons or wetlands with their water mouths remaining closed most of the time. The littoral drift produced by the surf dominates, creating sedimentary barriers that are transferred only during winter risings. The case of Tubul-Raqui wetland, located in the southern end of the Gulf of Arauco, is an exception, because even though it is a coastal river, is stays permanently open and connected to the sea. This configuration helps keep its (river) mouth protected from direct surf action.

Additionally, the Andean rivers of the Mediterranean and wet temperate zones have river mouths that are open throughout the year. The largest flow rate recorded and its minor seasonal variability, deliver the energy needed to overcome the surf action and open free to the sea. The existence of sandbars in their mouths depends on the degree of surf exposure, and the same goes for the slopes and the depth of the channel.

Finally, it is important to note that the tectonic events that take place off the coast of Chile, are responsible for generating large seismic occurrences that may even be accompanied by tsunamis. The historical records indicate that, on average, in Chile, there have occurred between 2 and 3 tsunamigenic earthquakes every century. These events produce major changes on the ground, as upheavals and subsidence, and can also change the morphology of the coast dramatically. An example of the above is the disappearance of the great sedimentary bar at the mouth of the Mataquito River after the earthquake and tsunami of February 27 2010. This structure was swept away almost completely, but has been rehabilitated quickly during the following months, highlighting the hydro-sedimentary dynamics responsible for shaping the river mouths of the central-southern Chile.

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