Annex E

Coastal Investigation

Annex E COASTAL INVESTIGATION

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Annex E COASTAL INVESTIGATION

E1 Introduction

The Agos Dam, once built, will reduce sediment release to the downstream reaches. This may cause some changes in the environment of coastlines of the Infanta Peninsula (Infanta-General Nakar Alluvial Plain). In this context, this Annex looks into the probable features of future coastal condition.

The study firstly examined the historical background of formation of the Infanta Peninsula and present condition of the coastal area. Then, an analysis was attempted to figure out the littoral sediment transport purposing to provide information for predicting the future condition of the coast. Finally, the study proposed the method of monitoring of coastlines and also possible countermeasures to be adopted if any adverse condition arises.

A major difficulty encountered was the scarcity of information for the study, particularly, the data relevant to sea current, waves, seabed topography, grain sizes of coastal sand, etc. Therefore, the study had to be based on several broad assumptions, visual observation, quick sampling and other simplified approaches. In this respect, the study is regarded to remain at a preliminary level. The subsequent further study is recommended at the end of this Annex.

E2 Available Coastal Data and Field Survey Conducted

E2.1 General

For studying the issue on the coastal change at Infanta Peninsula that may be caused by the construction of the Agos Dam, collection of the relevant data was attempted in both the Philippines and Japan. To supplement the scarcity of availability of the existing data, preliminary field survey was also conducted.

E2.2 Data for Analysis of Present Condition

For analyzing the historical background and present conditions of the coast, collected were satellite imageries, aerial photographs, reports and papers, and other published data. Interview to the local people residing along the coastline was conducted to collect the on-site information.

As a result of visit to the concerned agencies, the study found that no informative data relevant to the existing condition of the Infanta coast were obtainable from the existing literatures. Hence, the study had to rely mainly on the information available from the following sources:

Aerial Photographic and Satellite Data:

Three aerial photographs and two satellite imageries were collected with an objective of analyzing the geographical change in and around the Infanta Peninsula for the last 50 years. The photographic data collected are as follows:

a) 1951	aerial photograph	US Army
b) 1966	aerial photograph	PICOREM
c) 1984	satellite photograph	USGS LANDSAT
d) 1995	aerial photograph	NAMRIA
e) 2001	satellite photograph	USGS LANDSAT

These photographic data contain the information of topographical features in the respective years, covering the whole area of the Infanta Peninsula of about 120 km^2.

Interview to Local Residents:

The objective of interview survey was to hear verbally the present condition of the coast, such as recent change of coastlines, seasonal erosion and/or sedimentation, damage to the facilities on the coast, dominant wind direction, etc. The interview was made to local residents of senior ages who live near the coast for a long time.

E2.3 Data for Coastal Sediment Analysis

To predict the coastal impact in terms of the topographical change of coastal area, the features of sediment transport along the coast needs to be examined. For this purpose, the existing reports/papers and other published data relevant to climate, hydrology and hydraulics were collected. Supplemental field survey was also conducted to obtain necessary field information, such as visual confirmation of in-situ conditions and sampling of coastal sand for grain size analysis.

The sediment transport consists of sediment yielded from the Agos River Basin and littoral drift along the beach.

To examine sediment yield from the basin, it was necessary to collect the data for the river discharges, grain sizes of the riverbed sediments and the representative river cross sections.

River Discharge

Flow duration curve at the river mouth was derived based on monthly discharge data at Banugao streamflow gauging station (SGS) for the period from 1950 to 1973. The discharge at the river mouth is estimated in proportion to the ratio of the catchment areas of the two sites.

River Cross Section

A typical river cross section is selected from the river cross sections near the river mouth. The cross sectional data were made available from the topographic survey conducted under the Study.

Grain Size of Riverbed and Coast Sands

Information of grain size of the sands was obtained by sieving the samples taken under this study at selected places in the river and beach. The grain size of sand is a major factor influencing the formation of sand bar at both the river mouth and coast.

Analysis of the sediment transport along the coastline requires the data on wave conditions specific to the area. However, visit to the agencies concerned revealed the unavailability of the data. Hence, the study was obliged to derive the wave conditions based on wind speed/direction data.

Wind Speed/Direction Data

Wind data (speed and direction) were made available from PAGASA records which have been taken for the period of decades at Infanta meteorological observatory. The wind data so collected cover both the daily and monthly data for the period from 1961 to 2000. The method of calculation to derive wave condition from wind speed and direction data is called the “wave forecasting” method.

E3 Historical Change of Infanta Peninsula

E3.1 General

An attempt was made to analyze the historical background of formation of the Infanta Peninsula. The purpose of analysis is to make clear the origin of Infant Peninsula and the historical changes up to the formation of present peninsula. The analysis adopted two approaches: one is geo-morphological study on a macro basis encompassing a historical period of some 20,000 years and the other is to examine topographical changes on a micro basis for the recent 50 years.

E3.2 Historical Development of Infanta Peninsula in Last 20,000 Years

Figure E3.1 shows graphically the historical background of formation of Infanta Peninsula over 20,000 years dating back to the Wurm Gracial Epoch. This analysis was made from the geo-morphological viewpoint based mainly on the information available from the literatures and the interpretation of recent satellite imageries.

At the time when the sea level was lower than the present level by about 100 m in 15,000 to 20,000 years ago, the Pollillo Strait was still a land bridge connecting the Infanta Plain and Polillo Island above the sea level. The sediment yields from the Agos River are supposed to be very active during the period due to extensive incision of the river valleys coupled with lowering of the river bed levels. A wide fan deposit was created in the Polillo Strait in the age.

In the subsequent ages after the re-rise of sea level, the fan has continuously developed over the area of older fan deposit and has formed the present shape of peninsula with the accumulation of sediments by near-shore current and also by yields from the Agos River Basin. The inferred process of the peninsula development is detailed in Figure E3.1.

E3.3 Change of Infanta Peninsula in Last 50 Years

Using the satellite imageries and aerial photographs listed in in the foregoing Subsection E2.2, the change of coastlines in these 50 years was analyzed. Figure E3.2 shows the latest condition in 2000 as an example of the study output, where the 1:50,000 scale base map used in the Figure shows the condition in 1951. The results of the analysis are summarized below:

<u>Change of Agos River Water Course</u>

a) At the area of the top of fan, relatively hard terraces have developed over the long period. This contributes to form the stable river course in the area. The change of the river courses is observed to be limited to the downstream part near the river mouth.

b) Major change of the river course is observed in the stretch between the end of old fan located near Anoling and the river mouth. It seems that a new fan of moderate scale seems to be still in the process of development in the area.

c) In a broad term, waterway courses in the river mouth area tend to move northward. This is due to the development of sand bar at the outlet of southern courses.

<u>Changes of Sand Bar and Tideland</u>

a) The changes of sand bar at the river mouth indicate active sediment yields from the Agos River. The yielded sediments have filled the portions of coastline including inner low-lying area and moreover developed sand dunes. It also contributed to the formation of sand bar in conjunction with the accumulation of sands transported by near-shore current.

b) Notwithstanding active sediment yields from the Agos River, the protrusion of the river mouth sediments to the seaward direction has been of a limited extent during these 50 years (Figures E3.2). This is because the sediment deposited at the river mouth is constantly transported southward due to near-shore current. Yet, the sedimentation at the river mouth seems to be active.

c) The sediment transported southward accumulates along the southern coast extending up to the Dinahican area and partly diffracts into the Lamon Bay forming small sandbars along the south coast of the bay. The rest of sediment is transported to southern sea bottom.

d) In the southern part of the Peninsula plain, small streams originated from the mangrove swamps flow into the Lamon Bay. These streams are virtually the flow of small gradient in the low wet land and do not yield excessive sediments. Nevertheless, the gradual development of low-lying tideland is observed around the river mouth, expanding year by year. This may be the result of sediment yield due to artificial development in the mangrove forests, such as land reclamation, fishpond construction, etc.

e) Littoral drift in the Lamon Bay appears to accumulate sands along the south coast. But the wave force is not so strong as to create sand bar at the river mouth of the streams. The flow due to the tidal change and the flow from the stream basin seem to flush the sands transported by littoral drift. Thus, no clogging of the river mouths is observed.

f) Spit in Lamon Bay (near Tacligan Point) appears to be developing due to the littoral drift from the east.

g) Sediment yield from the small streams pushes the south coastlines gradually towards the Lamon Bay, but the extent is not so active as expanding the mangrove area. An exception is the inner area of spit near Tacligan, where mangrove habitat area seems to be expanding gradually.

<u>Changes of Near-Shore Current</u>

a) The near-shore current does not change so much during the last 50 years. It flows from north to south along the coast of Infanta Peninsula, and then turns the direction from east to west at Dinahican Point. Further, it flows along the coast of Lamon Bay, forming the spit of the Tacligan Point.

b) Only the aerial photographs in 1951 show the near-shore current from the Dinahican Point to the east. It seems that the flow is of a temporary nature that was induced by strong local wind.

Change of Mangrove Forest

a) A large part of the mangrove forest area, which was in the natural state in wide areas in 1951, has decreased drastically during these 50 years. At present, mangrove forests exist only in the low-lying lands near Dinahican Point and some part near the coastline.

b) Mangrove forest has been encroached artificially from inner land even in the area where the nipa palm co-inhabits. Decrease of mangrove forest is not due to the natural changes, since the waterway of creeks, which flow through the lowland of mangrove forest, has not changed for the last 50 years.

c) Of the artificial encroachment, development of fishpond for shrimp and crab was dominant. The development was particularly active in the areas along the relatively large streams due to its easy accessibility on the water surface.

E4 Present Condition of Coastal Area

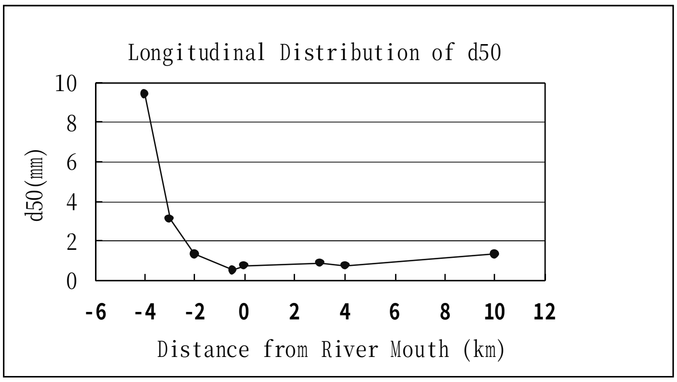
To confirm the present condition of coastal area, field reconnaissance and interview to the local residents along the coast were conducted in February 2002. The results are described below.

E4.1 Sampling of Coast Sand and Analysis of Grain Size

Sampling of coast sand was conducted at nine (9) points along the coastline of Infanta and General Nakar to obtain the information of grain size distribution of the sand. The sampling was conducted in the following manner:

- Excavate an about 20 cm deep hole and gather sand sample of about 10 kg. The sample was put in a plastic bag.
- At each place, sampling was made at a point on the slope of swash zone of about one (1) meter above the sea level at the time of sampling.
- Location of samplings was delineated by a handy GPS.

The result of particle size analysis is shown in Figure E4.1 and the distribution of d_{50} along the coast is shown in the figure below and also in Table E4.1(1).



As shown in the figure, the grain size of sand represented by d_{50} is coarser northward and finer southward. This implies that the sediment transport by littoral drift is evidently southward. Accordingly, it is deemed that sediment discharged from the Agos River mouth is transported to the south direction.

E4.2 Field Reconnaissance and Interview to Local Residents

The results of interview and field reconnaissance are as follows:

(1) Northern coast of the Agos River

In the northern coast of the Agos River mouth, the slope of beach is generally steep and the width of breaker zone is as short as about 10 meters. Beach sand contains coarse cobbles, more in the northern part and less in the southern part. Fine sand is dominant only at the beach of the southernmost area near the Agos River mouth.

The results of the interview are as follows:

- Shoreline was about 50 meters inland side 10 years ago.
  (at a location about 3 km northwest from the river mouth, and the respondent was about 50 years old man)
- Shoreline was about 60 m inland side 20 years ago.
  (at a location about 2 km northwest from the river mouth, and the respondent was about 30 years old man)

- Shoreline has advanced about 100 m in these 25 years. Recently, shoreline seems to advance by about 1.5 m yearly on the average.
  (at a location about 2 km from the river mouth, and respondent was a woman of age of more than 45 years)

An excavated hole of 1m depth was found at a small hamlet located 3 km northwest from the river mouth. The hole is at about 100 m inland from the shoreline. Walls of the hole consist mostly of coarse-grained cobbles. It is inferred that heavy coastal sedimentation has taken place in the past. (See photograph attached)

Also, the photograph attached at the end of this Annex E shows the typical condition of the northern coast. The cobbles covering the coast consist of particles of rock origins apparently different from those observed in the Agos River Basin. This infers that the cobbles as well as sand are transported from the north by littoral current.

(2) Southern Coast of the Agos River

The present condition of southern coast of the Agos River is divided into two parts: (i) northern beach located close to the Agos River mouth, where the beach seems to be subject to erosion at local places, and (ii) middle to southern beach, where the beach seems to be quite stable.

The beach is flat and shallow over a long distance of about 50 m from the shoreline, but the surf zone is about several meters due to small wave height.

The beach is covered with sand mixed with cobbles. The beach gradient on the swash zone is about 1/8 at northern part and 1/14 at southern part, measured by a clinometer at selected typical sections. The features of southern and northern parts seem to be different each other, since the northern part is somewhat erosive and the southern part is very stable.

The results of interviews are as follows:

- Shoreline has retreated about 200 meters since 1940 and about 120m since 1985. The 1990 Tsunami with a wave height of 5 to 6m destroyed beach road and many houses and flushed away the beach to some extent.
  (at a location about 1 km southeast from the river mouth, and the respondent was about 50 years old man)
- Shoreline has advanced over a long distance in 1964 or 1965. After then, the shoreline has retreated more than 100 meters. The coast was lost last year too. The rate of erosion is about several meters annually in these years. Generally, the sea is very calm during the southwest monsoon, while the coast is erosive during the northeast monsoon. The 1990 Tsunami flushed away many houses and eroded the beach.
  (at a location about 1 km southeast, and the respondent was about 45 years fisherman)

- Shoreline has not changed so much during recent years, with no significant accretion nor erosion. Many houses and beach in a width of about 15 m were lost by typhoons in 1984 and 1985.
  (at about 7 km southeast from the river mouth, about 40 years old man)
- Fishery port tends to be accumulated with sand, resulting in the accretion of sand beach. Shoreline around the port has advanced about 30 m during the last 10 years.
  (at Dinahican, official staff of the fishery port)

The general conditions of the southern coast are shown in the photographs attached at the end of this Annex E.

