Chapter 23

THE HISTORY OF A TIDAL LAGOON INLET AND ITS IMPROVEMENT (THE CASE OF AVEIRO, PORTUGAL)

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The described case history is known since the Xth century, and on a scientific level since the end of XVIIIth. Origin and free evolution of the inlet up to 1800, as well as results obtained by artificial improvement attempts subsequently undertaken, are analysed, in order to investigate the main features of local physiography and the way it reacts to human interventions intended to meet ever-increasing navigation requirements. The remarkable success of the projects undertaken, especially of that being executed, seems to legitimate the inference of some principles of general interest as long as tidal lagoon inlets' improvement is concerned. Stress is laid upon difference from principles valid in estuaries' amelioration.

THE ORIGIN AND DEVELOPMENT OF THE LAGOON

The lagoon of Aveiro (fig.1) is a large body of water, 32 miles long and 1.8 miles wide, in the central west coast of Portugal, separated from the ocean by a sandy barrier beach, 600 to 8.400 feet in width. There is an extensive area tributary to the lagoon, but the only important river draining to it is the Vouga, supplying from 40.000 cusecs during maximum floods to none in the dry season. Crest elevation of the dunes in the barrier beach reaches forty feet above datum (lowest possible low-water). Maximum range of spring tide in the open sea is twelve feet, with semi-diurnal tides. The wetted surface of the lagoon is about 17500 acres and tidal flow through the inlet reaches 3 500 000 000 cu.ft. in a spring tide.

Formation of the lagoon is geologically very recent, so that documents are available to follow its evolution since the beginning, in the Xth century, when a sandy spit started to proceed southwards from Espinho, progressively isolating from the sea the ancient bay, wich extended to the mouth of the Vouga River (see figures 2 and 3). Besides the old charts, many other kinds of documents (judicial, economical, legal, historical) support this evidence, as the whole life of Aveiro and the rich and densely populated country round the lagoon has always been, and still is, intimately connected with the condition of the vast body of water and its inlet.

In the Xth century, Ovar was an important sea port, and the tides circulated in the estuary of the Vouga, whose bed was at a lower elevation than now. In no one of the documents of this time is there any reference to the existence of a lagoon. Ovar, Aveiro, Vagos, etc. are all described as being on the sea coast.

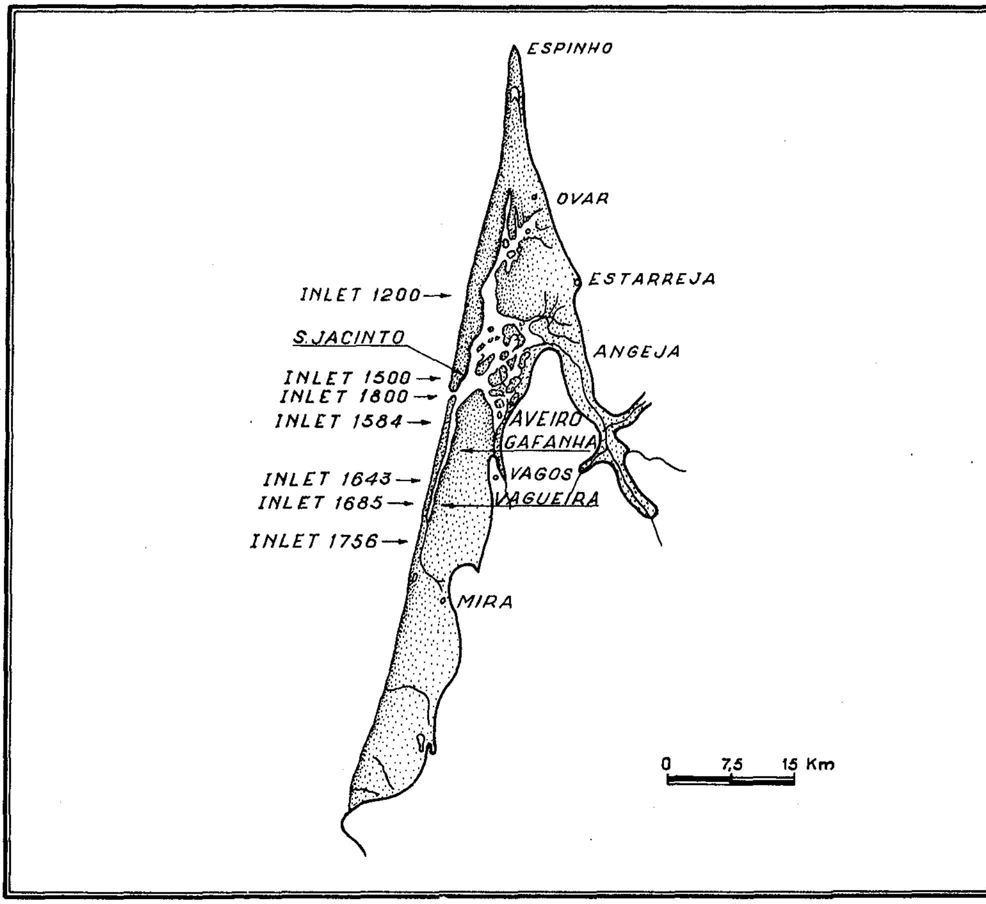


Fig. 1. The lagoon of Aveiro.

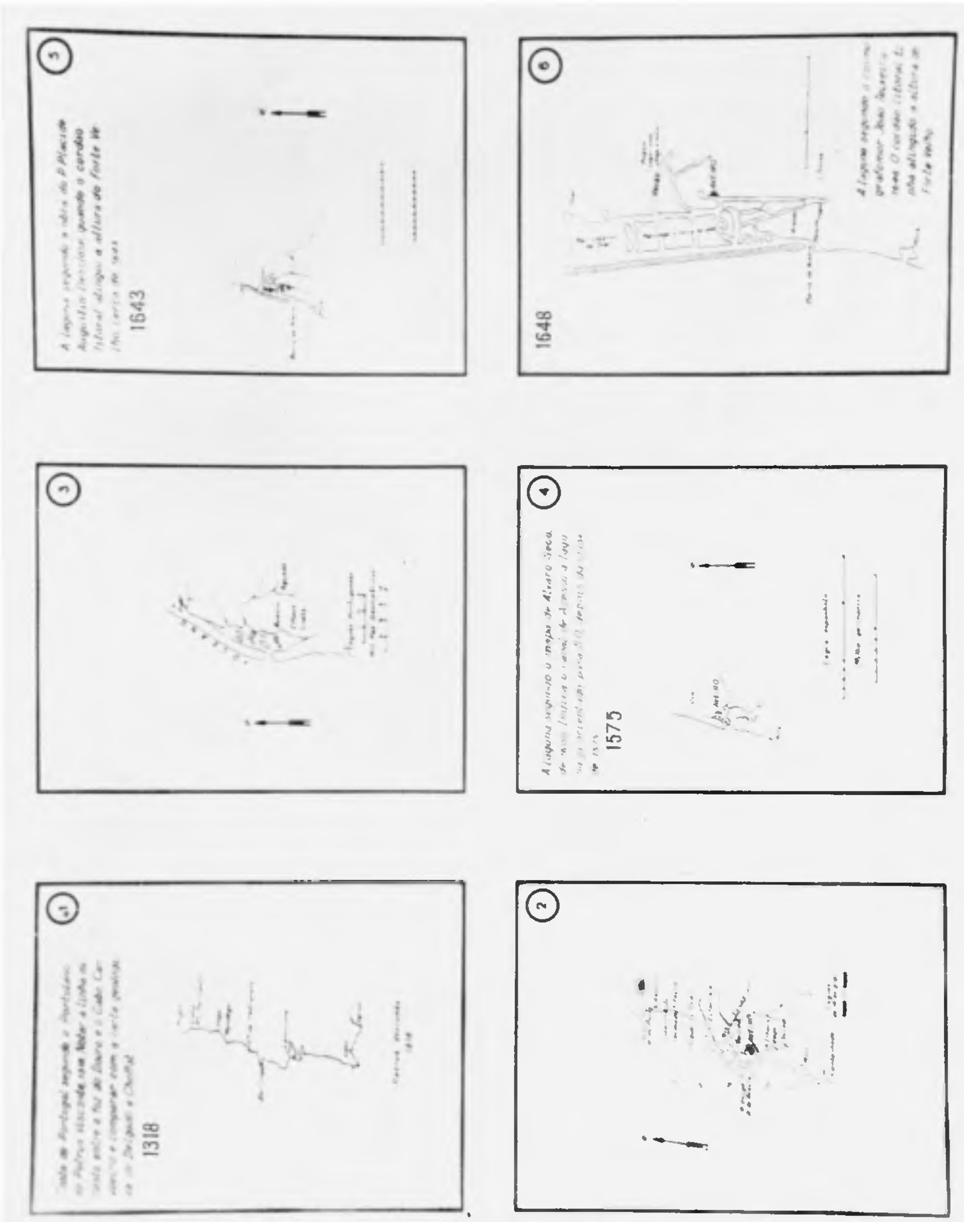


Fig. 2. Charts representing the lagoon up to 1648.

In the XIIth century, the entrance to the recently formed lagoon still was located to the North of Torreira. Three centuries later, the bar reaches the position of São Jacinto, and in the beginning of the XVIth century the situation of present artificial inlet is attained by the migrating sandy point. Preliminary warnings of a deteriorating inlet can be traced in the literature by the third quarter of the century.

This time is the golden age of Aveiro, and the surrounding country. More than 100 commercial ocean ships and 50 caravels for cod fishing in Newfoundland were registered in the port. City's prosperity was at the peak.

The first serious trouble with the inlet happened in winter 1575, when the sandy spit was located to the south of Gafanhas and the channel directed southwestwards: a violent storm caused the bar to be obstructed almost totally. But this first trouble was temporary: three years later, Aveiro still was able to contribute with numerous ships to the Great Fleet of King Sebastião, without disturbing its commercial and fishing activities.

In 1584, the inlet was situated two miles to the south of its present location. By the end of the century it was extremely unstable: three to four times in the year the channel's beacons had to be changed. Notwithstanding, sailing directions in the middle of XVIIth century mentioned Aveiro as a very safe port. In 1643, the inlet was located near Vagueira, and since then situation rapidly grew worse. By 1685, with the bar near "Quinta do Inglês", navigation in the entrance channel was very difficult and no more than 14 ships were coming to the port in a year.

By this time began the attempts to restore the ancient safe channel. The city of Aveiro called for the assistance of two hydraulic engineers from Holland, whose advice was not encouraging: natural inlet should be closed and a new one artificially opened accros the barrier beach near S.Jacinto, the project being hard to undertake, expensive and incertain in its results. The city was disappointed with such an advice, and nothing was done by the time.

In the middle of the XVIII th. century, the inlet reaches the sands of Mira, so completing the formation of the barrier beach and the lagoon, at the end of an evolution that had started about seven hundred years earlier.

During this century, the mean number of ships coming to the port fell to 2.4 per year. It is interesting to remark that, while in many years no ship at all entered the lagoon, in some years a lot of them succeeded to come in: 10 ships in 1761, 36 ships in 1765, for instance. In spite of a systematic tendency to the obstruction of the inlet as it proceeds to the south, some alternatenesses occur, sometimes during consecutive years, in wich the situation improves to the point that people believes the troubles

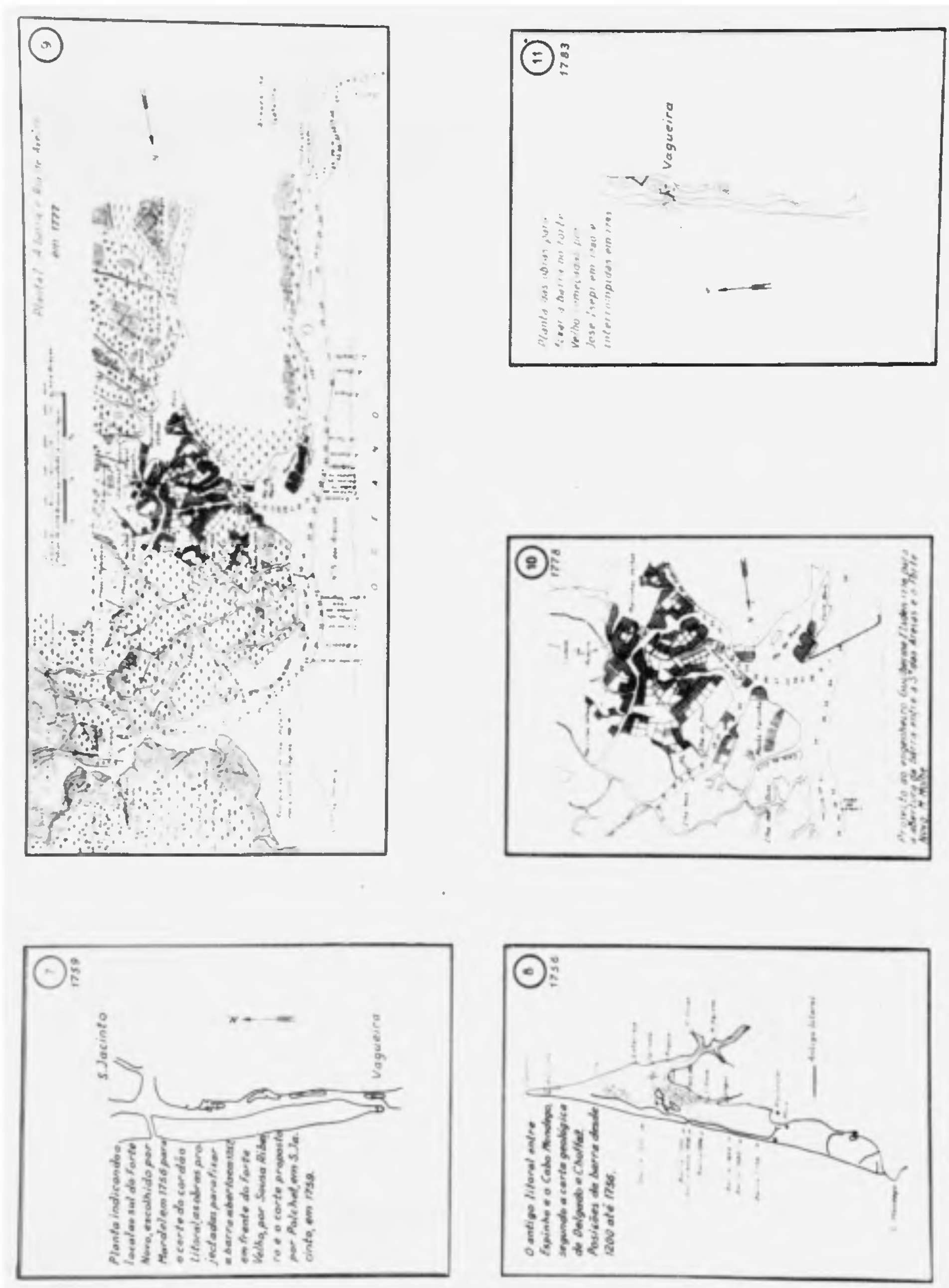


Fig. 3. Charts representing the lagoon from 1759 to 1783.

to be temporary and the port to return by itself to the ancient prosperity.

