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# VIETNAM COASTAL ZONE VULNERABILITY ASSESSMENT and First Steps Towards Integrated Coastal Zone Management

## REPORT No.5

## PILOT STUDY
## FLOODING AND LAGOON MANAGEMENT
## THUA THIEN HUE PROVINCE
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Prepared by :
Marine Hydrometeorological Center, Hydrometeorological Services, Hanoi, S.R of Vietnam
Polish Academy of Sciences, Institute of Hydroengineering, Gdansk, Poland
Joint Venture : Frederic R Harris BV - Delft Hydraulics, The Hague, The Netherlands

and

National Institute for Coastal and Marine Management, Coastal Zone Management Center, Ministry of Transport, Public Works and Water Management, The Hague, The Netherlands

# VVA Pilot Study Hue

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# VVA Pilot Study HUE

## Summary

1. The emphasis in the Vietnam Vulnerability Assessment (VVA) programme has been placed on conducting, together with Vietnamese counterparts, an extended analysis of Vietnam's coast's vulnerability (VA) to accelerated sea level rise. One of the three major outputs formulated in the project documents consists in strengthening the capability (staff and equipment), communication and inter-agency cooperation of Vietnamese counterpart organisations in the context of Integrated Coastal Zone Management (ICZM).

In pursuing the above objective, in addition to the basic VA activities, in order to address short-term problems and demonstrate techniques and benefits of integrated approaches and actions, the VA component has been supplemented by *3 short Pilot Studies* on selected local coastal zone problems. The problem for Nam Ha in Pilot Study 1 was identified as coastal erosion and dike protection within the strategy referred to as *'managed retreat'*.

In the course of this **Pilot Study 2 (PS2)** it has become clear that the central issue around which ICZM concepts for Hue should be built consists in the flooding and its impact on the lagoon-oriented life (primarily lagoon salinity), i.e. both human activities and natural processes.

Three **visits** to Hue have been paid, in addition to other travel (Haiphong and HCMC) for the search and retrieval of relevant documents. After the basic second trip to Hue and the field trip of the lagoon system and vicinity, the major occupation of the Study Team consisted of desk studies i.e. extensive reading and translation (almost all documents retrieved are in Vietnamese!), analysis of the lagoon problems, **discussions** within PO and outside (including visits to institutions and individuals in Hanoi), receiving comments on the findings, and formulation of solutions to the problem, within the scope envisioned for PS2 and with due account of the limited means and time constraints.

**Interviews** with experts during the site visits and elsewhere in Vietnam (Hanoi and Haiphong) have facilitated better and faster understanding of the PS2 problems. The documents made available through such interviews and discussions have proved very valuable sources of information, despite the language barriers.

An element of **integration** has been reached in PS2 through involvement of numerous individuals (perhaps more than 25 people in one way or another) from HMS/MHC and many other Vietnamese institutions in Hanoi, Hue, Haiphong and elsewhere, covering the various disciplines embodying both PS2 and ICZM itself, throughout all stages of PS2. Discussions with the European PS2 team, and even the translation job alone, have brought about better understanding and dissemination of the knowledge of coastal and lagoonal phenomena in general and those of Hue in particular.

**Videotaping** of the site visits, Scientific Meeting #2 and other activities centered around PS2 and VVA Mission 3 has assisted the study team in recording important features and events. Hundreds of photographs taken may be invaluable also at later stages of VVA. Some of them are incorporated in this report and some are stored within VVA **GMS**.

Hence the following **methodological components** of the study have been accomplished:

(a) 3 site trips, including one extensive field trip;
(b) interviews with external experts and institutions;
(c) internal desk studies, including extensive translations from Vietnamese into English, computer work, graphical processing etc by VVA PO team;
(d) analysis of the PS2 problems within the extended study team and presentation of tentative findings during VVA Scientific Meeting #2;
(e) adoption of measures solving some of the problems encountered and preparation of draft report;
(f) reviews and comments by external experts (in Vietnam, Poland and the Netherlands);

(g) revisions and printing of the final report.

2. The Thua Thien Hue province, which encloses our study area of PS2, is situated at latitude 16°14'-16°45' North and longitude 107°02' -108°11' East, in the narrow strip of Central Vietnam, 660 km from Hanoi to the North, 1,060 km from Ho Chi Minh City (HCMC) to the South. Thua Thien Hue (TTH) has special original features of natural environment, land, the sea and lagoons, historic sites, architecture, cultural tradition and human behaviour. The lagoon system proper has been particularly challenging in terms of the objectives set for Pilot Studies.

General potentials, mineral resources and industry, aquaculture and sea products, agriculture, forestry, transportation and tourism of Thua Thuien Hue are summarized as at present (Section 2.1) and as planned and anticipated (Section 2.2).

The Study Area is defined as the Tam Giang - Cau Hai lagoon system, described somehow loosely as below, and with numerous couplings and interactions with other components of the Thua Thien Hue Province, in the broad sense of spatially etc integrated Coastal Zone Management. The Tam Giang - Cau Hai lagoon area so defined encompasses four out of eight districts in Thua Thien Hue. The four districts adjacent to the lagoon are Phong Dien, Quang Dien, Phu Vang and Phu Loc, of which the three occupying the majority of the lagoonal acrage are Quang Dien, Phu Vang and Phu Loc, with a total surface area of 154,282 hectares (Quang Dien - 15,896; Phu Vang - 25,386 and Phu Loc - 113,000 ha).

**The Tam Giang - Cau Hai lagoon** is the largest and most typical lagoon among the twelve brackish tropical water bodies stretching between 11 - 17° North of Central Vietnam, from Thua Thien to Ninh Thuan. It is nearly closed, with two narrow inlets, and is considered a very interesting basic type of lagoon.. It consists of Tam Giang, Sam (An Truyen), Thuy Tu and Cau Hai lagoons. The lagoon is about 68 km long, from Vinh Long mountain in SE to the O Lau River mouth at its NW end. It occupies 21,600 hectares i.e. 4,3% of the Thua Thien-Hue Province area or 17,2% of the province's plain area.

