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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

THE STATE SECRETARY OF PLANNING
THE STATE OF PIAUÍ
THE FEDERATIVE REPUBLIC OF BRAZIL

FINAL REPORT

THE FEASIBILITY STUDY ON THE NAVIGATION OF THE PARNAÍBA RIVER BASIN

VOL. 3 SUPPLEMENTAL REPORT ON PILOT SPUR DIKES

MARCH 1995

PACIFIC CONSULTANTS INTERNATIONAL (PCI)

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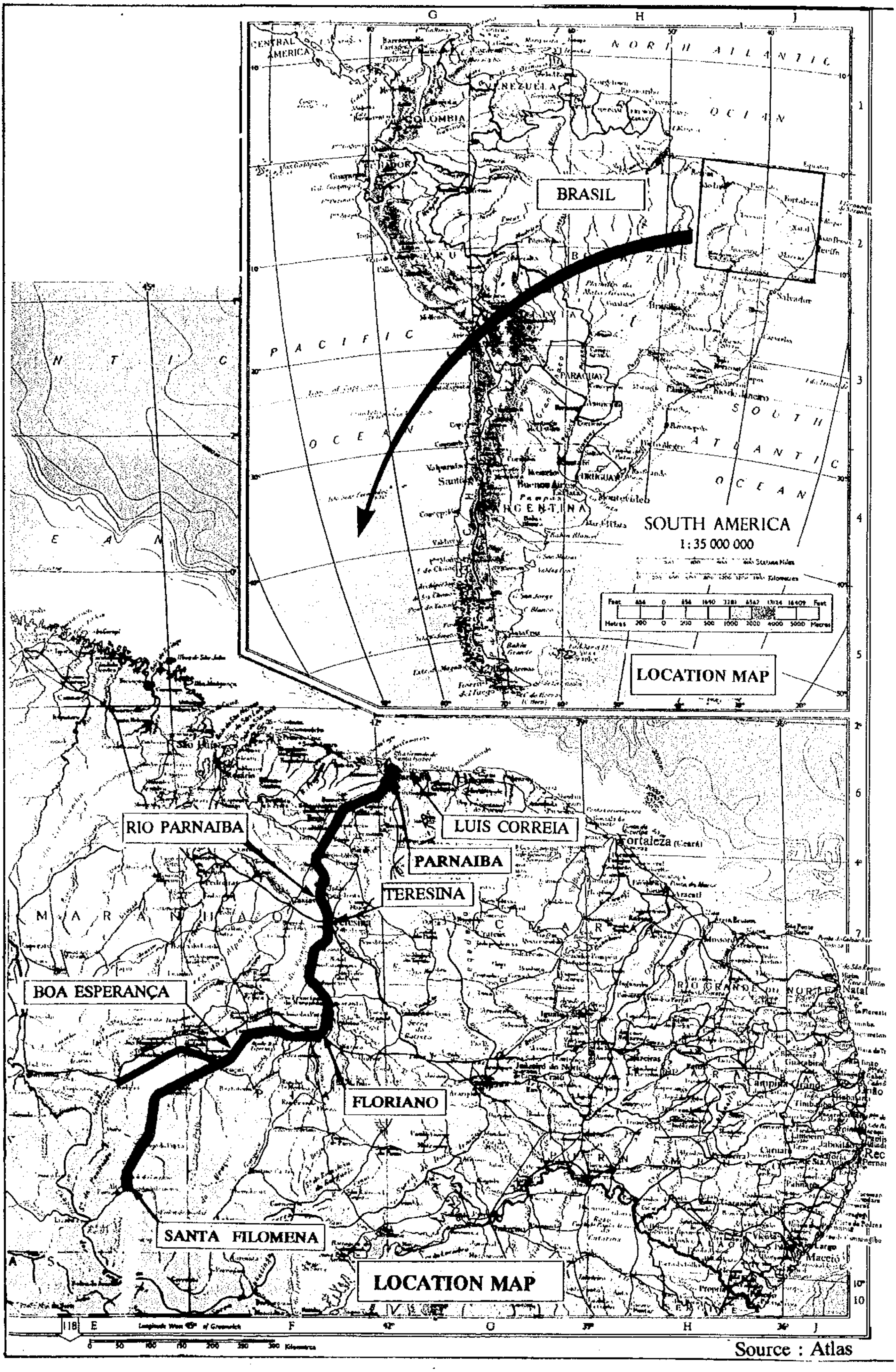

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1. OVERVIEW OF TEST SPUR DIKE

1. Overview of Test Spur Dike Construction

1.1 Function and Objective

The field test on the effects of spur dikes was preliminary discussed as an construction method to prevent bed aggradation and to control the development of alternating bars, thereby providing the effective compound cross section.

However, to achieve this objective, the monitoring practice require a long time in order to reach the intended test effect, and the construction of a large-scale spur dike may reduce the discharge capacity of the river course.

With these issues taken into account, the objectives of the test spur dike construction have been restricted to the following two:

(1) Concentration of running water in the navigation waterway during the low water period, thereby ensuring the required draft for ships.

(2) Small-scale modification of the low water channel alignment and a shift to the river body side

1.2 Site Selection

For the test spur dike construction site, sand bars were studied and can be classified into single, double and multiple forms, based on the mosaic photograph taken by aerial photography, and their sites were selected.

However;

(1) The date of the taking of the aerial photograph for the present survey was changed from the originally planned April to June, because consideration was given to climatic conditions and the possible decrease in the water level. This resulted in the preparation of the mosaic photographs being completed toward the end of August.

(2) Preparation of the bar inventory based on the mosaic photograph was delayed and was to be completed after September.

(3) The change in the date of taking the aerial photographing made it difficult to select the construction site based on the mosaic photograph.

(4) The spur dike construction involves numerous underwater works, making it essential to avoid construction during the flooding period.

(5) It became necessary to select the test construction site and to conduct the longitudinal and cross sectional surveying according to the limited existing information and the report during the June local survey.

The local survey was conducted in June 1993 based on the mosaic photos (INTERPI) obtained from the aerial photographing in 1983. The result of this study revealed that there are several points which hinder ship navigation in the low-water period due to the presence of sand bars in the middle and lower reaches.

With consideration given to the practical convenience involved in the construction and monitoring, the construction sites have been located at Teresina, Uniao and Buriti dos Lopes where navigation was partly hindered by the presence of sand bars during the local survey conducted in June 1993. Three sites are necessary from the view point of their comparison of their endurance by structure type.

Fig. 1.1 shows the location map of the proposed construction sites for spur dike.

(1) Teresina

The shoal is formed throughout the mid section of the river course (20 to 40 cm during the low water period), and the navigation waterway from the right bank to the left bank sides is undefined, giving a sharp approach angle for the assumed waterway.

(2) Uniao

The shoal is located on the left bank side of the river course, with the sand bar located in front of the middle reach and wharf causing navigation difficulties.

(3) Buriti dos Lopes

Sand bars stretch from the right to left banks, providing a sharp approach angle for navigation from the left to the right banks during the low water period.

The proposed spur dike sites at Teresina, Uniao and Buriti dos Lopes are shown in Figs. 1.2 - 1.4 .

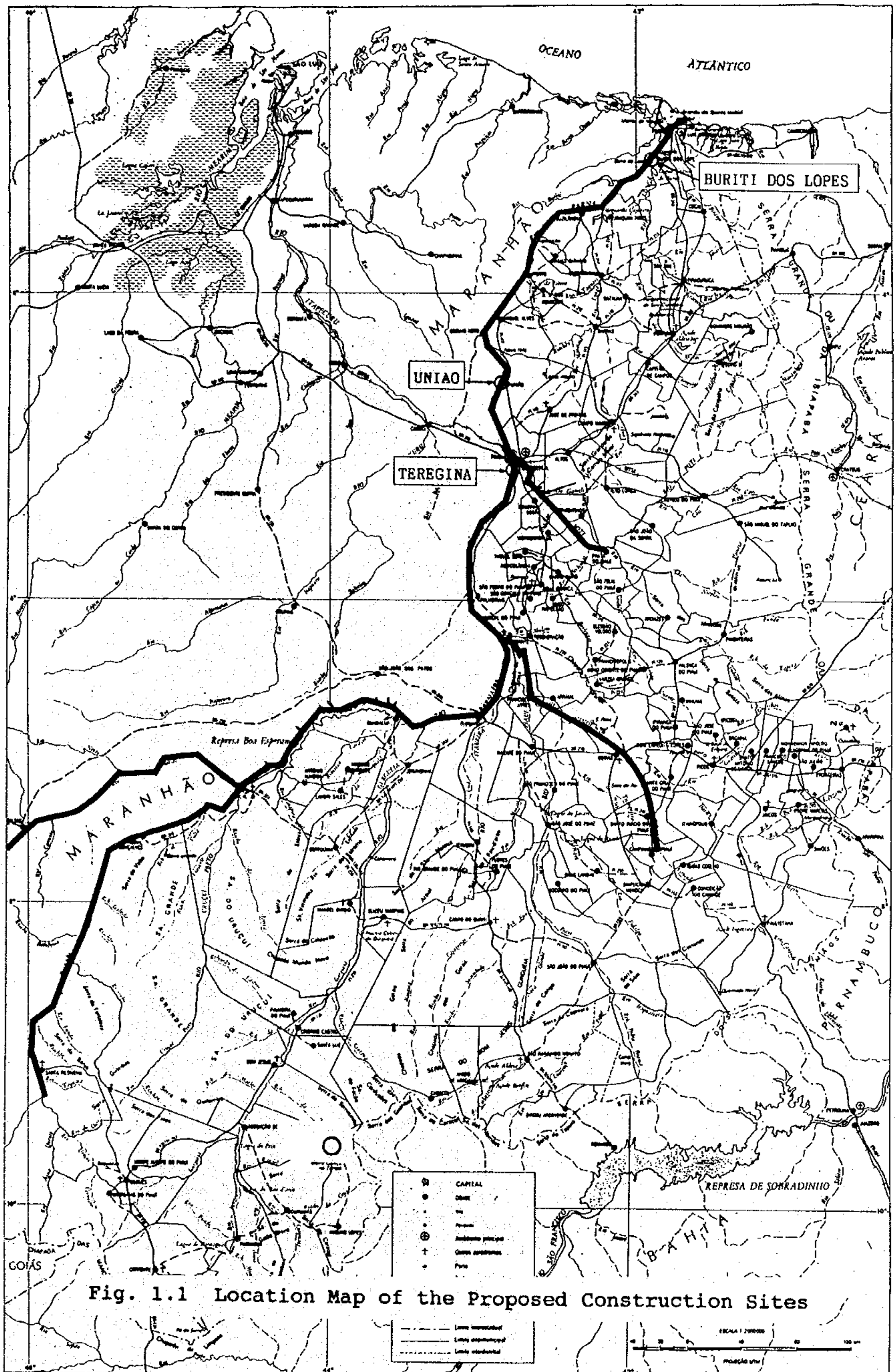
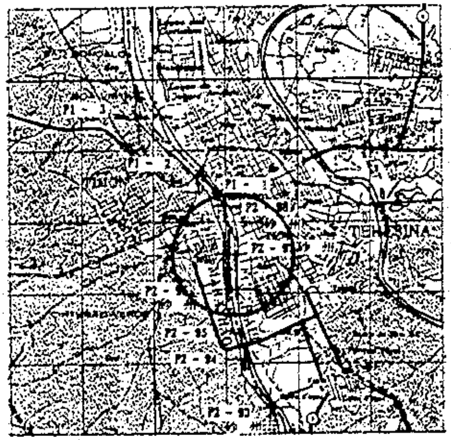
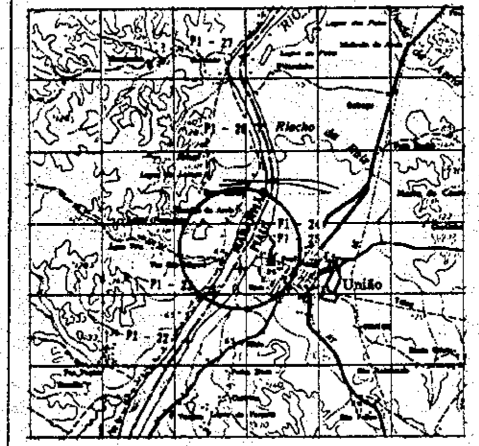


Fig. 1.1 Location Map of the Proposed Construction Sites



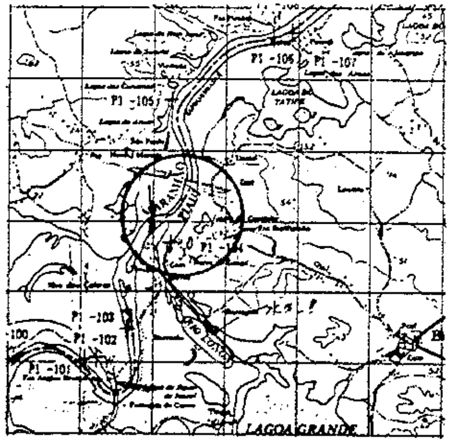
Spur Dike Site at Teresina.

