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Cost of beach maintenance in the Gulf of Cadiz (SW Spain)

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Abstract

Beach erosion problems have been solved by adding sand to the beaches along the Gulf of Cadiz. The Gulf is located in SW Spain between the Portuguese border and the Strait of Gibraltar. During the last decade, more than 12×10^6 m^3 of sand have been nourished in 38 restoration operations carried out on 28 beaches. The main characteristics of the nourishment campaigns (year, volume, budget, transport method, sand data, etc.) are presented. Location of sand borrow sites and distance to the beaches are also shown. Monitoring programs have been performed in order to calculate sediment loss rates. These results have been related to the beach length, the berm width and the budget in order to obtain a variety of relationships for maintenance cost as, for example, the total annual cost for each beach. This information is very useful when developing a strategy in coastal zone management. Furthermore, at least in reef-protected beaches, small yearly renourishments similar to the yearly losses, instead of greater nourishments performed with a periodicity of many years, lead to an economical saving, as well as to a better use of the natural resources.

Keywords: Beach nourishment; Coastal zone management; Beach erosion; Gulf of Cadiz

1. Introduction

The coastline of the Gulf of Cadiz has been in recession for at least the last century. Subsidence phenomena, sea level rise or manmade barriers, as groin constructions like the breakwater built in the Portuguese bank of the Guadiana River mouth, are the causes.

Analysis of field data and aerial photographs over the last half century show that the coastline has suffered a recession rate of approximately 1 m/year in some points of the Spanish Southwest Atlantic coast (Muñoz-Perez and Enriquez, 1998).Because of the erosion, the Spanish Coastal Authority, in the past dependent upon the Ministry of Public Works and presently belonging to the Ministry of the Environmental Protection, decided to begin a coastal protection program.

Erosion is caused by a negative sediment budget and, at the present, adding sand to the physiographic

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unit appears to be the most natural way to solve the erosion problem. Some beach nourishment projects have sometimes been complemented with the construction of some permeable and short groins adjusted to the beach profile. This was only carried out when an important reduction of the annual nourishment requirement justified it (Muñoz-Perez and Gutierrez-Mas, 1999).

Monitoring the behaviour of several beaches since the first nourishment allowed for a comparison with previous works, as well as to establish real mean rates of erosion for each job and predict renourishment requirements in the future. Other countries have been monitoring for a much greater length of time (see amongst others, Wijnberg, 1995; Lin and Sasso, 1996; Shak and Ryan, 1996), and compilations of information on this topic have also been performed. For instance, a database that documents beach nourishment episodes, which have occurred on the US Eastern shoreline (from New York to Florida) was presented recently by Valverde et al. (1999). Also, the economic importance of beaches and their tourism has been examined by Houston (1995, 1996). The federal spendings for shoreline preservation and the revenues for the government and benefits for the national economy have been compared (King, 1999). Nevertheless, the yearly cost of the different beach nourishment programs is a little published parameter yet. The range of this value could prove to be very interesting in providing a better design tool for future nourishment projects and to decide whether they should be carried out or not.

The main aim of this paper is to describe a morphological and economical evaluation of the beach nourishment maintenance strategy carried out in the Gulf of Cadiz during the 1990s.

2. Data compilation

The coastline which is to be studied is located along the Gulf of Cadiz, facing the Atlantic Ocean on the southwest coast of Spain, between the Guadiana River mouth and the Strait of Gibraltar. A general view of the area and the location of the 28 beaches, where the 38 nourishments were carried out, are presented in Fig. 1. The region has a mesotidal range with a medium neap to spring variation (1.20–3.30 m). Most of the beaches are composed of fine-medium sand ($D_{50} = 250$ μm) consisting of 85–95% quartz and 5–15% calcium carbonate. In many beaches, the typical profiles intersect a submerged reef and, consequently, are not sand rich. Wave decay due to the wave breaking over the submerged reef, the changes on the resulting beach profile shape and the stability of the beach were discussed by Muñoz-Perez et al. (1999a).

Wave climate data have been collected by two waverider buoys included in the Spanish Wave Recording Network (known as REMRO). The first of these buoys, named "Seville", was installed in front of the Guadalquivir river mouth anchored at a depth of −12 m. The second one, named "Cadiz", was anchored at a depth of −22 m, 3 miles seaward from a rocky shoal in front of the city of Cadiz. Statistically elaborated data are available in the Maritime Works Recommendations ROM 0.3–91 (MOPT, 1991).

Geophysical campaigns have been performed over the entire width of the coast in order to identify submerged borrow sand areas (Esgemar, 1991; Geomytsa, 1991a,b, 1994). Soundings of the sea bottom were carried out to check the thickness of sediment deposits. Location of borrow sites and dredged volumes are shown in Fig. 2. A large number of surface grab sediment samples were also collected to identify the borrow sand characteristics.