Even when it became evident that facts would no longer support this opinion, many people sustained that the correct way to restore port entrance conditions should be to improve, by fixing and deepening, the southern natural inlet, according to the location that resulted from the free evolution of littoral processes. This opinion prevailed until the beginning of XIXth century, when Reinaldo Oudinot and Luis Gomes de Carvalho choosed the location of the present artificial inlet. Later on, it still was in the base of the criticism exerted against this project in spite of its successfulness.

Obstruction of the inlet was a tremendous disaster, not only to maritime activities but to the whole life of the neighbouring country: Lagoon and open sea fisheries became impossible, fertilizers provided by lagoon weeds disappeared or deteriorated, the low lands were no longer drained, salt-making ceased, naval yards stopped, and above all, due to loss of drainage, the lagoon became an immense swamp and the sanitary condition of the country very poor (the city of Aveiro had no more than 5300 inhabitants in 1736, 4400 in 1767, 3500 in 1797, when the number of deaths became double of that of births).

RESTORATION OF THE INLET

It is of interest to mention some attempts made to restore the inlet since the middle of XVIIIth century, when events became very serious. In 1756 the engineer in charge tried to re-open the closed inlet without getting any success. In the following year, captain Sousa Ribeiro took the same way and, with the help of a big flood, succeeded to widen and deepen an occasional channel, opened by a storm near Vagueira, and the enlarged channel maintained itself for eight years, but, after the unsuccessful efforts to fix the new inlet in its position, it began again to proceed southwards, reaching in 1771 the Mira sands (where the old natural bar had entirely closed in 1757). In 1777, British engineer Elsden was charged of the project and its execution: he tried, unsuccessfully, to restore the inlet in the position it now occupies. In 1780, Italian master of Hydraulics Iseppi was contracted to solve the problem: he tried unsuccessfully, during three years, to open and fix an inlet near Vagueira. In 1787, the inlet opened by Sousa Ribeiro totally closed, and it was ordered to field-marshall Luis Valleré to elaborate a project for restoring the channel, wich he did'nt succeed to. In 1791, E.Cabral, master of Hydraulies, was charged to open and fix, at least, a small outlet able to assure the drainage, so urgently needed: but the littoral sands did'nt allow even this apparently modest requirement.

Finally, in 1801, engineers R.Oudinot and Luis G. de Carvalho were charged with the project and works to restore and fix the inlet. In the same year this remarkable project was presented and approved, the works starting in the following months, placed under the exclusive direction of Carvalho since 1803.

According to the project, the artificial inlet should be located as close as possible to the center of masses of the lagoon waters, so that, on the whole lagoon the circulation of tides and drainage of fresh waters should occur in the best hydraulic conditions. Past history of the inlet confirmed that this would be the only reasonable way to succeed in fixing it, it was stated.

Cutting the barrier beach and opening the new inlet was obtained by means of a long and strong dike, wich, firmly rooted in the vicinity of Gafanha, ran accross the lagoon to the barrier beach, compelling the waters of the northern and most important body of the lagoon and the river flood to flow against and to pierce the littoral barrier, at the same time leading to the inactivity and closure of any natural inlet located to the south (see fig. 4).

Construction of the dike was extremely hard, especially the last streches, totally separating the northern and southern bodies of the lagoon. Care had to be taken against a sudden and incomplete cutting of the barrier beach. Works proceeded accross all kind of troubles, including the French invasions, untill the 3 rd.April 1808,at 7 p.m.. In this historical moment, when a big flood raised the water level inside the lagoon about seven feet above the outside level, Luis Gomes de Carvalho ordered the demolition of the temporary fascine works that protected the beach in the location choosed for the new inlet and, with the point of his boot, opened the trail through wich the accumulated water rushed down to the sea, for ever restoring the lagoon's inlet. Drainage problems were definitively solved and first step given to restore navigation.

For the first time, human intervention overcame natural agents in modelling the inlet. Indeed, Carvalho's works gave satisfaction to all requirements for about one century, as long as maintenance cares were provided and with the only exception of some very anomalous meteorological situations.

BEHAVIOUR OF THE RESTORED INLET

It is of interest to consider the behaviour of the lagoon and its restored inlet during the 120 years elapsed till the following improvement works.

During about 25 years maintenance cares were reasonably provided and inlet's condition very satisfactory (for instance, statistics give 186 sea-going ships entered in the port in 1835). Maintenance was subsequently neglected, so that ten years later the jetty was seriously damaged. (figs 5 and 6).

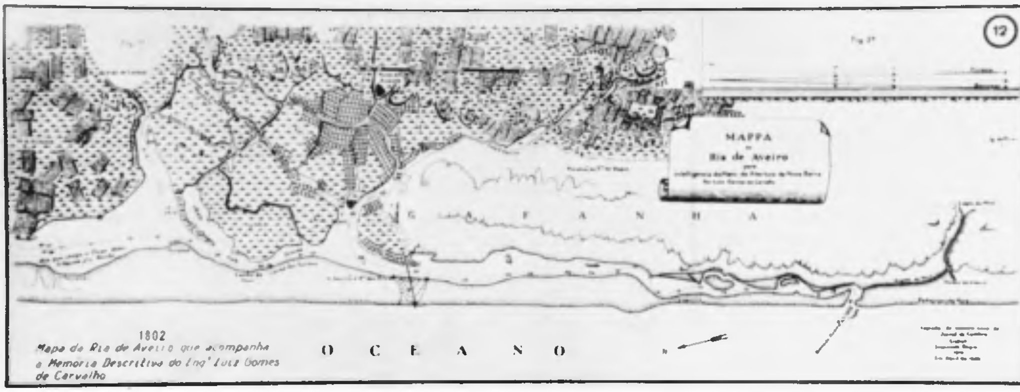


Fig. 4. Project of Luiz Gomes de Carvalho for opening the artificial inlet.

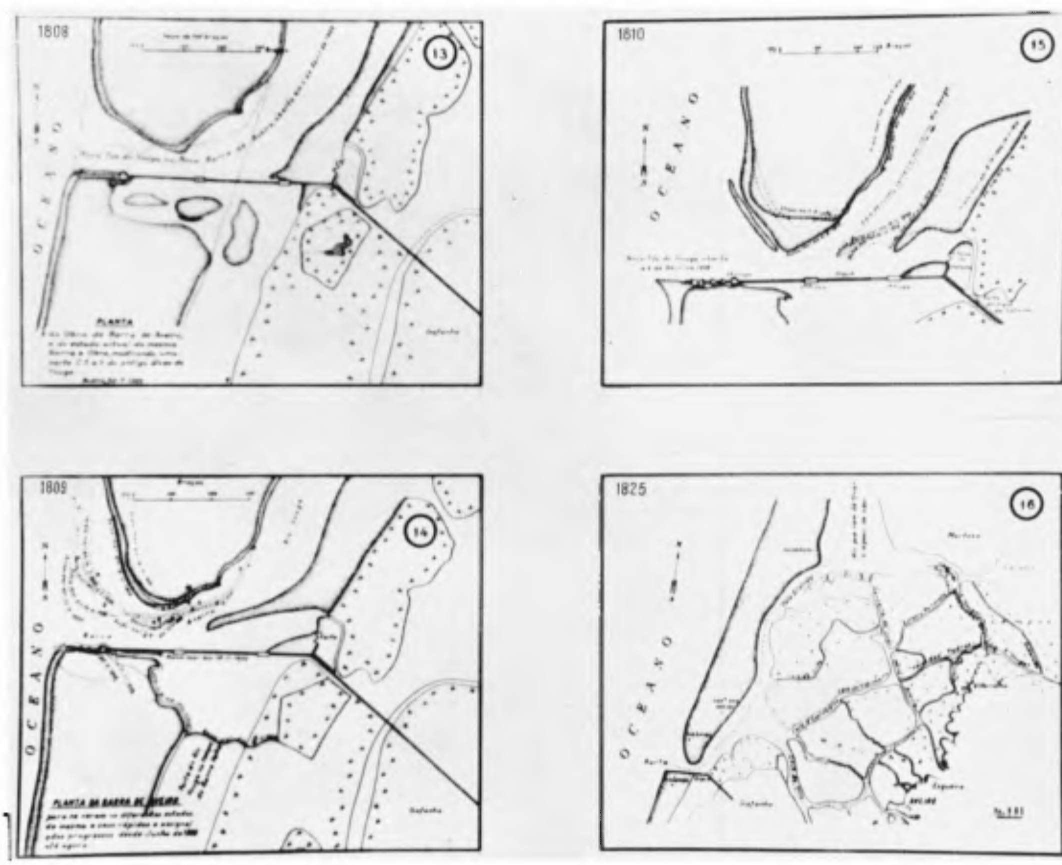


Fig. 5. Behavior of the artificial inlet up to 1825.

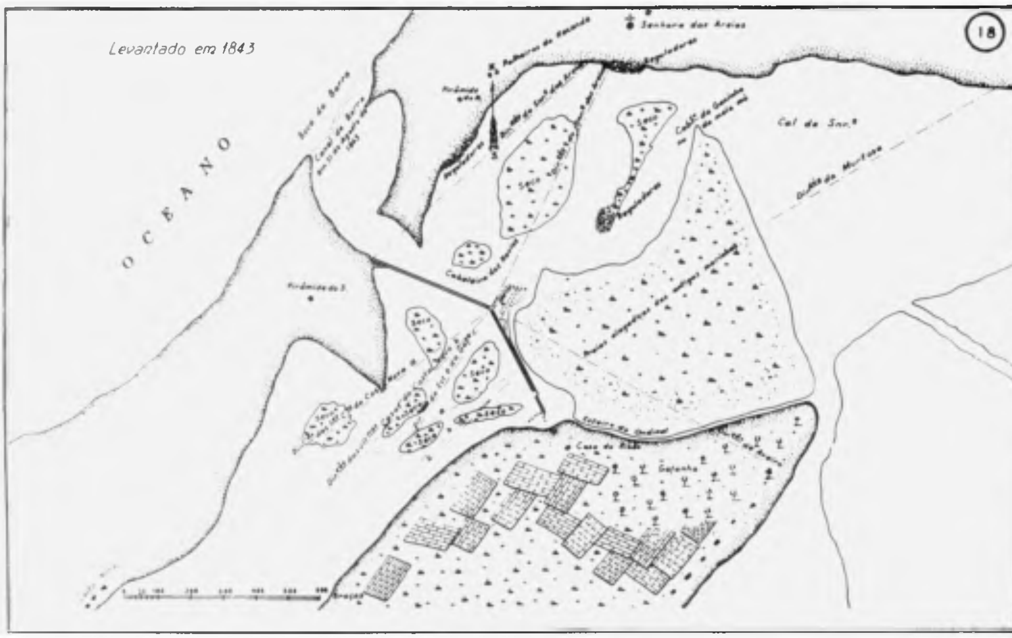


Fig. 6. Configuration of the inlet in 1843.

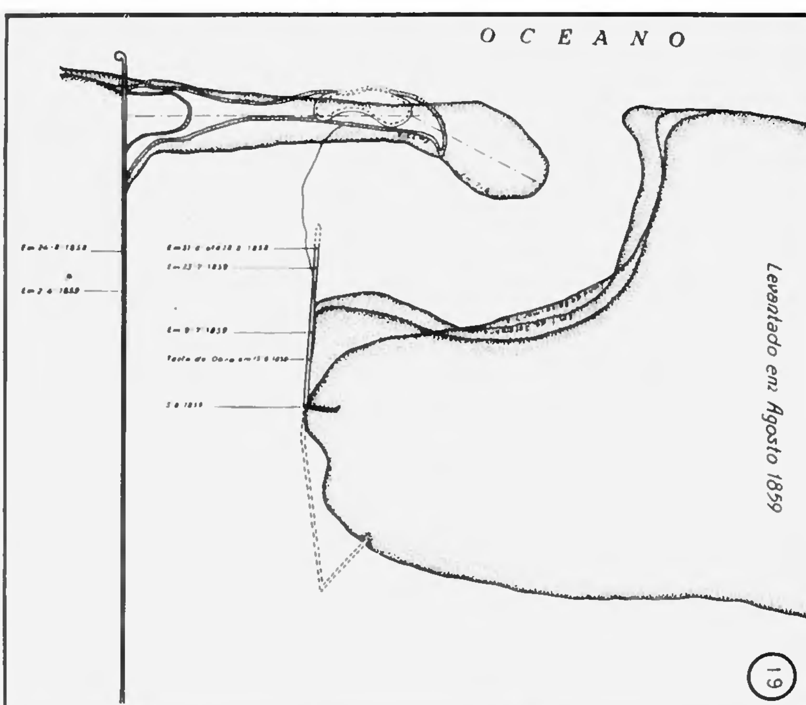


Fig. 7. The inlet's anomalous configuration of 1859.