Fig. 1.2 Proposed Spur Dike Site at Teresina



Spur Dike Site at Uniao.

Fig. 1.3 Proposed Spur Dike Site at Uniao



Spur Dike Site at Buriti dos Lopes.

Fig. 1.4 Proposed Spur Dike Site at Buriti dos Lopes

2. RIVER CONDITIONS AT THE SPUR DIKE SITES

2. River Conditions at the Spur Dike Sites

2.1 Location

The Teresina construction site is located 1,600 meters on the upstream side of the bridge at Teresina, with the piers of a new bridge standing nearby.

The Uniao construction site is located at the wharf at Uniao.

The Buriti dos Lopes construction site is near the right bank side with the revetment dike 600 meters on the downstream side of from the confluence between the Rio Parnaíba and the Rio Longa.

These sites are represented as follows according to the Brazilian coordinate system:

Site Location

Site	East	North
Teresina	742,000	9,436,000
Uniao	736,000	9,493,000
Buriti dos Lopes	174,000	9,652,000

2.2 Channel Patterns

Teresina :

The river course generally meanders with an approximate curvature radius R = 2,500 m.

Uniao :

The river forms a generally straight water course at this location. The water course during the low water period connects thalwegs along the alternating bars.

Buriti dos Lopes :

The river is considered to form a meandering water course.

There is a narrow portion with a river width of 300 meters at a point 2,400 meters on the upstream side of the Rio Longa. Its water course width is 120 meters during the low water period. The river width gradually increases from this point, and a sand bar is found on the left bank side. At this point the water course is divided into two. The water course on the right bank side converges with the Rio Longa, before converges again with the water course passing through the hinterland of the bar on the side of the Province of Maranhão (the bank opposite to the end of the revetment dike). The line of the water course was found to be separating the bar appearing above the water level on the downstream side of this position during the low water period (Fig. 2.1).

Fig. 2.1 Aerialphotograph at Buriti dos Lopes Site

2.3 Flooding

Teresina :

According to the water levels recorded by CHESF during the period from 1982 to 1992, the maximum flood depth is 7.57 meters (Discharge : 3,800 m3/s) which was recorded in May 1985. The average annual maximum flood depth for 11 years is 5.65 meters, with a corresponding discharge of 2,000 m3/s.

Uniao :

Water level observations by CHESF have been conducted since 1986 on the right bank side 1600 meters on the downstream side of the wharf. The maximum annual flood depth is 7.52 meters, measured in 1986. The height of the flood which occurred in May 1985 is said to be about 1.5 meters above the natural levee.

Buriti dos Lopes :

Water level observations by CHESF were not conducted in this position. According to the records kept at Luzilandia, located in the vicinity, the maximum flood depth was 8.44 meters (Discharge : 6,700 m3/s) in the event of the flood in April 1985. The average annual maximum flood depth is about 6 meters (Discharge : 3,300 m3/s).

2.4 Sand Bars

Teresina :

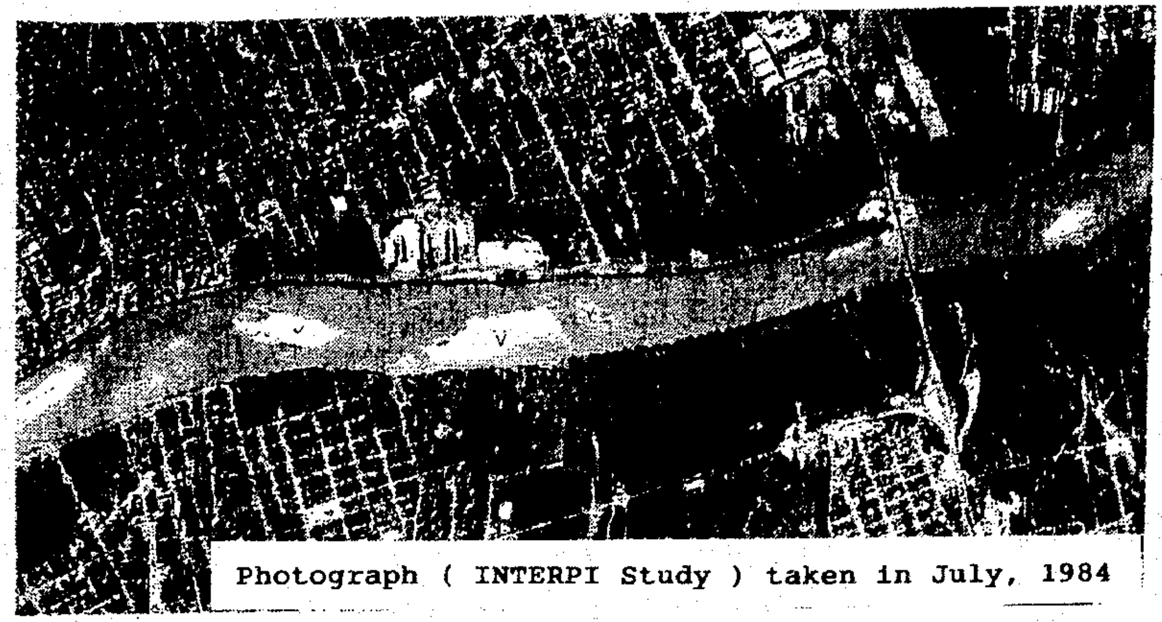
Based on the mosaic photo taken in August 1993, attempts were made to describe the front line of the alternating bar (Fig. 2.2). The bars at this site can be classified as alternating bars, and the wave-length at the alternating bars is estimated at approximately 2,500 meters. Especially, the bar on the immediately upstream side of the construction site is located in the middle region, and the bar length above the water level was 1,170 meters. Plants were observed to grow on this bar.

Fig. 2.3 show the mosaic photos taken by aerial photography in July 1984 and June 1993. Their comparison reveals that the positions are approximately the same. The shift to the downstream side by the flood (Q = 3,800 m3/s) in which Teresina was inundated in 1985 is not shown very clearly. This bar is considered to be generally stable.

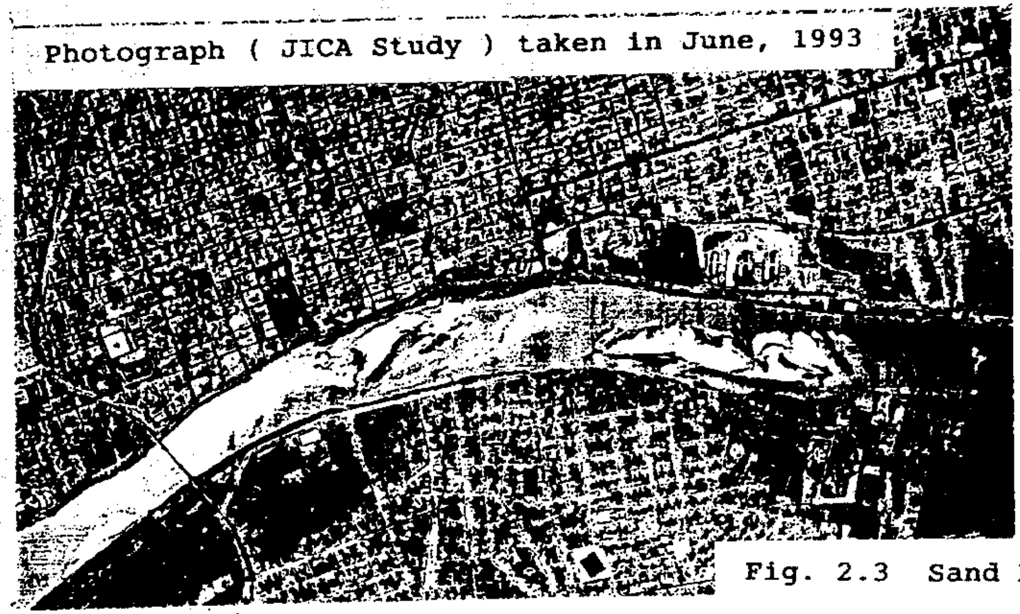
Uniao :

From the mosaic photo, the sand bar around the construction site is considered to be an alternating bar. The bar is located on the left bank side 2,000 to 3,000 meters on the upstream side of the spur dike construction site, and on the right bank side on the immediately upstream side.

Fig. 2.2 Leading -edge Line for Alternating Bars (Teresina)



Photograph (INTERPI Study) taken in July, 1984



Photograph (JICA Study) taken in June, 1993

Fig. 2.3 Sand Bar Positions (Teresina)

When the front line of the alternating bar (Fig. 2.4) is defined, the wave length of the alternating bar is estimated at approximately 4,400 meters. Plants were observed to grow on the downward side of the middle portion of the sand bar on the bank side opposite to the wharf, and ground is considerably high. Sedimentation and erosion are repeated on the upstream side according to the water level. The bar is shifting toward the left bank and is considered to be stable. According to the mosaic photo from INTERPI taken in 1984, the positions of the bars on the right and left banks are almost the same. (Fig. 2.5)

Buriti dos Lopes :

A large bar is found on the bank opposite to the Rio Longa gradually expanding from the narrow section of the Rio Parnaíba. Plants were observed to grow on the higher positions of the bar. This bar exhibits a complicated shape because of the relationship with sedimentation in the wider section of the river course, variations in the local flow and the former river course. However, there is considered to be no movement on the downstream side of the bar.

On the downstream side, there is a bar on the right bank side. This bar is not very high, and is considered to be below the water level during the high water period.

2.5 Water Course

The results of the site surveys conducted in January and June 1993, the mosaic photos and measurements have revealed the following :

Teresina :

During the low water period ,the major water course is located on the right bank of the bar in the middle region, and on the left bank side at the point of the new bridge piers.

When the deepest portions are connected according to the survey plan, it shows that the water course is shifted at the point 240 meters on the upstream side of the piers.

By visual observations at the site, the water course appeared to be shifted to the immediately downstream side of the middle bar.