The study area is controlled by the **river system** of Thua Thien Hue. The total catchment basin of the Thua Thien Hue rivers is 4,000 sq km. The total runoff discharge to the lagoon is estimated about $6km^3$/year, stemming from the three rivers O Lau, Huong and Dai Giang. River Bo is the most important tributary of the Huong (Perfume) River, while River Truoi is an important branch of Dai Giang.

3. The Study Area, the Tam Giang - Cau Hai lagoon, was basically formed in Holocene and late Pleistocene, keeping pace with glaciation and changing sea level. In modern geological times it has been subject to substantial transformations, particularly conspicuous as the migration of its tidal inlets, now Thuan An and Tu Hien. The tectonic factors and morphology of both inlets bring about frequent changes. At present the Thuan An inlet is 350 m wide, 5 - 6 m deep on the average, and is oriented NNW-SSE. Tu Hien is only 50 m wide, with average depth of 1 m, aligned from NE to SW.

Because of serious climatic effects, **hydrochemical** factors play an important role, and clearly vary in the lagoonal system. The salinity varies from 1 to 33ppth, below 10ppth in the rain season, and above 20ppth in the dry season. In Tam Giang, the bottom layer in the dry season reaches 29.9ppth (13ppth in the rain season). The salinity exchange patterns due to tides are very complex, bringing about 20 - 27.7ppth in amplitude at the Thuan An inlet, 5.5 - 5.9ppth in Tam Giang, and 1 - 2ppth in Vinh Xuan (Thuy Tu). --- Nutrients in the lagoon system display poor and nonuniform distribution because of bad water exchange.

The **biological** structure of the ecosystem of Tam Giang - Cau Hai is typical of the Tonkin Gulf. It includes 171 species of pelagic plants of 4 types, with both freshwater and saltwater species. Algae appear in the dry season with high salinity. Pelagic fauna encompasses more than 30 species, mainly brackish Copepoda. Phytobenthos includes 47 kinds of algae and 12 kinds of higher level.

A substantial segment of the **lagoon resources** stems from aquaculture, which can produce 2500 to 3000 tons/year, of which shrimp amounting to 2,000 tons/year; including 22 kinds of cash fish such *as Ciprinus centralis, Siganus guttatus, Mugil cephalus* etc over the total area of 890 hectares. The annual production of sea plants (algae) is 500 - 1,000 tons. Yet the best value the Tam Giang - Cau Hai lagoon provides is the job opportunity for 300,000 people (of which 195,000 living closely to the lagoon) on 90,000 hectares of which nearly 22,000 ha are the water bodies of the lagoon, 49,000 ha of coastal plains and 19,000 ha of land (dunes etc). Because of the lagoon's regulating works, freshwater can be made available to the population. About 5000 - 7000 boats sail on the lagoon. Obviously, the lagoon can reduce typhoon effects and is also an important means of transportation. My Thuan port can handle 3000-DWT vessels.

In Vietnam's central provinces, there occurs regular annual **flooding**. Some of the more tragic events have taken place in the Quang Tri Thua Thien Regon in 1971, in Quang Nam in 1962, in Binh Dinh in 1982, in Hue in 1983, in 16 Eastern Provinces of the South in 1952, and in most Central Provinces in 1964. Recent examples of large floods (1961, 1966, 1978, 1984 and 1991) have seen hundreds of thousands of hectares of crops destroyed. Just slightly *before VVA Mission 3* began in November 1995, the central areas of Vietnam from Quang Binh to Binh Dinh provinces bore the brunt of the loss of life and the damage to property inflicted by three powerfull typhoons, Ted, Yvette and Zack. The three typhoons were all of strength 11 or 12, which occur only once every few years. The typhoons left in their wake 137 deaths, 199 injuries and 46 missing in one month from October 5 to November 3, 1995.

Since 1954, there have been 212 typhoons hitting or directly affecting Vietnam. The areas most affected by typhoons are the coastal provinces of the North and Central Regions. By and large, every year typhoons and violent storms strike the coast of Central Vietnam, causing death toll, damage to sea dikes and losses to agricultural crops and infrastructure. Typhoons are normally accompanied by storm surges. During the past 30 years, one half of the typhoon population have caused storm surges of over 1 m, 30% of typhoons over 1.5m, and a few typhoons were coupled with a surge exceeding 2.5m. The high water levels so caused frequently destroyed sea dykes, and initiated flooding of lowland coastal areas through overtopping and breaching of dykes. These destructive storms bring intense rainfall accompanied by strong winds, resulting in overall flooding due to atmospheric, landborne and sea-induced factors. The salinisation of the flooded soil can render farms inoperative for several years.

With its area of 21,600 ha, 31 townships and 4 districts drawing towards the lagoon system, 49,000 ha of adjacent land with a lot of problems in the fields of economy, ecology and environment, 19.000 ha of coastal area, 18% area of the Thua Thien - Hue Province altogether and 300,000 people attached to this area, the Tam Giang - Cau Hai lagoon plays a very important role in the province's economic activities and has a great asset of natural resources. Without any exaggeration it can be said that the lagoon determines the rate and patterns of the socio-economic development of the entire province, and the central Vietnam as well..

Since the inception of PS2 it has become clear that the whole region suffers from flooding in a variety of ways. However, the knowledge of the ecosystem, natural resources, usage etc of the Tam Giang - Cau Hai lagoon is far from completeness. Hence **the definition** of the Pilot Study #2 problems and objectives have been formulated as follows, with the intention to outline the possible ways of solving the problems in terms of ICZM, but not to solve the problems so defined.

*'Given that **flooding** creates most hazards for Thua Thien Hue on a large scale, with the city of Hue as the most conspicuous centre of vulnerability, and the Tam Giang - Cau Hai lagoon system on a regional scale, that the natural lagoon ecosystem attracts various human activities, and that both the natural ecosystem and the population of lagoon system users are equally affected by the flooding, outline as broadly as possible the processes and their interactions in the lagoon system, together with the effects due to climate change and socio-economic developments, and indicate the ICZM methodology applicable to solution of the natural, environmental and socio-economic problems so arising'.*

**4.** The general **users structure** in Thua Thien Hue is illustrated by photographs, tables and other material based on **GIS/GMS database** compiled in Hanoi under the **VVA** programme.