In 1838, a big flood destroyed the dike near Gafanha and re-opened the ancient inlet in Vagueira. From 1847 to 1856, Carvalho's dike and jetty were rebuild and at the same time the entrance channel progressively returned to the convenient direction and depths.

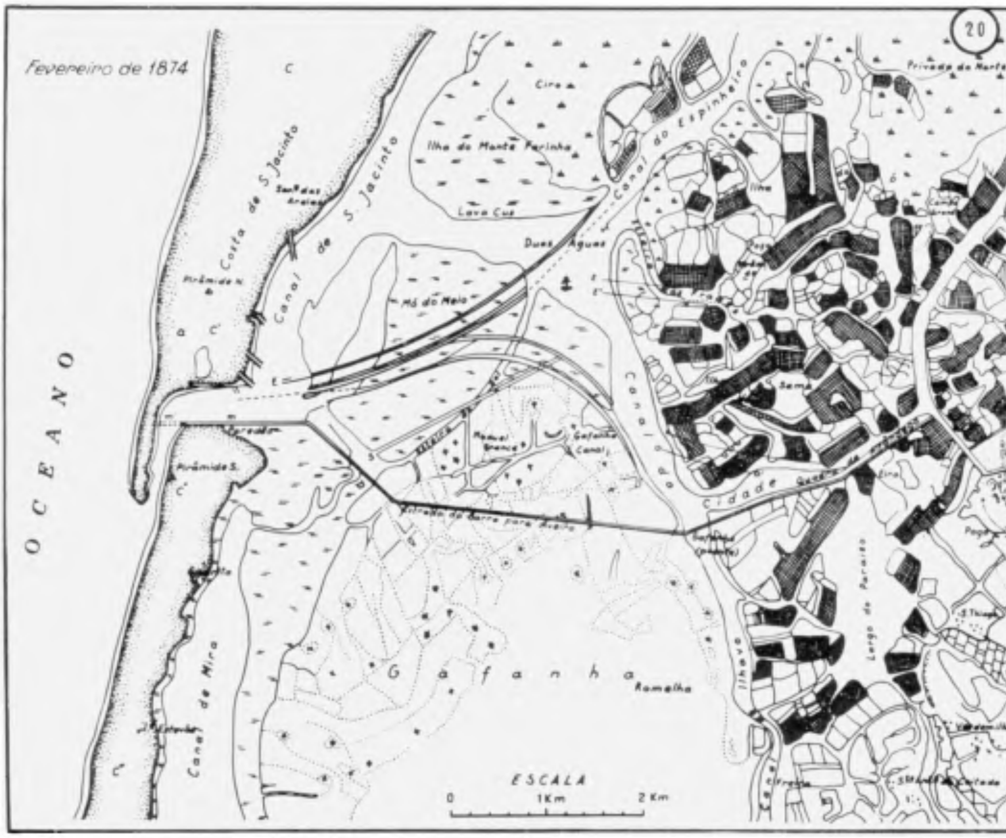
In 1859, Silvério Pereira da Silva, director-engineer of the port, proposed to continue Carvalho's jetty to the low-water line in the beach and to build a new experimental jetty on the northern side of the inlet's channel. By this time, the inlet presented one of its very anomalous configurations, running northwards for about 3.000 feet, parallel to the coast-line, then turning to west and southwest in its outer extremity. Silvério's project as mentioned above restored in a few months the convenient westward channel (fig. 7).

Another important measure taken by Silvério was the full reintegration of the southern body in the lagoonar unity, wich he succeeded by promoting the closure of the Vagueira inlet in 1863 and subsequently restoring a free and large communication between the southern and northern bodies, achieved in 1877. Automatic closure of the southern inlet was ingeniously obtained by allowing the flood tide to be admitted through it and raising difficulties to the circulation of the ebb tide, by means of a number of sluices provided in Carvalho's trans-lagoonar dam near Forte da Barra.

In 1873-1874, an anomalous inlet configuration was again registered, after a very long dry season. This time (see fig. 8), a strong sandy spit, 400 feet wide, emerging in high water, advanced from the north to 1.000 feet south of the Carvalho's jetty, parallel to the coast-line and at a distance of about 1.100 feet opposite to the inlet's mouth. Silvério faced the situation by continuing the jetty towards the sandy spit, wich was then cut by the first big flood.

Silvério's project for lagoon and inlet's general improvement is worth to mention for the large scale of the works contemplated (see fig. 9). During 10 years it was carried out by the author, but it still was very far from completion when resources exhausted and Silvério retired in 1886. Notwithstanding, this project remained the basis of all improvement conceptions untill 1927.

In 1908-1909, in similar meteorological conditions, an inlet's configuration similar to the one of 1873-1874 occured. According to a committee of engineers appointed to report on the problem in 1909, documents existing in the archives of the port showed that different configurations and extents of sandy spits advancing southwards, and also northwards, opposite to the inlet's mouth, occured from time to time since the restoring of the inlet in 1808.



Fjg. 8. The inlet's anomalous configuration of 1874.

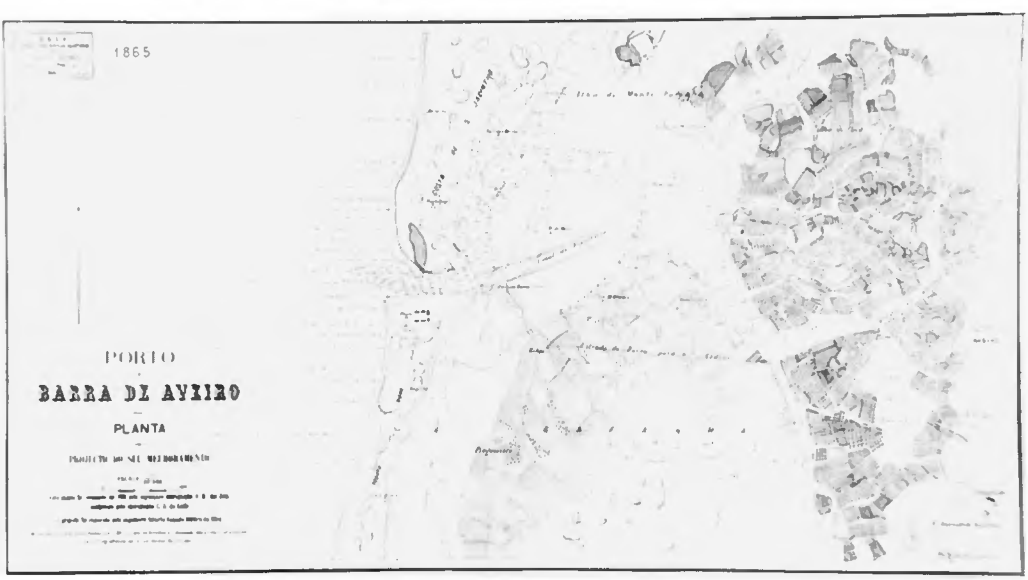


Fig. 9. General Silverio's project for the improvement of the lagoon and its inlet.

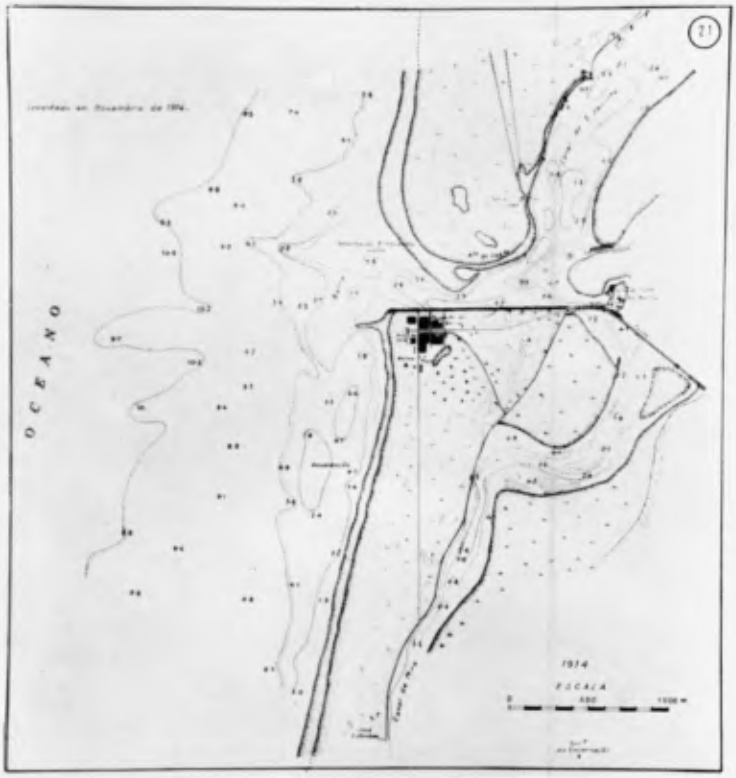


Fig. 10. Configuration of the inlet in 1914.

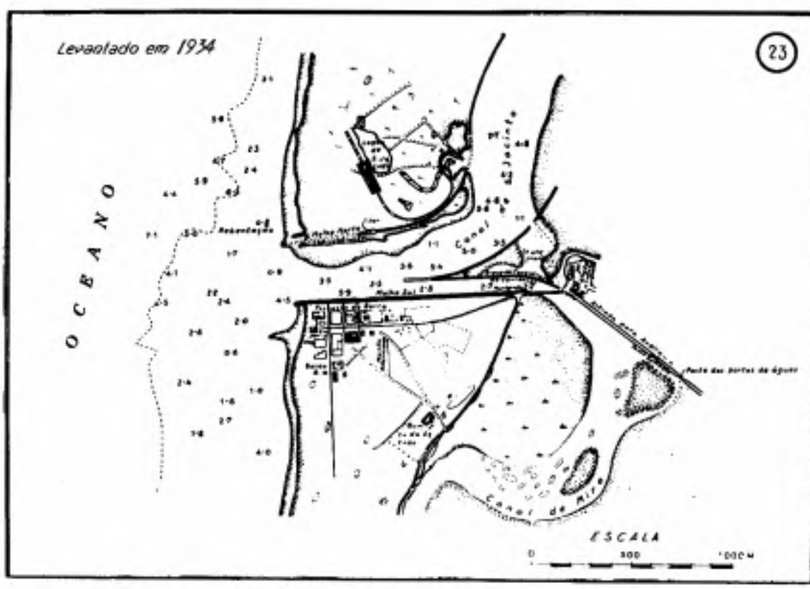


Fig. 11. Configuration of the inlet in 1934.

THE CANALIZATION OF THE INLET

The 1808 inlet channel became unable to meet ever -increasing navigation requirements since the middle of the XIX th. century. Thence, projects have been prepared for further improvement works, all of them being based on Silvério's 1874 plan until 1927.

In April 1927, director-engineer of the port, João von Hafe, presented his project, based on an entirely new conception. Currents from the northern and southern bodies of the lagoon should be harmonized by a triangular system of dikes in the upstream section of the inlet channel, this one should be totally canalized through the barrier beach and the northern jetty would go out on the sea for about 1 000 feet, a substantial dredging should be made in the inlet channel. The author would prefer to build two outer jetties, brought to depths of 30 feet under datum, but for the moment resources were not available and depths of only 10 feet would be enough for the needs contemplated.

In 1930, a committee of British consulting engineers from "Sir Alexander Gibb & Partners" reported on the problem. They gave the preference to von Hafe's conception but they thought fitt to introduce some modifications in his project, namely by reducing by 800 feet the length of the northern jetty, by widening the inlet channel from 1 000 to 1 150 feet and modifying the interrelation between the widths of the entrance channels to the northern and southern bodies of the lagoon, as well as by dredging an outer navigation channel 660 feet wide and 1 650 feet long out in the sea.

The Council for Public Works accepted the advice of the British committee, but von Hafe protested against the modifications brought to his project, and especially against the suppression of the outer northern jetty, he thought to be of fundamental importance to the successfulness of the project, as long as a clear inlet channel was to be obtained. But the committee's ideas prevailed, unhappily, as future will show.

Works started in 1932 according to von Hafe's modified project and were concluded in 1936. They consisted in a jetty limiting the northern bank of the inlet channel, continued northeastwards by an interior dike, and in a triangular system of dikes for concording the currents from southern and northern bodies of the lagoon (see fig. 11), as well as in a substantial dredging in the channel for providing the filling between the dikes.

Surveys made in 1934-35 and in 1949 (see figs. 11 and 12) show the results obtained. The entrance channel was sensibly improved, the outer bar was repelled seawards by 1 000 feet, emerging sandy spits opposite the inlet never reappeared, controlling depth on the outer bar increased from 14 to 16 or 17 feet in mean high-water, tidal range at the entrance of the lagoon increased from 7 to 9 feet in spring tides. But some serious deficiencies were revealed, namely, the instability and subdivision of the outer channel and the strong transverse currents wich occured in it under wave action; moreover, littoral sands entered the inlet channel in big amounts, forming a beach against the inner face of the northern jetty and so narrowing the channel, as foreseen by von Hafe when he sustained the integrity of his project, especially of the northern jetty's length. This was very harmful, not only to the admission of tides into the lagoon, but also to navigation, due to the strong currents in the narrow section of the channel, that prevented ships to cross it at the time required to be on the outer bar at local high water time.

Then, the new channel soon became unfit for the increasing navigation, and a new project had to be studied.

THE FIXING AND DEEPENING OF THE OUTER CHANNEL

The new project for the improvement of the entrance channel to the port of Aveiro was presented in 1937. It consists in the lengthening of the northern breakwater for 2300 feet an in the building of a new southern breakwater, 2600 feet long, taking root 1300 feet to the south of the old Carvalho's jetty and slightly convergent with the former (see fig. 12).