A conventional topographic surveying technique was employed in the aerial part of the beach. A differential leveling with reference to a benchmark located in the seaside promenade was performed at the hour of the spring low tide. It was possible to survey up to elevation −1.00 m. Due to the fact that bathymetric contours were made with an echosounder on boat and differential global position system (DGPS) at the spring high tide, an area of overlap with the aerial topography relates both surveys to the same datum or "zero level". For a comprehensive description about the accuracy of the method, see Muñoz-Perez (1995). The total cost of the monitoring works was US$450,000 during the last decade, only 1.2% of the beach restoration investments.

Currents were also measured. The final aim of these measurements being the calibration of the mathematical models developed to study different aspects of the coastline evolution.

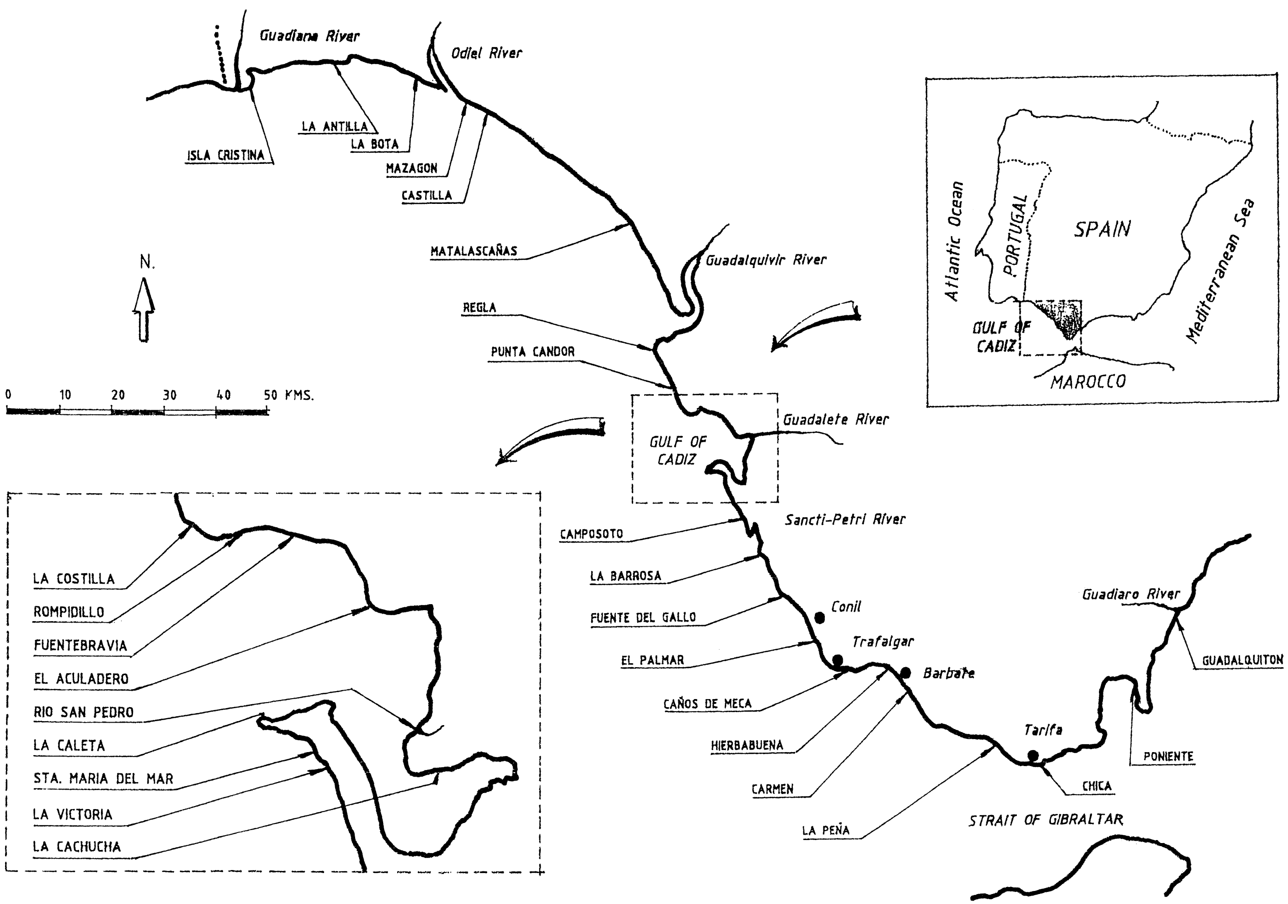

Fig. 1. Location of the 28 beaches renourished in the decade 1989–1998.