Inhabitants of the three districts attached most directly to the lagoon count nearly 400,000, almost one-half of the Thua Thien - Hue population. The population linked to the lagoon by jobs of their households can be estimated at 195,000, of which most in Phu Loc - 68,000 people/32,000 labourers and Phu Vang - 66,000 people/18000 labourers. Some other estimates are lower, e.g. Vo Van Phu (1995) gives the figure of 120,000 people attached to the lagoon, but this certainly depends on the strength of lagoon ties. The population growth rate is determined as 8,6%. Sea fisheries are mainly concentrated in 17 villages with 7053 households and 12,346 workers.

Both Vietnam and its central provinces, including the study area, undergo substantial transformations in all socio-economic domains, although the rate of change differs from province to province. Aside from the general trends, spurred so dramatically by the *doi moi* policies, the pilot study problems defined in Section 3.4, accentuated in the study area, add a new dimension to the area's general development features. Hence outlined are two major groups of development factors – (1) those stemming from Vietnam's accelerated growth and general socio-economic trends, and (2) the ones typical of the study area, including the context of the flooding and lagoonal problems.

The land-use trends predicted for the 30-year scenario (SE2) all over the coastal regions of Vietnam display the folowing:

- **aquaculture** will grow by making use of lowland fallow zones, not necessarily at the cost od agricultural land. Although its share in the total acrage of the central provinces is expected to grow only from 0.2% to 0.5%, in thirty years, it still denotes a dramatic growth;
- **rice production** will increase owing to higher productivity per hectare, while the overall rice acrage may decrease by 10-15%, but rather insignificantly in the central provinces, in view of their food deficit;
- vegetables and other field **crop production** should increase through both extension of acrage (form some 5% to 15% of total area in the central provinces) and addition of the third crop;
- orchards, tree- and bush-crops should increase through the use of indigenous forest and barren land; their share in the central provinces should increase from 3% to 8% of total area;
- natural **forest area** is expected to decrease in size (from 23% to 15% in the central provinces) but the production of timber and the acrage of timber forest should increase (from 2.5% to 15% in the central provinces!);
- the acrage occupied by **infractructure**, including special land for irrigation systems, will grow;
- virtually most new activities will take place on the land reclaimed from the present barren areas, although the latter will not be fully transformed in the nearest future – their share in the central provinces should fall down from 42% to 31% of the total area.

Development factors on the provincial level include as well **integrated watershed management**, sustainable **coastal zone management**, **tourism** and **infrastructure**.

In the domain of **regional development,** leading experts on the Thua Thien Hue province set the following priorities for flood control: *afforestation, building reservoirs, construction and conservation of dikes.* The plans for the construction of reservoirs in the Perfume River catchment basin are most realistic for Ta Trach (storage of 500 million cu.m, 30-MW power plant, irrigation of 5,000 hectares of rice fields, anticipated completion by the year 2000). Two other reservoirs, Thac Ong (Co Bin; for irrigation and power of 65 MW, flood control notwithstanding) and Binh Dienh (a small reservoir on Huu Trach, after the year 2010) seem more distant. Huge dike construction and upgrading schemes are either under way or finalized. River diversion projects, to help relieve the floodwater burden around Hue and flush the lagoon system, are not unlikely. All three types of measures (reservoirs, dikes, diversion) can go ahead together with re- and aforestation plans, vital not only to economy and environment but also to flood control in view of the prevention and mitigation of land denudation, increased erosion and numerous aftereffects, such as deficit of coastal sediments.

On top of those paramount flood-oriented plans, one also faces those of more general socio-economic nature, linked to flood control more indirectly. For TTH they ***include upgrading of Thuan An Port, Chan May Harbour*** project, *tourism, mining, agriculture* and *aquaculture* projects, all aligned along integrated development patterns. Plans for an oil refinery in TTH seem to be abandoned but the hazard of oil spills and pollution in the lagoon system persists.

In analysis of anticipated changes in the lagoon users structure, emphasis is placed on the features enumerated below, while all present and planned ***flood control*** are discussed later (Chapter 6), when they are more appropriate. The discussion centers about i.a. changes in salinity patterns, partly saltwater intrusion but mostly effects in the lagoon proper; positive (irrigation) and negative (salination?..) effects in agriculture; flushing aspects connected with more dredging problems, inlet stability worsening, lagoon users effects; depletion of sediment from the catchment area, sediment deficit in the coastal zone; lagoon system's stability etc.

*Inter alia*, it is noted that the total **population** of the study area will grow rapidly, perhaps at a rate higher than elsewhere beyond the coastal strip. The growing *urban population* of Hue will exert more and more pressure on the lagoon system, such as transportation and cargo handling, aquaculture etc. The *rural population* of the lagoon itself will gradually change its occupation structure on the strength of the primary and secondary transformations, such as a move to more aquaculture (primary) and increasing construction of dwellings in the wake of improving welfare figures (secondary).

Both the acrage and unit productivity of **aquaculture** will increase. This stems from the price structure favouring seafood, general governmental strategies etc.

As a consequence of other changes discussed, there will be a lot of **infrastructure** activities, such as roads, communications, wastewater treatment. The sector of **services** will grow at the cost of other, more 'basic' sectors such as agriculture.

If implemented, the **Chan May** Harbour scheme will have a dramatic impact on the lagoon system, not only in physical sense (e.g. coastal morphology) but, first and foremost, on the users structure. The scheme would provide a lot of employment during construction of the harbour facilities and their infrastructure (i.a. access roads) after afterwards, through permanent jobs at Chan May. New population centres are likely to arise. Aftereffects can encompass construction of trade centres, hotels and the like.