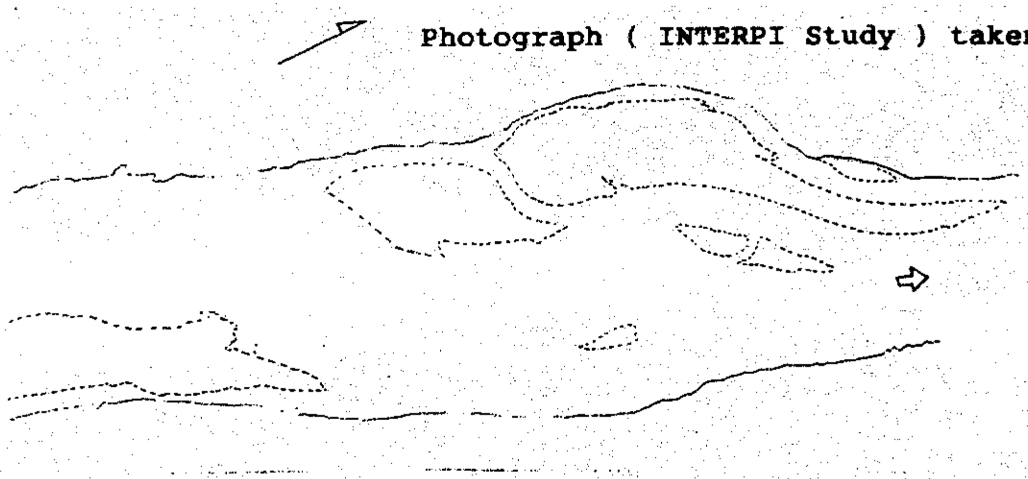
Uniao :

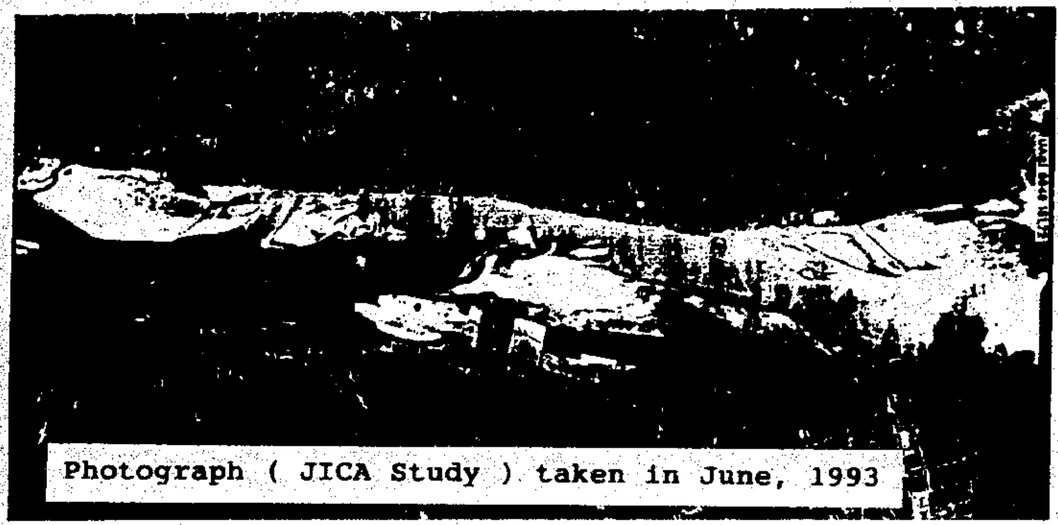
The major water course is along the alternating bar during the low water period.

For the area surrounding the test construction site, the water course is found along the bar of the right side on the immediately upstream side of the wharf. It is located on the right for the downstream section.

Fig. 2.4 Front Line for Alternating Bars (Uniao)

Photograph (INTERPI Study) taken in July, 1984





Photograph (JICA Study) taken in June, 1993

Fig. 2.5 Sand Bar Positions (Uniao)

Buriti dos Lopes :

The water course diverges into two at the bar at the wider section. The major water course is found along the right bank. Converging with the water course of the Rio Longa, it shifts toward the left bank at around the end of the revetment dike. The smaller water course located between the bar and left bank again converges with the major water course at the end of the bar. The water course is observed to traverse the bar on the downstream right bank side.

2.6 Water Depth

Teresina :

The water level, subjected to a site survey in June 1993, was recorded as an elevation of 54 meters, and the shoal given as 20 to 40 cm deep at the middle region. The deepest region was recorded to be 1.4 to 4.0 meters.

Uniao :

The water level according to the local survey conducted in June 1993 had an elevation of 42.5 meters. The shallow area was 20 to 40 cm in depth around the leading edge of the bar on the left bank side. In the deepest section, the water was about 2.5 meters deep along the right bank side.

Buriti dos Lopes :

The water level, by a local survey, was measured to have an elevation of 4.4 meters. The deepest part was 3 to 3.5 meters deep along the right bank. The width capable of ensuring a water depth of 1.4 meters or more is within the range from 10 to 140 meters.

A water level gauge was not installed at this point. The water level was found to be recorded at Luzilandia on the upstream side.

2.7 Bed Materials

According to the grain size analysis conducted in June 1993, the river bed materials are given as follows :

Grain size	Teresina	Uniao	Buriti
d50	0.35	0.22	0.093
d60	0.40	0.24	0.105
dm	0.44	0.305	0.131

(mm)

dm...Mean diameter

This shows a representative sandy river.

2.8 Hydraulic Condition

To grasp the river course characteristics, information on the average water depth, waterway width to water depth ratio, average velocity, friction velocity and the dimensionless tractive force at the average annual maximum discharge is listed below.

Hydraulic Specifications of River Course

	Teresina	Uniao	Buriti
Aver. annual maximum (m3/s)	2,000	2,200	3,400
Waterway width (B : m)	425	685	738
Water depth (Hm : m)	3.65	2.77	3.43
Ratio (B/Hm)	116	247	215
Mean diameter (mm)	0.436	0.305	0.131
Density*	1.559	1.559	1.559
Friction velocity	0.08	0.06	0.07
Aver. velocity (m/s)	1.32	1.17	1.35
Dimensionless T*	0.89	0.82	2.35
Velocity coefficient	17	19	20

Note :
Density*..Density in water
T* .. Dimensionless tractive force
Table 2.1 lists the section is characteristics

Generally, a sand bars condition in Japan is classified into 3 categories , based on the waterway width to water depth ratio (B/Hm) at the average annual maximum discharge.
(Fig. 2.6 : Sand bar classification in Japan).

Classification : Alternate bars
: Alternate or double bars
: Multiple

Applying the Japanese classification, the bars condition at the 3 sites will be as below ;

Teresina : Alternate or double bars
Uniao : Multiple
Buriti dos Lopes : Multiple

Compared with the rivers in Japan, the dimensionless tractive force is shown to be smaller with respect to the average grain size.
(Fig. 2.7 Relationship between T* and Dm in rivers of Japan)

Table 2.1 Section Characteristics at 3 Sites

Teresina

(H)	(A)	(R)	(B)	(V)	(Q)
51.300	0.000	0.000	0.000	0.000	0.000
52.156	77.032	0.440	174.978	0.342	26.357
53.011	238.718	1.050	227.279	0.611	145.899
53.867	474.280	1.508	314.183	0.778	369.031
54.722	777.853	1.860	417.467	0.842	655.174
55.578	1136.776	2.690	421.573	1.077	1224.655
56.433	1499.213	3.511	425.680	1.287	1929.122
57.289	1865.163	4.323	429.787	1.478	2757.272
58.144	2234.626	5.126	433.893	1.656	3701.019
59.000	2607.604	5.921	438.000	1.823	4754.701

Uniao

(H)	(A)	(R)	(B)	(V)	(Q)
40.000	0.000	0.000	0.000	0.000	0.000
40.778	70.017	0.660	106.044	0.485	33.981
41.556	177.613	0.967	183.645	0.626	111.211
42.333	390.096	0.903	431.668	0.598	233.350
43.111	792.874	1.412	560.889	0.806	639.051
43.889	1285.649	1.887	680.578	0.978	1257.344
44.667	1816.682	2.648	684.933	1.226	2227.189
45.444	2351.102	3.403	689.289	1.449	3407.339
46.222	2888.910	4.154	693.644	1.655	4782.369
47.000	3430.105	4.899	698.000	1.848	6338.712

Buriti dos Lopes

(H)	(A)	(R)	(B)	(V)	(Q)
1.000	0.000	0.000	0.000	0.000	0.000
1.500	14.821	0.419	35.286	0.331	4.908
2.000	35.286	0.755	46.571	0.490	17.307
2.500	71.143	0.733	96.857	0.481	34.213
3.000	132.143	0.897	147.143	0.550	72.709
3.500	208.786	1.307	159.429	0.707	147.670
4.000	291.571	1.694	171.714	0.841	245.168
4.500	404.000	1.451	278.000	0.758	306.371
5.000	708.172	0.976	724.687	0.582	412.226
5.500	1071.187	1.471	727.374	0.765	819.779
6.000	1435.545	1.964	730.061	0.928	1332.221
6.500	1801.247	2.454	732.747	1.077	1939.339
7.000	2168.293	2.943	735.434	1.215	2635.331
7.500	2536.682	3.429	738.121	1.346	3413.947
8.000	2906.414	3.914	740.808	1.470	4272.377
8.500	3277.490	4.396	743.495	1.588	5205.889
9.000	3649.909	4.877	746.182	1.702	6213.180

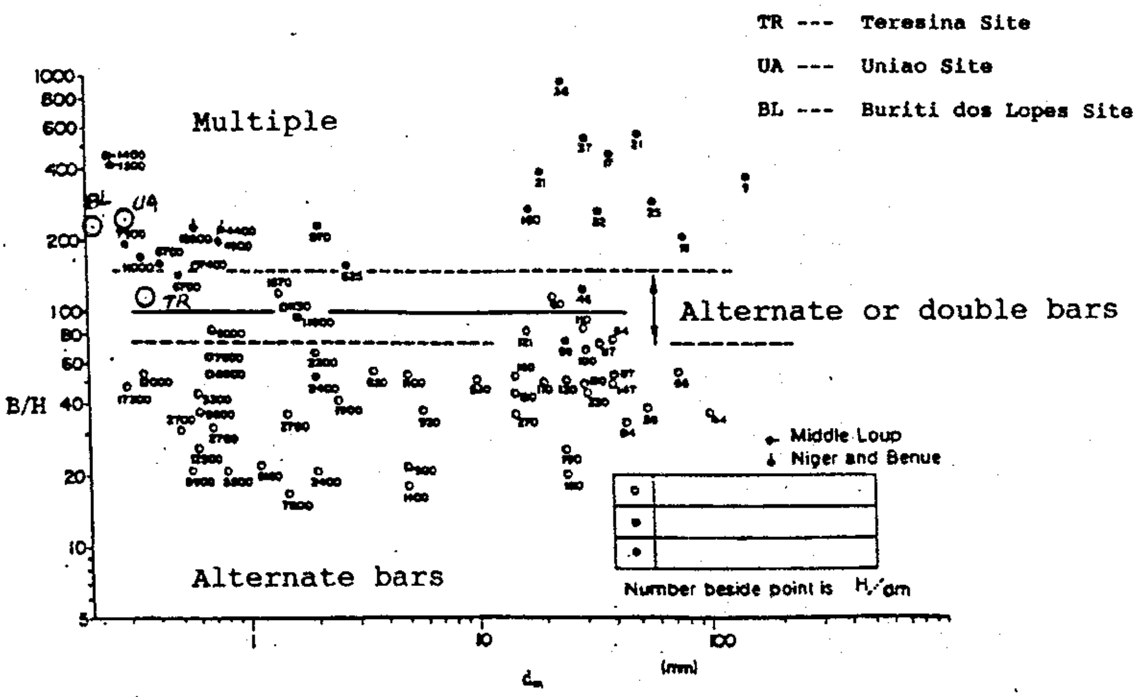


Fig. 2.6 Sand Bar Classification in Japan

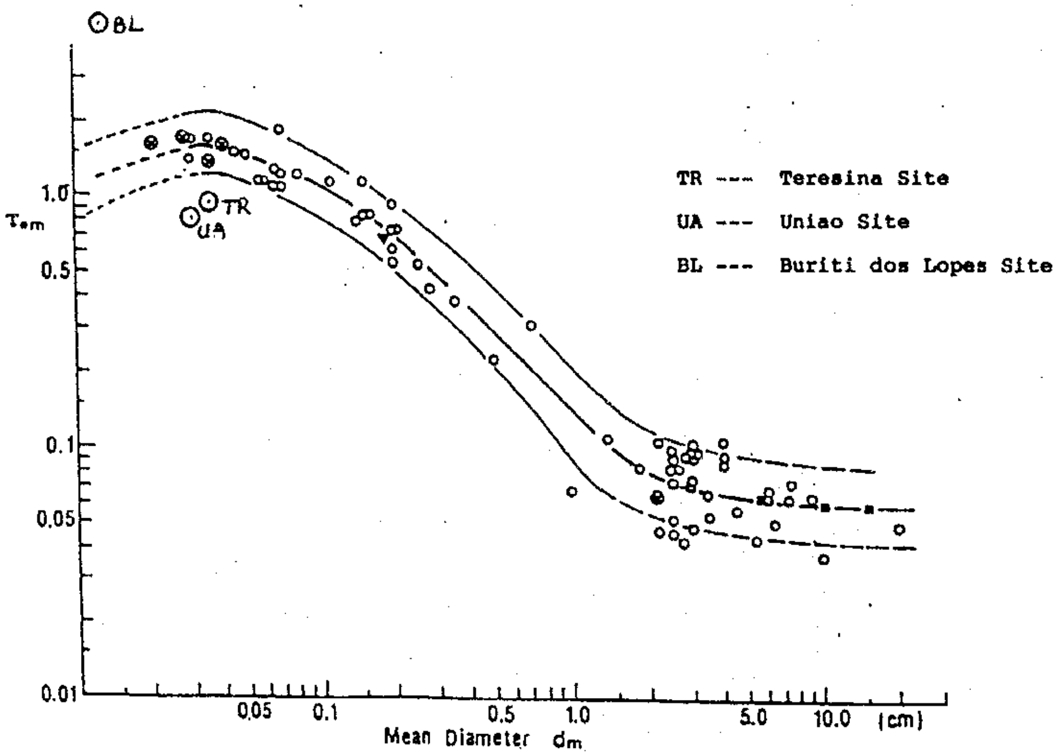


Fig. 2.7 Relationship T* and dm in Rivers,Japan

3. SPUR DIKE PLAN

3 Spur Dike Plan

3.1 Current Situation

The current situation at the spur dike sites can be summarized as follows, according to the local survey and measurements:

Teresina :

The shoal is formed throughout the mid section of the river course (20 to 40 cm during the low water period), and the navigation waterway from the right bank to the left bank sides is undefined, giving a sharp approach angle for the assumed waterway.