Purposes of the project were: a controlling depth of 24 feet in mean high-water over the outer bar (i.e., situating the bar's crest at - 4.00 m, under datum); a straight entrance channel, running west-east, free from crosscurrents; and an inlet practicable without restrictions other than depths available, wich necessitated the removal of the sandy beach from inside the inlet channel.

It was thought that the designed works, causing the removal of the canal's beach, would improve navigation through it and increase the tidal flow admitted to the lagoon. They would protect the inlet from invasion by sands in the shallow zone and direct the canal to WSW, wich is supposed to be the direction of the coastal ebb current. The outer bar would be formed in greater depths, thence more exposed to the littoral currents. The entrance channel would be protected, accross the shallow zone, from cross waves currents, highly dangerous to navigation and harmful to the maintenance of depths.

Works started effectively in 1949 and still are on way. Results are shown by the numerous surveys made since then, from wich we reproduce some ones (figs.13 to 21). As can be seen, the beach inside the inlet's

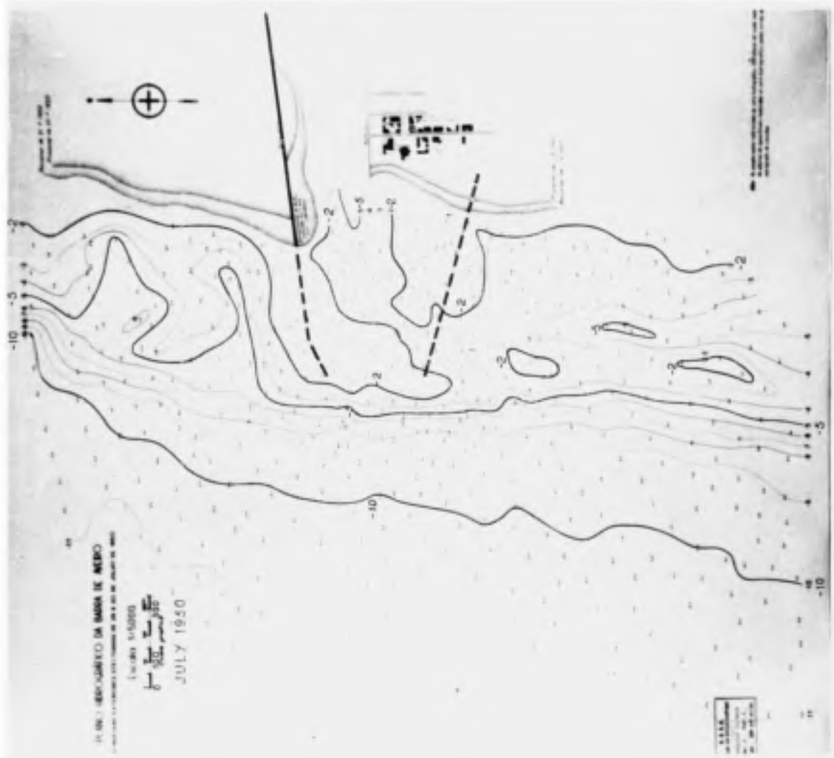


Fig. 13. Hydrographic survey of the inlet in July 1950.

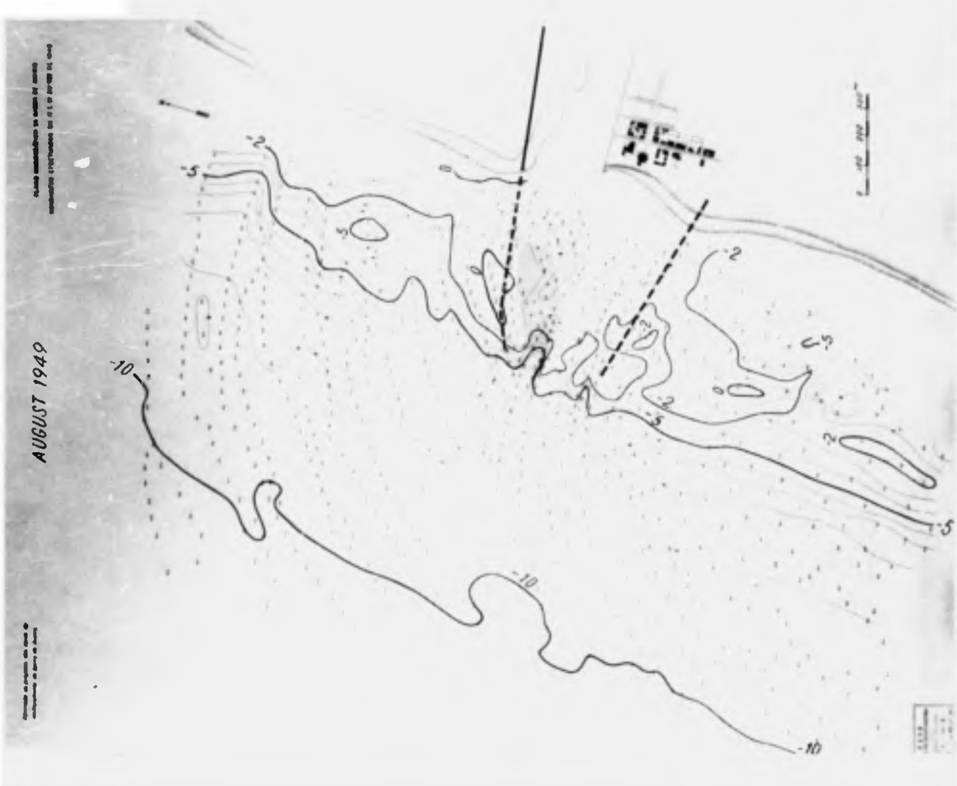


Fig. 12. Hydrographic survey of the inlet in August 1949.

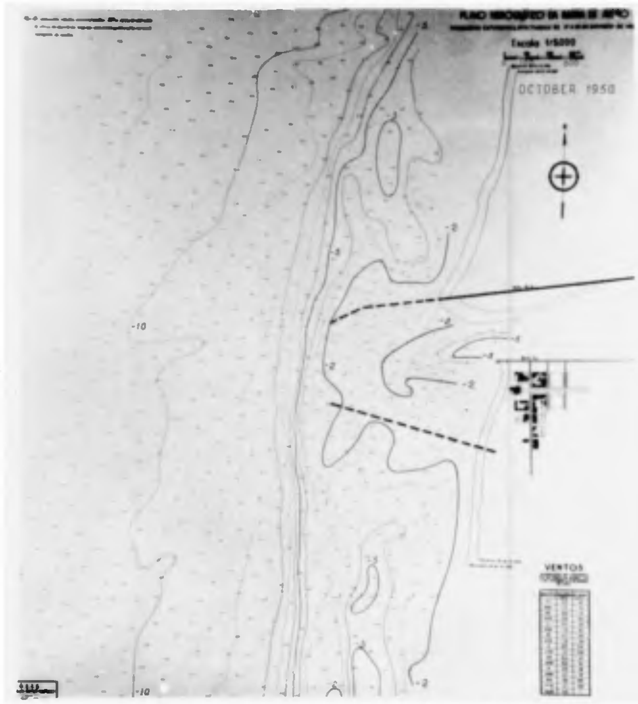


Fig. 14. Hydrographic survey of the inlet in October 1950.

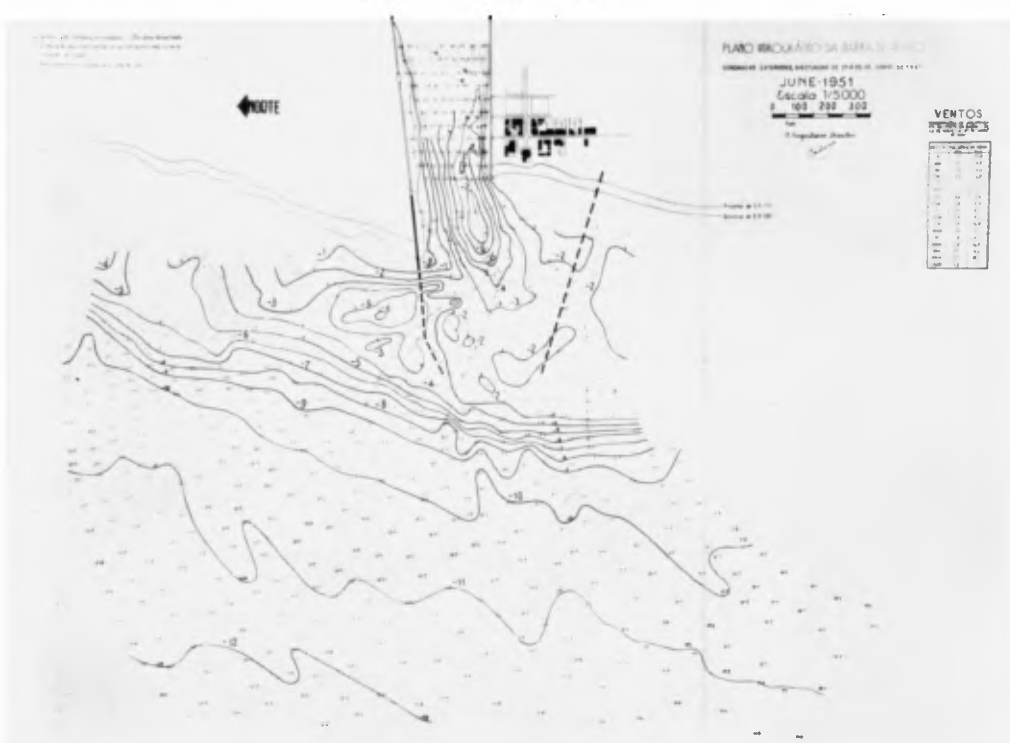


Fig. 15. Hydrographic survey of the inlet in June 1951.

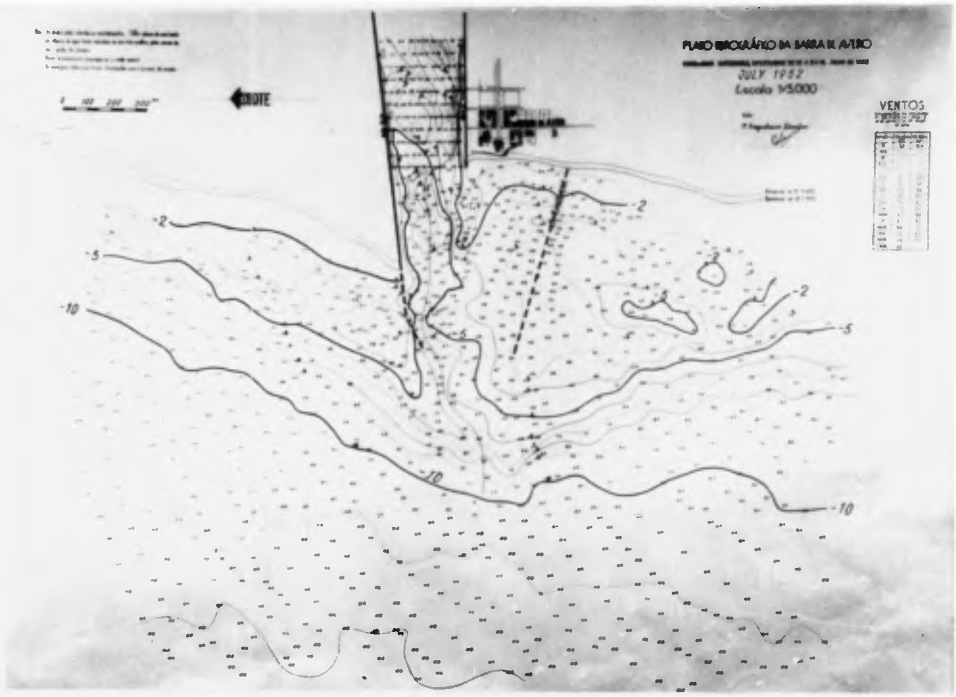


Fig. 16. Hydrographic survey of the inlet in July 1952.

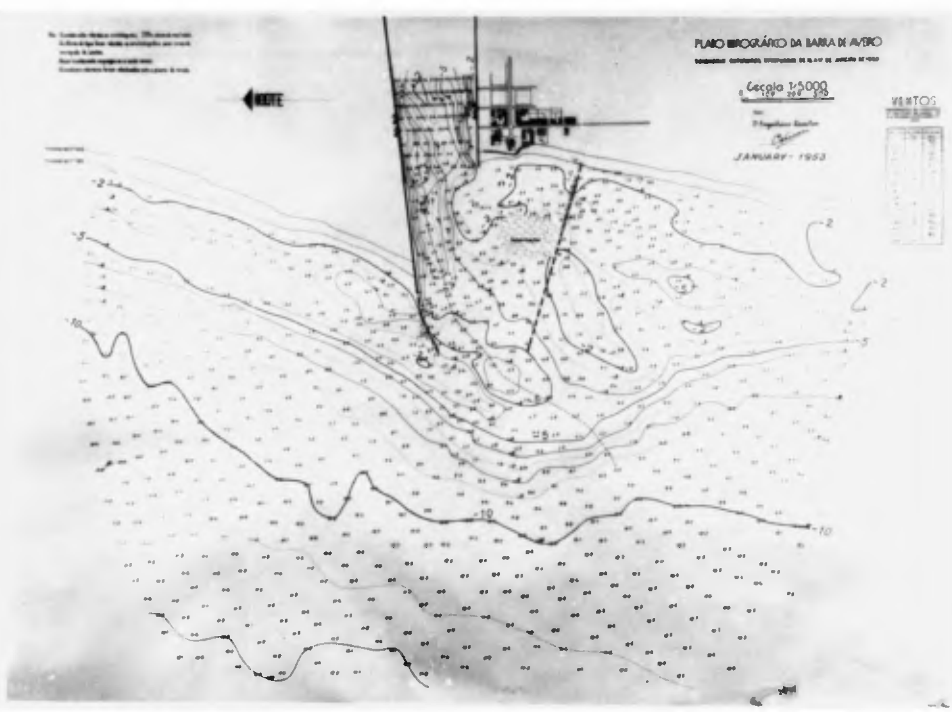


Fig. 17. Hydrographic survey of the inlet in January 1953.