(3) Summary of Observation

The findings from the field reconnaissance generally coincide with the result of the aerial photograph analysis.

The Agos River has yielded a large amount of sediment from old age and the sediment is transported southward by near-shore current with wave force caused by wind from the north. In the case of attack of typhoon of which north wind is usually dominant, strong wave might have changed the coast especially at the southern coast near the Agos River mouth.

The flow courses of the Agos River have changed heavily in the past due to accumulation of sandbars in the river mouth area. The river course tends to move northward, while sand bars in the southern area seems to be developing. The southern sand bar functions as if it were a jetty creating a sheltered area for waves at southern area of the river mouth. Local scouring at south of the river mouth is caused by the unbalance of sediment transport, which resulted from the existence of sand bar.

In a general term, the whole coast of Infanta Peninsula is under a stable condition, although the occasional local scouring is seen in the area just south from the Agos river mouth.

E5 Prediction of Coastal Change after Completion of Agos Dam

E5.1 General

To predict the possible coastal change after the construction of the Agos Dam, it is necessary to grasp the present condition quantitatively, especially the present condition of coastal sediment transport.

Sediment transportation in coastal area takes place by the forces of wave, tidal current and wind. It is said that, among these factors, the near-shore current generated by wave generally plays a major role for the sediment transport and the coastal impact is caused mainly by unbalance of sediment transport at the particular locations.

The assessment of future coastal change needs to be made based on various data specific to the objective site, such as sediment yield from the basin, energetic major wave condition throughout the year, sediment size and topography of seabed. Due to the lack of these data, however, the study at this stage had to adopt a simplified method.

Sediment yield from the Agos River Basin was evaluated on the basis of monthly mean discharge and on the assumption of uniform flow for a selected section of the Agos River. Representative sand size of sediments of bed load and littoral drift was obtained by sand sampling and grain analysis conducted under this study.

Wave condition in deep water was estimated from wind speed and direction data measured at Infanta by PAGASA. The near-shore wave condition was evaluated in consideration of wave refraction and sea depth and on the assumptions of parallel depth and uniform seabed. The calculation of sediment transport was made for seven (7) sections by dividing the total coastal stretch of Infanta Peninsula. The coastal change was preliminarily forecast by the one-line model based on the sediment transport rate evaluated for each coastal section.

The evaluation is based on the present geographic condition. Hence, the result represents the coastal change under the present condition, and its application should be limited to the prediction of the near future conditions where the geographic condition is not much different from the present.

The long-term prediction of coastal change should be made on a longer time scale in the next detailed design stage.

E5.2 Sediment Yield

To estimate the sediment yield of bed load from the Agos River Basin, which is presumed to be the main material of coastal formation process, the study conducted sand sampling/grain size analysis and calculation of sediment yield by the bed load formula. Sand sampling and analysis were conducted separately from the evaluation of suspended load.

(1) Sand Sampling and Analysis

Sand sampling for this specific analysis was conducted at five points in the river mouth area of the Agos River and five points on the beach of Infanta Peninsula.

The sampling was done on the surface of sand bar at respective points.

From the results of the grain size analysis, the d_{50} values were defined as shown in Table E4.1. The representative grain size of sands is regarded as 0.4 mm.

(2) Sediment Yield Calculation

With the bed load formula, sediment yield was calculated on the assumption of uniform flow. The method of calculation of sediment transport is described below:

a) The bed load formula used is the Doken Formula, which is widely used for the calculation of bed load in Japan. The formula was derived from hydraulic experiment.

b) The long-term monthly discharge at the river mouth is shown in Table E5.1, which were estimated based on the discharge data at Banugao SGS for the period from 1950 to 1978 in proportion to their catchment area ratios. The catchment area at the Banugao SGS is 889 km^2, while that of the river mouth is 940 km^2.

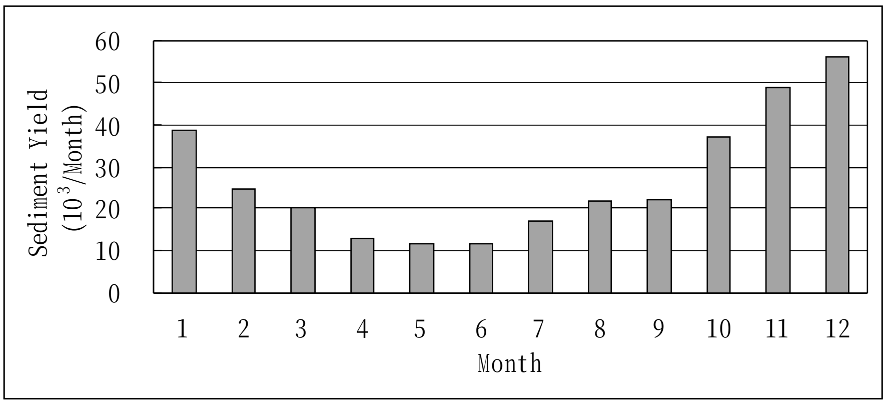
c) Of the river cross sections in the downstream reach of the Agos River, Section No.12 was selected as a representative section for the calculation. The cross section was measured through the topographic survey performed in the 2nd Field Investigation of this Study.

d) The longitudinal slope of the river is adopted as 1/492 based on the longitudinal river profile derived from the results of the above river cross-section survey.

e) The coefficient of Manning's roughness (n) is assumed to be 0.035.

The bed load yield estimated by the above method is tabulated in Table E5.2. The annual mean bed load yield of the Agos River is estimated at 322.7x10^3 m^3/year. The ratio of sediment yield of bed load to suspended load is about 0.33 as explained in Annex C of this Volume V.

The calculated monthly sediment yield of the Agos River is shown below:



Monthly Sediment Yield of Agos River

As seen in the above figure, major sediment yield is distinguished in the period of NE monsoon from October to February and less in summer season in the period of April to June.

E5.3 Coastal Sediment Transport

The main force for long-shore littoral drift is said to be wave-forced near-shore current.

Since there is no wave data which can be applied to this specific coastal area, the wave condition in deep sea is estimated from the wind data measured at Infanta.

To evaluate the sediment transport, the whole coastal stretch from the Gabriel Point to the Dinahican Point was divided into seven (7) segments. The sediment transport rate was calculated for each segment based on the estimated wave condition in which the effect of wave refraction and sea depth was taken into account.

(1) Wind Data Measured at Infanta

Wind data at Infanta were collected for the latest 40 years from 1961 to 2000.

The monthly wind data are summarized in Figure E5.1, which summarizes the number of occurrences of winds, being classified by wind speed level and direction. Predominant wind direction throughout the year is the north wind.

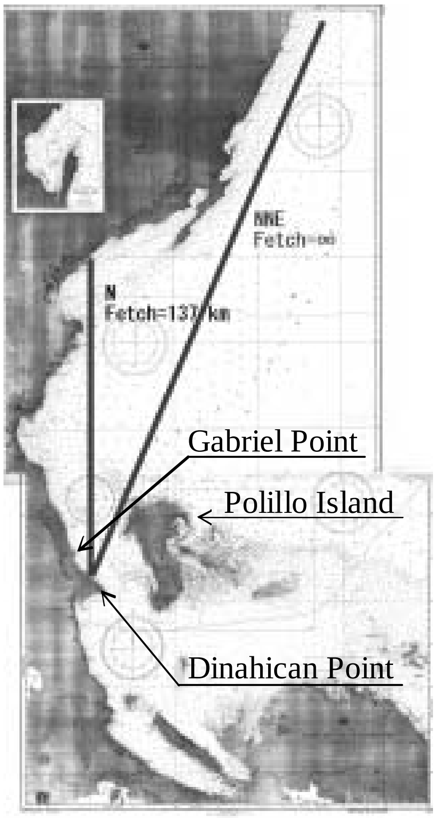
In addition, monthly wind data are graphically plotted according to the wind speed and wind direction as shown in Figure E5.2. As seen in the Figure, it is obvious that the north wind is almost eminent throughout the year except the period from July to September, while the southwest wind is predominant for the period from June to September.

The frequency of wind speed and direction is analyzed based on the 40 years monthly wind data tabulated in Table E5.3 (1), which shows the data normalized to the frequency in a year. From the data for the past 40 years, major 40 daily winds are selected as shown in Table E5.4. The frequency of wind speed and direction of the major winds is tabulated in Table E5.3 (2).

(2) Wind Wave in Deep Sea

Wave condition in deep sea is calculated from the wind data, such as wind speed, direction, length measured as wind blowing distance (fetch) and duration of wind blowing time. This method is so called SMB method, which is widely used for estimation of the significant wave in deep sea.

Due to the existence of the Polillo Island, the Infanta Peninsula is situated in a sheltered area so that the direct wave from open sea hardly reaches the Infanta Peninsula. The right-side figure shows the representative fetch and its direction.



The effective fetches adjusted by the shield effect are shown in Table E5.5.

For the respective cases of different wind directions with different fetches, the values of significant wave were calculated as shown in Table E5.6.

Then, the wave energy expressed as $(T_{1/3}H_{1/3})^2$ is calculated for the representative wind waves as shown in Table E5.7, where $T_{1/3}$ and $H_{1/3}$ are the significant wave period and significant wave height, respectively.

The ratio of energy of respective waves to the total energy is shown in Table E5.8. The wave energy ratio is calculated applying the following procedures and assumptions:

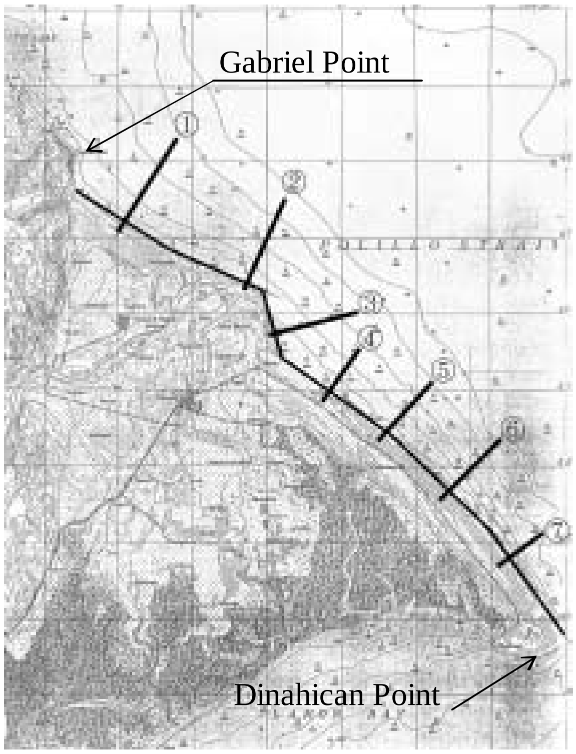
- Frequencies of occurrence of different wind conditions was estimated on daily basis referring to the distribution of monthly wind records for 40 years. The calculated result is deemed to represent the wind frequencies occurring in ordinary years.
- Calculation also takes into account the occurrence of major winds like 40 events listed in Table E5.4. It was assumed that major winds may occur every year.
- Total energy is thus estimated to be the sum of wave energies calculated for the ordinary wind condition and for the major wind condition.
- The wave originated by the northeast (NW) wind and diffracted by the Polillo Island was neglected, considering the limited number of occurrence of strong NW winds measured at Infanta.

It is interpreted from the Tables that predominant wave in ordinary years is from the north and the significant wave height $H_{1/3}$ in deep sea is about 0.22 m to 0.36 m. In the case the heavy storm attacks the beach, the significant wave height in deep water rises up to 3.38 m and its contribution to the total energy affecting the coastal area is very large.

(3) Wave in Shallow Water

Coast from the Gabriel Point to the Dinahican Point was largely divided into seven sections according to its face angle to the sea. Wave condition in shallow water was calculated for each of these coastal sections.

As the water depth changes, wave height and wave length also change. The shallow water wave conditions are calculated by a commonly used method as described below:



- The wave length in shallow water was calculated by dispersion relation.
- The wave height in shallow water was calculated considering the effect of water depth and refraction.
- Wave refraction was calculated on the assumption of uniform and parallel bathymetric line.
- Wave shoaling was calculated by the equation from small amplitude wave theory.

The wave incident angle at each coast section and the result of calculation of shallow water are tabulated in Table E5.9.

(4) Sediment Transportation

Sediment transportation was calculated by the CERC (Coastal Engineering Research Center, Bagnold/Inman/Komar, 1977) equation, which is most widely used for calculation of the sediment transportation. The calculated sediment transport rates are tabulated in Table E5.9. The result of sediment transport at each coastal point is shown in Figure E5.3, and the seasonal change of sediment transport shown in Table E5.10 and Figure E5.4.

As seen in the Figures, the sediment transport, in other term coastal change, concentrates in the period from November to December. From the Tables, it can also be said that the wave energy and the coastal change are very large when the big storm comes, even though its frequency is small.

On the other hand, in the ordinary conditions when the wave is relatively calm, the coastal change will be small. Only the wave from north, of which the wave height is 0.22 to 0.36 m, transports the littoral drift. The annual sediment transport assessed at each point is as follows:

Annual Sediment Transport Volume at Each Coastal Point

Point	Sediment Transport Rate ($10^3 m^3$/year)
Coastal Point-1	12.5
Coastal Point-2	9.4
Coastal Point-3	8.3
Coastal Point-4	13.0
Coastal Point-5	14.3
Coastal Point-6	14.4
Coastal Point-7	13.8

From the above results, the annual sediment transport rate is estimated at about 8.3×10^3 m^3/year to 14.4×10^3 m^3/year.

(5) Coastal Change

On the basis of the estimated sediment transport rate, the present tendency of coastal change can be assessed. A simplified method was applied to calculate the sediment transport at every coastal point and the coastal change. The method is so called 'One line Model', which is useful for predicting the macroscopic change of coastline. The result of coastal formation process under the present condition, derived through the calculation, is shown in Figure E5.5.

Although the sediment transport quantity estimated above is of a limited accuracy because of the lack of in-situ field data, the tendency of coastal change so indicated is believed to represent the likely condition. The tendency of coastal change under the present condition is estimated as follows:

Coastal Point 1 to 2:	stable (+1.0m/year)
Coastal Point 2 to 3:	shoreline retreat (-3.6m/year)
Coastal Point 3 to 5:	weak shoreline retreat (-1.2m/year)
Coastal Point 5 to 7:	stable (+0.2m/year)

The shoreline retreat presumed in the section of Points 2 to 5 is the result of the present formation of sand bar deposited at the river mouth. The tendency of coastal change estimated above is consistent with the information obtained through interviews to the local residents.