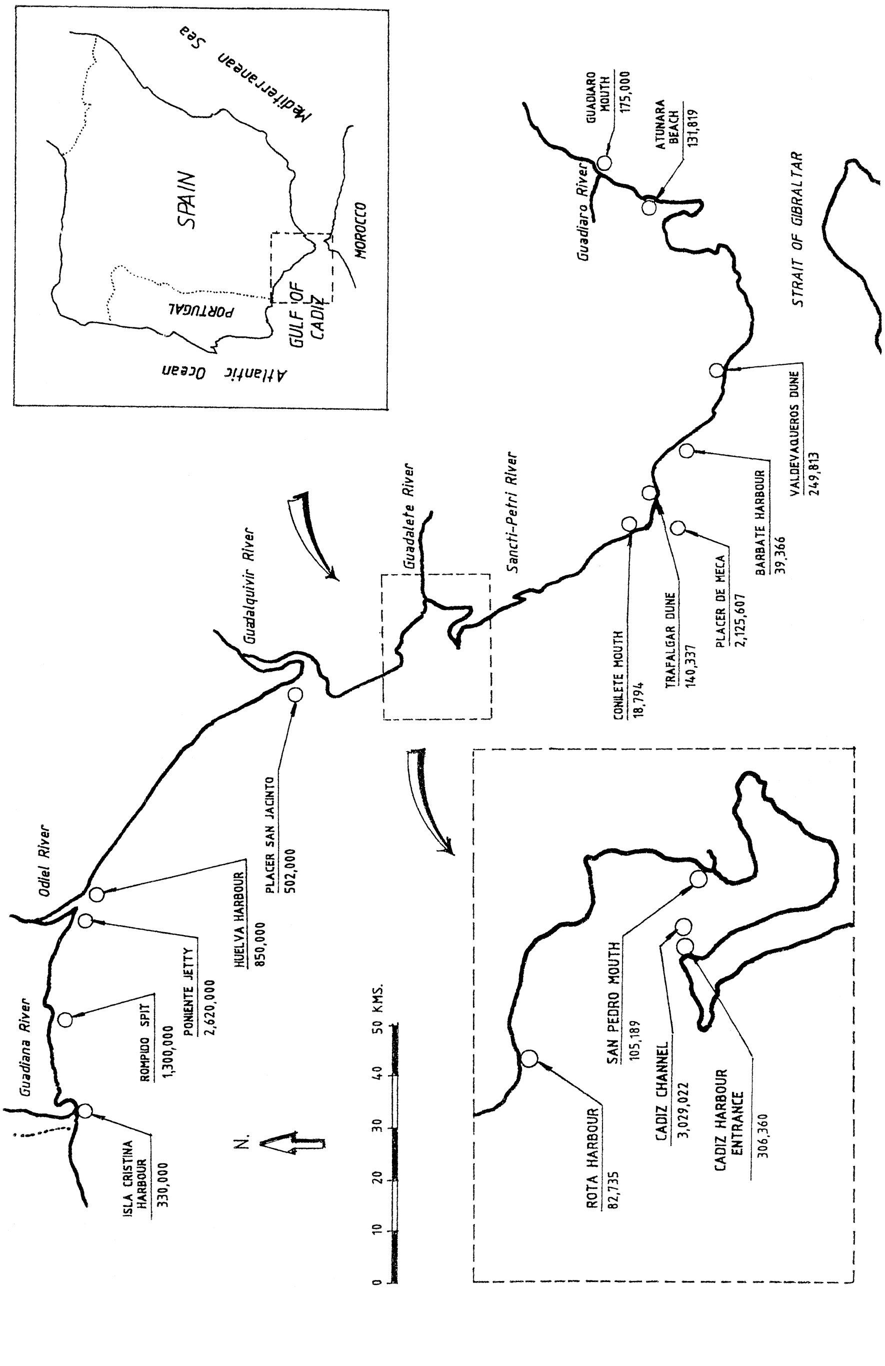

Fig. 2. Location of the sand borrow sites in the Gulf of Cadiz.

Once the beach restoration was finished, new bathymetric surveys were carried out in the majority of cases. These were performed once per year for, at least, a period of 2 years. Hence, profile comparisons could be made and erosion rates estimated.

3. Results and discussion

Data collected for the 38 beach nourishments performed during the last decade are presented in Table 1. From left to right, the data specified are the following.

• Date (year) and name of the beach where restoration works were carried out. Successive restorations performed on the same beach are shown by different ordinal numbers. So, Fuentebravia, Fuentebravia II and Fuentebravia III would note the first, second and third nourishment projects. There were 38 sand-pouring operations accomplished on 28 beaches from 1989 to 1998.

• Volume of sand poured in the nourishment, which was generally surveyed in the hopper and is expressed in cubic meters. Total volume was 12.0×10^6 m^3 with a maximum in Victoria Beach (2.0×10^6 m^3).

• Final budget, in US$, where Spanish taxes as 16% value added tax (VAT) are not included and cost of hard structures such as groins, when necessary, are not considered. All costs were adjusted for Spanish inflation factors and converted to 1999 dollars. Global investment was US$$37.5 \times 10^6$, that is US$$3.7 \times 10^6$/year.