**Thuan An** efects can be similar to those of Chan May but their scale will be smaller. On the other hand, in view of the high investment cost, the authorities may decide first on the upgrading of Thuan An, only followed by the huge scheme of Chan May.

Developments in the **tourism** sector can be fairly diversified as to scale and services offered. Beach resorts planned will certainly provide employment for some present lagoon population. If more foreign and domestic tourists, now coming mostly for the historic values of Hue City, are attracted by expanding coastal recreation, and if the door to Laos is opened more widely, the effect of tourism and recreation on the users structure may become more conspicuous.

**Pollution and environment** problems should be given one of the highest priorities. Industry does not seem to create major pollution hazards but aquaculture and agriculture may become become bottlenecks of further growth in uncontrolled ecologically.

**5.** The environmental boundary conditions of the study area are described in Chapter 5 of the main body of this report. Some general characteristics of Central Vietnam's coastal lagoons are shown first such as the location and morphology, hydrological characteristics and their effects, water temperature, salinity regime, dissolved oxygen and other water quality characteristics. Section 5.1 deals with regional climate and meteorology. Here are some excerpts.

Water temperature changes seasonally and during the day alike. In 24 hours, the water temperature increases from the morning value at 5 to 6 o'clock, through its maximum at noon (in January and February) or at 13 to 15 o'lock (April to Jume) to its minimum at 5 to 6a.m. on the next day. The amplitude of temperature oscillations is 4 - 8°C during the day (rainy season) and 6 - 12°C (dry season), or 8 - 10oC on the average.

Average air temperature in the Thua Thien - Hue province varies from 19.7°C in January to 29.3°C in June (Tab.5.1.1), the maximum value reaching 40.7°C (Tab.5.1.2), and the minimum being 10.2°C. The yearly temperature amplitude is 9 - 10°C, while the daily temperature can vary in the range of 7 - 8°C.

The rainfall regime sharply differs in rainy and dry season. The monthly average rainfall can vary from approx. 30 mm (February) to approx. 530 mm (November) in case of Thuong Nhat station located upstream the Ta Trach

River (see Tab. 5.1.4), and for Hue station the monthly minimum value is approx. 25 mm (March) while the maximum is approx. 740 mm (October).

Wind conditions measured on land (at Hue Station) are characterized by high occurrence of calm weather, which exceeds 20% in all months of the year and reaches 33% at maximum (being 27.6% on the average). The most frequent winds blow from NE (about 12%) and NW (about 15%), see Table 5.1.12. The average wind speed is low (from 1.4 to 3.2 m/s), and the maximum goes up to 8--14 m/s, see Table 5.1.13. -- Winter monsoon period is from September to March, with the average wind speed 2-4 m/s, the maximum is 40 m/s; the observed wave height is 3.5 - 6.0 m. Monsoons from south-west are observed in the period May - August, with wave heights of 4.0 - 6.0 m. During this period there occur *typhoon*s, when i.a. the Thua Thien Hue area is seriously impacted by very high wind speeds. The occurrence of typhoons and their damage are described in the main body of the text.

The stations located most closely to the study area, which can be used for *wave data* are those of Son Tra (10-m depth of water) and off-Ouy Nhon (ship measurements at depths of 200 m). -- If wave data are to be computed from wind data, then it seems most reasonable to employ the wind measurements of Bach Long VI (depth h=50 m) for winter and Ouy Nhon for summer, as they seem to provide representative fetches.

From the *databases measured*, more representative of the study area (VVA files) one has for the Con Co station (107.22E/17.10N) the maximum wave height of 9 m observed in the years 1979--1994. The long-term statistics employed the Fisher-Tippet type I distribution for Con Co, with the following figures for respective return periods of 10, 50, 75 and 100 years: 11.6 m; 12.8 m; 13.9 m; 14.5 m.

The **water budget** of the lagoon catchment area stems from the following main rivers: O Lau, Bo, Huong (with its branches Huu Trach and Ta Trach) and Dai Giang. The inflow must be balanced by the outflow (or more precisely, bidirectional exchange) through the tidal inlets of thuan An and Tu Hien. Other components of the lagoon's water budget are surface run-off, evaporation, precipitation, retention and groundwater interactions. By different techniques one arrives at an estimate of 6.3 to 7.3 billion cu.m of water conveyed yearly by the river system towards the sea. The exchange through Thuan An should be computed; estimates for March and November 1993 give about 6 nad 30 million cu.m per day, respectively.

The Vietnamese **water quality** standards (four classes depending on the use for daily-life in the urban and rural settings; specific industrial areas; farming and irrigation in agriculture; entertainment, physical training, sports and aquaculture) have been confronted vs. some data measured and it is concluded that at present most parameters of the study area are in the first class, so may be regarded fairly clean. Because of intensive use of Tam Giang - Cau Hai for aquaculture and development of infrastructure, the improvement of living standards in the Thua Thien Hue province will bring about deterioration of water quality, as many experts fear. One of symptoms can be seen in the change in metal concentration in Huong River during two successive years (Tab.5.3.3.2).

An analysis of **climate change impact** on the study area, in terms of its boundary conditions, shows that special actions must be taken in advance with regard to *reservoir operation rules; drought control; prevention of acid soil and salt intrusion; and entrapment of sediments* in reservoirs due to denudation processes (prevention of sediment deficit in the coastal strip). All other actions due to accelerated sea level rise are self-explanatory in the context of our extensive VVA programme.

6. **Flood control and protection measures** are discussed in terms of the basic **strategies**:

(1) *Flood mitigation*, which encompasses a range of measures which can reduce the frequency and severity of flooding; such as flood prediction, non-structural measures to reduce runoff, and structural measures which can be taken to protect low-lying land and coastal areas;
(2) *Emergency preparedness*, by which one means steps aimed at foreseeing the impact of flooding;
(3) *Disaster management*, which aims at best tackling situations as they arise, mobilization of the emergency services and the provision of commands for decision-making and the coordination

Since the historical flood in August 1971, the Vietnamese Government has applied **six general measures** for short-term and long-term flood control:

1. Reforestation and watershed protection;
2. Constructiun of medium and large-scale reservoirs in the upstream areas;
3. Strengthening of dyke systems;
4. Flood diversion whenever necessary;
5. River dredging and clearance to provide discharge channels;
6. Dyke monitoring, repair and upgrading.