E5.4 Future Coastal Change

It is presumed that, after the construction of the Agos Dam, about 90 % of sediment yield from the Agos River Basin will be reduced. It is estimated that the bed load yield of 322.7×10^3 m^3/year at present will decrease to 32.3×10^3 m^3/year after the completion of the Agos Dam. This will give a certain impact on the coastal area.

(1) River Mouth

According to the result of calculation, the rate of annual sediment transport along the coast is about 8.3 to 14.4×10^3 m^3/year, which corresponds to 1/30 to 1/50 of the sediment yield of Agos River under the present condition. This means that, in ordinary years, far excess amount of sediment is yielded from the Agos River and only a part thereof transported to the southern coast of Infanta Peninsula. Most of the sediment is deposited in the river mouth area, estuary, riverbed, coast and seabed. This may be one of the reasons why the river course just upstream of the Agos River mouth is meandering actively due to accumulation of sediments and further the sand bar at the river mouth is growing.

In the future, the accumulation of sand bar at the river mouth will become less active and resultantly the front of river mouth retreats toward inland, since the sand bar at the river mouth is the result of deposit of sediment yield from the Agos River. The coastline will tend to form a more straight line in NW-SE direction without a protrusion at the river mouth.

After the completion of the Agos Dam, the dry season flow will be reduced to 22-25 m3/sec, which is less as compared with the 90 % discharge under the present condition (30 m3/sec). However, clogging of the river mouth would be unlikely, considering the following factors: (i) the dry season flow is still maintained, (ii) there is virtually no change in flood flow regime, which contributes most to flushing sand bar at the river mouth, (iii) the wave force is not so strong in the sea, and further (iv) sediment transport from the north coast is not much.

(2) Southern Coast from River Mouth

Due to the growth of sand bar at the Agos River mouth, the wave generated by the wind from the north refracts around the sand bar and the wave height is reduced. Consequently the sediment transport is small at this area. If the transport rate of southern coast is larger, the shoreline at the south of sand bar is somewhat erosive.

However, this is considered as a temporary phenomenon. The shoreline retreated at the south area of river mouth will become less active, if the Agos River changes its river course to south and/or the sand bar in front of the river mouth is washed out and begins to supply the coastal sediment southward.

(3) Total Stretch of Coast of Infanta Peninsula

Generally, the coast of Infanta Peninsula appears to be in the stable state at present. But if the sediment supply to this area is reduced, the coast may be subject to erosion due to near-shore current starting at northern part. Hence, it is necessary to monitor the coastal change and carry out adequate countermeasure if any adverse effect arises. The measure should be planned taking into account the total balance of sediment transported to the Infanta Peninsula (sediments from the Agos River and littoral drifts from the north).

E6 Installation of Monitoring System and Measures for Future Coastal Change

E6.1 Monitoring System for Coastal Line

(1) General

The objective of monitoring for coastal line is to observe the impacts on coastlines, which may arise after the construction of the Agos Dam.

Generally the items of coastal monitoring are as follows:

a) Grain size, grain distribution and grain shape of seabed material
b) Sea bottom slope
c) Shoreline topography
d) Shape of breaker line
e) Shape of river mouth
f) Topographic change around the structures
g) Current observation
h) Interview to inhabitants

Among the above items, the item c) is particularly necessary for monitoring of the effect of the Agos dam construction. A part of information about the seabed change will also be obtained by the observation of this item.

Shoreline position and its change are the most conspicuous and important among the dimensions of seabed change. As the tendency of seabed change can be inferred by the changes of shoreline position to some extent, the measurement of shoreline position and its change is regarded as one of the most important items as pointed out in many coastal studies carried out so far.

(2) Methodology

A possible approach is to estimate the shoreline position and its change by comparing aerial photographs taken at different years. Aerial photographs show sedimentary and/or erosive features of the coastal lines that are difficult to detect from the ground. Interpretation from the aerial photographs, however, involves difficulty in determining the shoreline position, because the diurnal position of the shoreline varies owing to tides and waves.

On the other hand, ground survey provides the highest quality data in terms of accuracy. The shoreline position at the mean sea level can be obtained by positioning and direct leveling on the beach at the timing coincident with the mean sea level given by the tide table.

An importance is the determination of the exact shoreline position on the site. The shoreline position should be delineated in relation to the mean sea level. For this purpose, tidal stage, wave conditions and beach profile should be known at the time of survey.

In order to survey promptly the shoreline position covering a wide range, a simplified measurement is occasionally employed as a alternative method to the

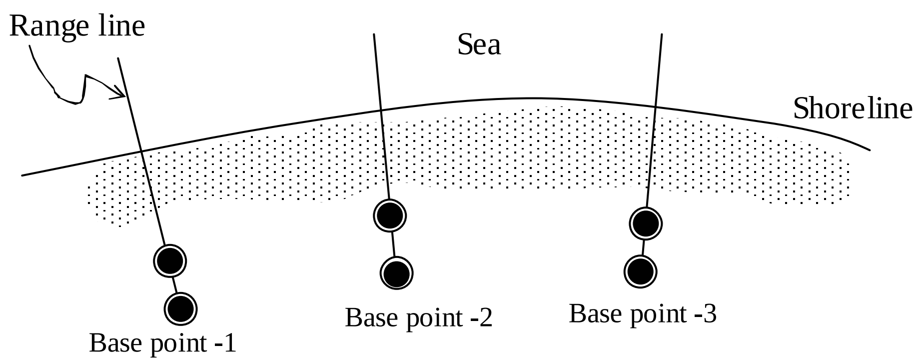
NERC (Near-shore Environment Research Center, Japan) field experiments.

In this method, the shoreline position is specified to be the position of the one-third point of swash zone width from the backwash limit, measured as an average of 10 wave periods or more. The shoreline position can thus be co-related to the mean sea level based on the data of beach profile and tide table.

(3) Establishment of Base Points

To make the survey easier and to maintain the required survey accuracy, the range lines should be set along the shore at intervals of at least 0.5 km.

Each range line should be provided with two to three base points for facilitating the survey (See the figure below). The base points are used as fore-sighting and/or back-sighting points for the determination of measurement direction and as altitude datum for beach profile survey. The beach profile data are used for assessing the changes of profile and shoreline point delineated in surveys at different periods.



The base point should be made with a deep-buried concrete post so as not to be easily removed. The position and elevation of each base point should be surveyed before the measurement of shoreline position. Co-relation in elevation between the base point and mean sea level should also be clarified.

Base points should be set before the construction of the Agos Dam, and the existing shoreline position should be surveyed to use it as the base line information versus the future change.

(4) Frequency

In order to obtain the useful data, measurement of shoreline change should be carried out at least twice a year routinely to clarify the yearly as well as seasonal change.

Additional measurement should be put into practice in the case a large coastal change has occurred, for example, after a very big storm takes place.

The results of survey should be kept in custody with the records of date of survey, location of samplings and other data observed. Photographs of structures near the shoreline should also be kept in records with the maps showing their locations.

(5) Organization for Monitoring Work

The monitoring of coastal impacts should be conducted by an organization concerned with this kind of monitoring with entrustment from MWSS.

The Department of Environmental Natural Resources (DENR) would be a suitable organization because it has already been managing coastal resources. The discussion among the concerned agencies is necessary to determine a suitable organization that will be responsible for the continuous monitoring.

E6.2 Measures for Future Coastal Change

(1) General

Appropriate countermeasure should be taken at an appropriate time, should any adverse impact arise. There may be two countermeasures to cope with the coastal change that might occur in the future as described below.

(2) River Mouth Treatment

Possible consequences after the construction of the Agos Dam might be threefold as presumed below:

- Sediment yield from the Agos River will be reduced.
- River course meandering at the river mouth will become stable due to reduced sediment accumulation.
- There is a minor possibility of clogging of the river mouth, in case the water flow is excessively low in the dry years and the flow has a less force to flush away sand bar formed at the river mouth.

To cope with these concerns, construction of a training jetty is proposed as shown in Figure E6.1. The purpose of the training jetty is as follows:

- To make the river mouth more stable and to protect the riverbank
- To discharge the sediment to the coast more smoothly
- To protect the northern and southern coasts of the Agos River
- To prevent the sea waves from intruding to the inside of the river mouth

The training jetty should be bent slightly to the south for the purposes described below:

a) Prevent the high waves from intruding to the river area during storms

b) Concentrate the flow to make the river outlet in the stable condition and consequently maintain the minimum water depth at river mouth for prevention of clogging

c) Facilitate the supply of sediment to the southern coast

The length of the jetty protruding to the sea should not be too long to mitigate the coastal impact due to the jetty itself. The reasons are as follows:

a) Prevent the occurrence of adverse near-shore current that will cause the erosion at the surrounding coast

b) Facilitate smooth discharge of sediment to the near-shore area for further transport along the southern coast

At this study stage, it is not possible to delineate the exact location of river mouth in the future. Present natural condition of river mouth is so complicated to predict the future shape of the river courses.

In the future, however, the river course at the river mouth will be more stable. After such a tendency is observed, the riverbank would be protected to fix the river course. The jetty will be constructed as the extension of the riverbank protection.

(3) Beach Protection

The beach protection should be done very carefully in utmost consideration of the sediment transport balance. If the sediment along the coastline is unbalanced at one place, the erosion that occurred at the place spreads to the adjacent area (downstream side of littoral drift). Hence, it is important to adopt the most adequate countermeasures that will have the lightest secondary impact to the coast.

One of the methods commonly adopted for preventing the coastal erosion is to construct the jetties. The jetty is expected to cause a relatively less coastal impact, if the appropriate dimension is adopted. Its construction involves less difficulty as compared with other countermeasures such as the detached breakwater, submerged breakwater and headland. The coastal revetment is also one of the selections, but it will deteriorate coastal use for recreational and aesthetic purposes.

As for the sediment transportation, the most active part is breaker zone. If the jetty is constructed in the whole length of breaker zone to stop the sediment transport along the beach, the coast of downstream side of littoral drift will result in heavy erosion. Hence, the length of the jetty protruding to the breaker zone should be as short as possible in order not to stop the whole sediment transport.

Generally, the coastal impact is not easy to predict, so that the construction of coastal structure should be carefully done step-wise by monitoring the result of the previous work. A preliminary plan of typical jetty structure is shown in Figure E6.2.

Figure E6.3 shows a conceptual plan of alignment of jetties on the coast. Interval of jetty installations along the coast should be determined on a trial basis through observation of local erosion and sedimentation appearing actually on the coast. It is supposed to take the period of decades until a stable coastline condition is created.

(4) Materials

The materials for construction of jetties on the coast and training jetty at the river mouth are available either from the riverbed of the Agos River (boulders and cobbles) or rock quarries easily found in mountainous area in the west. The boulders (or large rock particles) are used for armoring the surfaces and cobbles (or small rock particles) used for core material of the jetty embankment.

E6.3 Further Studies in Subsequent Stages

A preliminary plan of the proposed countermeasures was discussed in the preceding Sections. The plan should be further refined and detailed in the subsequent studies, preferably during the detailed design stage. The items of further studies are proposed below:

a) Directional wave measurement in deep sea

To determine the wave conditions for design of the coastal protection structure, the wave data are necessary. Wave conditions are dependent on significant wave height, significant wave period and wave direction. It is also needed to determine the energetically predominant wave condition influencing the coastal changes.

The location of wave measurement should be the place where water depth is more than 20 meters and near the Infanta coast.

As an example of equipment for wave measurement, an ‘equipment for measurement of oceanographic phenomena’ which was developed as a joint product of the Ministry of Land, Infrastructure and Transport, the Association of Ocean Survey, and Kaijoo Co., Ltd. in Japan, will be useful. The equipment, installed in deep sea, measures the wave height, wave direction, current velocity and direction by using the ultrasonic wave in the seawater.

b) Bathymetric and geographic survey around the river mouth.

This survey is required to obtain the information for planning and design of the structures at river mouth.

c) Sand sampling at coast and river for grain analysis

d) Cross sectional survey on the beach

e) Daily discharge at the downstream point of the Agos River

f) Tidal current measurement

g) Periodical aerial photography and mapping

h) Three dimensional numerical model of local coastal area

To verify the coastal change and predict more accurately the future coastal change.

i) Wind measurement

As there is no other handhold data about the oceanographic phenomena, the wind measurement at Infanta is important and should be continued.

E7 Cost for Monitoring and Countermeasures

(1) Monitoring Work

The costs for monitoring work consist of costs for the initial establishment of base points and the recurrent measurement of beach cross sections/shoreline points. The establishment of base points should be carried out before the completion of Agos Dam and the measurement of beach cross sections/shoreline points should be carried out at least twice a year, with additional measurements as required in case the big change of coast occurs. The base point should be installed at every 0.5 km interval along the coast of Infanta Peninsula. The mean sea level of the area should be calculated from the tide table. The cost is estimated as follows:

Cost of Monitoring Work

Item		Unit	Quantity	Unit Price (US$)	Amount	
					US$ equiv.	Peso equiv.
1	Establishment of Base Points (Initial Work)	Place	20	400	8,000	400,000
2	Survey of Beach Cross Sections and Shoreline Positions (twice a year)	Section	20 (Per survey)	40	800	40,000

Note: These costs are included as an item of O&M cost for Agos Dam.

(2) Coastal Protection Work

<u>Training Jetty</u>

As described in Section E6.2 above, the construction of a training jetty is envisaged on the left bank of river mouth. It is supposed that the timing of implementation will be at the period of decades after the construction of Agos Dam, when the river mouth appears to become in the stable condition.

<u>Jetties along the Southern Coast</u>

In case the tendency of retreat of coastal shoreline is observed in the long time span, the coastal protection work will be necessary. One of suitable countermeasures is considered to be the provision of a series of jetties. The timing of implementation is difficult to predict at this study stage, but it would be decades of period after the completion of the Agos Dam.

The cost for the protection works is estimated below:

Cost of River Mouth and Coastline Protection Works

Item	Unit	Quantity	Unit Price (US$)	Amount	
				US$ equiv.	Peso equiv.
1. General Installation ((2+3)x30%)	Lump Sum	1	-	1,953,000	97,650,000
2. Jetty	Place	200	30,000	6,000,000	300,000,000
3. Training Jetty	m	300	1,700	510,000	25,500,000
4. Miscellaneous ((1+2+3)x20%)	Lump Sum	1	-	1,692,600	84,630,000
Total				10,155,600	507,780,000

Note: Necessity of these costs is unknown, depending on actual need of the protection works. For a conservative assessment of the Project, however, the costs are included as a part of O&M cost of Agos Dam, incurred over a period of 40 years after the completion.