View points of the site are illustrated in Fig. 3.1

- The thalweg of the deepest bed during the lower water period shifts from the right bank to the left bank (PT-1).

- There are many shoals having a depth of 20 to 40 cm on the downstream side (400 meters) of the sand bar in the middle region (PT-2).

- The deepest bed is formed on the immediately downstream side of the middle bar region, and the thalweg side from this point may shift toward the left bank (PT-3).

Uniao :

The shoal is located on the left bank side of the river course, with the sand bar located in front of the middle reach and wharf so causing navigation difficulties.

Fig. 3.2 shows some view points of the Uniao site.

- The thalweg of the deepest bed for the navigation waterway during the low water period is located along the right bank side, and is along the natural levee on the downstream side (PU-1).

- There are numerous shoals having a depth of 20 to 30 cm on the upstream side of the bar on the left bank side during the low water period (PU-2).

- The bar on the upstream side of the wharf may expand downstream (PU-3).

Buriti dos Lopes :

Sand bars stretch from the right to the left bank, providing a sharp approach angle for navigation from the left to the right bank during the low water period.

View points of the Buriti dos Lopes site are illustrated in Fig. 3.3 and Fig. 3.4

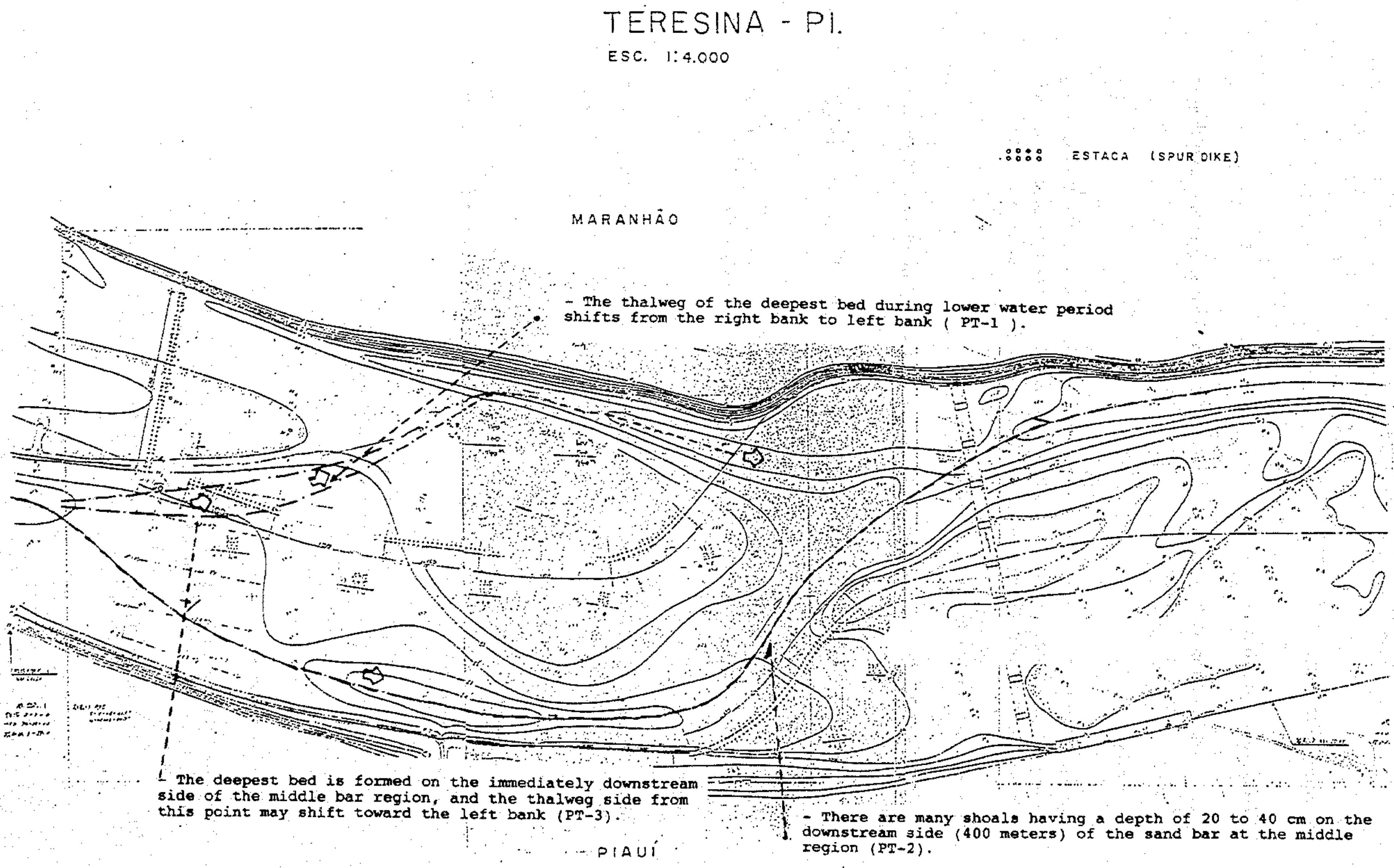


Fig. 3.1 Teresina Site Situation

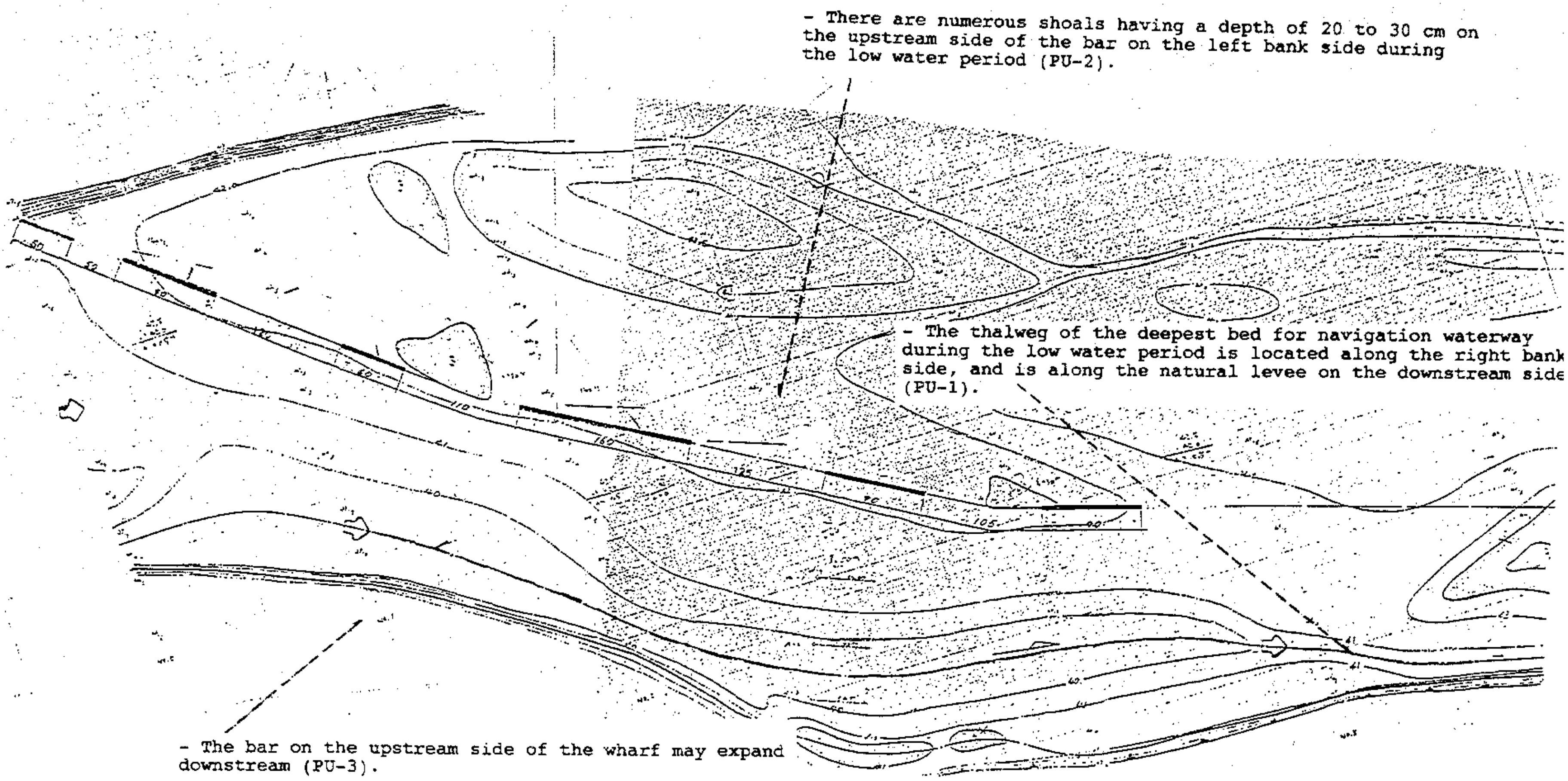


Fig. 3.2 Uniao Site Situation

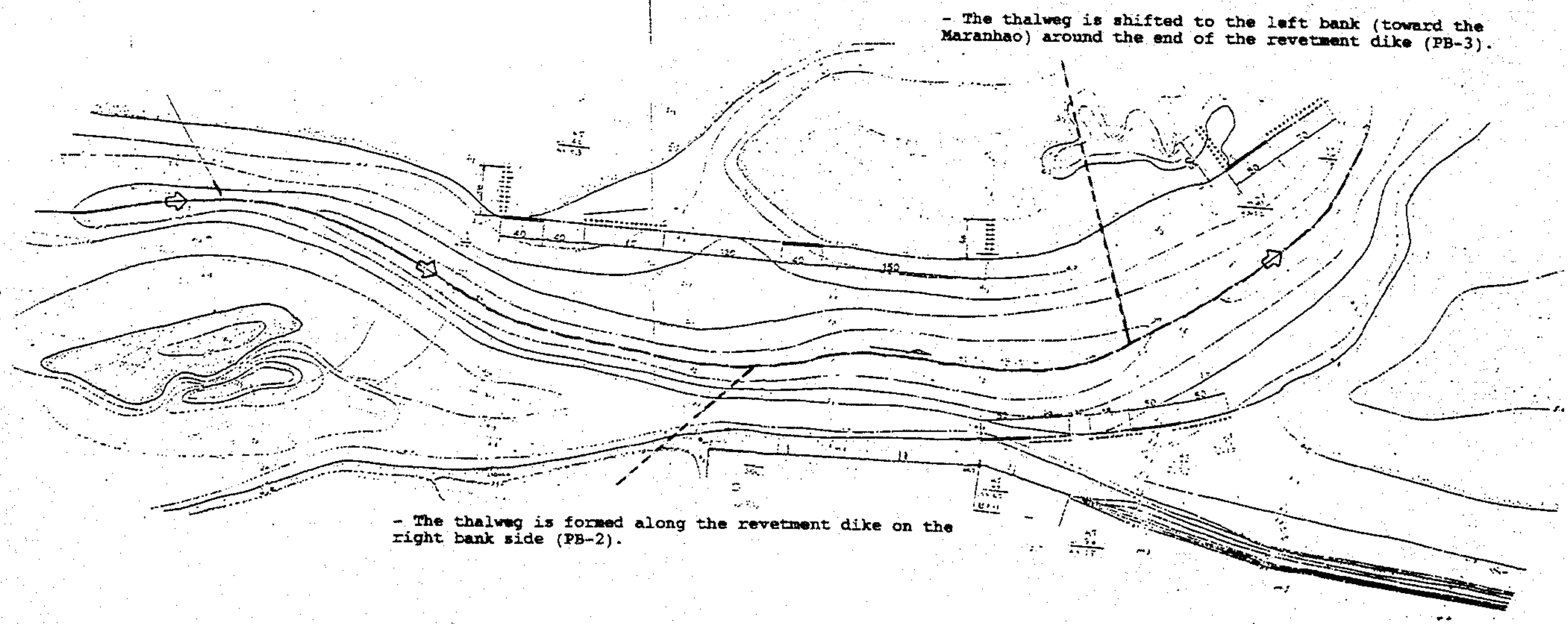


Fig. 3.3 Buriti dos Lopes Site Situation (1)

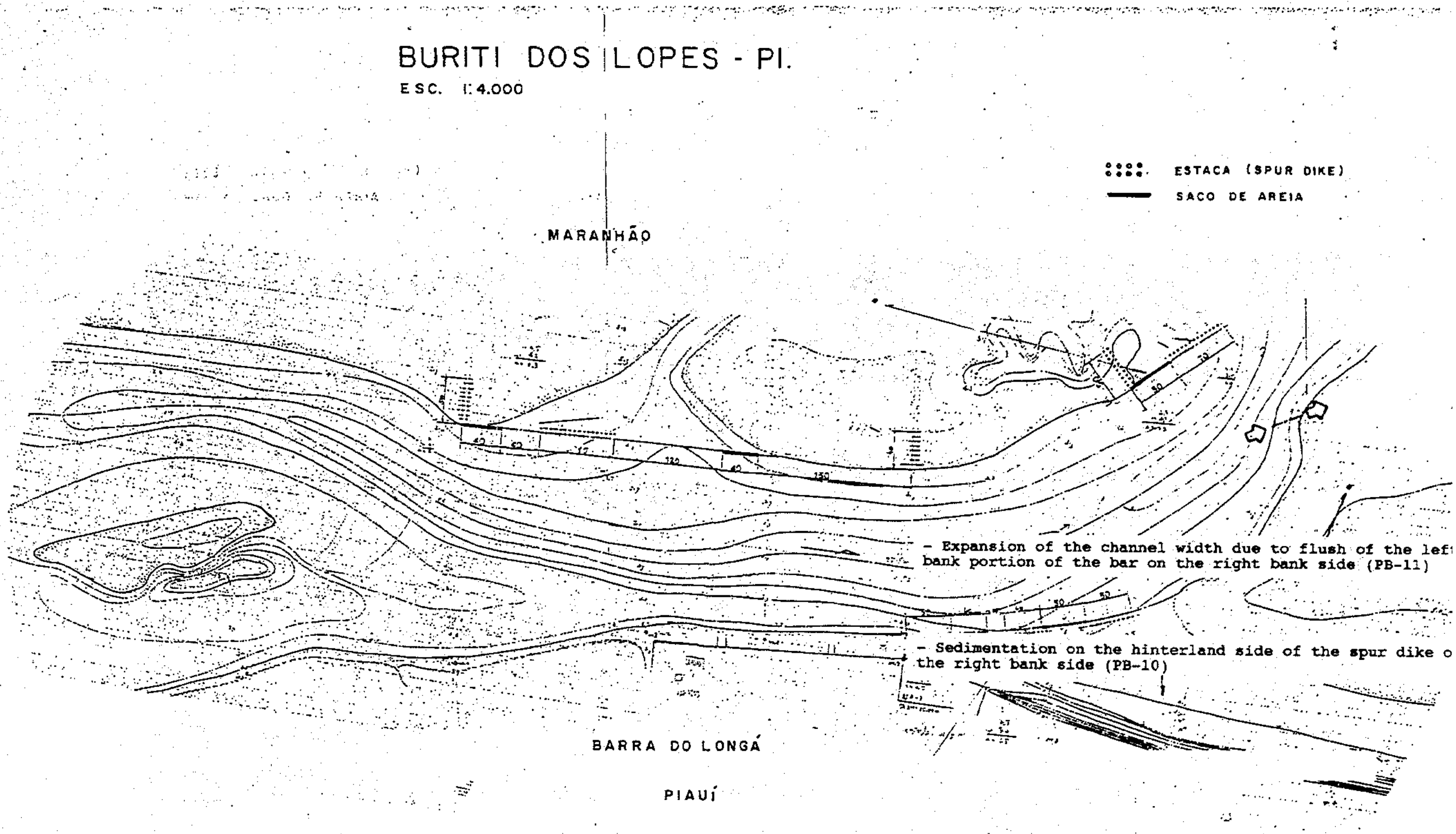


Fig. 3.3 Buriti dos Lopes Site Situation (2)

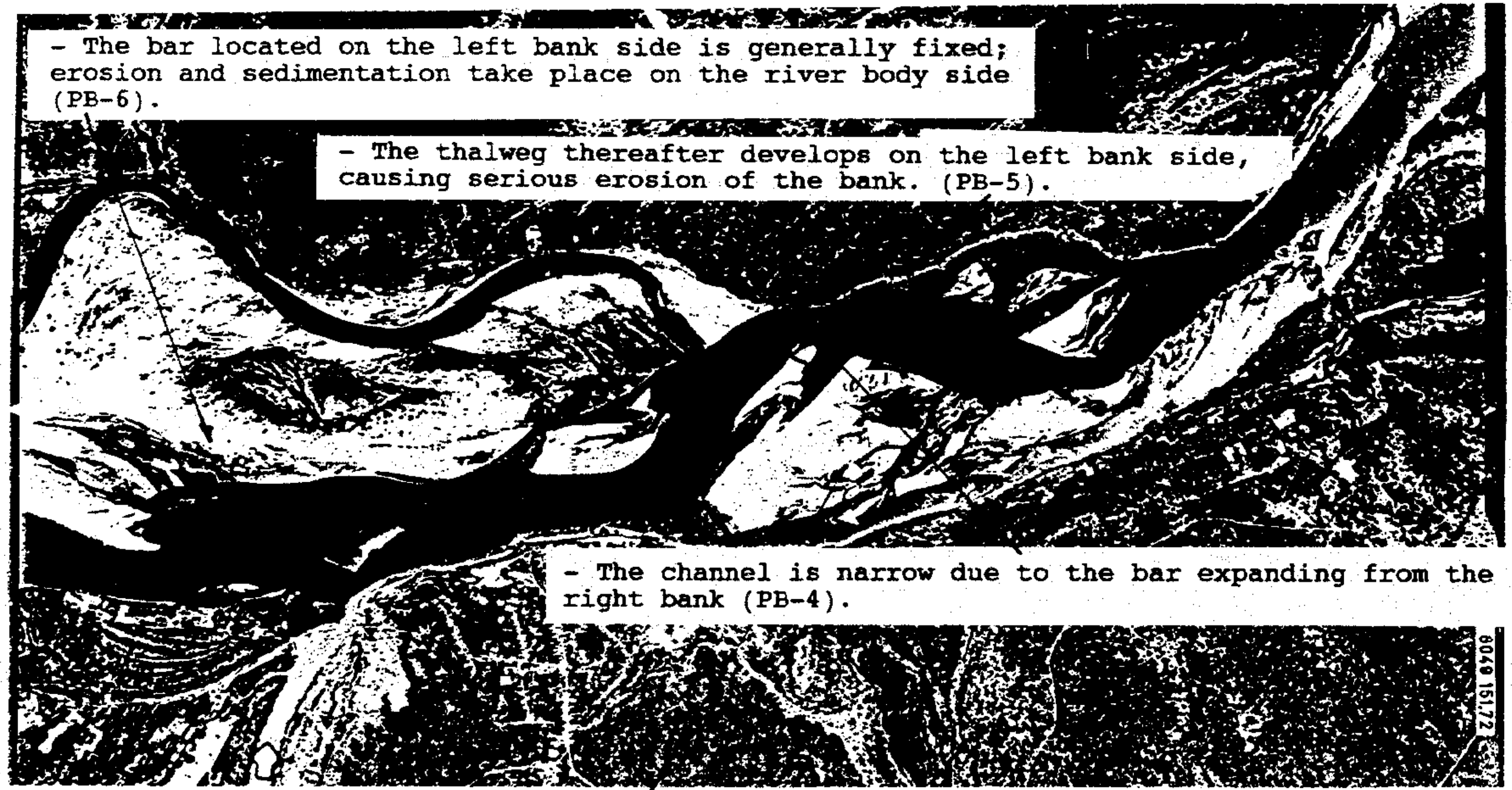


Fig. 3.4 Buriti dos Lopes Site Situation

- The thalweg of the deepest bed is located along the left bank of the small bar in front of the Rio Longa.

- The thalweg is formed along the revetment dike on the right bank side (PB-2).

- The thalweg shifts to the left bank (toward the Maranhão) around the end of the revetment dike (PB-3).

- The channel is narrow due to the bar expanding from the right bank (PB-4).

- The thalweg thereafter develops on the left bank side, causing serious erosion of the bank. (PB-5).

- The bar located on the left bank side is generally fixed; erosion and sedimentation take place on the river body side (PB-6).