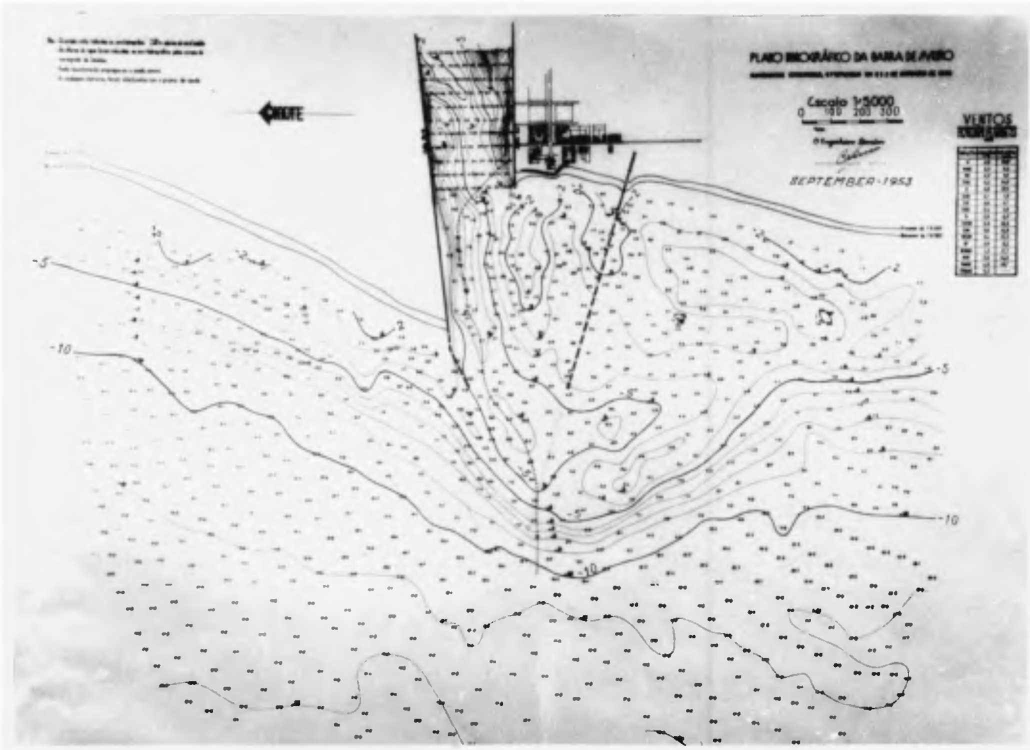


Fig. 18. Hydrographic survey of the inlet in September 1953.

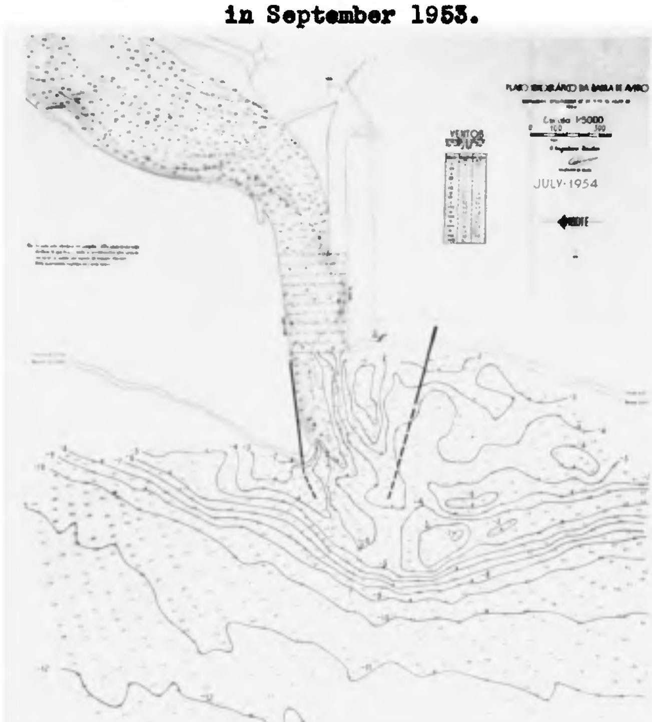


Fig. 19. Hydrographic survey of the inlet, July 1954.

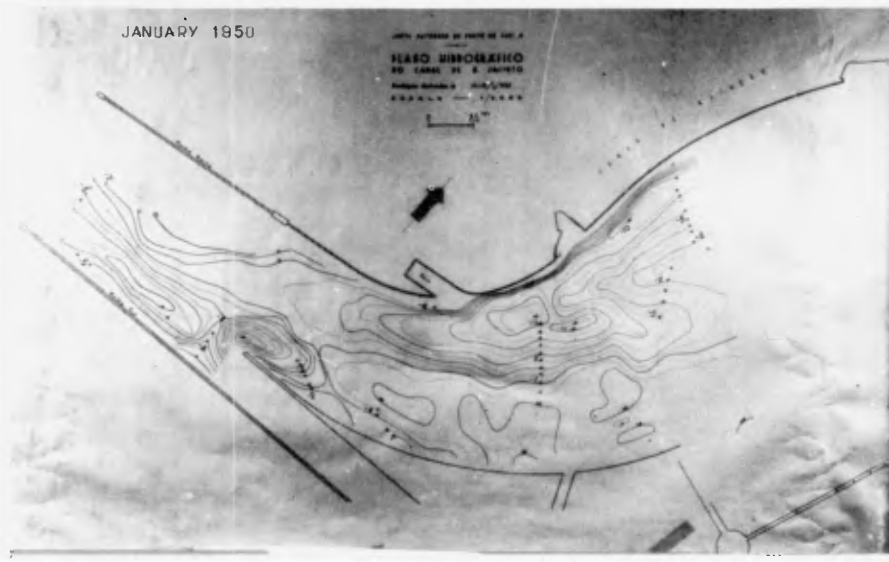


Fig. 20. Hydrographic survey of the inner channel in January 1950.

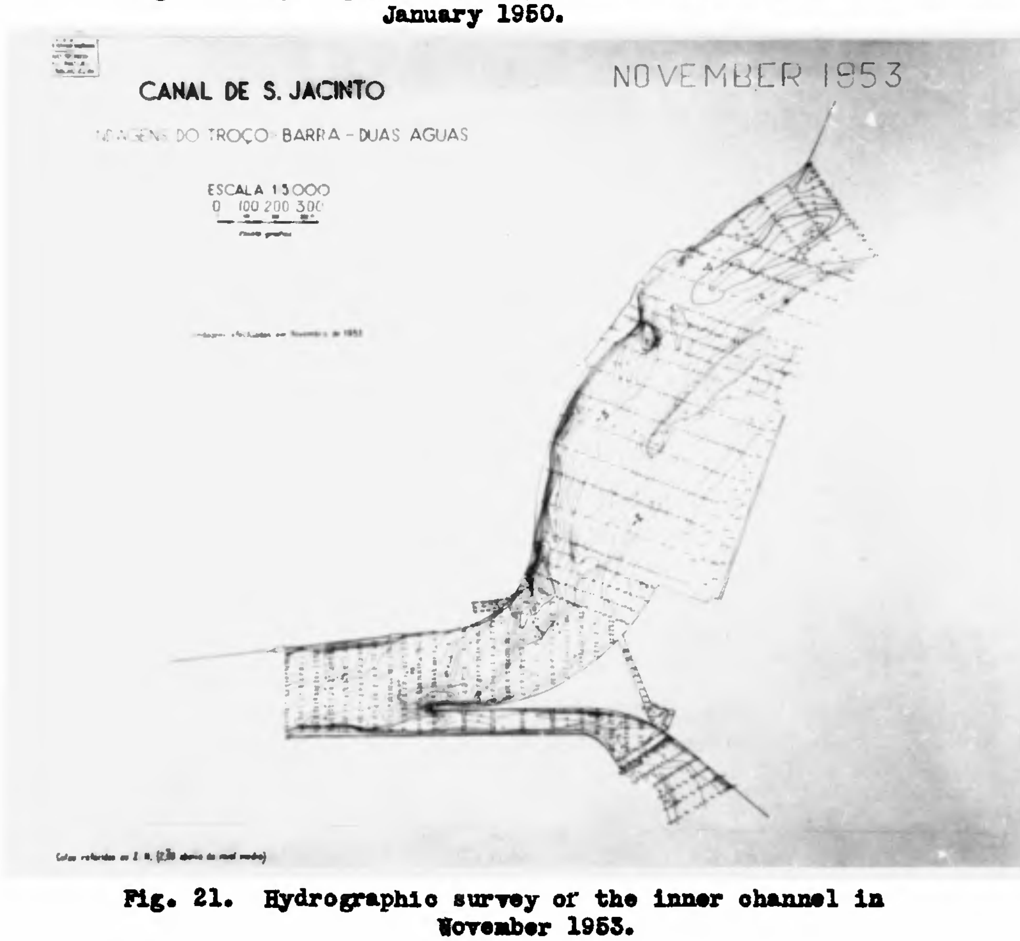


Fig. 21. Hydrographic survey of the inner channel in November 1953.

canal disappeared, greatly improving the situation, when the northern break water reached the length sustained by von Hafe. Depths on the outer bar are beyond those foreseen in the project, having increased as it was being repelled seawards.

FEATURES OF LOCAL PHYSIOGRAPHY

From the described evolution of the inlet and the measured results of the works undertaken it is possible to derive the broad lines of the local physiography, concerning the behaviour of the coastal beach, the inlet and the lagoon.

In fact, the collected data show:

i. that the littoral drift is alternative in direction, according to the meteorological season, but the southward drift clearly predominates in normal years;

ii. in those years, the mean southwards balance of the foreshore littoral drift scarcely reaches 200.000 m3 annualy;

iii. in anomalous meteorological epochs, massive accumulations of sands in the beaches and sea bottom adjacent to the inlet can occur, with results that went from total obstruction before the fixing of the inlet, to the formation of strong emerging sand-spits opposite the inlet when this was simply fixed, and to the raising and widening of the outer bar after it has been canalized: so has been the case in 1839, 1859, 1874, 1909, 1949-1950;

iv. anomaly consists in the long-lasting prevalence of a given meteorological feature, wich strongly influences the bottom topography;

v. the modelling action of the lagoon's ebb current on the outer bottom can be permanently traced only after the canalization of the inlet;

vi. the greater the importance of the inlet, the bigger the volume of sand in the outer bar, canalization effect under this point of view being evaluated in half a million cubic meters;

vii. changings in the volume of the accumulated sand due to meteorological variations by far exceed this effect, the measured accumulation in 1949-1950 having attained three to four million cubic meters;

viii. reinforcement of the inlet action always causes the ou ter bar to be reppelled seawards and consequently deepened, in spite of the increased volume of sand in the bar platform (fig. 22);

ix. the flow through the inlet is hydraulic, that is, due to the difference of head between the ocean and lagoon water, wich acoounts for the steep slope of the surface profile along the inlet canal,required for carrying a substantial amount of water in and out the lagoon in accordance with hydraulic laws; this is clearly shown by the instantaneous profiles and other characteristics of the tidal flow through the inlet canal (see figs. 23 and 24);

x. inside the lagoon, through its different channels and bodies, tidal flow may be either hydraulic or governed by tidal wave propagation, according to the geometrical characteristics of the channels and the bodies of water they connect

RESULTS OF THE WORKS UNDERTAKEN

Detailed analysis of the results of the performed works will add some knowledge to the foregoing remarks and help to infer some rules valid in the treatment of inlets' problems.

Variation in the volume of sands in the platform of the outer bar, from 1650 feet north of the northern breakwater to the parallel of the southern breakwater's root, is shown in Table 1. When considering the figures therein, it is necessary to retain, besides the date of the different works, the meteorological characteristics of the surveyed years. Meteorological records show that year 1865 is situated in a very rainy period, hence in a period of southwest winds; year 1914 has been normal; in 1934 southwest winds were exceptionally prevailing; in the period 1943 to 1947 an exceptional drought was registered, with a strong predominance of northern winds, slightly attenuated in the following year.

Superposition of the longitudinal profiles of the entrance channel accross the outer bar, projected on a vertical plane parallel to the southern jetty (the jetty of Gomes de Carvalho), is particularly instructive. In fact, it reveals some permanent effects of the works carried out, such as the displacement of the outer bar seawards with the reinforcement of the lagoon's ebb current, no matter the volume of the sand deposit (see fig. 25). At the same time the bar platform is widened and the bar crest is deepened, even when comparing situations like that of 1865 (extreme erosion) with that of August 1949 (extreme deposition, with an accretion of about 4.000.000 cubic meters of sand on the bar).