Tables

Table E4.1(1) Result of Sand Grain Analysis (Along the Coast)

No.	Distance from the Agos river mouth (km)	d_{50} (mm)
1	-4	0.68
2	-4	9.40
3	-3	3.10
4	-2	1.30
5	-0.5	0.51
6	0	0.71
7	3	0.90
8	4	0.74
9	10	1.30

Table E4.1(2) Result of Sand Grain Analysis (River Bed and Coast)

No.	Agos River d_{50}(mm)	Coastal d_{50}(mm)
1	0.27	0.29
2	0.40	0.57
3	0.34	0.40
4	0.27	0.36
5	0.70	0.65
Mean	0.40	0.45

Table E5.1 Generated Discharge Flow at the River Mouth of Agos River

(Unit: m^3/sec)

Year	January	February	March	April	May	June	July	August	September	October	November	December
1950	233.61	119.37	133.92	52.60	29.23	26.96	54.77	72.21	55.09	204.49	216.80	272.60
1951	195.25	118.85	43.69	34.76	88.63	44.08	49.58	161.05	67.20	78.91	404.62	383.35
1952	236.70	135.88	49.29	44.85	30.74	49.57	46.11	155.95	107.77	421.26	109.58	294.92
1953	177.33	188.77	54.29	53.12	26.23	50.28	31.53	105.53	49.09	176.50	189.72	406.90
1954	158.10	106.79	181.60	42.70	30.22	23.76	29.97	44.60	50.88	60.66	123.41	411.28
1955	328.79	74.48	46.48	47.23	30.07	58.28	51.49	37.01	71.22	155.05	281.74	190.10
1956	161.01	118.74	149.89	163.55	71.57	67.98	89.82	98.47	153.48	252.68	274.85	546.41
1957	250.34	80.28	40.74	29.64	20.38	21.20	36.27	80.89	61.71	86.28	105.84	72.97
1958	143.78	78.92	72.57	81.29	73.57	66.58	83.84	65.42	89.96	197.39	189.95	68.41
1959	138.69	92.55	135.68	31.66	19.97	23.66	38.30	59.38	69.51	83.48	220.26	203.65
1960	151.75	183.91	54.85	44.21	65.82	78.96	70.82	235.74	139.78	239.83	189.23	190.76
1961	193.19	155.27	117.81	73.17	94.74	68.38	59.35	59.89	111.68	191.33	288.67	116.55
1962	164.70	133.50	76.92	72.44	32.79	31.20	91.22	79.04	202.50	109.22	206.20	184.46
1963	145.55	162.35	80.22	65.75	23.56	43.26	56.70	102.45	142.69	109.63	106.58	190.99
1964	151.72	152.16	124.90	75.64	42.75	59.03	88.28	112.33	115.16	116.33	315.42	295.46
1965	190.92	114.10	70.17	29.48	25.06	24.44	62.51	57.68	72.26	139.39	223.25	304.32
1966	99.18	75.93	29.76	19.74	69.66	28.28	31.13	36.80	83.25	189.48	283.30	259.38
1967	198.65	77.62	73.70	52.46	42.32	58.55	46.82	104.26	79.07	62.82	222.30	181.87
1968	147.24	150.05	147.61	92.97	30.92	26.32	44.76	89.49	93.26	123.89	131.29	78.32
1969	80.86	34.62	42.68	25.87	14.60	11.29	34.33	57.02	68.75	67.90	111.57	298.40
1970	144.39	56.72	24.33	39.22	15.50	21.83	34.38	26.66	118.25	203.29	390.38	226.79
1971	126.68	176.20	159.82	46.20	183.45	214.81	245.17	101.96	53.32	226.28	255.36	340.36
1972	135.65	66.79	76.93	63.28	61.09	59.30	288.97	190.85	129.46	105.95	192.04	229.64
1973	89.54	105.69	55.93	44.52	42.06	53.59	58.99	44.27	55.15	178.97	315.07	409.38
1977	205.77	192.42	117.01	51.12	42.91	29.66	92.66	84.79	123.26	95.64	261.64	127.10
1978	95.26	72.97	41.78	18.72	30.30	38.89	41.28	128.96	148.24	316.09	223.44	283.07
maximum	328.79	192.42	181.60	163.55	183.45	214.81	288.97	235.74	202.50	421.26	404.62	546.41
minimum	80.86	34.62	24.33	18.72	14.60	11.29	29.97	26.66	49.09	60.66	105.84	68.41
average	167.10	116.34	84.71	53.70	47.62	49.24	71.50	92.03	96.61	161.26	224.33	252.59

*)Basin Area : 940km^2 at the river mouth

E5.2 Calculated Sediment Yield of Agos River

(Unit: $10^3 m^3$)

Year	January	February	March	April	May	June	July	August	September	October	November	December	Mean
1950	52.91	25.49	31.54	12.50	7.45	6.69	13.42	17.38	13.05	46.83	47.84	60.83	27.99
1951	44.87	25.38	10.84	8.47	21.08	10.58	12.22	37.53	15.73	18.90	84.20	82.85	31.05
1952	53.53	29.93	12.15	10.76	7.81	11.82	11.41	36.43	24.53	90.24	24.92	65.33	31.57
1953	41.04	39.28	13.30	12.61	6.74	11.98	8.00	24.85	11.71	40.86	42.28	87.45	28.34
1954	36.89	22.70	41.96	10.27	7.69	5.94	7.63	11.06	12.11	14.77	28.20	88.30	23.96
1955	72.09	16.17	11.50	11.29	7.65	13.77	12.66	9.28	16.61	36.23	60.66	43.77	25.97
1956	37.52	26.26	35.11	36.84	17.24	15.90	21.35	23.28	34.73	56.79	59.32	114.20	39.88
1957	56.31	17.35	10.16	7.31	5.31	5.33	9.11	19.34	14.52	20.56	24.12	17.56	17.25
1958	33.78	17.07	17.47	18.81	17.69	15.59	20.01	15.85	20.69	45.32	42.33	16.53	23.43
1959	32.64	19.84	31.95	7.77	5.21	5.92	9.58	14.48	16.24	19.93	48.54	46.65	21.56
1960	35.51	39.71	13.43	10.61	15.94	18.30	17.07	53.34	31.82	54.17	42.18	43.91	31.33
1961	44.43	32.77	27.86	17.04	22.45	15.99	14.47	14.59	25.41	44.04	62.01	27.58	29.05
1962	38.32	28.41	18.45	16.88	8.30	7.67	21.66	18.92	44.91	25.68	45.66	42.57	26.45
1963	34.17	34.15	19.20	15.41	6.09	10.40	13.86	24.17	32.46	25.77	24.28	43.96	23.66
1964	35.51	33.31	29.47	17.57	10.63	13.93	21.01	26.44	26.38	27.53	67.19	65.44	31.20
1965	43.94	24.34	16.92	7.27	6.45	6.10	15.19	14.09	16.84	32.79	49.14	67.22	25.02
1966	23.44	16.46	7.58	4.98	16.81	7.00	7.90	9.23	19.24	43.64	60.96	58.16	22.95
1967	45.59	16.81	17.72	12.47	10.53	13.82	11.57	24.57	18.32	15.26	48.95	42.01	23.13
1968	34.54	32.88	34.62	21.34	7.85	6.54	11.09	21.28	21.41	29.25	29.95	18.76	22.46
1969	19.33	7.88	10.61	6.44	3.88	2.95	8.66	13.93	16.07	16.41	25.38	66.02	16.46
1970	33.91	12.52	6.28	9.48	4.10	5.48	8.67	6.84	27.06	46.57	81.51	51.50	24.49
1971	29.88	36.85	37.26	11.06	42.35	47.43	55.26	24.06	12.66	51.40	55.49	74.38	39.84
1972	31.94	15.12	18.45	14.87	14.87	13.99	64.13	43.93	29.54	24.95	42.76	52.08	30.55
1973	21.29	22.48	13.68	10.68	10.46	12.72	14.39	10.98	13.07	41.39	67.12	87.93	27.18
1977	47.10	39.98	27.68	12.17	10.66	7.31	21.98	20.22	28.16	22.65	56.73	29.98	27.05
1978	22.56	15.86	10.40	4.74	7.71	9.41	10.28	30.41	33.63	69.56	49.18	62.94	27.22
maximum	72.09	39.98	41.96	36.84	42.35	47.43	64.13	53.34	44.91	90.24	84.20	114.20	60.97
minimum	19.33	7.88	6.28	4.74	3.88	2.95	7.63	6.84	11.71	14.77	24.12	16.53	10.56
average	38.58	24.96	20.22	12.68	11.65	11.64	17.02	21.79	22.19	36.98	48.88	56.07	26.89

*)Basin Area : 940km^2 at the river mouth

*)Annual Sediment Yield 322.66 x 10^3 m^3/year (net)

Table E5.3(1) Frequency of Wind Direction and Speed in a Year from Monthly Data for 40 Years

(Unit: day/year)

Daily Wind	1m/s	2m/s	3m/s	4m/s	5m/s	Subtotal
NNW	1.5	14.5	1.5	0.0	0.0	17.5
N	50.3	93.0	47.2	10.7	2.3	203.5
NNE	13.0	16.0	11.4	2.3	0.0	42.7
NE	3.0	6.1	0.0	0.0	0.0	9.1
ENE	0.0	0.0	0.0	0.0	0.0	0.0
E	2.3	0.0	0.0	0.0	0.0	2.3
ESE	0.8	0.0	0.0	0.0	0.0	0.8
Total	70.9	129.5	60.2	13.0	2.3	275.8

Notes: Normalized in a year
Records of ES to NW are not included.

Table E5.3(2) Frequency of Major Daily Wind Speed and Direction Selected in 40 Years

(Unit: day/40year)

Daily Wind	8m/s	9m/s	10m/s	13m/s	19m/s	Subtotal
NNW	0	0	0	0	0	0
N	11	4	1	1	1	18
NNE	4	4	0	0	0	8
NE	0	0	0	0	0	0
ENE	2	0	0	0	0	2
E	0	0	0	0	0	0
ESE	0	0	1	0	0	1
Total	17	8	2	1	1	29

Notes: Normalized in 40 years
Records of ES to NW are not included.

Table E5.4 Major 40 Daily Wind Speed at Infanta (1961-2000)

No	Yea	Month	Day	Daily Wind Speed(m/s)	Degree	Direction
1	1967	11	4	27	180	Others
2	1967	11	3	19	360	N
3	1981	11	24	15	310	Others
4	1985	10	18	14	340	Others
5	1966	12	27	13	360	N
6	1977	11	13	12	320	Others
7	1978	10	26	12	340	Others
8	1966	11	20	10	340	Others
9	1967	1	16	10	360	N
10	1978	9	27	10	120	ESE
11	1961	12	7	9	20	NNE
12	1964	11	27	9	360	N
13	1964	12	18	9	30	NNE
14	1970	10	13	9	320	Others
15	1970	11	19	9	360	N
16	1975	12	27	9	340	Others
17	1977	2	22	9	20	NNE
18	1977	11	14	9	140	Others
19	1982	1	30	9	20	NNE
20	1989	10	10	9	360	N
21	1989	11	29	9	360	N
22	1993	12	5	8	360	N
23	1994	10	21	8	70	ENE
24	1961	11	22	8	20	NNE
25	1962	11	6	8	360	N
26	1964	11	19	8	360	N
27	1964	12	5	8	360	N
28	1964	12	14	8	320	Others
29	1965	1	18	8	360	N
30	1967	1	18	8	360	N
31	1971	1	4	8	360	N
32	1973	12	25	8	360	N
33	1974	12	21	8	20	NNE
34	1975	12	17	8	20	NNE
35	1977	3	4	8	360	N
36	1978	8	14	8	160	Others
37	1982	1	17	8	20	NNE
38	1982	12	7	8	360	N
39	1983	7	15	8	140	Others
40	1984	12	7	8	360	N

Note: Wind direction from ES to NE were classified to Others due to each fetch direction

Table E5.5 Directional Effective Fetch

Wind Direction	Distance (km)	Compensation Coefficient	Effective Fetch(km)
NNW	74	0.67	50
N	137	0.67	92
NNE			∞
NE	26	1.00	26
ENE	24	1.00	24
E	27	1.00	27
ESE	28	1.00	28

Table E5.6 Estimated Wind Wave by S.M.B Method

Wind Direction	Wind Velocity U(m/s)	Significant Wave $H_{1/3}$(m)	Significant Wave $T_{1/3}$ (sec)	Wind Direction	Wind Velocity U(m/s)	Significant Wave $H_{1/3}$(m)	Significant Wave $T_{1/3}$ (sec)
NNW	1	0.028	0.778	N	27	5.165	8.007
NNW	2	0.101	1.427	NNE	1	0.028	0.778
NNW	3	0.202	1.934	NNE	2	0.103	1.454
N	1	0.022	0.645	NNE	3	0.220	2.075
N	2	0.103	1.454	NNE	4	0.372	2.655
N	3	0.220	2.075	NNE	5	0.557	3.205
N	4	0.361	2.591	NNE	6	0.771	3.730
N	5	0.518	3.032	NNE	7	1.012	4.234
N	6	0.689	3.429	NNE	8	1.279	4.720
N	7	0.870	3.790	NNE	9	1.569	5.190
N	8	1.058	4.122	NE	1	0.027	0.766
N	9	1.253	4.430	NE	2	0.092	1.319
N	10	1.453	4.717	NE	3	0.177	1.752
N	11	1.657	4.987	NE	4	0.274	2.112
N	12	1.865	5.241	ENE	8	0.691	3.104
N	13	2.075	5.483	E	1	0.027	0.768
N	14	2.288	5.712	E	2	0.093	1.326
N	15	2.502	5.931	ESE	1	0.027	0.770
N	19	3.376	6.720	ESE	2	0.093	1.329

Note: Calculated by Equations of Significant Wave[Wilson,1965]

Legend : $H_{1/3}$:Significant Wave Height
$T_{1/3}$:Significant Wave Period

Table E5.7 Energy of Representative Wind Wave

(Unit: N/S)

Daily Wind	1m/s	2m/s	3m/s	4m/s	5m/s
NNW	5	204	1,493		
N	2	221	2,036	8,572	24,192
NNE	5	221	2,036	9,559	
NE	4	145			
Daily Wind	8m/s	9m/s	10m/s	13m/s	19m/s
N	186,500	302,064	460,553	1,268,377	5,042,685
NNE	356,955	649,939	1,106,416		
ENE	45,084				

Note: Energy=(H1/3xT1/3)2

Table E5.8 Energy Contribution Ratio of Representative Wind Wave to Total Energy

(Unit: %)

Daily Wind	1m/s	2m/s	3m/s	4m/s	5m/s	Subtotal
NNW	0.00	0.44	0.34	0.00	0.00	0.78
N	0.02	3.06	14.31	13.60	8.23	39.22
NNE	0.01	0.53	3.46	3.25	0.00	7.25
NE	0.00	0.13	0.00	0.00	0.00	0.13
Subtotal	0.03	4.16	18.11	16.85	8.23	47.38
Daily Wind	8m/s	9m/s	10m/s	13m/s	19m/s	Subtotal
N	7.63	4.49	1.71	4.72	18.75	37.31
NNE	5.31	9.67	0.00	0.00	0.00	14.98
ENE	0.34	0.00	0.00	0.00	0.00	0.34
Subtotal	13.27	14.16	1.71	4.72	18.75	52.62
Total=	93.42%				Total:	100

Note: Annual total energy generated by wind is assumed to be consist of monthly averaged daily wind (365 days) and major wind during 40 years of 1/40 frequency.