On top of the present flood control system, which is to be well maintained and has to be upgraded according to new challenges and demands, there will be new measures and initiatives facing general socio-economic trends and climate change alike. The major directions of those developments can be outlined as follows:
(a) construction of **new dykes** and rehabilitation of the present dyke system;
(b) construction of **new reservoirs** in the catchment basin of the study area;
(c) **diversion** of some river branches.

Aside from those major steps, some common protective measures to reduce flood from **reaching setllements** are:
*- Improving channels; - Construction or strengthening of existing dikes; - Increasing pumping capacities.*

In practice, some moves for the future are already made, such as

(a) **Dykes**. Central provinces, including Thua Thien Hue, have already been targeted for dyke upgrading and expansion, so it semms to be only a matter of time when such activities are undertaken under inter- national aid programmes.
(b) Construction of **reservoirs,** as outlined elsewhere in this report;
(c) River d**iversion** plans have materialized to a lesser extent.

Our analysis of flood impact and control on the lagoon system users has shown the following. Flooding, stemming from both atmospheric,inland and seaborne factors, exerts a number of impacts on the flooded area i.e. our lagoon system; these impacts including

(1) loss of life and health and material losses due to inundation of land;
(2) aftereffects in agriculture and other branches of economy;
(3) seasonal and/or short-term changes in salinity and water quality of the lagoon system, coupled with water exchange and flushing patterns;
(4) seasonality of sedimentation processes in the lagoons system and its catchmnet basin;
(5) seasonal, short-term and long-term changes in the morphology of the lagoon system, in particular its tidal inlets and river mouth sections;
(6) seasonal and other changes in the lagoon ecosystem, including migration of species, local transformations of habitats etc;
(7) seasonal and other changes in land use and socio-economic features associated with all above changes;
(8) many secondary and indirect effects.

The above impacts should be analysed vis-a-vis the present flood control practices and the measures planned for the future. Some impacts are both positive and negative, so a delicate balance should be sought in planning of flood control strategies.

In planning of flood control for the future, a reasonable blend of different measures must be offered to a growing variety of the lagoon users, and the advantages and shortcomings of those measures must be*compromised by* the use of *integrated management techniques* (cf. Chapter 11). It is quite likely that that blend will consist of dyke construction and upgrading; construction of reservoirs; some diversion schemes; drainage measures; and respective infrastructure.

The effect of *dykes* on the lagoon users structure is rather passive at present -- the dyke system is intended to protect the enclosed areas from either saltwater or freshwater. In future dykes may become a more active tool of flood control if a huge scheme of river endikement is implemented and the river waters are conveyed straight and fast towards the sea, without meandering and overflowing to the lagoon. Such a choice is however less conceivable having in view the loss of the function of lagoon flushing, very essential to that ecosystem.

The construction of *reservoirs* will lead to flood reduction and environmental protection, will make more reasonable use of frsh water for irrigation etc and will not impair aquaculture by not affecting the desired salinity regime. Yet one should not forget the most conspicuous `byproduct' of reservoirs, i.e enforced sedimentation on their bottoms and the subsequent reduction of downstream sediment transport and overall sediment deficit in the lagoon system.

*Diversion* of Song Huong waters towards Cau Hai can have one important advantage of flushing the lagoon, thus helping its water quality and ecosystem; the intrinsic instability of Tu Hien can only be remedied by allowing more water into Cau Hai.

Mitigation of salinity intrusion, efficient drainage and other infrastructural activities will be necessary to accompany the major efforts of dyke and reservoir construction.

Whatever the flood control schemes decided for the study area, the users structure will change accordingly; e.g. less salinity intrusion will foster agriculture; more reservoirs and sediment entrapment will impair beaches and tourism etc.

7. The **lagoon and coastal morphodynamics** is inherently coupled with the stability of the TTH tidal inlets. The sediment budget data (computed, estimated and/or retrieved otherwise) are as follows.
Sediment input from rivers: Song BO: 192,000 tons/year; Song HUONG: 450,000 tons/year; Song O LAU: 40,000 tons/year; Dai GIANG: 35,000 tons/year; thus total → 270,000 cu m per year.
Sediment sinks: 60,000 cu m per year due to sand and gravel mining + unknown quantities to be estimated for Ta Trach Reservoir ... & other reservoirs when implemented ++ ... (up to 200,000 cu m yearly?)
Sediment output (from the lagoon to the sea): to be estimated (more precise data needed)
Av concentration in the rain season: 50 mg/l
Av inlet flow velocity: 4-5 m/s in the rain season, below 1 m/s otherwise
Sedimentation patterns (circulation, grain distribution ...) to be explored

On the coastal side one has the littoral drift estimates: 300-400-500,000 cu m per annum net NW → SE Sediment transport estimates have been based on rough computations by Unibest, a Dutch software. More accurate computations should rely more heavily on improved wave figures, typical of at least the two predominant wave regimes in winter and summer; refined refraction plans for the study area; corrected data on coastal circulation (nonwave-induced currents such as tidal, inertial and wind-induced); refined data for bedforms and bed roughness.

During the Quaternary the beaches of Thuan Thien Hue were generated by the system of Rivers Huong, Bo, O Lau, which brought in sediment into the earlier gulf. During the first stage (unknown duration) there occurred the generation of the river bed. The coastline at that time was not affected. The second stage (medium Holocene) faced a system of dunes in Phong Dien and Phu Vang, consisting of a series of dunes 7--8 m high. At that time the sea level was higher by 4-5 m (4500 years ago) than at present, while 2--3 m higher 3000 years ago. Together with a system of dunes there was an ancient lagoon, which was later filled up with alluvial sediments to create the present day Hue plain. Finally, in the third stage (late Holocene), a system of very high dunes was generated from Quang Tri to Tu Hien inlet. -- At present, the sediment of the lagoon proper consists of coarse to fine sand, silt and clay. Samples with coarser silt and silty clay are found in shallow water of the lagoon while finer silt and clay are sampled in deeper water.