• Transport method (ground transport by trucks or maritime dredging by trail suction) is specified. Ground transport by trucks, from adjacent beaches or dunes, was performed to nourish 13 beaches. The volume transported was 6.5% of the total volume, while the cost was only the 5.5% with an average value of US$2.7/m^3. Distances vary from 0.4 to 11.2 km with 4.2 km as the average value. On the other hand, volume dredged had an average cost of US$3.1/m^3 and an averaged distance of 10.9 km within a range from 0.5 to 35 km.

• The main characteristics of the sediment are also presented. It refers to the mean diameter, in microns, of the borrow sand which is very similar to the native one. Three different areas can be distinguished along the coastline according to the grain size. The western one, between Guadiana and Guadalquivir rivers, has a median grain size diameter which varies from 350 to 670 μm with an average value of 450 μm. Sand size is finer between Guadalquivir river and the Strait of Gibraltar: $D_{50} =$ 280 μm. A coarser grain size of 1000 μm is present in Guadalquiton beach, in the Mediterranean Sea. Weight of the silt–clay fraction is negligible, about 1.6%. The percentage of the bioclastic fraction, i.e. the part composed of flat shell fragments which are, usually, very quickly transported seawards (Muñoz-Perez et al., 1999b), is also indicated. This value varies extensively, from 3% to 32% with an average of 12.9%.

• The type of profile is specified: reef supported or sand rich.

• Location of the borrow site (submerged or emerged) and distance (kilometer) from the borrow area to the beach nourishment.

Working with the previously described characteristics and along with the beach dimension, a new set of parameters related to the maintenance management are developed. These values presented in Table 2 are as follows.

• The erosion rate is computed by averaging the losses after nourishments and based on total beach profile measurements, throughout a monitoring period of at least two years. It is expressed in cubic meters per year. These data are not specified in 14 nourishment operations because no monitoring works were performed.

• Length of the beach where restoration works were carried out and berm width achieved with the nourishment. Both of these values are expressed in meters. The block diagram shown in Fig. 3 clarifies the meaning of beach length and berm width.

• Sediment loss per year per longitudinal meter, obtained by dividing the yearly erosion rate by the beach length. Average value is 37.5 m^3/m/year. Greatest values correspond to Aculadero, Fuentebravia and La Peña beaches (58, 90 and 108 m^3/m/year, respectively).

• Unit cost of sand (US$/m^3), id est, the relationship between the real total budget and the fill volume of the nourishment. The average value is about US$3/m^3 with a maximum of US$6.7/m^3.