Table E5.9 Result of Calculation of Near Shore Wave Condition and Sediment Transportation (1/2)

θ	W	Coast	$T_{1/3}$(sec)	α o(deg)	Ho(m)	Hb(m)	α (deg)	Ks	Kr	h_b	$Q_S(m^3/day)$
N	w=3	C1	2.08	32.80	0.22	0.216	15.839	1.044	0.935	0.293	7.41
		C2	2.08	23.60	0.22	0.223	11.637	1.044	0.967	0.296	5.96
		C3	2.08	74.00	0.22	0.137	28.967	1.044	0.561	0.237	4.31
		C4	2.08	34.60	0.22	0.215	16.624	1.044	0.927	0.293	7.60
		C5	2.08	44.20	0.22	0.204	20.564	1.044	0.875	0.288	8.15
		C6	2.08	45.00	0.22	0.203	20.871	1.044	0.870	0.851	8.15
		C7	2.08	53.70	0.22	0.189	23.957	1.044	0.805	0.280	7.79
N	w=4	C1	2.591	32.80	0.36	0.354	16.369	1.031	0.936	0.460	25.49
		C2	2.591	23.60	0.36	0.364	12.022	1.031	0.968	0.472	20.64
		C3	2.591	74.00	0.36	0.226	23.302	1.136	0.548	0.293	11.15
		C4	2.591	34.60	0.36	0.351	17.183	1.031	0.928	0.456	26.12
		C5	2.591	44.20	0.36	0.334	21.267	1.031	0.877	0.433	27.58
		C6	2.591	45.00	0.36	0.332	21.585	1.031	0.872	0.431	27.55
		C7	2.591	53.70	0.361	0.310	22.272	1.073	0.800	0.398	23.69
N	w=5	C1	3.072	32.80	0.52	0.509	17.573	1.018	0.939	0.692	68.99
		C2	3.072	23.60	0.52	0.524	12.893	1.018	0.970	0.710	55.92
		C3	3.072	74.00	0.52	0.325	25.688	1.107	0.553	0.443	30.55
		C4	3.072	34.60	0.52	0.505	18.451	1.018	0.932	0.688	70.70
		C5	3.072	44.20	0.52	0.481	22.865	1.018	0.882	0.656	74.61
		C6	3.072	45.00	0.52	0.478	23.210	1.018	0.877	0.653	74.52
		C7	3.072	53.70	0.52	0.447	26.691	1.018	0.814	0.607	69.49
N	w=6	C1	3.429	32.80	0.69	0.667	17.392	1.008	0.939	0.866	131.32
		C2	3.429	23.60	0.69	0.687	12.762	1.008	0.969	0.893	106.71
		C3	3.429	74.00	0.69	0.424	28.697	1.048	0.561	0.622	66.58
		C4	3.429	34.60	0.69	0.662	18.259	1.008	0.931	0.859	134.49
		C5	3.429	44.20	0.69	0.630	22.624	1.008	0.881	0.810	141.16
		C6	3.429	45.00	0.69	0.627	22.965	1.008	0.876	0.805	140.91
		C7	3.429	53.70	0.69	0.585	23.740	1.048	0.804	0.776	123.43
N	w=8	C1	4.122	32.80	1.06	1.016	20.085	0.962	0.946	1.365	432.27
		C2	4.122	23.60	1.06	1.045	14.702	0.962	0.973	1.419	354.87
		C3	4.122	74.00	1.06	0.649	26.712	1.076	0.555	0.839	172.28
		C4	4.122	34.60	1.06	1.008	21.099	0.962	0.939	1.352	441.55
		C5	4.122	44.20	1.06	0.960	26.229	0.962	0.894	1.253	455.17
		C6	4.122	45.00	1.06	0.955	26.633	0.962	0.889	1.243	453.49
		C7	4.122	53.70	1.06	0.892	24.169	1.041	0.806	1.152	355.07
N	w=9	C1	4.43	32.80	1.25	1.200	18.859	0.981	0.942	1.551	609.63
		C2	4.43	23.60	1.25	1.234	13.821	0.981	0.971	1.607	498.08
		C3	4.43	74.00	1.25	0.766	24.871	1.106	0.551	0.992	247.80
		C4	4.43	34.60	1.25	1.191	19.806	0.981	0.935	1.537	623.45
		C5	4.43	44.20	1.25	1.134	21.526	1.026	0.878	1.463	590.00
		C6	4.43	45.00	1.25	1.128	21.849	1.026	0.873	1.456	589.75
		C7	4.43	53.70	1.25	1.054	25.098	1.026	0.809	1.370	554.99
N	w=13	C1	5.483	32.80	2.08	1.965	18.684	0.984	0.942	2.632	2114.76
		C2	5.483	23.60	2.08	2.021	13.695	0.984	0.971	2.698	1715.95
		C3	5.483	74.00	2.08	1.256	28.381	1.052	0.560	1.641	939.62
		C4	5.483	34.60	2.08	1.952	19.621	0.984	0.935	2.616	2166.58
		C5	5.483	44.20	2.08	1.859	24.348	0.984	0.887	2.496	2281.42
		C6	5.483	45.00	2.08	1.850	24.719	0.984	0.882	2.483	2278.26
		C7	5.483	53.70	2.08	1.730	28.464	0.984	0.821	2.304	2115.61

(to be Continued to Next Page)

Table E5.9 The Result of Calculation of Near Shore Wave Condition and Sediment Transportation (2/2)

θ	W	Coast	$T_{1/3}$(sec)	α o(deg)	Ho(m)	Hb(m)	α (deg)	Ks	Kr	h_b	Q_S(m^3/day)
N	w=19	C1	6.72	32.80	3.38	3.170	19.559	0.969	0.944	4.081	7120.23
		C2	6.72	23.60	3.38	3.259	14.324	0.969	0.973	4.218	5812.88
		C3	6.72	74.00	3.38	2.023	28.361	1.052	0.560	2.699	3124.57
		C4	6.72	34.60	3.38	3.148	20.544	0.969	0.938	4.045	7282.81
		C5	6.72	44.20	3.38	2.999	23.053	1.002	0.883	3.883	7101.06
		C6	6.72	45.00	3.38	2.984	23.401	1.002	0.878	3.868	7097.76
		C7	6.72	53.70	3.38	2.790	26.915	1.002	0.815	3.653	6675.41
NNE	w=3	C1	2.08	10.30	0.22	0.229	5.169	1.044	0.994	0.298	2.85
		C2	2.08	1.10	0.22	0.230	0.554	1.044	1.000	0.299	0.31
		C3	2.08	51.50	0.22	0.193	23.222	1.044	0.823	0.282	7.95
		C4	2.08	12.10	0.22	0.228	6.062	1.044	0.992	0.298	3.32
		C5	2.08	21.70	0.22	0.224	10.736	1.044	0.972	0.297	5.58
		C6	2.08	22.50	0.22	0.224	11.117	1.044	0.970	0.296	5.74
		C7	2.08	31.20	0.22	0.218	15.129	1.044	0.941	0.294	7.20
NNE	w=4	C1	2.655	10.30	0.37	0.384	5.664	1.008	0.994	0.517	11.60
		C2	2.655	1.10	0.37	0.386	0.607	1.008	1.000	0.519	1.27
		C3	2.655	51.50	0.37	0.327	25.593	1.008	0.831	0.428	30.27
		C4	2.655	12.10	0.37	0.384	6.644	1.008	0.992	0.516	13.51
		C5	2.655	21.70	0.37	0.377	11.776	1.008	0.974	0.507	22.54
		C6	2.655	22.50	0.37	0.377	12.194	1.008	0.972	0.506	23.19
		C7	2.655	31.20	0.37	0.367	16.615	1.008	0.945	0.493	28.84
NNE	w=8	C1	4.72	10.30	1.28	1.304	5.798	1.000	0.994	1.779	253.62
		C2	4.72	1.10	1.28	1.311	0.621	1.000	1.000	1.786	27.70
		C3	4.72	51.50	1.28	1.110	26.241	1.000	0.833	1.527	671.73
		C4	4.72	12.10	1.28	1.302	6.801	1.000	0.992	1.777	295.38
		C5	4.72	21.70	1.28	1.281	12.058	1.000	0.975	1.753	493.54
		C6	4.72	22.50	1.28	1.279	12.486	1.000	0.973	1.751	507.72
		C7	4.72	31.20	1.28	1.246	17.018	1.000	0.946	1.713	632.72
NNE	w=9	C1	5.19	10.30	1.57	1.601	5.562	1.015	0.994	2.058	394.62
		C2	5.19	1.10	1.57	1.609	0.596	1.015	1.000	2.068	43.10
		C3	5.19	51.50	1.57	1.360	23.991	1.031	0.825	1.785	1021.33
		C4	5.19	12.10	1.57	1.598	6.524	1.015	0.992	2.053	459.55
		C5	5.19	21.70	1.57	1.573	11.561	1.015	0.974	2.018	767.05
		C6	5.19	22.50	1.57	1.570	11.971	1.015	0.972	2.014	789.00
		C7	5.19	31.20	1.57	1.530	15.613	1.031	0.942	1.971	946.81

Legend:
- θ :Incident wave direction
- W :Wind speed (m/s)
- Coast :Point of the place
- $T_{1/3}$(sec) :Significant wave period
- α o(deg) :Angle of incident wave crest of deep water wave to the alongshore line
- Ho(m) :Significant wave height in deep water
- Hb(m) :Breaking wave height
- α (deg) :Angle of incident wave crest of shallow water wave to the alongshore line
- Ks :Shoaling coefficient
- Kr :Refraction coefficient
- h_b :Breaking water depth
- Q_S(m^3/day) :Sediment transport rate (with aperture)

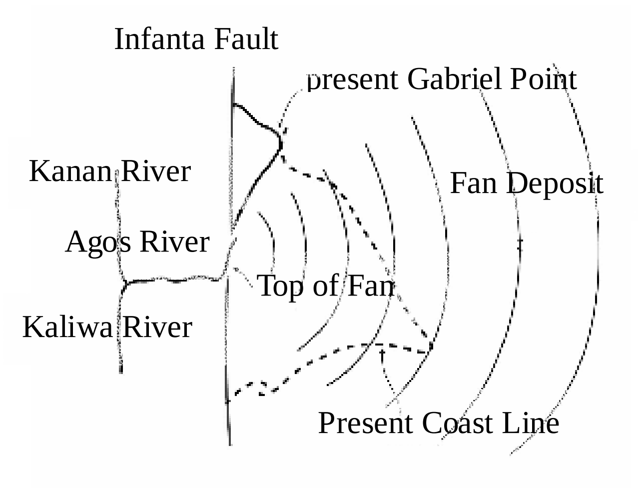
Table E5.10 Calculated Sediment Transport at Each Coastal Point

(Unit: m^3/month)

Month	C1	C2	C3	C4	C5	C6	C7
1	1797.39	1228.12	1582.04	1887.73	2227.93	2244.64	2211.87
2	737.96	513.47	648.00	773.54	907.63	914.25	924.16
3	431.30	318.29	328.19	448.37	506.93	509.20	494.11
4	160.51	129.11	93.36	164.82	176.58	176.68	168.86
5	55.29	44.47	32.16	56.77	60.82	60.86	58.16
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	55.29	44.47	32.16	56.77	60.82	60.86	58.16
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	53.50	43.04	31.12	54.94	58.86	58.89	56.29
10	423.25	342.32	220.47	434.00	446.20	446.31	424.48
11	4556.79	3631.18	2332.20	4680.97	4833.06	4836.08	4523.34
12	4259.74	3100.26	3049.40	4435.46	5038.95	5062.19	4862.32
Total	12531.01	9394.75	8349.10	12993.38	14317.80	14369.95	13781.77

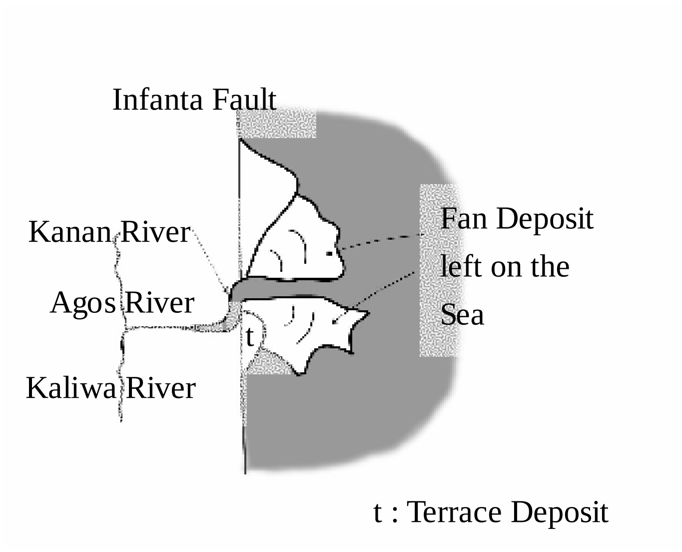
Figures

(1) About 20,000 to 15,000 Years Before (Wurm Glacial Epoch)



a). Sea water level ; More than 100m below the present level. Polillo strait was above sea level.
b). Agos River ; Formation of V-shape valley due to incision of valley bottom. By lowering of temperature, devastation of mountain slopes causing increase of sediment yield. Large scaled Fan Deposit formed at present Polillo Strait.
The Top of Fan of Agos River located about 100m south from present position.