The same fact can be seen in a curve in wich abscissae re-

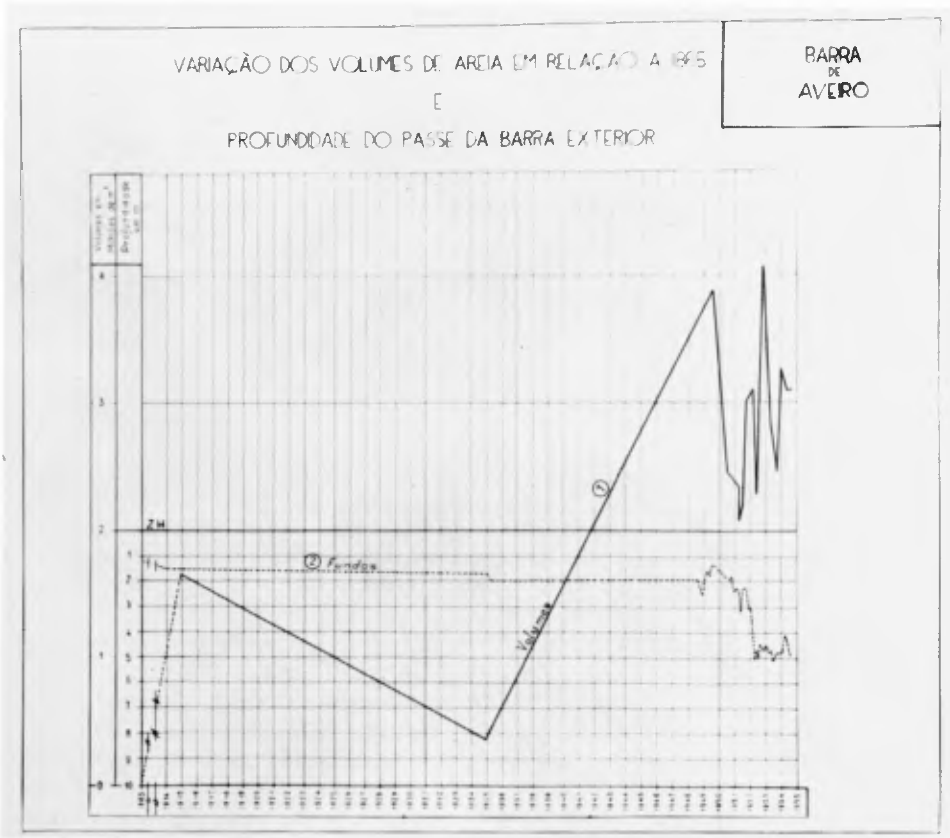


Fig. 22. Variation in the volume of the sand deposits over the outer bar (curve 1) and in the controlling depths over the same (curve 2), from 1865 to 1954.

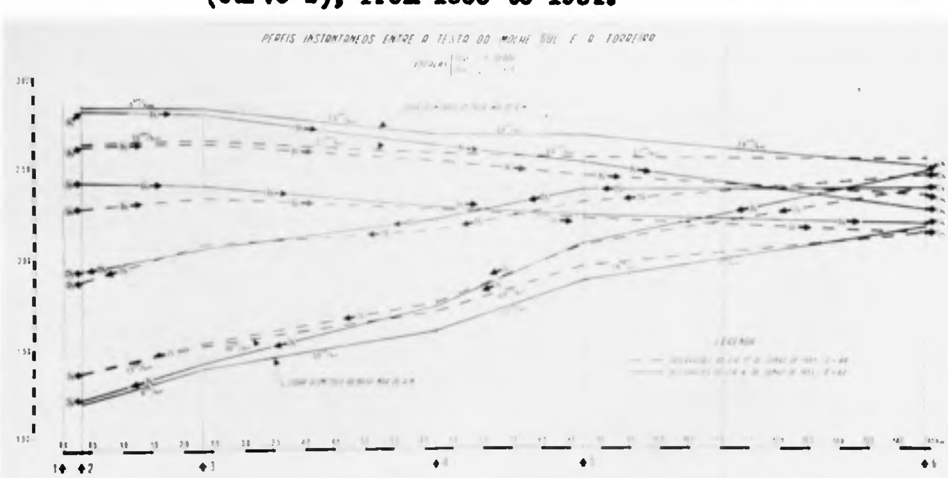


Fig. 23. Tidal profiles along the inlet and northern main channels of the lagoon (in neap-tides).

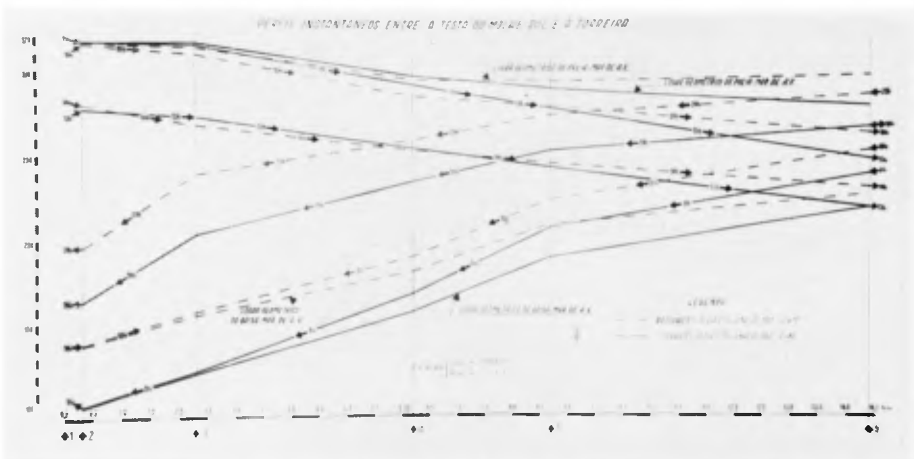


Fig. 24. Tidal profiles along the inlet and northern main channels of the lagoon (in spring-tides).

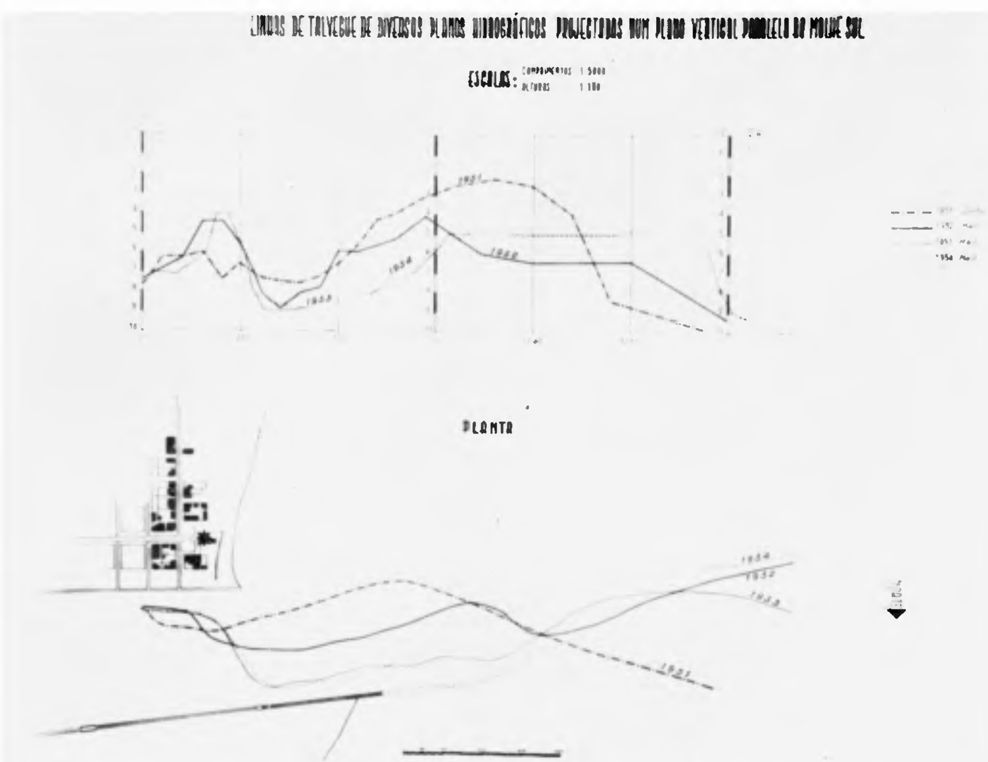


Fig. 25. Projection, on a vertical plan parallel to Carvalho's jetty, of the profiles along the talweg of the entrance channel.

Table 1

CHANGES IN THE VOLUME OF SAND ON THE OUTER BAR OF AVEIRO

Date of surveys		Changes with reference to 1865 (c.m.)	Changes with reference to the preceding survey (c.m.)	
Month	Year		Deposition	Erosion
	1865	—	—	—
XI	1914	1.661.800	1.661.800	—
I	1935	378.000	—	1.283.800
VIII	1949	3.892.700	3.514.700	—
VII	1950	2.457.400	—	1.435.300
III	1951	2.349.200	—	108.200
IV	1951	2.083.100	—	206.100
VI	1951	2.115.200	32.100	—
IX	1951	2.979.730	2.979.730	—
III	1952	3.104.350	124.620	—
V	1952	2.292.650	—	811.700
VIII	1952	3.180.850	888.200	—
XI	1952	4.089.320	908.470	—
I	1953	3.516.790	—	572.530
V	1953	2.813.250	—	703.540
IX	1953	2.463.100	—	350.150
I	1954	3.258.530	795.430	—
IV	1954	3.107.170	—	151.360

present the outer bar crest's distance to a base-line accross the inlet canal and the ordinates represent the envelop to its depths under datum. If this curve can be accepted — as it seems up to now —, it will be possible to predict the minimum depth to be expected in a given position of the outer bar crest (see fig. 26).

The characteristics of the tide in different points of the lagoon were also affected by the inlet's improvement, as shown in Table 2.

The reaction of the inlet channel to the works performed is shown in Table 3 and Table 4. The very remarkable improvement in the hydraulic characteristics of the inlet channel, especially as a result of the project now being executed, is of vital importance to the maintenance of depths in the whole inlet, including the inner and outer bars, as this measures its ability as regards the admission of tide.(figs.27 to 30).

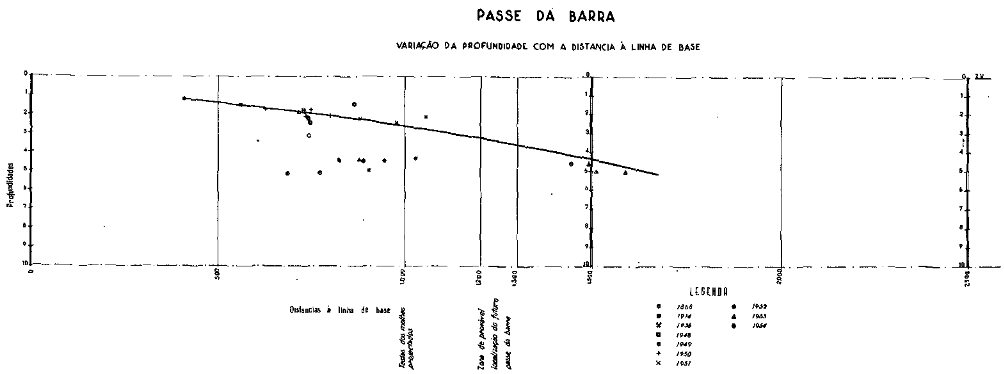


Fig. 26. Controlling depths on the outer bar (ordinates) as a function of its distance to a base-line (abscissae). Envelope-curve of the minimum depths corresponding to each position of the bar-crest.

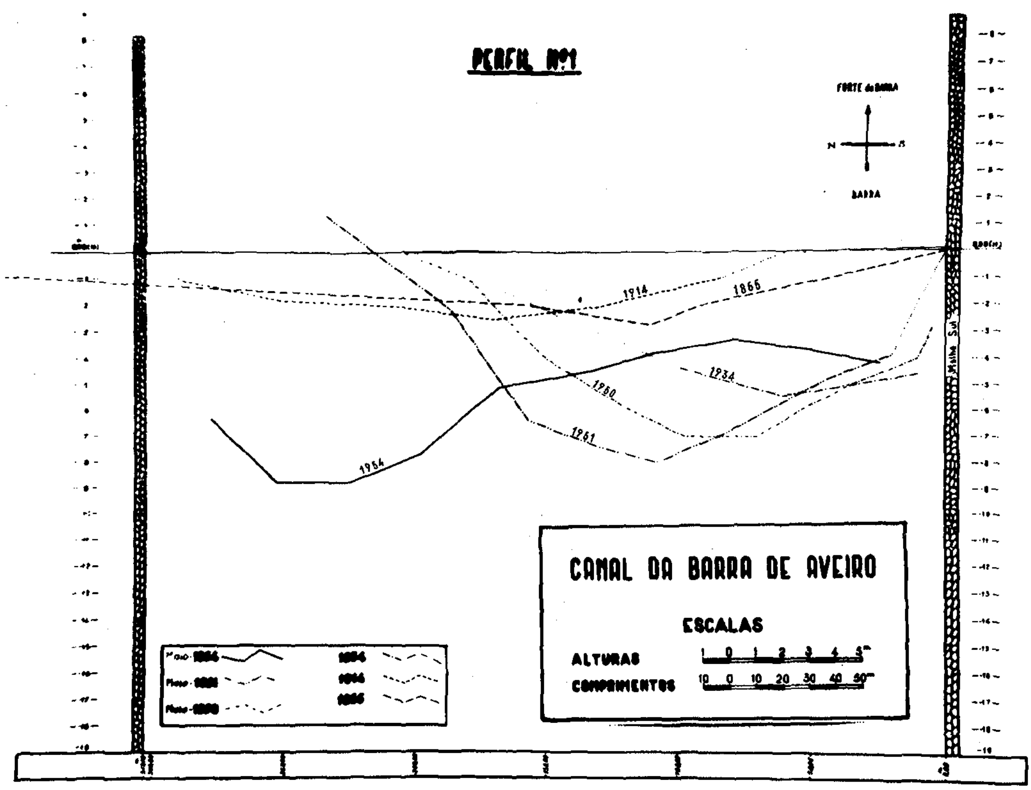


Fig. 27. Evolution of the inlet's channel cross-sections due to the works (range No. 1.).