Table 1
Beach nourishment in the Gulf of Cadiz in the last decade

Year	Beach name	Volume (m^3)	Total budget (US$)	Transport method	Sand: D_{50} (μm)	Sand: Percent silt	Sand: Percent shell fraction	Kind of profile	Borrow area	Distance (km)
1989	Castilla Beach	1,690,000	3,813,333	Trail suction	600	1.5		Sand rich	Poniente jetty	6.3
1990	La Antilla	1,300,000	5,333,000	Trail suction	500	1.3		Sand rich	Rompidillo spit	6.1
1990	La Cachucha	82,030	505,406	Trucks	300	2.6	8	Sand rich	San Pedro mouth	3.8
1991	La Caleta	41,440	81,032	Trucks	310	3.6	3	Reef supported	Cortadura beach	1.4
1991	Victoria	2,000,050	5,527,742	Trail suction	250	2.4	11	Sand rich and reef supported	Cadiz Channel	5.2
1991	Sta. Maria del Mar	306,360	557,419	Trail suction	350	1.5	16	Reef supported	Cadiz Harbour entrance	6.0
1991	La Peña	67,035	216,774	Trucks	230	1.2	29	Reef supported	Valdevaqueros dune	11.2
1991	Caños de Meca	16,103	39,914	Trucks	230	1.7	10	Reef supported	Trafalgar dune	2.4
1991	Río San Pedro	23,159	59,649	Trail suction	220	1	15	Reef supported	San Pedro mouth	0.5
1992	Regla	502,000	2,650,000	Trail suction	250	2.5	8	Reef supported	Placer San Jacinto	4.2
1992	Caños de Meca II	124,234	263,619	Trucks	230	1.5	12	Reef supported	Trafalgar Dune	2.4
1992	Fuentebravia	75,000	212,748	Trucks	390	0.3	9	Reef supported	Rota Harbour	0.9
1993	Carmen	23,150	43,413	Trucks	220	0.5	15	Sand rich	Barbate Harbour	0.6
1993	Poniente	131,819	187,062	Trucks	390	0.3	8	Sand rich	Atunara beach	6.7
1993	El Palmar	18,794	33,727	Trucks	250	1.2	12	Sand rich	Conilete mouth	2.0
1993	La Peña II	170,000	413,641	Trucks	240	1	31	Reef supported	Valdevaqueros dune	11.2
1993–1994	La Barrosa	463,607	1,242,564	Trail suction	290	3.4	15	Sand rich	Placer de Meca	25.1
1994	Fuentebravía II	275,133	540,733	Trail suction	280	2.5	12	Reef supported	Cadiz Channel	8.1
1993–1994	El Aculadero	172,448	267,613	Trail suction and trucks	390	0.5	17	Reef supported	Cadiz Channel	4.5
1994	La Hierbabuena	16,216	40,516	Trucks	220	0.8	12	Sand rich	Barbate Harbour	0.4
1994	Caños de Meca III	496,000	1,021,936	Trail suction	300	3.5	14	Reef supported	Placer de Meca	4.0
1994	Fuente del Gallo	399,000	1,037,419	Trail suction	230	2	18	Reef supported	Placer de Meca	13.0
1994	Isla Cristina	330,000	887,000	Trail suction	350	1.3		Sand rich	Isla Cristina Harbour	4.1
1995	La Bota	930,000	3,187,000	Trail suction	670	1.5	< 20	Sand rich	Poniente Dique Juan Carlos I	13
1995	Chica	12,778	40,516	Trucks	230	1.5	32	Reef supported	Valdevaqueros Dune	11.2
1995	El Rompidillo	7,735	11,581	Trucks	220	1	11	Reef supported	Rota Harbour	0.6
1996	La Costilla	197,000	948,746	Trail suction	380	3	9	Sand rich	Cadiz Channel	11.0
1996	Aculadero II	75,625	240,946	Trail suction	250	3.5	14	Reef supported	Cadiz Channel	4.5
1996	La Costilla II	94,566	292,351	Trail suction	350	1.2	8	Sand rich	Cadiz Channel	11.0
1996	Fuentebravía III	134,808	351,675	Trail suction	300	3	11	Reef supported	Cadiz Channel	8.1
1996	Mazagón	425,000	1,406,364	Trail suction	350	2		Sand rich	Huelva Harbour	7.2
1996	Matalascañas	125,000	413,636	Trail suction	350	2		Sand rich	Huelva Harbour	18.3
1997	La Antilla II	300,000	2,000,000	Trail suction	350	0.3		Sand rich	Huelva Harbour	35.1
1997	Sta. Maria del Mar II	60,181	228,381	Trail suction	300	0.3	10	Reef supported	Cadiz Channel	6.0
1997	La Barrosa II	30,000	142,575	Trail suction	300	0.2	10	Sand rich	Placer de Meca	25.0
1998	Camposoto.	737,000	2,578,453	Trail suction	300	0.5	3	Reef supported	Placer de Meca	31.5
1998	Punta Candor	19,211	100,373	Trail suction	320	0.5	8	Reef supported	Cadiz Channel	14.2
1998	Guadalquitón	175,000	538,400	Trail suction	1000	0.9	10	Sand rich	Guadiaro mouth	0.8