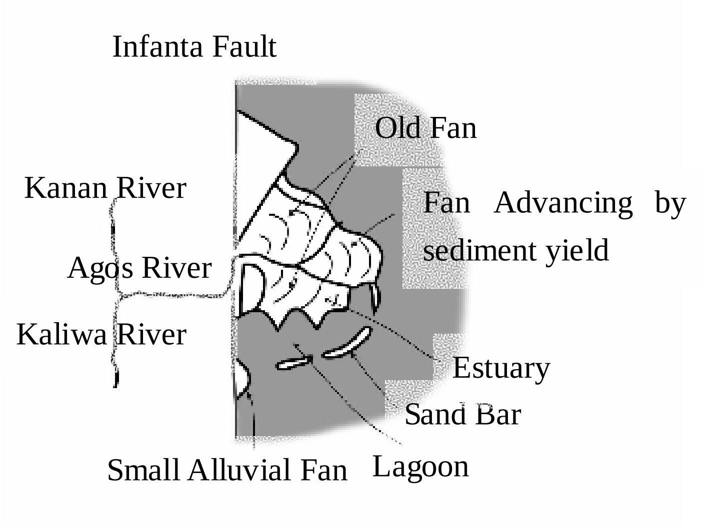
(2) About 7,000 to 5,000 Years Before (Marine Transgression in Late Glacial Epoch)



a). Sea water level ; More than 5m above the present level. The Fan of Infanta was under the sea level except the top of Fan. Sea intruded in the valley formed by erosion.
b). Agos River ; By rise of sea water level, erosion of river valley was weakened. Plains formed in the river valley.

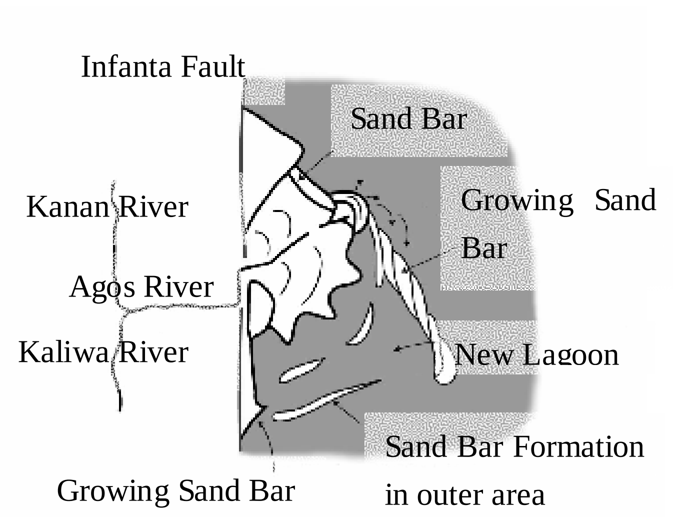
Figure E3.1
Development Image of Infanta Peninsula (1/2)

(3) About 2,500 Years Before



a). Sea water level ; Sea water level was about 3m above the present sea level.
b). Agos River ; River mouth was located more inland side than the present. Sediment was transported by monsoon , and the river mouth advanced sea ward. The Plain in the river valley become more stable and Terrace Deposit was formed.
c). Coast ; Sand bar was formed around the rim of Fan. Estuary and Lagoon have been formed inland. Sand Dunes were formed in the ages of 1). about 5,000 to 4,000 years ago 2).about 3,000 to 2,500 years ago 3). about 1,600 to 800 years ago.
d). Vegetation ; Mangrove began to grow in Lagoon and peat accumulated.

(4) About 1,500 Years Before to Present



a). Sea water level ; Sea water level descended to present sea level.
b). Agos River ; River mouth moved north. By marine regression and sediment supply the river mouth advanced to the present position.
c). Coast ; Sediment from Agos River was transported by near-shore current. Sand bar grew to south-east direction and a new sand bar was formed by the sediment defracted at Dinahican Point.
d). Vegetation ; Mangrove propagated in the area between the old and new sand bars. Wet land inside old sand dunes turned to dry land. Nipa palm began to inhabit progressively from inland side.

Figure E3.1
Development Image of Infanta Peninsula (2/2)

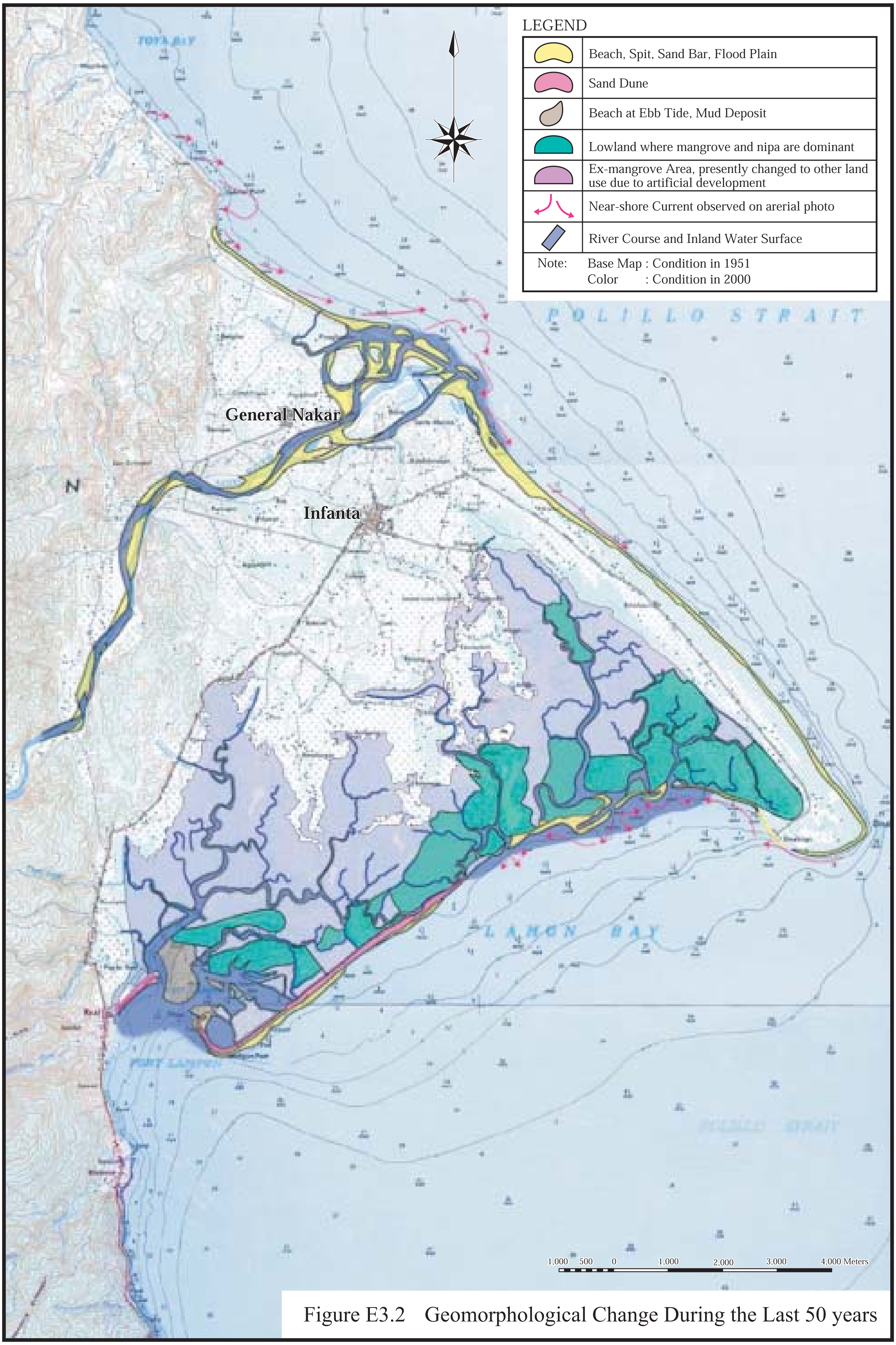


Figure E3.2 Geomorphological Change During the Last 50 years

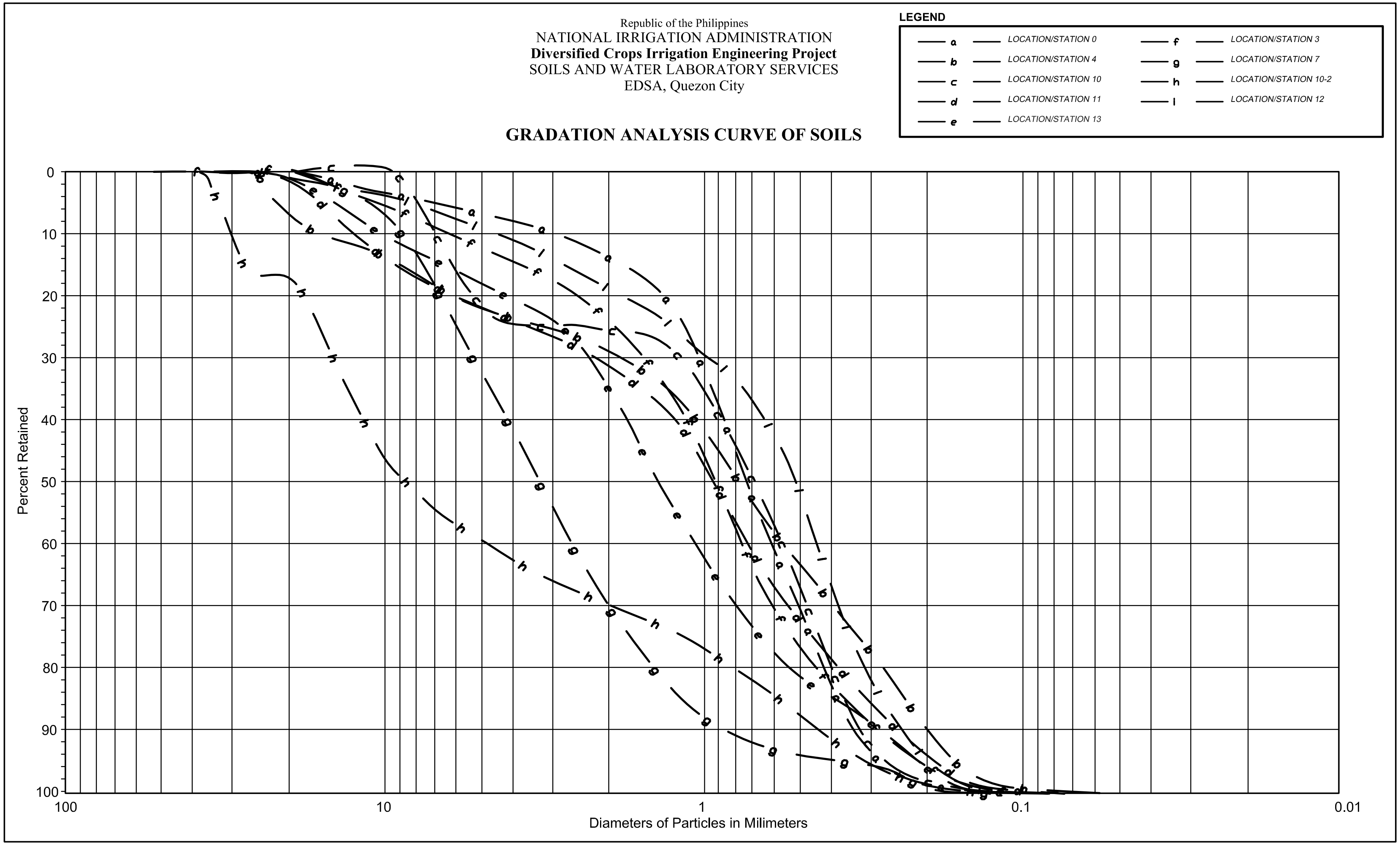
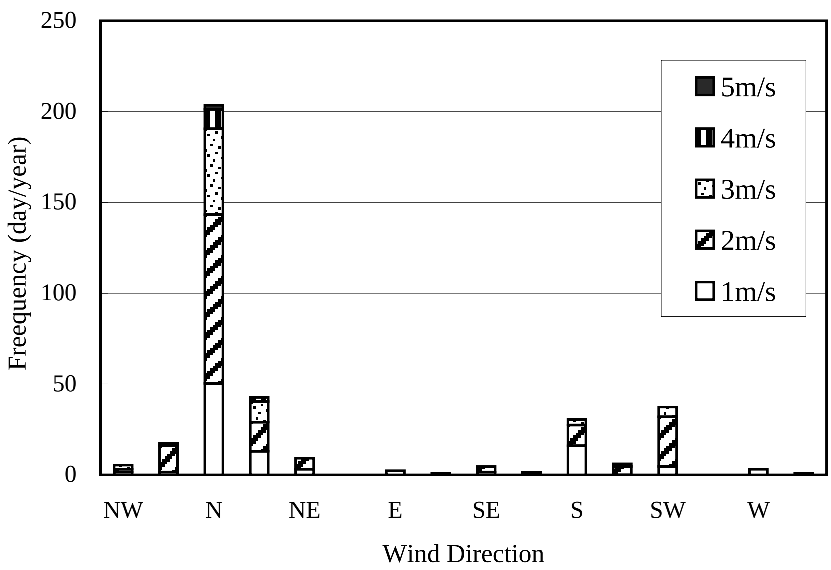


Figure E4.1 Grain Size Analysis of Sand Sampled at Infanta Peninsula Coast



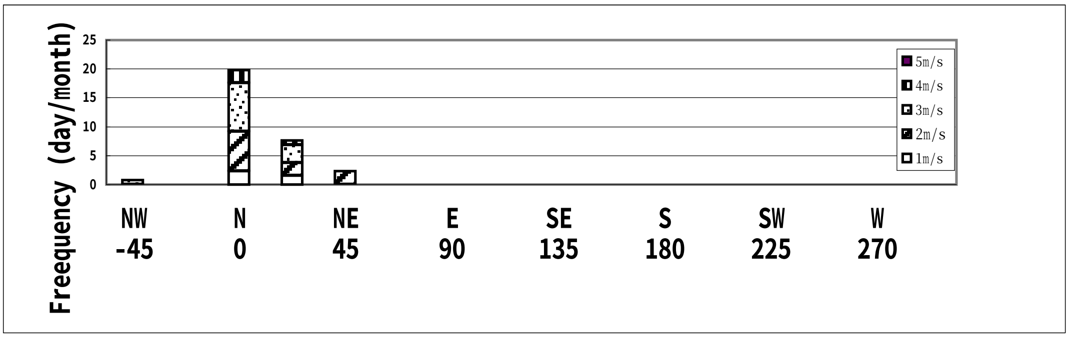
Normalized Occurrence in A Year (unit:day/year:normalized in a year)