- A small water course is located on the bar at the end of the revetment dike, separating the left bank and the bar (PB-7).

3.2 Spur Dike Installation

The following describes the spur dike installation based on the understanding of the current situation:

Teresina :

- The low water course should be ensured on the right bank side up to 200 meters on the upstream side of the bridge pier from the middle bar.

- A channelized spur dike should be provided on the downstream side of the middle bar.

- A Spur dike should be provided to shift the low water course on the right bank side toward the left bank side.

Uniao :

- For the current water course during the low water period, the flowing water is concentrated on the right bank side in order to maintain the thalweg of the deepest bed.

- Control of the spreading of the flowing water toward the top end of the bar on the left bank side (PU-4).

Buriti dos Lopes :

- Layout of the spur dike based on the water course alignment during the low water period

- Flowing water control to lead it into the small water course (along the right bank) of the bar on the right bank side (PB-8).

- The direction of the water flow between the small bar found on the river body side at the end of the bar on the left bank side and the bar on the right bank side to should be shifted slightly to the right (PB-9).

3.3 Effects of the Spur Dike

It is desirable that the spur dike construction causes the following phenomena:

Teresina :

- The current water course during low water period can be fixed.

- The deepest bed traversing from the right bank to the left bank can be made still deeper.

- The draft for the vessel navigation can be ensured at the datum water level .

Uniao :

- The draft for the navigation in the low water course can be ensured at the datum water level .

- The deepest position can be ensured by concentrating the flowing water onto the right bank side.

- Removing the shoal around the wharf on the right bank side.

- Sand sediment between the spur dikes on the left bank and the hinterland.

Buriti dos Lopes :

- Sedimentation on the hinterland side of the spur dike on the right bank side (PB-10).

- Expansion of the channel width due to the flushing of the left bank portion of the bar on the right bank side (PB-11).