In recent forty years, the tidal inlet of Tu Hien was closed 3 times -- in 1953, 1979, 1994. In 1979, the salinity in Cau Hai was measured at 9 - 33ppth before closure and 11ppth after, thus proving the importance of lagoon flushing through the inlets. The last series of closing and opening events was initiated in 1989, with dramatic migration of Tu Hien in November 1994. Tu Hien is felt responsible for inundation, fertilization and flushing of the entire Cau Hai lagoon.

The migration is also an inherent feature of the other inlet, Thuan An. During this century, Thuan An has been moving 40 m/year to the north. At present the migration is slow and the old inlet at Phu Thuan. is approached.

Thuan An is directly affected by the Perfume River waters, which are flowing to the sea very dynamically, especially during the flood season. -- The history of the migration of both inlets, Thuan An and Tu Hien, from 1404 to date is well illustrated in **Figure 7.2**.

It is quite obvious that, for the sake of the lagoon sanity, Tu Hien should be opened and measures should be taken to avoid its closure. Hence Tu Hien should be investigated in terms of both technical means and general regional geography. The stability of both tidal inlets of the lagoon can be discussed in terms of the tidal prism volume and inlet cross-section, cf. Shore Protection Manual (1984). From the sketch in **Figure 7.3** it may be seen that the present cross-section area of both Tu Hien and Thuan An is too small to comply with the requirements of morphological stability. This is particularly true for Tu Hien, with its present cross-section area of 50 sq.m, versus tens of thousands sq.m required. The situation with Thuan An is not so dramatic because the inlet is not only tidal but also riverine, and is controlled by the Perfume River waters to a large extent. -- A more detailed analysis is necessary to support dredging operations etc, especially in view of the planned flood control measures and subsequent lagoon transformations.

8. Analysis of the **lagoon ecosystem** should be focused on the nutrients and primary production, followed by flora anf fauna, biodiversity and bioproductivity, linking to the lagoon's economic value.

In terms of *hydrochemistry*, the surface waters of Tam Giang can be split up in 4 areas as follows:

- 1st area: changing from fresh to fresh brackish water (close to O Lau River mouth),
- 2nd area: changing from fresh to fresh brackish and medium brackish water (Dam market to An Gia),
- 3rd area: variable in time, from fresh brackish, medium brackish water to salt brackish water (Mai Duong to An Xuan, Vinh Hung to Da Bac, Phu Loc to Tuy Van),
- 4th area: variable in time, from fresh water to fresh brackish, medium brackish, salt brackish and salt water (close to Thuan An inlet).

*Phytoplankton* is acounted as 171 species, of which Chrysophyta are abundant ( 119 species). Marine species predominate (78.36% of total), the freshwater species being 19.29% of the total. Freshwater phytoplankton grows in the wet season (October to December by 6.69%), while the marine one increases in dry season (April to June, by 18.32% of total). -- There are 59 species of bottom plants, most of them being marine and/or Bacillariophyceae. Their bulk does not change with time. -- Big-size plants include 40 kinds of sea algae and 11 kinds of seagrass. Sea algae develop with high biomass over large areas. Seagrass develops on sand and clayey sand, and its quantity is also substantial.

Most phytoplankton concentrates in the area with salinity over $30^{o}/_{oo}$, and decreases with decrease in salinity. For $15^{o}/_{oo}$ salinity there are 36 species, at $10^{o}/_{oo}$ - 25 species, and at $5^{o}/_{oo}$ - 6 species. Freshwater phytoplankton adapts very badly to salinity. There are very few species in Bacillariophyceae rank in area of $15^{o}/_{oo}$ salinity. As the salinity in Tam Giang lagoon varies seasonally, it causes the change in species composition of marine phytoplankton throughout the year.

In the Thua Thien - Hue lagoon system, there are 30 *zoo-plankton* species and 32 *zoo-benthos* species; brackish, fresh and seawater ones. The distribution of zoo-plankton and zoo-benthos depends mainly on salinity concentration. The average quantity of zoo-plankton is estimated at 1950 pieces/$m^3$ and that of zoo-benthos at 570 ones/$m^3$. By and large, the Thua Thien - Hue lagoon is poor in zoo-plankton and zoo-benthos.

Among *fish*, typical brackish water fish species are the largest community of the lagoon system. The different kinds of such fish (Clupeidea, Engranlidae, Atherinidae, Belonidae, Hemirhamphidae, Mugilidae, Serranidae, Theraponidae, Apogonidae, Leignathidae, Lutianidae, Gobiidae, Siganidae, Bothidae, Soleidae) have accomodated to the seasonally varying salinity in the lagoon.

Typical seawater fish species live close to the inlets of Thuan An and Tu Hien, and appear in the body of the lagoon only in dry season (April to August); such typical fish is Perciformes. The distribution of them (80 representatives) depends on salinity of lagoon. This fish is highly productive in terms of fisheries. -- Typical freshwater species develop in river mouth areas; there are 60 species of such fish. -- It is appropriate to note that the fish system structure in the TG-CH lagoon has both tropical and temperate zone features at the same time. Seasonal variability of fish species is also notable.

In the domain of *aquaculture*, *algae* (Gracillaria) are the main type and the major source of foreign currency. The natural alga productivity is 1-2 kg/m$^2$, but on farms the average productivity reaches 1.5-2.0 t/year/ha. In the neighbourhood of river banks, where salinity is 7-15$^o/_{oo}$, algae can be farmed most conveniently

Among aquacultural *invertebrates*, shrimp, crab and lobster are the most attractive and productive species. In lagoon proper, Penaecidae shrimp is the most common; it can live only 1-2 years and secures high productivity. The total area of shrimp farming is 460 ha. In future, this area will be doubled at Tan My and An Truyen, where salinity is 15-25$^o/_{oo}$. It is expected that in the year 2000 the total area will be 1500 ha. The present production covers only 50% of demand. Crab farming began in 1993; its area is now 16 ha at Thuan An.