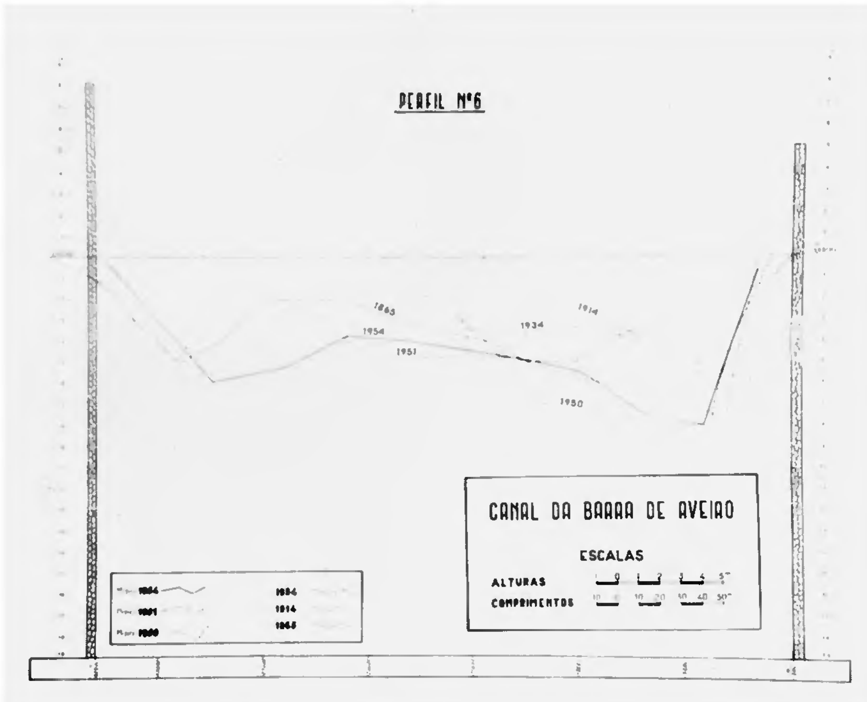


Fig. 28. Evolution of the inlet's channel cross-sections due to the works (range No. 6).

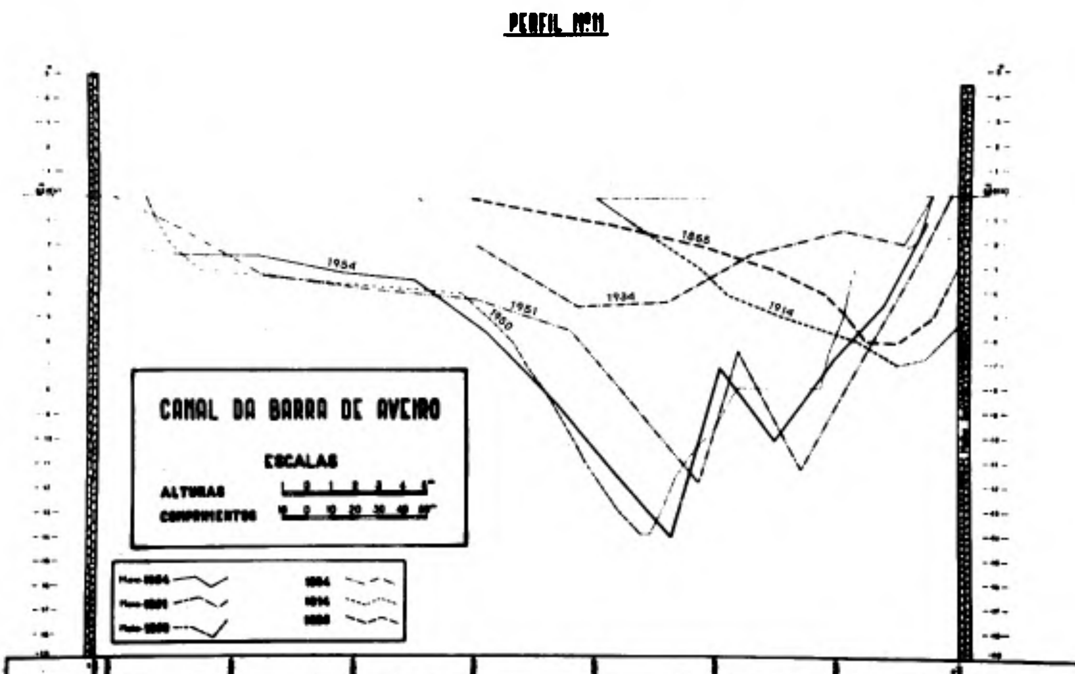


Fig. 29. Evolution of the inlet's channel cross-sections due to the works (range No. 11).

Table 2

NON HARMONYC TIDAL CONSTANTS IN THE LAGOON

STATIONS	TIDE GAUGE					
	Nº.2		Nº.1		S.Jacinto	
DATES	U m	Ep h min	U m	Ep h min	U m	Ep h min
September-1934	—	—	—	—	0,54	III 09
August-1942	—	—	1,23	II 33	—	—
August-1949	—	—	1,19	II 36	0,98	II 51
August-1950	—	—	1,16	II 35	1,07	II 59
September-1950	—	—	—	—	—	—
April-1951	1,25	II 22	—	—	1,05	II 41
June-1951	—	—	—	—	1,06	II 47
September-1951	—	—	—	—	1,16	II 46
September-1952	1,34	II 22	—	—	1,16	II 38
September-1953	1,34	II 23	—	—	1,14	II 49

As far as the tidal prism admitted to the lagoon is concerned, calculations by Earl Brown or Marzolo's method show that before 1932 it amounted to 50.000.000 c.m. in a spring tide, increasing to 65.000.000 c.m. after canalization works and to about 150.000.000 c.m. nowadays. Maximum tidal capacity of the lagoon is estimated to about 180.000.000.c.m. Therefore, it seems that the inlet canal has been correctly dimensioned.

Evolution of the inner bar is also an interesting item when results of the works undertaken are considered.

Comparison of the longitudinal profiles of the inner channel in 1865, 1914 and 1934 and after (see fig. 31) shows that canalization of the inlet caused the deepening of the downstream section, the occurrence of great depths near the extremity of the current-guiding dikes, and the westward displacement and a considerable erosion of the inner bar.

As for the project being executed, results are shown in fig 32 concerning variations in the total amount of sand in the inner bar, and in Table 5 and fig. 33 concerning the hydraulic characteristics of the inner channel up to S.Jacinto: in spite of the oscillation due to meteorological features, a remarkable tendency to the improvement of the channel, especially in the downstream canalized strech, can be traced.

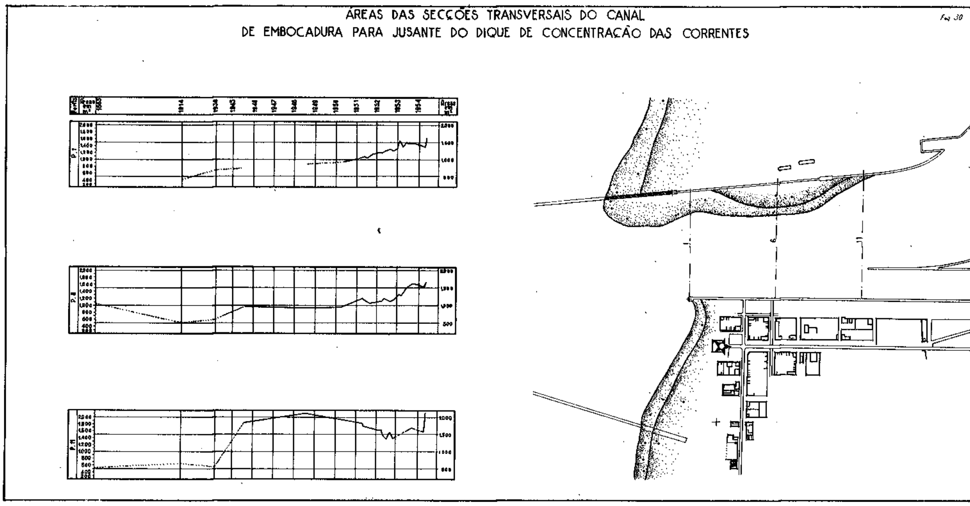


Fig. 30. Areas of cross sections.

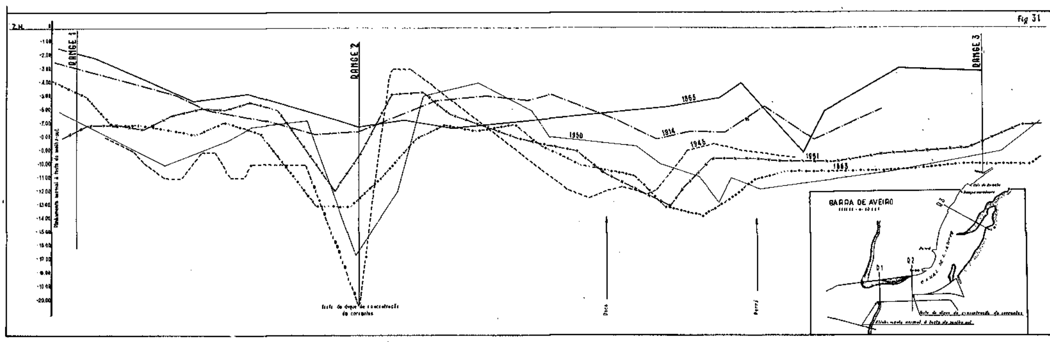


Fig. 31. Longitudinal profiles along the talweg between the inlet's mouth and S. Jacinto, from 1865 to 1953.

LAGOON INLET OF AVEIRO

Variation in the volume of sands in the inner bar

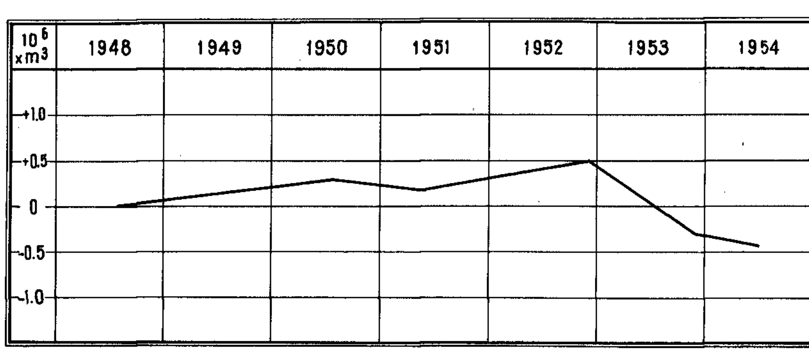


Fig 32 variation in the volume of sand on the inner bar from 1948 to 1954.

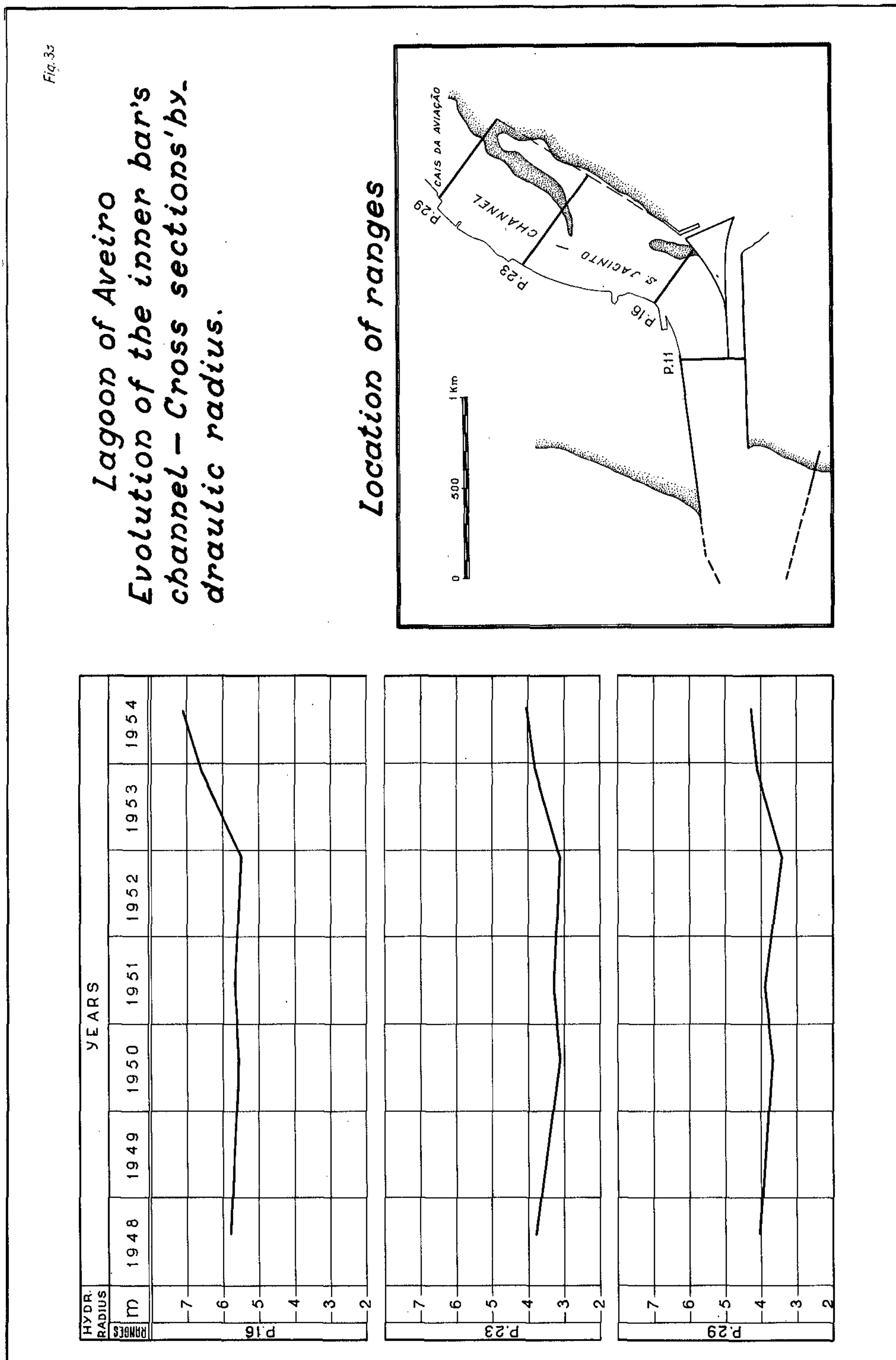


Fig. 33. Variation in the hydraulic radius of the inner channel's cross sections (ranges Nos. 16, 23 and 29) from 1948 to 1954.