- Modification of the water flow direction around the end of the spur dike construction section.

3.4 Test Construction Section

Teresina :

The test construction section measures about 800 meters from the middle bar region up to the upstream side of the bridge pier. This is considered to be appropriate for the following reasons:

- The bar in the middle region is generally stable.

- The major water channel is located on the right bank side of this bar. There is no existing obstruction which may change this channel to the left bank.

- The spur dike to shift the low flow channel should be installed in the section from the bar of the middle region to the pier.

Uniao :

The test construction section shall be about 1,000 meters from a position 800 meters on the upstream side of the wharf. Furthermore:

- There has been no change in the bar position on the right bank side for the last ten years.

- The major existing water flow is located along the right bank, and the water is further concentrated by the spur dike laid out on the left bank side.

- There is no obstacle which may change the major water flow on the upstream and downstream sides of the construction section.

When these factors are taken into account, the construction section is considered to be adequate to achieve the objective of the spur dike installation.

Buriti dos Lopes :

The test construction section is about 900 meters long, ranging from a point 200 meters on the downstream side of the small bar in front of the Rio Longa to a point 400 meters on the downstream side. The length of the bar on the left bank side appearing above water level is about 2,000 meters. There is a concern over the construction section being subjected to erosion and sedimentation on the river body side.

3.5 Discharge Capacity

Generally, the discharge capacity of a low water channel for the rivers in Japan is based on the average of annual maximum flood discharge or flood discharge of 2 - 3 years return periods. Because the bar scale and cross section condition of the low water channel for rivers with material of a mean diameter of 1 cm above correspond to the depth and tractive force in these flood discharges. But, less flood discharge forms sand bar scales for sandy rivers. A discharge less than these flood discharges will be checked for the low water channel capacity of sandy rivers.

The design discharge capacity for navigation channels varies according to the desired navigation period, river discharge, its variation pattern and the required draft for navigation. It usually employs the average of the annual 355-day discharge or the average of the annual 275-day discharge for the navigation period throughout the year. (referred from "Gendai Suisei-Ron,1992" by Dr. K.Yamamoto)

For Brazilian rivers, the capacity of the low water channel must be checked for a discharge corresponding to the bar scale in view of river management.

For this study, the average of the annual 355-day discharges at the sites for the navigation channel capacity will be taken in account.

Teresina : 240 m3/s
Uniao : 250 m3/s
Buriti* : 340 m3/s
(Note: The discharge at Buriti is represented from Luzilandia W.L Station)

3.6 Crest Level

The crest level of the spur dike shall calculated from the datum water level at the time of the design discharge for the channel. It should be about 30 to 50 cm higher this level.

The low water channel width shall be similar to the water surface width confirmed at the time of the local survey.

The water level shall be calculated by the uniform flow calculation. The roughness coefficient shall be assumed as n = 0.02 from an average grain size of d = 0.2 to 0.24 mm. The uniform flow calculation is made at the following water levels .

Water Level Calculation at 3 Sites

	W.L (m)	S.Area (m2)	H.R (m)	Width (m)	Velocity (m3/s)	Q (m3/s)
Teresina :						
	El. 53.4	318	1.521	209	0.783	250
	El. 53.7	382	1.778	214	0.868	330
Uniao :						
	El. 42.2	326	1.398	204	0.745	243
	El. 42.5	367	1.568	204	0.807	296
Buriti :						
	El. 4.11	336	1.651	203	0.824	277
	El. 4.20	420	1.827	230	0.881	370

Consequently, the datum water level for the navigation channel and the crest level of the dikes are defined as follows ;

Teresina :

The datum water level is calculated to be El. 53.4 m. Since the elevation of the bank terrace and the bar elevation is El. 54 to El. 55 , the crest level of the dike is calculated as El. 55.5 (+2.1 m) in consideration of the effect of the flood tractive force.

Datum water level	: El. 53.4 m
Crest level	: El. 55.5 m

Uniao :

The calculated datum water level is El. 42.3 m and, the crest level is El. 42.8 with the allowance of 50 cm.

Datum water level	: El. 42.3 m
Crest level	: El. 42.8 m

Buriti dos Lopes :

The datum water level is calculated as El. 4.45 m the crest level of the sand bag structure as El. 4.8 m , and the pile structure crest level as El. 6.0 m

Datum water level	: El. 4.45 m
Crest level :	
for sand bag Str.	: El. 4.8 m
for pile Str.	: El. 6.0 m

3.7 Structure Type

Teresina :

Procurement of eucalyptus lumber is relatively easy in the Teresina area. As the Rio Parnaíba has a gradual slope the pile dike can be used for the gentle flowing river.

Generally, wooden piles having a diameter of about 15 cm are arranged in two and three rows at an interval of 1 meter. The staggered ones will be arranged in three rows at the interval of 1 meter.

Uniao :

The sand bag spur dike method, a bagged mixture of bed material and soil cement and tested at Rio Pindare in the Province of Maranhão, should be used. This provides easy construction and uses river bed materials.

Local branches and leaves are laid under the bags to prevent local scouring.

Local branches and leaves are laid under the bags to prevent local scouring.

Fig. 3.5 illustrates the standard cross section at each height.

Buriti dos Lopes :

Sand bag and pile dike structures at this site were used to check the endurance of the structures under the same hydraulic conditions.

3.8 Layout

According to " The Manual for River Works in Japan " by the Ministry of Construction Japan , the direction of the spur dike structure is based on the dike construction objectives, the site river condition, etc.. Fig. 3.6 shows the cross dike structure and longitudinal dike structure samples.

It is pointed out that the longitudinal dike is considered to be effective in ensuring a water depth for a navigable waterway. (" Gendai Suisei- Ron ")

The cross dike structure requires a greater construction cost than the longitudinal dike, and the interval of the spur dikes can be increased, when based mainly on the longitudinal dike structure. Thus, the spur dike structure shall be based on the longitudinal dike structure in principle, with partial dependence on the cross dike structure.

3.9 Structure Length and Interval

There are said to be no definite standards for a spur dike length for a longitudinal dike with respect to a navigation waterway and the spur dike interval.

The following points are indicated for the cross dike:

- The spur dike interval is 1.5 to 2 times the spur dike length.

- Recommended values by Flengs :

Strait section	--- B * 5/7
Convex bank	--- B * 2
Concave bank	--- B * 1/2
	B: Waterway width

- Recommended values by Winkle :

It should be planned that the waterway be controlled by the spur dike has the design discharge capacity .

Assuming that the flow spreading behind the spur dike is 6.6 deg., according to Winkel's recommendation, and the profile of the waterway between the dikes is that of

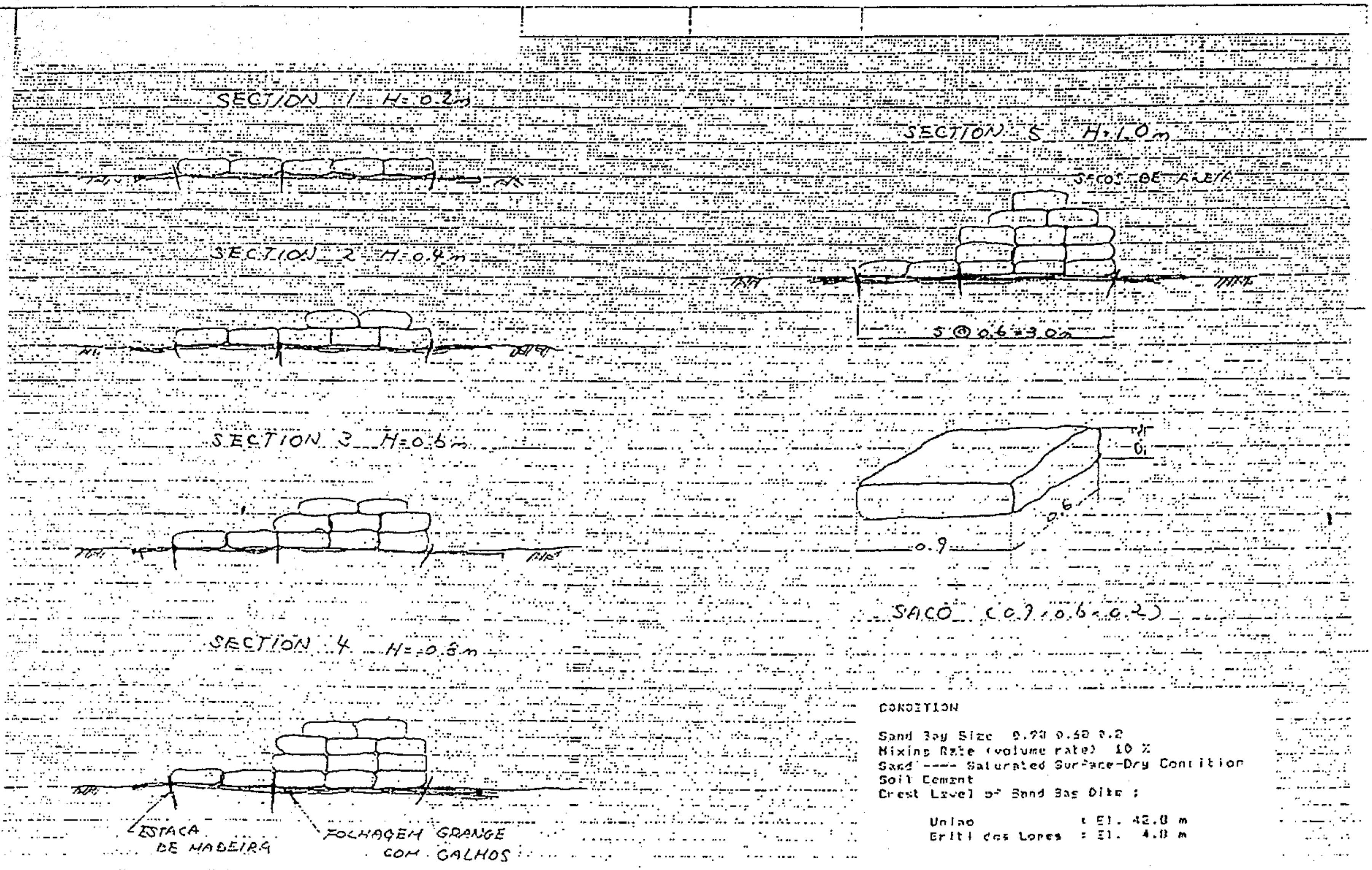
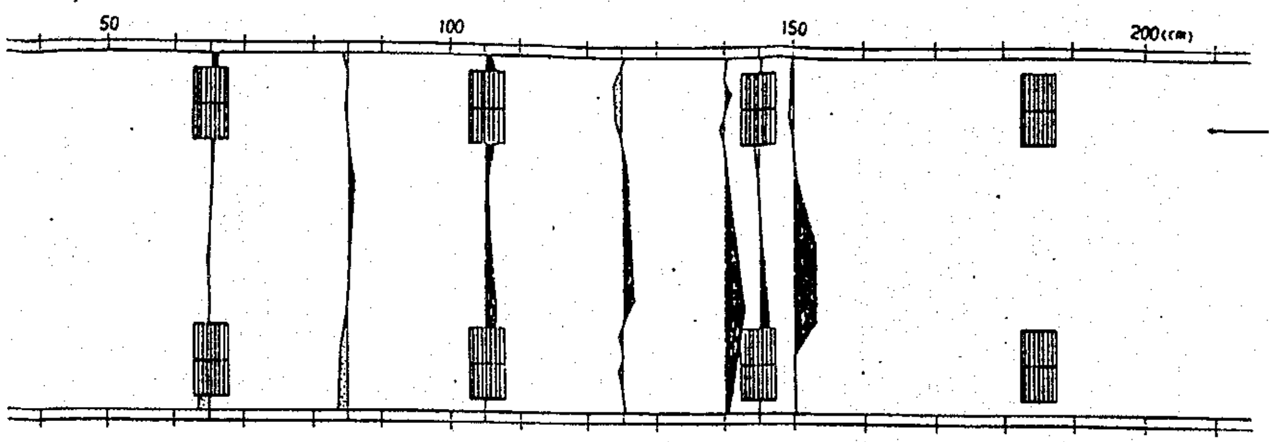
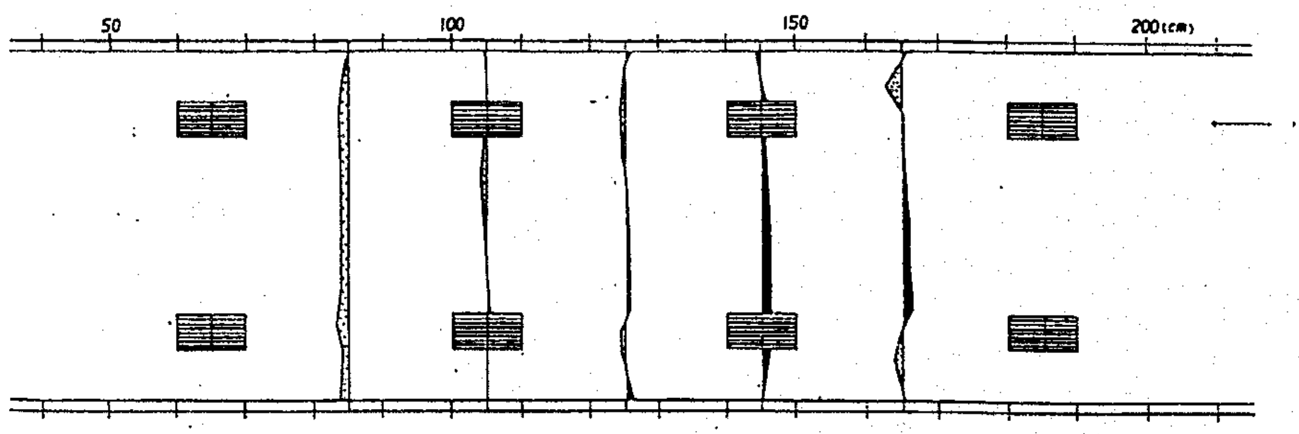