*Fish* farming in brackish water of the Thua Thien Hue lagoon began in 1993. The most common fish species are Epinephelus, Siganus and Gobius. In the eighties, the average fish productivity was 2287 tons/year, with the peak in 1984 and 1988; the problem being coupled with the migration of the Tu Hien inlet and changing fishery technologies.

In terms of *biodiversity*, the Tam Giang - Cau Hai lagoon system is a fairly typical tropical ecosystem, although with a certain tendency to temperate features. The lagoon is well fit for aquaculture, especially in view of diversified nutrients structure, which must be preserved if the lagoon ecosystem is to remain undamaged.

Diversification of the lagoon waters, both vertical and horizontal, controls heavily the living conditions of various species. The latter include 235 water flora species, 86 invertebrates, and 21 shrimp and crab species. 163 fish species breed in the lagoon, of which 22 are highly productive.

Potential exploitation of *biological resources* encompasses the following four main groups of *water plants:*
- Industrial purposes: *Glacilaria*, with average productivity of 700 - 800 kg/ha/year, at times 1 ton/ha/year
- Drug production: *Caloglorra*, of limited productivity
- Livestock fodder: *Enteromorpha, Valisneria, Ceratophyllum*
- Fertilizers: *Enteromophorpha, Cymodocea, Blyxa, Najas.*

In general, *aquacultural productivity* is still estimated as very low compared with other branches. -- 23 fish species secure 2-5% of the overall product. The aquacultural production in the lagoon is given by Phu (1995) as 2287 ton/yr in the 80ties (of which 85% fish) and 3296 ton in the 90ties (with 80% of fish); cf. Appendix 8.

9. Mathematical modelling of lagoon processes begins with an overview of different models of the circulation and mixing dynamics of lagoon systems.

Upon analysis of various requirements it is concluded that the state of the art of lagoon modelling in Vietnam is far from satisfying the growing demand, to the best of the Mission staff's knowledge; nor ist it detailed enough to represent real conditions. Some data measured over the lagoon system (mostly 1993) are already available, and some other field campaigns are under way, so obviously this database can be helpful in modeling validation. The only existing model, prepared by Dr Pham Van Huan, is a 2D wind driven model. Other modelling attempts at MHC and the Institute of Oceanology, Hanoi, seem to be immature.

The model derived by Dr Pham Van Huan has also been attempted as a 3D extension for a part of the lagoon (the region of Thuan An inlet), but no publications are available. According to Professor Ngo Dinh Tuan, the obtained results have not been acceptable. In Dr. Pham Van Huan's apparently working 2D model (see Appendix9), the lagoon is covered by a regular grid 500x500m. The governing equations are solved by finite differences, probably using explicit scheme (time step 30s). The only forcing function introduced is wind. Introduction of river discharge and water level variation due to tides was mentioned, but none of these effects has been incorporated in the working version of this model. The density problem has not been taken into account. Calculations carried out concentrated on steady state cases. Unfortunately, no comparison between model results and real conditions has been made. This model can be treated as the starting point for further works. The intention of Dr Pham Van Huan is to continue with modelling by taking into account the forcing functions mentioned above.

For future modelling attempts the Mission staff has suggested the following two-step approach for modelling of the lagoon system.

As the *first step* one can propose to set-up 2D model (depth averaged). This model should incorporate the main rivers: Huong (and Bo), O Lau and Dai Giang. The lagoon itself should be covered with relatively fine grid to enable reproduction of inlets quite accurately. In such areas as Tam Giang - Cau Hai it is recommended to introduce non-uniform grid, eg. curvilinear grid, which enables refinement in areas of special interest (like inlets). With such a 2D model it is possible to incorporate salinity and temperature variation in horizontal plane, wind field over the area, and water level variation due to tides. As a result we get changes in water levels, depth averaged velocity patterns, spatial and temporal distribution of salinity, temperature, water density.

In the *second step* one can propose an extension of 2D model to 3D (layered) model. In that case one gets a detailed information on velocity patterns and other phenomena like salinity intrusion. These types of models are very useful for detailed studies, but they are more demanding with respect to data collection.

***Basic problems*** of such two-step attempts are outlined and an example of possible approach to 2D modelling is given for the Tam Giang - Cau Hai lagoon (not a real 2D model for this lagoon, but only illustration of the strategy proposed). To observe the possible 'seasonal behavior' of the lagoon one can carry out very simplified runs as shown in the main body.

*Water quality modelling* **is a next step in** expansion of mathematical models for lagoons and coastal pollution alike. Light on this problem is shed only, and some basic problems are mentioned to clear the way, given that a reliable hydrodynamic model is worked out. Depending on dimensions of this model, the flow has to be delivered in a 1D, 2D or 3D format. To run the model the data shown in the main body has to be incorporated. In the process of calibration/validation, the concentration of the analyzed quantities has to be available. The calibration/validation procedure should cover seasonal changes.

**10**. The identification and **analysis of the problems arising in PS2** context have been pursued in respective Chapters 1-9. The **synthesis** presented in Chapter 10 should be regarded as an achievement *per se*, for it results from a lot of interaction with the Vietnamese partners, stems from an analysis of various purely Vietnamese sources, cross-checking etc. and is written in English, thus being useful for both Vietnamese and foreign readers.

In analysis of anticipated changes in the lagoon users structure, emphasis is placed on the features enumerated below. The discussion centers about i.a. changes in salinity patterns, partly saltwater intrusion but mostly effects in the lagoon proper; positive (irrigation) and negative (salination?..) effects in agriculture; flushing aspects connected with more dredging problems, inlet stability worsening, lagoon users effects; depletion of sediment from the catchment area, sediment deficit in the coastal zone; lagoon system's stability etc.