Table 2
Maintenance cost of beaches in the Gulf of Cadiz

Year	Beach name	Sediment loss (m^3/year)	Beach length (m)	Berm width (m)	Sediment loss/beach length (m^3/year/m)	Cost of sand (US$/$m^3$)	Material supply		Maintenance cost		
							Volume/beach length (m^3/m)	Volume/dry surface (m^3/m^2)	Per unit of beach length (US$/year/m)	Per unit of dry surface (US$/$m^2$)	Total (US$/year)
1989	Castilla Beach	100,000	2000	110	50	2.26	845	7.7	113	17.4	226,000
1990	La Antilla	50,000	3500	50	14	4.10	371	7.4	59	30.2	205,000
1990	La Cachucha		560	35		6.16	146	4.2			
1991	La Caleta		360	20		1.96	115	5.8			
1991	Victoria	70,000	3500	70	20	2.76	571	8.2	55	23.0	193,200
1991	Sta. Maria del Mar	30,000	600	45	50	1.82	511	11.3	91	20.7	54,600
1991	La Peña	65,000	600	18	108	3.23	112	6.2	350	20.0	209,950
1991	Caños de Meca		750	3		2.48	21	7.2			
1991	Río San Pedro		370	8		2.58	63	7.8			
1992	Regla	35,000	1500	38	23	5.28	335	8.8	123	46.7	184,800
1992	Caños de Meca II		750	24		2.12	166	6.9			
1992	Fuentebravia		725	14		2.84	103	7.4			
1993	Carmen	5000	1200	3	4	1.88	19	6.4	8	12.5	9400
1993	Poniente		700	23		1.42	188	8.2			
1993	El Palmar		800	4		1.79	23	5.9			
1993	La Peña II	85,000	800	30	106	2.43	213	7.1	259	17.2	206,550
1993–1994	La Barrosa	45,000	1200	40	38	2.68	386	9.7	101	26.1	120,600
1994	Fuentebravía II	65,000	725	60	90	1.97	379	6.3	176	12.5	128,050
1993–1994	El Aculadero	35,000	600	40	58	1.55	287	7.2	91	11.1	54,250
1994	La Hierbabuena	4000	730	3	5	2.50	22	7.4	14	17.9	10,000
1994	Caños de Meca III	26,500	750	70	35	2.06	661	9.4	73	19.5	54,590
1994	Fuente del Gallo	52,000	1200	30	43	2.60	333	11.1	113	28.7	135,200
1994	Isla Cristina	40,000	1800	40	22	2.69	183	4.6	60	12.3	107,600
1995	La Bota	50,000	4200	40	12	3.43	221	5.5	41	18.7	171,500
1995	Chica		120	25		3.17	106	4.3			
1995	El Rompidillo	4000	800	2	5	1.50	10	4.8	7	7.5	6000
1996	La Costilla	15,000	1200	20	13	4.82	164	8.2	60	39.2	72,300
1996	Aculadero II	11,000	600	20	18	3.19	126	6.3	58	19.8	35,090
1996	La Costilla II		1200	10		3.09	79	7.9			
1996	Fuentebravía III	62,000	725	31	86	2.61	186	6.0	223	15.7	161,820
1996	Mazagón	30,000	1500	28	20	3.31	283	10.1	66	33.1	99,300
1996	Matalascañas	30,000	700	18	43	3.31	179	9.9	142	33.1	99,300
1997	La Antilla II		2000	40		6.67	150	3.8			
1997	Sta. Maria del Mar II	10,000	600	12	17	3.79	100	8.4	63	32.2	37,900
1997	La Barrosa II		1200	3		4.75	25	8.3			
1998	Camposoto.	45,000	3000	28	15	3.50	246	8.8	52	30.9	157,500
1998	Punta Candor		200	14		5.22	96	6.9			
1998	Guadalquitón		500	30		3.08	350	11.7			

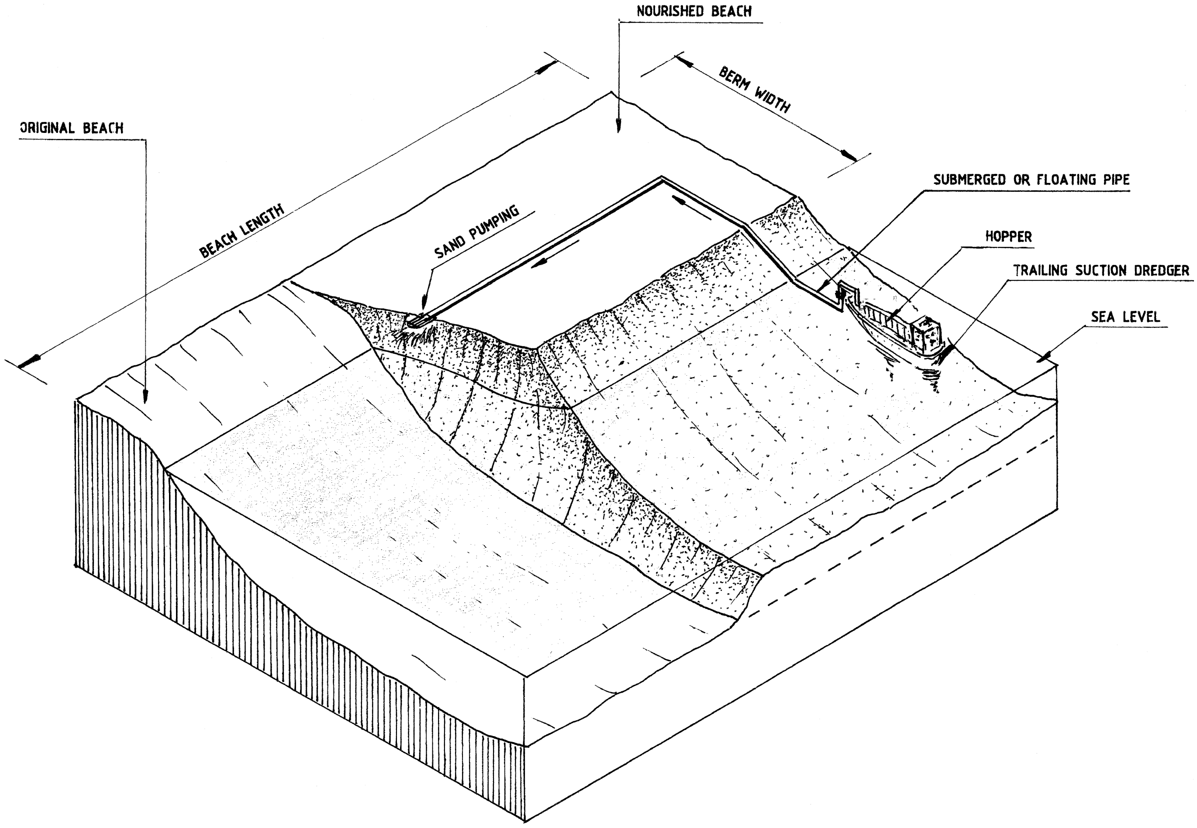

Fig. 3. Block diagram clarifying some concepts of a beach nourishment.