	1m/s	2m/s	3m/s	4m/s	5m/s	Subtotal
NW	1.5	1.5	2.3	0.0	0.0	5.3
NNW	1.5	14.5	1.5	0.0	0.0	17.5
N	50.3	93.0	47.2	10.7	2.3	203.5
NNE	13.0	16.0	11.4	2.3	0.0	42.7
NE	3.0	6.1	0.0	0.0	0.0	9.1
ENE	0.0	0.0	0.0	0.0	0.0	0.0
E	2.3	0.0	0.0	0.0	0.0	2.3
ESE	0.8	0.0	0.0	0.0	0.0	0.8
SE	1.5	3.0	0.0	0.0	0.0	4.6
SSE	0.8	0.8	0.0	0.0	0.0	1.5
S	16.0	11.4	3.0	0.0	0.0	30.5
SSW	0.0	4.6	1.5	0.0	0.0	6.1
SW	4.6	27.4	5.3	0.0	0.0	37.3
WSW	0.0	0.0	0.0	0.0	0.0	0.0
W	3.0	0.0	0.0	0.0	0.0	3.0
WNW	0.8	0.0	0.0	0.0	0.0	0.8
Total	99.1	178.3	72.4	13.0	2.3	365.0

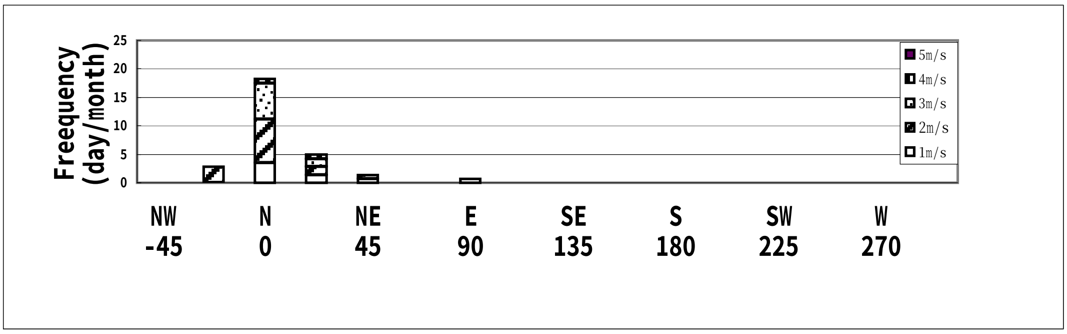
Occurrence of Monthly Mean Wind Direction and Speed in 40 Years (unit:month)

	1m/s	2m/s	3m/s	4m/s	5m/s	Subtotal
NW	2	2	3	0	0	7
NNW	2	19	2	0	0	23
N	66	122	62	14	3	267
NNE	17	21	15	3	0	56
NE	4	8	0	0	0	12
ENE	0	0	0	0	0	0
E	3	0	0	0	0	3
ESE	1	0	0	0	0	1
SE	2	4	0	0	0	6
SSE	1	1	0	0	0	2
S	21	15	4	0	0	40
SSW	0	6	2	0	0	8
SW	6	36	7	0	0	49
WSW	0	0	0	0	0	0
W	4	0	0	0	0	4
WNW	1	0	0	0	0	1
Total	130	234	95	17	3	479

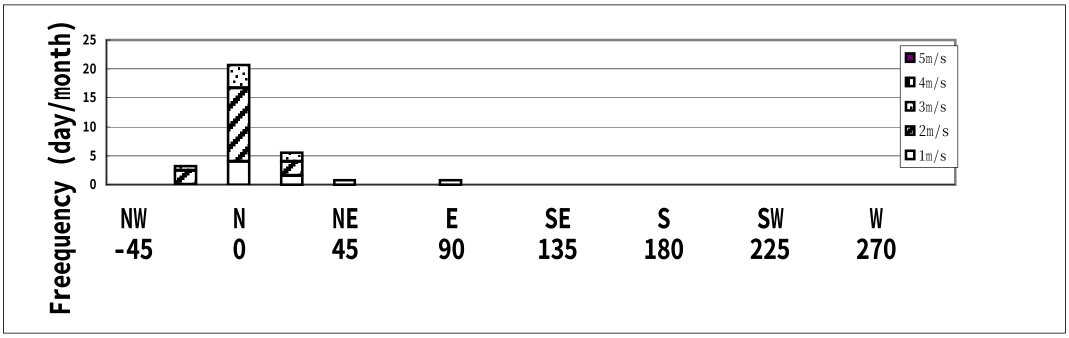
Figure E5.1 Frequency of Monthly Mean Wind Speed and Direction at Infanta



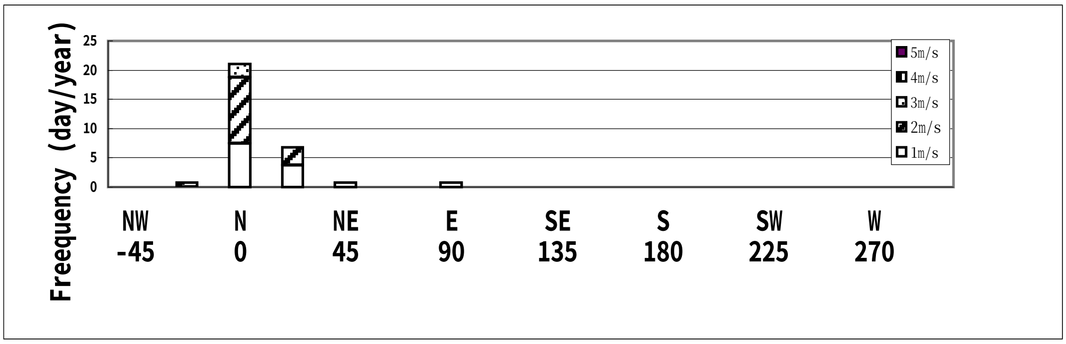
Wind Direction and Speed in January



Wind Direction and Speed in February

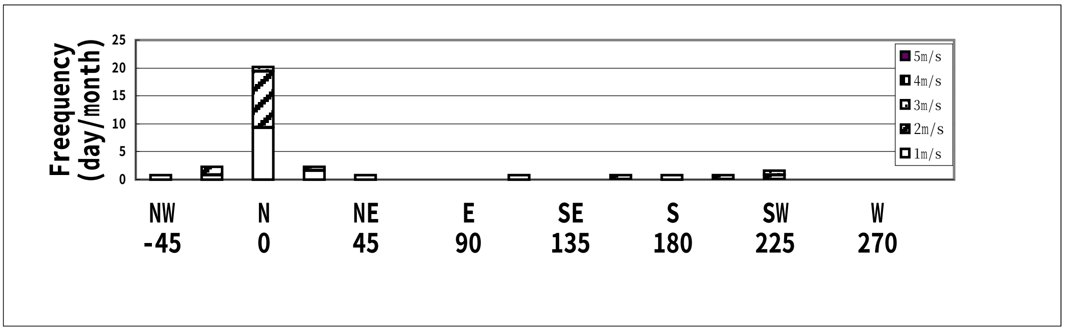


Wind Direction and Speed in March

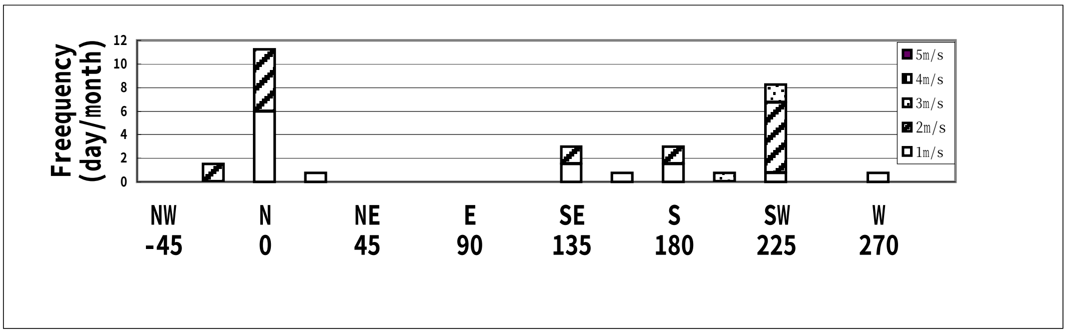


Wind Direction and Speed in April

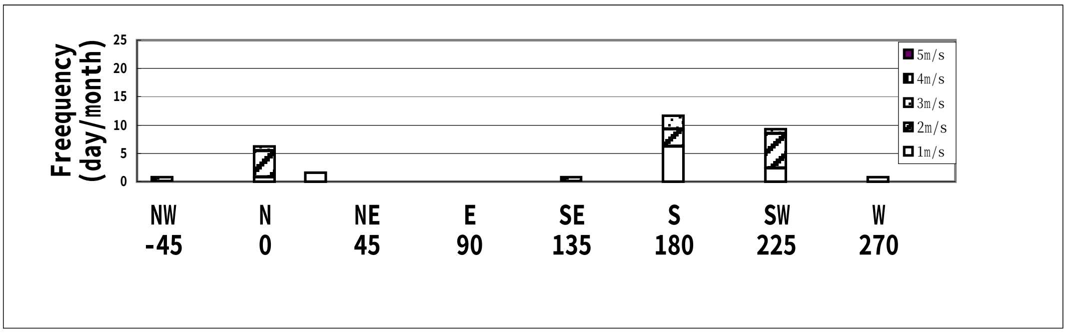
Figure E5.2(1) Monthly Wind Speed and Direction at Infanta Station (January to April)



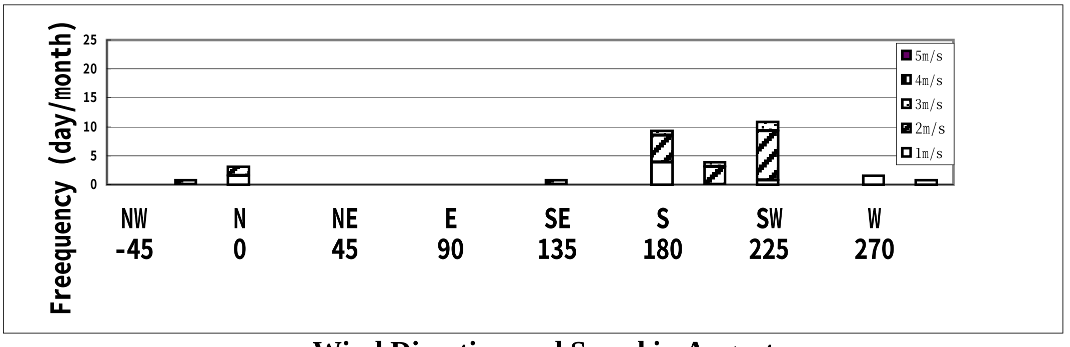
Wind Direction and Speed in May



Wind Direction and Speed in June

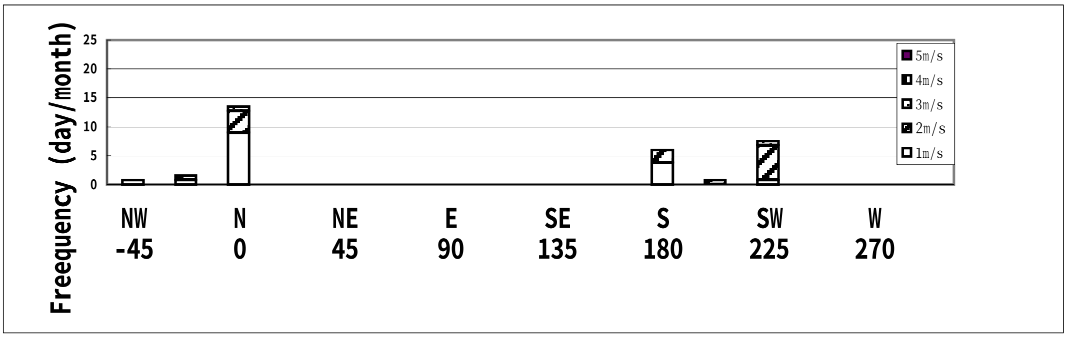


Wind Direction and Speed in July

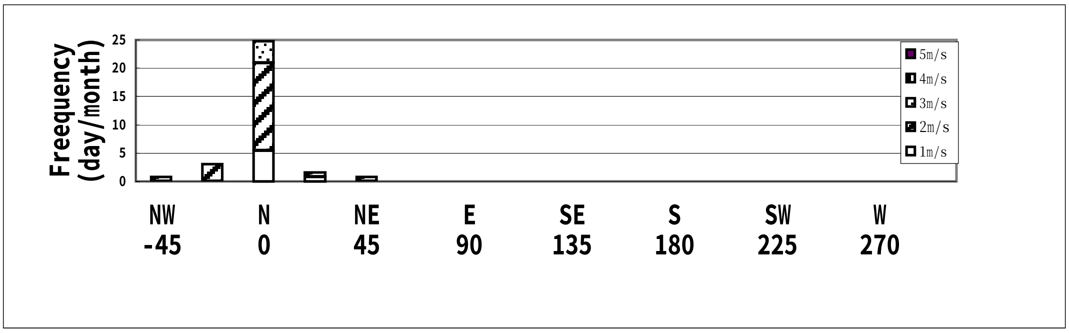


Wind Direction and Speed in August

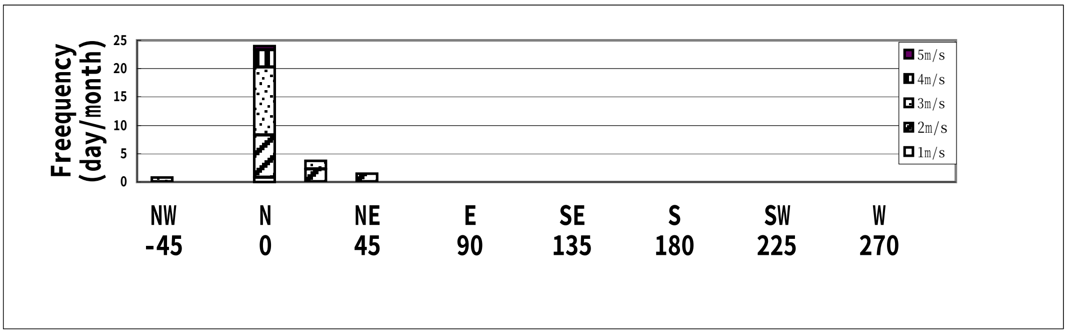
Figure E5.2(2) Monthly Wind Speed and Direction at Infanta Station (May to August)