Table 3

AREAS OF THE INLET CHANNEL'S CROSS SECTIONS

DATES				VIII	VII	V	VII	V	V	IX	V
RANGES	1865	1914	1934	1945	1948	1950	1950	1951	1953	1953	1954
P.1	—	410	683	—	—	913	937	1.062	1.497	1.464	1.595
P.2	523	403	633	—	917	909	1.017	1.032	1.640	1.435	1.640
P.3	549	499	510	804	888	802	929	1.068	1.743	1.501	1.511
P.4	668	647	595	769	741	789	766	1.216	1.677	1.778	1.635
P.5	879	520	535	721	888	866	817	1.186	1.730	1.701	1.528
P.6	1.064	505	591	939	918	957	1.014	1.192	1.491	1.633	1.653
P.7	736	370	623	925	1.155	1.101	1.087	1.237	1.309	1.520	1.520
P.8	599	428	621	1.229	1.345	1.138	1.073	1.254	1.390	1.311	1.471
P.9	546	390	678	1.296	1.504	1.203	1.147	1.277	1.504	1.259	1.524
P.10	505	423	659	1.342	1.825	1.266	1.278	1.417	1.674	1.467	1.691
P.11	517	643	579	1.837	2.122	1.945	1.916	1.830	—	1.705	2.139

Areas, in sq.m., under datum

Table 4

HYDRAULIC ELEMENTS OF THE INLET'S CROSS SECTIONS

Dates	1934			VIII - 1945			V - 1951			IX - 1951			VIII - 1952			IX - 1953		
Range number	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m
P.1	1.123	310	3,6	-	-	-	1.522	330	4,6	1.764	307	5,7	1.838	308	6.0	2.070	312	6,6
P.2	993	275	3,6	-	-	-	1.482	320	4,6	1.678	290	5,8	1.974	300	6.6	2.051	314	6,5
P.3	850	270	3,1	1.164	300	3,9	1.526	340	4,5	1.543	290	5,3	2.031	308	6.6	2.127	334	6,4
P.4	975	280	3,5	1.039	290	3,6	1.756	370	4,7	1.506	298	5,0	1.877	318	5,9	2.414	327	7,4
P.5	775	250	3,1	1.031	310	3,3	1.746	365	4,8	1.561	314	5,0	1.755	324	5.4	2.349	332	7,1
P.6	941	260	3,6	1.289	310	4,2	1.752	400	4,4	1.679	329	5,1	1.727	329	5.3	2.291	343	6,7
P.7	1.083	320	3,4	1.295	300	4,3	1.837	415	4,4	1.801	338	5,3	1.956	340	5.8	2.190	344	6,4
P.8	1.061	305	3,5	1.689	370	4,6	1.712	395	4,3	1.877	340	5,5	2.024	343	5.9	1.989	345	5,8
P.9	1.178	345	3,4	1.856	400	4,6	1.867	390	4,8	-	-	-	1.988	344	5.8	1.941	345	5,6
P.10	1.089	290	3,8	1.902	395	4,8	2.077	445	4,7	-	-	-	2.100	353	5.9	2.167	362	6,0
P.11	1.045	300	3,5	2.467	590	4,2	2.530	570	4,4	-	-	-	2.354	344	6.8	2.405	363	6,6

NOTES:

a) - Wetted area

p) - Wetted perimeter

$R = \frac{a}{p}$ - Hydraulic radius

Sections under mean level (+2.00^{m} above datum)

Table 5

HYDRAULIC ELEMENTS OF THE INLET'S CROSS SECTIONS
(INNER CHANNEL)

Dates	VII - 1948			VII - 1950			V - 1951			XI - 1952			XI - 1953			VII - 1954		
Range number	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m	a m2	p m	R m
P.12	1.639	283	5.7	1.406	281	5.0	1.774	278	6.4	1.680	280	6.0	2.105	281	7.4	2.025	281	7.2
P.13	1.818	321	5.6	1.873	323	5.8	1.984	322	6.1	2.163	320	6.7	2.312	322	7.1	2.430	322	7.5
P.14	1.870	323	5.7	1.805	327	5.5	1.792	326	5.5	1.758	324	5.4	2.133	324	6.6	2.245	325	6.9
P.15	1.895	358	5.3	1.885	360	5.2	1.967	356	5.5	2.065	358	5.8	2.295	359	6.3	2.288	357	6.4
P.16	2.190	374	5.8	2.123	379	5.6	2.188	379	5.7	2.058	375	5.5	2.347	372	6.6	2.650	374	7.1
P.17	2.320	410	5.7	2.504	409	6.1	2.350	408	5.7	2.060	407	5.0	2.687	408	6.5	2.589	410	6.3
P.18	2.742	468	5.9	2.694	468	5.7	2.392	471	5.0	2.450	469	5.2	2.601	469	5.5	2.592	465	5.5
P.19	2.625	523	5.0	2.600	522	4.8	2.438	522	4.6	2.508	522	4.8	2.488	523	4.7	2.650	523	5.1
P.20	2.665	549	4.8	2.450	549	4.5	2.330	550	4.2	2.008	549	3.7	2.600	551	4.7	2.425	550	4.4
P.21	2.506	585	4.3	2.446	583	4.2	2.294	583	3.9	1.945	582	3.3	2.797	586	4.8	2.579	584	4.4
P.22	2.311	605	3.8	1.875	603	3.1	2.208	603	3.6	1.923	603	3.2	2.639	606	4.3	2.495	604	4.1
P.23	2.302	604	3.8	1.885	603	3.1	2.027	603	3.3	1.878	603	3.1	2.314	605	3.8	2.425	604	4.0
P.24	2.225	613	3.5	2.052	610	3.3	2.158	613	3.5	2.172	613	3.5	2.615	615	4.2	2.381	612	3.9
P.25	2.347	609	3.8	2.097	605	3.4	2.321	606	3.8	2.090	605	3.4	2.582	607	4.2	2.967	610	4.8
P.26	2.440	558	4.3	1.690	552	3.1	2.105	553	3.8	1.808	550	3.3	2.252	558	4.0	2.448	555	4.4
P.27	2.290	635	3.6	2.150	632	3.4	2.367	634	3.5	1.850	632	2.9	2.473	637	3.9	2.527	635	4.0
P.28	2.345	618	3.7	2.088	617	3.3	2.174	617	3.5	1.943	615	3.1	2.331	617	3.6	2.404	617	3.9
P.29	2.195	547	4.0	2.015	546	3.7	2.135	547	3.9	1.830	543	3.4	2.281	549	4.1	2.341	547	4.3

NOTES:

a) Wetted area

p) Wetted perimeter

$R = \frac{a}{p}$) Hydraulic radius

Sections under mean level ($+2^{m}.00$ above datum)

Hence, the amelioration of the inlet always occasioned the inner bar to be deepened and reduced, and the neighbouring upstream channel to be improved on a considerable distance, without any dredging being undertaken. This clearly implies that littoral sands are by-passing the inlet, or preferably, that they are not retained by the inlet in their way downcoast: the volume of sand expelled by the ebb tide exceeds that brought in by the flood.

The same conclusion is also suggested by the analysis of the bottom contours in some surveys, namely that of July, 1954.

CONCLUSIONS

The treatment of estuaries has long been discussed in Engineering literature and a firm and well developed technics is available on the subject. Situation is radically different when lagoon inlets are considered and, at least to our knowledge, no systematic analysis has been published since the very remarkable article by Earl Brown on "Inlets on Sandy coasts" (in 1928) and that by Francesco Marzolo on "Bacini a marea e foci lagunari" (in 1935).

This is possibly why, from time to time, instances are found were inlets' problems are dicussed or dealt with according to the principles valid for estuaries' treatment, with the result that, in spite of tough attempts and heavy expenses, success is not obtained, as it always happen when nature is forgotten.

In fact, the improvement of an inlet on a sandy coast cannot depend either on the upstream current or on the propagation of the tidal wave, wich are essential factors in the improvement of estuaries. The former must essentially depend on the increase in the relation of the tidal volume circulated through the inlet to the volume of sands carried by the littoral drift, wich, in turn, is not necessarily a requirement in estuaries' amelioration.

In order to assure the increase of the tidal flow through an inlet, improvement of the hydraulic characteristics of the inlet channel is needed. For this purpose, from what has been reported about the case of Aveiro it seems advisable:

i. to fix the inlet as close as possible to the center of masses of the waters in the lagoon;

ii. to canalize the inlet channel accross the barrier beach, and to harmonize the currents from the different lagoon bodies, guiding them to the inlet channel in the best way to avoid the ocurrence of eddies and of any losses of energy;

iii. to situate the outer bar as far out in the sea as required for obtaining the depths wanted, wich must be done by means of jetties, these being in many cases, preferably, slightly convergent jetties.

In every case, natural conditions of the specific problem have to be carefully investigated and taken in account, no general rules being able to suppress the need for such a peculiar investigation.

Success obviously calls for littoral drift transposing the inlet, that is that the sand brought into it by the flood tide be expelled by the ebb, if necessary with the help of dredging. Otherwise, the inner bar would shoal very fast, the inlet would deteriorate, erosion downcoast would proceed to a large scale favouring the opening of a new inlet by some storm, wich in some instances has been enough to cause the closure of the preceding one and in any case would be very harmful to its maintenance.

RESUME

HISTOIRE D'UNE EMBOUCHURE LAGUNAIRE ET DE SON AMELIORATION

Carlos Kruz Abecasis

La lagune d'Aveiro est située au centre de la côte occidentale portugaise et aux environs d'une région très riche et très peuplée. De ce fait, et aussi à cause des graves préoccupations dûes à l'obstruction et à la mauvaise configuration de l'embouchure lagunaire pendant trois siècles, l'histoire de la lagune est connue avec un assez grand détail depuis longtemps, et on possède des données d'une valeur scientifique dès le XVIIIe siècle, lorsque la fixation et la désobstruction de l'embouchure ont été sérieusement étudiées. La réussite, quelques années plus tard, n'a pas empêché les discussions techniques concernant la physiographie de l'embouchure et son amélioration de se prolonger jusqu'à présent, chaque fois que se posaient de nouveaux problèmes d'aménagement.

On pense que les connaissances qui en ont résulté présentent un intérêt général.

A présent, la lagune a quelque 50 Km. de longueur, entre Ovar et Mira, et 25 Km. de largeur maximum, entre Luz et Trena. Sa surface d'eau est de 7.000 hectares environ. Des canaux et des lacs séparent entre elles de nombreuses îles et les haut-fonds résultant de la colmatation lagunaire. La rivière Vouga verse ses eaux dans la lagune, avec un débit qui va de 1.200 m3 par seconde en crue maximum, à presque zéro en temps sec. Le cube de marée à travers l'embouchure approche 100.000.000 de m3 en marée de vives eaux.

La formation lagunaire est géologiquement très récente. Elle a commencé vers le Xe siècle avec l'avance vers le sud d'une flèche de sable depuis Espinho. L'ancien golfe, qui atteignit jusqu'à l'embouchure de la Vouga, fut progressivement isolé de la mer. Au nord de l'embouchure artificielle, la flèche de sable a réussi à isoler des surfaces d'eaux profondes, pas encore totalement comblées par les dépôts d'origine lagunaire. Vers le sud, certainement parce que, lorsque la flèche de sable y arriva, la sédimentation littorale était déjà avancée, les surfaces d'eau isolées de la mer sont notablement moins importantes.

Une fois que, au XVIe siècle, la flèche de sable dépassa sensiblement la position de l'embouchure actuelle, sa progression s'accéléra et les premiers signes d'embouchure bouchée ont été enregistrés. Finalement, au milieu du XVIIIe siècle, la flèche de sable atteignit sa position la plus méridionale, vers Mira, et l'embouchure se ferma totalement. C'était un véritable désastre, et pour la navigation et pour la richesse et l'état sanitaire de toute la région voisine, privée de son organe essentiel de drainage et réduite à la condition d'un immense bourbier. Tout le pays voisin était ruiné.

Les essais en vue de rouvrir et fixer l'embouchure lagunaire ont tous failli jusqu'à ce que, en 1808, on ait réussi à couper le cordon littoral et à localiser définitivement l'embouchure à son emplacement actuel. Les problèmes sanitaires et de drainage étaient résolus pour toujours, et c'était le premier pas vers le rétablissement de la navigation.

Les années suivantes ont été consacrées à la consolidation difficile de cette victoire et à la préparation des phases suivantes de l'amélioration, demandées par la navigation, jusqu'à ce que, en 1927, un projet ait été approuvé.

L'exécution partielle de ce projet, de 1932 à 1936, a canalisé l'embouchure à travers le cordon littoral et raccordé les courants lagunaires dans son voisinage. Les conditions hydrauliques de l'embouchure ont été sensiblement améliorées et la profondeur sur la barre extérieure est passée de 14 à 17 pieds en marée haute moyenne.

Les nouveaux besoins de la navigation ont conduit à l'élaboration d'un nouveau projet d'aménagement, en 1937, dans lequel étaient prévues deux jetées extérieures convergentes et dont les buts étaient de porter la profondeur sus-nommée à 24 pieds, ainsi que de rectifier et abriter le chenal d'entrée. L'exécution commença en 1948, et les profondeurs obtenues dépassent celles envisagées au projet, depuis 1951.

La longue histoire de la lagune et de son embouchure, les transformations subies dans les derniers temps par les plages et les fonds voisins, par la barre extérieure et le chenal d'entrée, par la marée lagunaire et les chenaux intérieurs, sont examinées et discutées en vue de définir le régime physiographique local et les méthodes les plus efficaces d'améliorer les conditions naturelles.