• Restoration volume divided by the beach length (m^3/m).

• Volume requirements to get 1 m^2 of berm or dry beach.

• Maintenance cost in different units: price per year for every meter length beach, price for every square meter of berm and finally, the annual maintenance cost of each beach.

Despite the importance of the annual total cost parameter, the most adequate parameter to compare costs between different beaches is the annual maintenance cost per unit of beach length (US$/year/m). If one of the main goals of a nourishment scheme is to maintain the dry surface of the beach for tourist exploitation, this parameter is very useful in deciding where to best invest public funds. In our particular case, these values normally range from US$7 to US$142/year/m with an average of US$100/year/m and only La Peña and Fuentebravia restorations exceed US$150/year/m reaching a maximum of US$350/year/m.

It is noteworthy that the biggest erosion rate was observed directly after a big nourishment in reef-supported beaches. As Muñoz-Perez et al. (1999a) showed, no equilibrium beach profile is possible within a distance less than 30–100 m from the edge of the reef. So, as you feed more sediment, more sand is transported quickly seawards. Perched or reef-protected beaches, whose profiles are not sand rich, loose sand rapidly when the volume dumped surpasses the geometric limits set down by the morphological characteristics (Muñoz-Perez et al., 1999a). It is also worth noting the fact that a reduction in the volume of the successive restorations of the beaches of Santa Maria del Mar Beach and of Aculadero Beach (from 306,000 to 60,181 and from

172,448 to 75,625 m^3, respectively) was related to a substantial reduction in the annual rates of erosion (from 30,000 to 10,000 and from 35,000 to 11,000 m^3/year), while no significant changes in wave climate were observed during the monitoring period. The former figures were obtained by profile comparisons carried out with the yearly bathymetric surveys performed during the 2 years ensuing the nourishments.

For economical studies, it would be important to know whether a relationship exists between size of job (total cubic meters of project) and unit price. In order to accomplish this, Fig. 4 was prepared with the purpose of displaying the actual cost in US$/$m^3$ versus the nourishment volume, making a clear distinction between the contributions made by truck and trail suction. In the first place, it is noteworthy to state that the volumes transported by truckloads do not surpass 200,000 m^3. Their price, with only one exception, fluctuates between 1 and 3 US$/$m^3$ although bearing no defining trend. On the other hand, two separate groups can be defined amid the nourishments carried out by trail suction dredgers. The first one reaches up to 600,000 m^3 of sand. Though the costs are very spread out, a simple linear fit by the least squares method shows a decreasing tendency. The same tendency, the lessening of costs as volumes increase, though subject to a slighter dispersion rate, can be observed in the existing range between 600,000 and 2,000,000 m^3.

Fig. 5 shows the volume of sand placed on the beaches per year and, also, the annual cost of the nourishment in the last decade. The rather large nourishments and investments in the initial years are