Fig. 3.5 Standard Section for a Sand Bag Dike



Cross Dike Structure Arrangement



Longitudinal Dike Structure Arrangement

Fig. 3.6 Dike Structure Type

the Tone River in Japan , the substantial river width B before the next dike will be as below ;

BS= B + 2*Lg*tan(6.6)

Thus, the spreading rate alpha of the river width is expressed as:

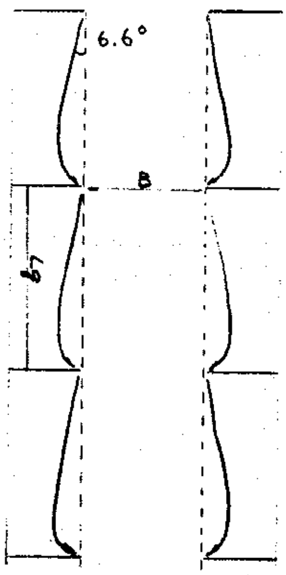
alpha = 1 + 0.23*Lg/B

Increases in the river width spreading rate leads to less water depth, so this (alpha) must be maintained below 1.15 from the viewpoint of ensuring a navigable waterway.

Therefore, the recommended value by Winkle is Lg = 0.65 *B

This value is similar to Frengs's value. Furthermore, if Lg increases, it causes a resulting in crease in the spreading angle. In order to prevent this condition, the following two conditions must be sought :

1) the dike interval to be less than 1/3*(sand bar length)
2) I * Lg < (v*v/2g)



Waterway Width between the Dikes

- DHL experiment

Lg < 0.3*$F*$F*h
($F : Velocity Coef.)

The following shows these values arranged at the discharge capacity for the channel. Flengs's values cover the values by Winkle and the DHL formula (DHL Report model investigation 1973: Verbetering bevaarbaarheid rivierkruising te Wijk bij Duurstede ; Morfologishe as pectem).

From Mr. Watanabe's Research Paper (Model Test of the Longitudinal Spur Dike for the Prevention of Bank Erosion) , the various factors are pointed out as following :

(1) When the dike interval (Lg) is sufficient than the sand bar length (Ls) or no sand bar occurs in the river, the bank line stretches to the next dike maintaing a certain angle ,and return to thawleg forming an arc .

(2) The bank line can be assumed as a line immune to either sedimentation and erosion. This line corresponds to the line which runs smoothly so that the flow line running through the front edge of the dike does not cause the peeling off behind the dike. It is assumed to be the critical angle where the peeling will no occur when the channel extends at a certain angle . This critical angle is about 6 to 7 deg. according to the experiment .

(3) Expanded length near the next dike is expressed as follows :

c : flow peeling angle (7 deg.)
f : flow return angle (45 deg.)

dL= 0.107 * Lg : Expanded length
BS= B + 2 (0.107 * Lg) : substantial river width

These values also are similar to Winkle's

For this study, the interval and length with consideration of the calculated values and site conditions, have been arranged to understand the efficiency of the spur dike or to check the formula proposed for the cross structure.

Figs. 3.7 - 3.9 show the general plans at the 3 sites.

	Teresina	Uniao	Buriti
B	200	200	200
$F	17	16	18
h	1.6	1.6	1.8

Interval	Lg :		
Flengs	100 - 200 m		
Winkle	130 m		
DHL	138	100	175
Length	Ls = 67 - 130 m		

Length and Interval of the Dikes

	Dike	Length (m)	Interval (m)
Teresina :			
	TS-1	200	
	TS-2	100	50
	TS-3	100	120
	TS-4	130	150
	TS-5	200	
Uniao :			
	US-1	50	
	US-2	90	50
	US-3	60	120
	US-4	160	110
	US-5	90	125
	US-6	90	105
Buriti :			
	BS-1	50	
	BS-2	40	0
	BS-3	80	40
	BS-4	40	120
	BS-5	40	160
	BS-6	50	240
	BS-7	120	0
	BS-8	90	
	BS-9	140	20