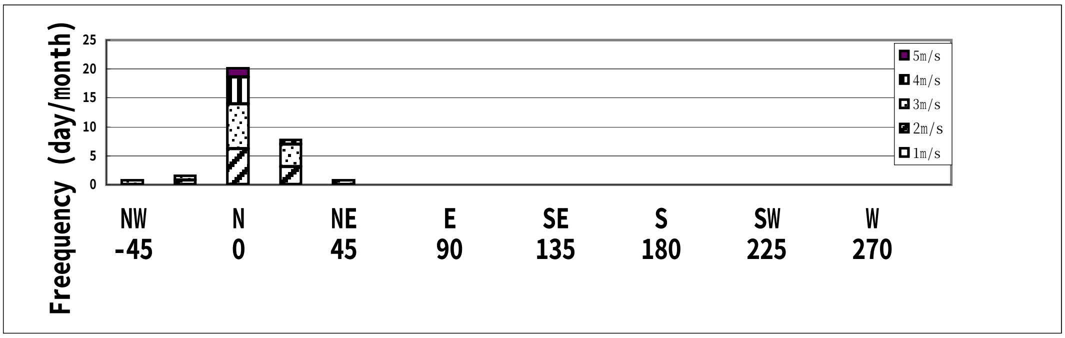
Wind Direction and Speed in September



Wind Direction and Speed in October



Wind Direction and Speed in November



Wind Direction and Speed in December

Figure E5.2(3) Monthly Wind Speed and Direction at Infanta Station (September to December)

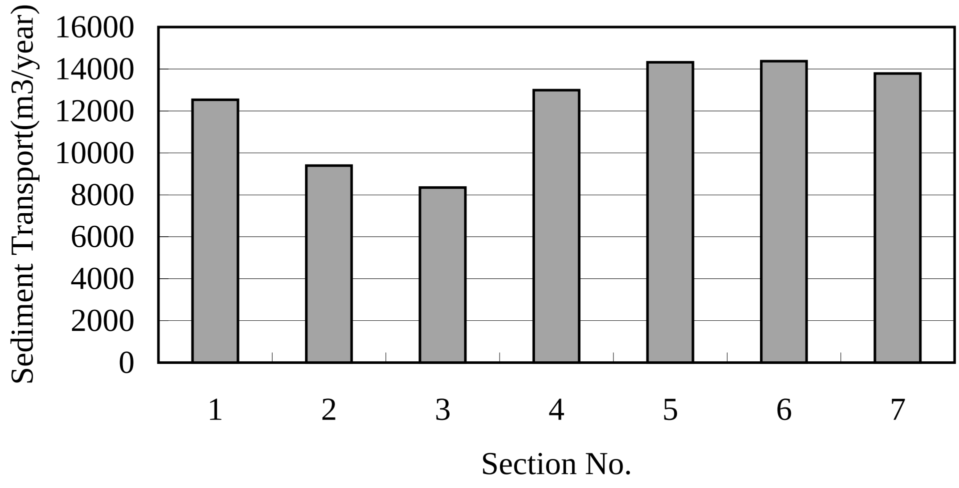


Figure E5.3 Calculated Littoral Drift at the Representative Coastal Point of the Infanta Peninsula Averaged Over Past 40 Years

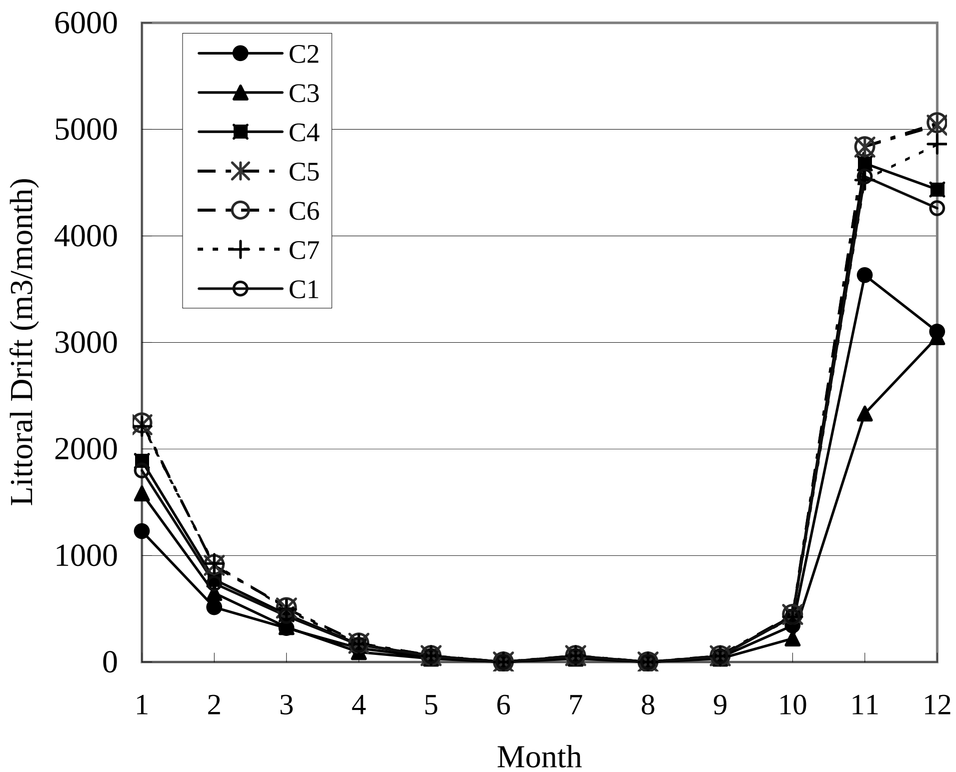
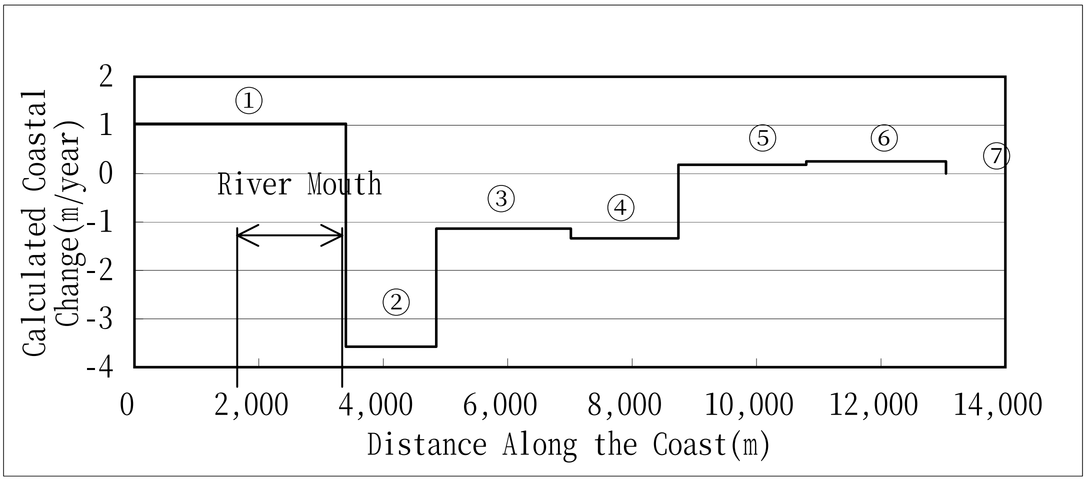


Figure E5.4 Seasonal Change of Calculated Littoral Drift Averaged Over Past 40 Years

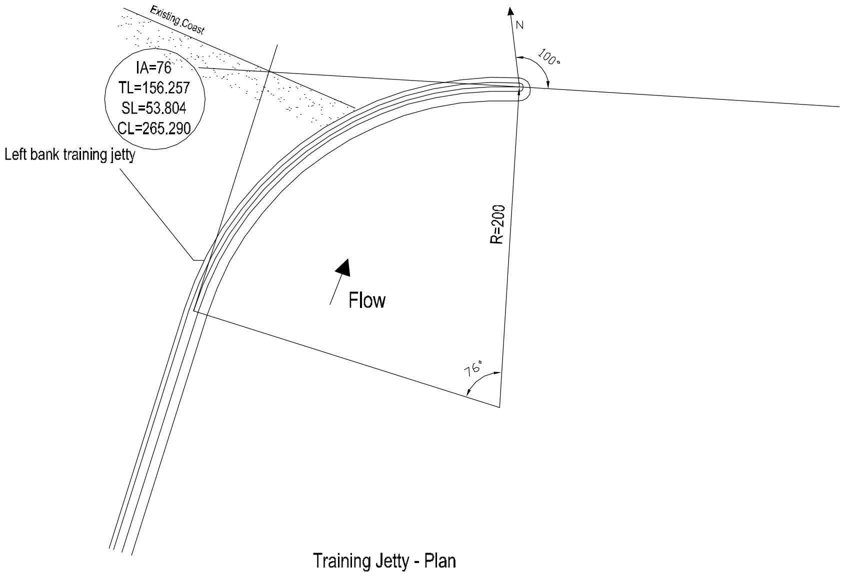


(+):Accretion (-):Erosion

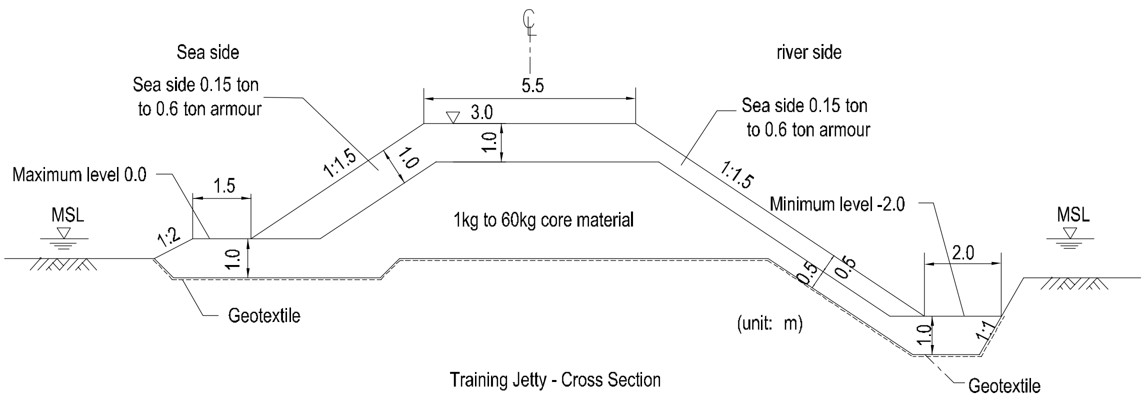
Coastal Point	①	②	③	④	⑤	⑥	⑦
Coastal Change	1.029	-3.577	-1.137	-1.339	0.181	0.251	

note) This calculation is on the basis of averaged last 40 years climate and present coastal line.

Figure 5.5 Calculated Present Condition of Coastal Change



Training Jetty - Plan



Training Jetty - Cross Section

Figure E6.1 **Training Jetty - Measures to Cope with Future Coastal Change**

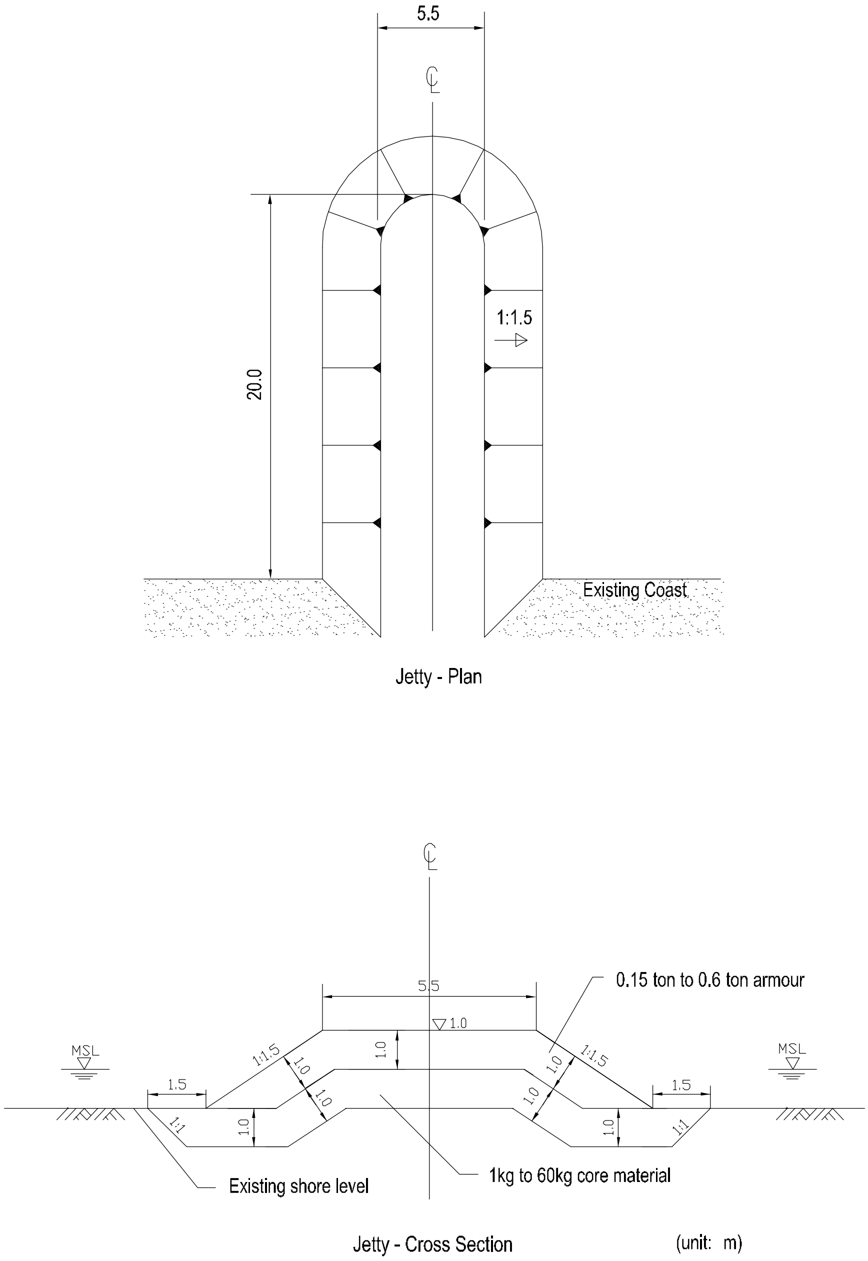


Figure E6.2 Jetty - Measurements to Cope with Future Change of Coastal Shoreline

Photograph

A Hole Found at Northern Coast

Typical Condition of Northern Coast

North Part subject to Local Erosion

Typical Condition of Southern Coast

Photographs
Infanta-General Nakar Coastline