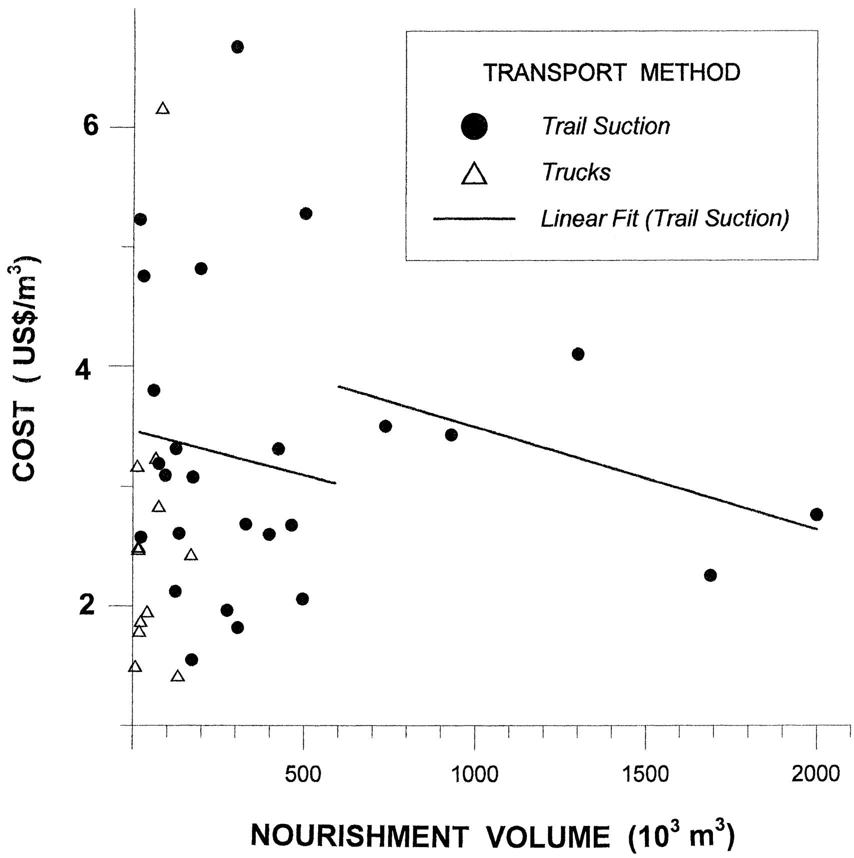

Fig. 4. Cost of sand (US$/$m^3$) in different beach restorations versus their nourishment volumes.

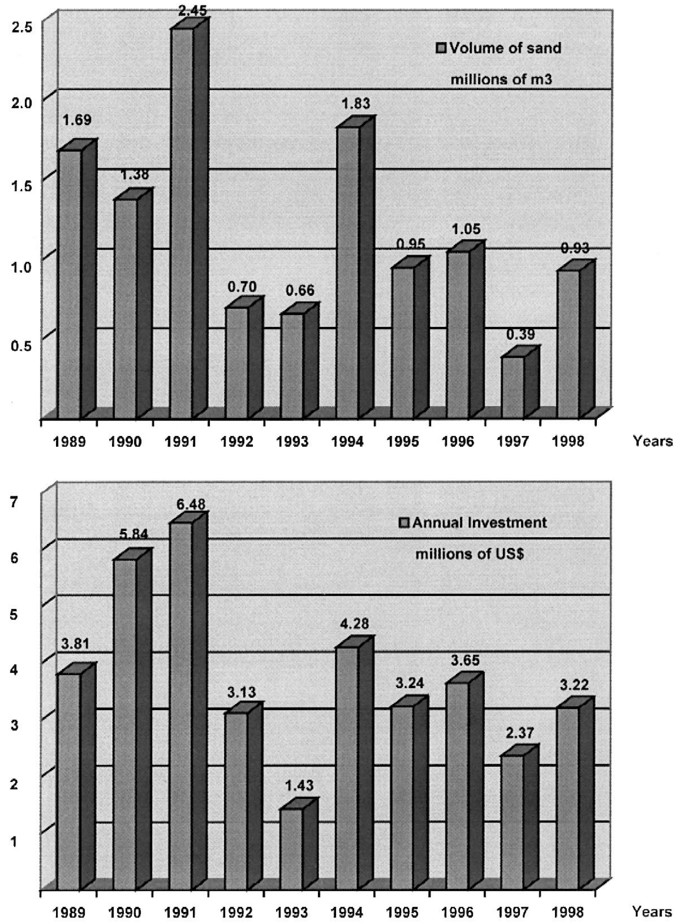

Fig. 5. Sand nourishments (m^3) and investments (US$) per year in the Gulf of Cadiz (1989–1998).

because of the need to replace the existing deficit. In later years, the need for sand has reduced and stabilized about 1×10^6 m^3 of sand corresponding to US$$3 \times 10^6$/year.

4. Conclusions

The data collected from the 38 beach nourishment campaigns that have been carried out on 28 beaches in the Gulf of Cadiz (SW Spain) during the last decade are presented. Within the values of the different parameters demonstrated, it is important to point out that the average annual volume nourished to maintain more than 400 km of coastline was 1.2×10^6 m^3. This imposed an averaged cost of US$3.75 $\times 10^6$ a year, which has to be related to the enormous income that tourism yields in the area every year.

The cost of transport by truck is slightly lower than the transport by dredger and dumping through tubes (US$2.7 against US$3.1/m^3), although the volume carried by the truck was only 6.5% of the total.

The relationships between the costs and the geometric characteristics of the beach suggest many parameters, all of them of great help when attempting to make decisions on sustainable and economical maintenance of the beaches within the framework of coastal zone management. Nevertheless, the annual maintenance cost per unit of beach length appears to be the most useful parameter when comparing the different investments done. Its average value becomes US$100/year/m, but with a great range of scatter: from US$7 to US$350/year/m.

Substantial decrease in the sand volumes nourished within successive restorations carried out on certain beaches led to drastic reductions in the yearly erosion rates. In addition, it may be concluded that, at least in reef-protected beaches, small yearly renourishment, similar to the yearly losses, instead of greater nourishment performed with a periodicity of many years, leads to economical savings, as well as to a better use of the natural resources.

Finally, it is noteworthy to point out that a decreasing tendency in the cost per unit of the sand poured can be acknowledged as the nourishment volume increases, this being specially noticeable in those volumes superior to 600,000 m^3.

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