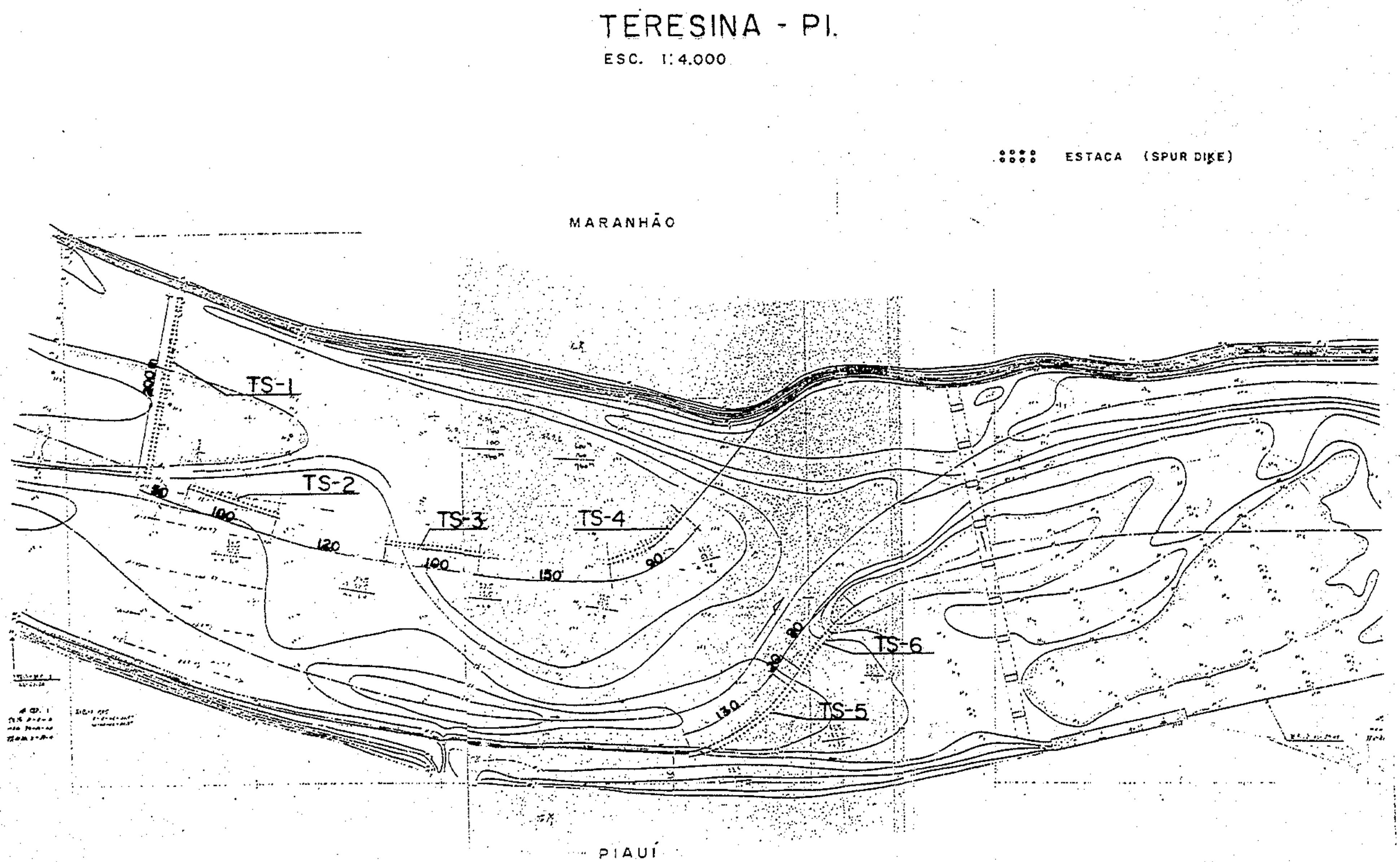


Fig. 3.7 General Plan for Teresina

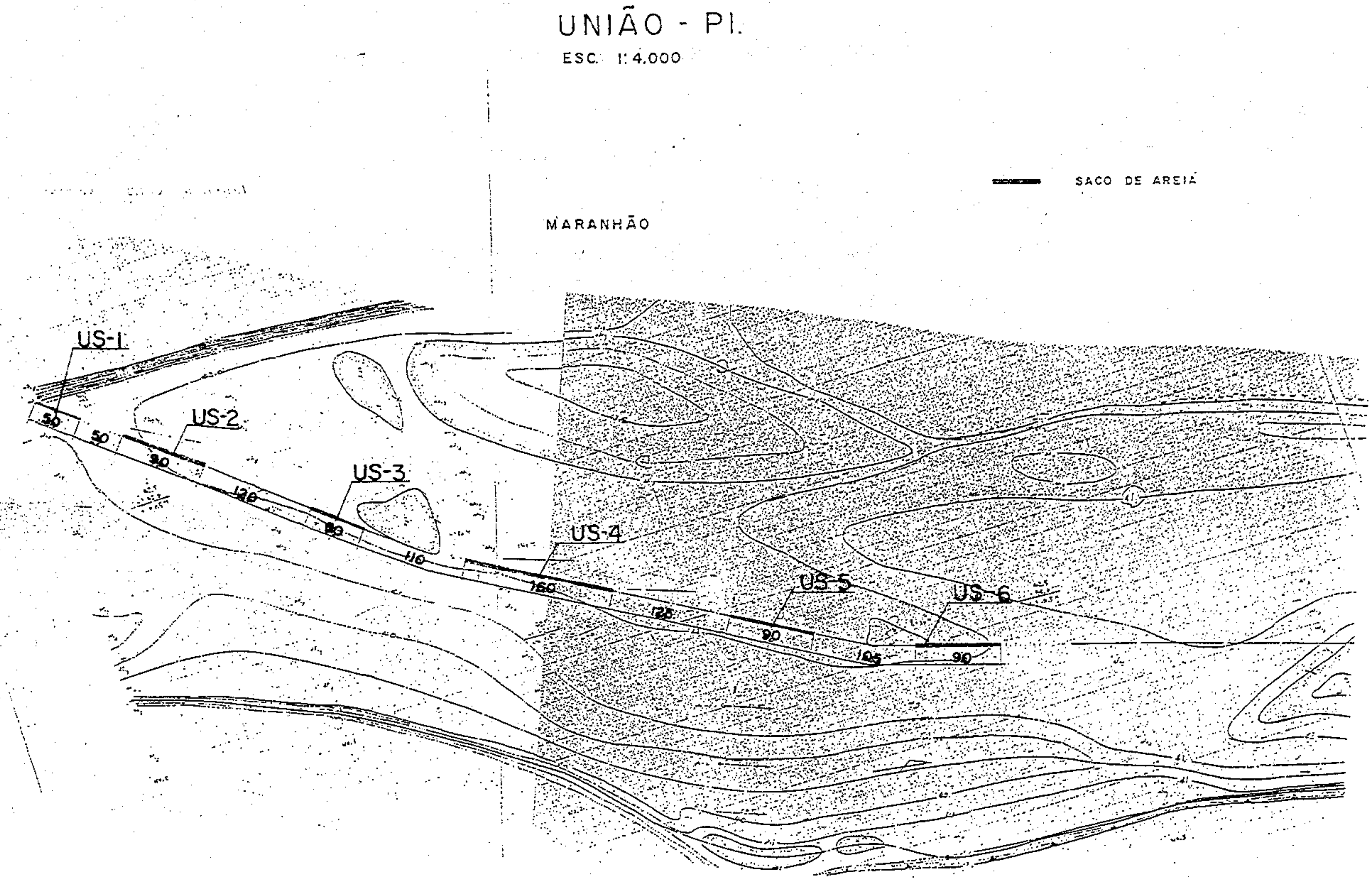


Fig. 3.8 General Plan for Uniao

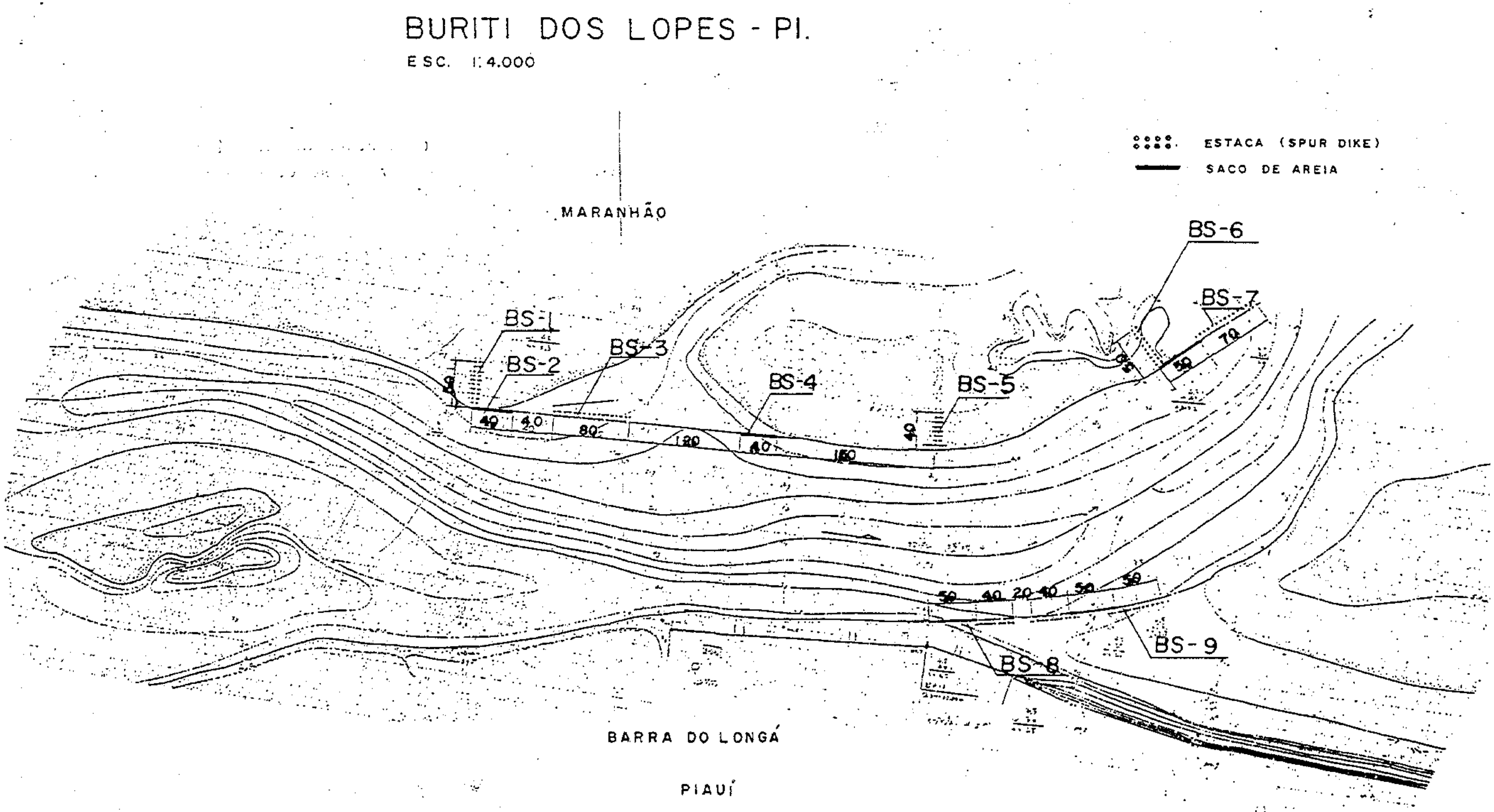


Fig. 3.9 General Plan for Buriti dos Lopes

4. CONSTRUCTION

4. Construction

4.1 Items of Work

For the pilot construction of 3 spur dikes at Teresina, Uniao , and Buriti dos Lopes , the following works were carried out during Phase 3.

(1) Preparation for contract documents
(2) Negotiations with local contractor
(3) Preparation with SEPLAN for official permission
(4) Supervision

4.2 Construction

The construction of 3 spur dikes was executed by a local contractor, based on the contract document dated October 8, 1993.

(1) Construction Site

	East	North
Teresina	742,000	9,436,000
Uniao	736,000	9,493,000
Buriti dos Lopes	174,000	9,652,000

(2) Construction Period

* Teresina : 08/Nov./1993 -- 07/Dec./1993
* Uniao : 20/Oct./1993 -- 17/Nov./1993
* Buriti dos Lopes : 22/Oct./1993 -- 15/Nov./1993

(3) Structure and Quantity

* Teresina
  Wood pile spur dike L=710 m

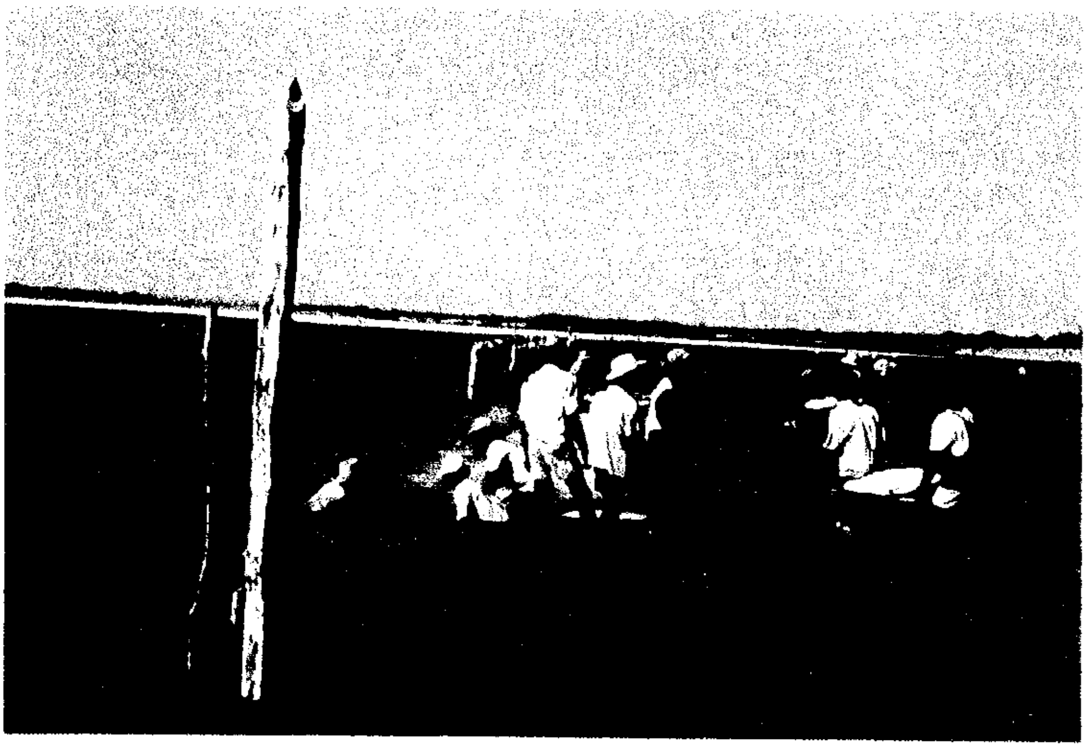
* Uniao
  Sand bag spur dike L=540 m

* Buriti dos Lopes
  Wood pile spur dike L=420 m
  Sand bag spur dike L=230 m

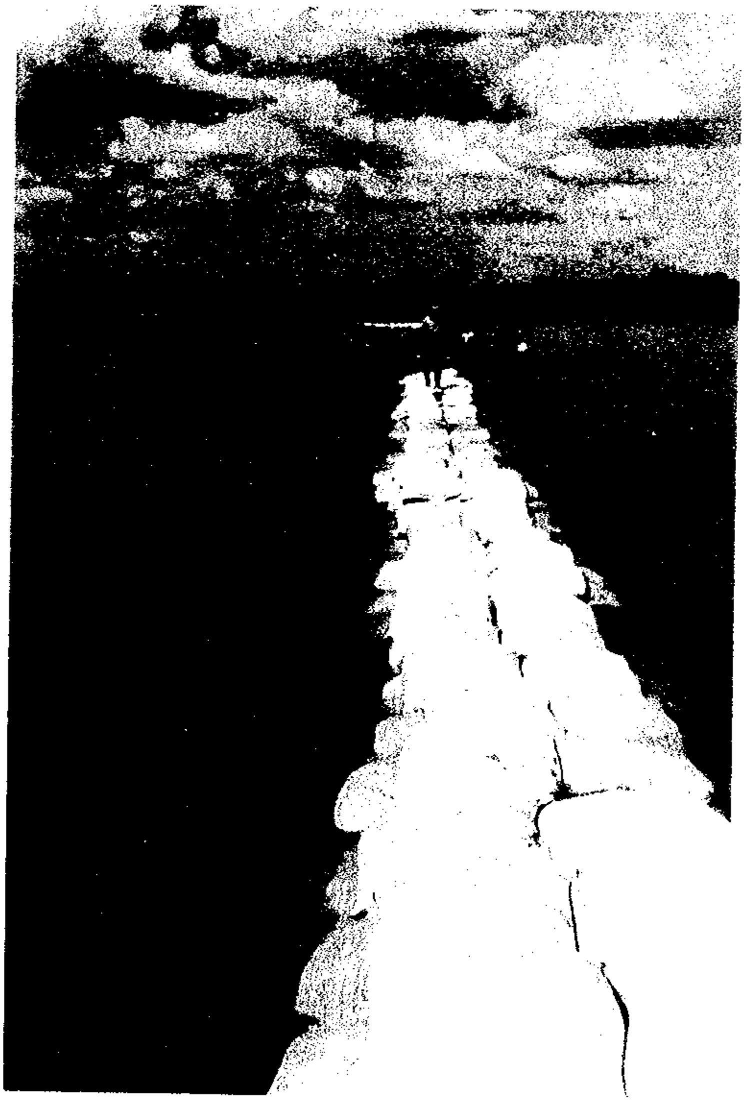
(4) Photographs

Photographs of the construction progress at the 3 sites are shown.

Spur dike construction work at Teresina



Spur dike construction work at Buriti dos Lopes



Spur dike construction work at Uniâo