*Inter alia*, it is noted that the total **population** of the study area will grow rapidly. Both the acrage and unit productivity of **aquaculture** will increase. There will be a lot of **infrastructure** activities, such as roads, communications, wastewater treatment. The sector of **services** will grow at the cost of other, more 'basic' sectors, such as agriculture. If implemented, the **Chan May** Harbour scheme will have a dramatic impact on the lagoon system. **Thuan An** efects can be similar to those of Chan May but their scale will be smaller. On the other hand, in view of the high investment cost, the authorities may decide first on the upgrading of Thuan An, only followed by the huge scheme of Chan May. Developments in the **tourism** sector can be fairly diversified as to scale and services offered. **Pollution and environment** problems should be given one of the highest priorities.

An analysis of **climate change impact** on the study area, in terms of its *boundary conditions*, shows that special actions must be taken in advance with regard to *reservoir operation rules; drought control; prevention of acid soil and salt intrusion; and entrapment of sediments* in reservoirs due to denudation processes (prevention of sediment deficit in the coastal strip).

Our **analysis of flood impact** and control on the lagoon system users has shown the following. Flooding, stemming from both atmospheric,inland and seaborne factors, exerts a number of impacts on the flooded area i.e. our lagoon system; these impacts including

(1) loss of life and health and material losses due to inundation of land;
(2) aftereffects in agriculture and other branches of economy;
(3) seasonal and/or short-term changes in salinity and water quality of the lagoon system, coupled with water exchange and flushing patterns;
(4) seasonality of sedimentation processes in the lagoons system and its catchmnet basin;
(5) seasonal, short-term and long-term changes in the morphology of the lagoon system, in particular its tidal inlets and river mouth sections;
(6) seasonal and other changes in the lagoon ecosystem, including migration of species, local transformations of habitats etc;
(7) seasonal and other changes in land use and socio-economic features associated with all above changes;
(8) many secondary and indirect effects.

The above impacts should be analysed vis-a-vis the present flood control practices and the measures planned for the future. In **planning of flood control** for the future, a reasonable blend of different measures must be offered to a growing variety of the lagoon users, and the advantages and shortcomings of those measures must be *compromised by* the use of *integrated management techniques* (cf. Chapter 11). It is quite likely that that blend will consist of dyke construction and upgrading; construction of reservoirs; some diversion schemes; drainage measures; and respective infrastructure. -- Whatever the flood control schemes decided for the study area, the users structure will change accordingly.

The **lagoon and coastal morphodynamics** is inherently coupled with the stability of the TTH tidal inlets. It is quite obvious that, for the sake of the lagoon sanity, **Tu Hien** should be opened and measures should be taken to avoid its closure. Hence Tu Hien should be investigated in terms of both technical means and general regional geography. The situation with Thuan An is not so dramatic.

Our analysis of the **lagoon ecosystem** is focused on the nutrients and primary production, followed by flora and fauna, biodiversity and bioproductivity, linking to the lagoon's economic value (cf. Ch. 8).

The measures proposed as a result of our analysis consist of two packages: (1) general strategies and (2) more specific measures for the study area proper. Group (1) is centered about (a) watershed management, control and rehabilitation, (b) coastal zone management, (c) control of coastal, estuarine and lagoonal ecosystems, (d) pollution control and environmental protection, (e) coastal erosion and protection, (f) hazardous wastes control and (g) education and public awareness.

In considering the measures for the study area one should be guided by the four circumstances: (1) flood control, as the major stipulation imposed in the problem definition; (2) socio-economic developments anticipated in the lagoon system, taking place 'in parallel' with flood strategies; (3) other important problems, linked directly or indirectly to flood control; (4) climate change factors.

It is essential that any measures taken will affect the primary properties of the lagoon system, such as *salinity; circulation and exchange of water and other matter; flushing of the lagoon and renewal of its components; sedimentation patterns; lagoon morphodynamics and inlet stability*. Many other effects are derivatives of the above but by no means secondary, e.g. aquacultural and agricultural productivity.

Illustration is provided for one of the alternatives aimed at improving the aimed at improving the present situation around the lagoon area consisting in **dike upgrading** (Anonymous, Sea dike ... 1993). The project is intended to rehabilitate and upgrade 7760 meters of sea dikes in order to reduce the incidence of sea water reaching areas protected by that dike.

Investigations and research must accompany new development programmes. Given for illustration is a brief list of projects under way, basing on citations from four various references acquired in the course of this Pilot Study #2.

11. Rational *planning of flood control* requires the use of adequate techniques aimed at coastal management. The same is true for **integrated coastal zone management** (ICZM), especially if triggered by climate change (CC).

Appriopriate systems, such as Geographic Information System (GIS) must be used for data management and clear-cut database support. Once arranged, a GIS system can be employed for a good many destinations serving the purposes of both VA and future projects. A Coastal Information System (CIS) can be put forth as a system which enables the systematic storage, compilation, interpretation and presentation and visualization of data of a specific set of coastal issues. The CIS selected for VVA is divided into four main modules:

1 **Coastal Data** *Management* System with GMS-DECIDE;
2 **Coastal** *Analysis* System with SPANS-EXPLORER;
3 *Databases* resulting from inventories, assessments and modelling.

In the coastal zone, as much as in flood control, and even more so in our pilot study's combination of flood control and CZM, one encounters a number of user-induced conflicts. Once it is realised what are the objects and context of management, one must

(1) identify the central issues around which the management will be centered;
(2) work out alternative strategies of management;
(3) evaluate as quantitatively as possible the benefits and shortcomings of the various strategies;
(4) take decision(s) on selection of the optimum management.

The element of **integration** at institutional, legislative, organizational etc levels, as well as in space and time of the management efforts, is taken for granted.

Evaluation (3) of various measures and outputs can be relatively simple if in monetary terms, which is seldom possible for environmental and ecologic values (cf. 11.2.2). Among a variety of techniques derived for decision taking (4) some are simpler and common while some other are only paving their way (cf. a short overview in 11.2.3). Some computer packages for implementation CZM concepts are commercially availabe (cf. 11.2.4).

In evaluation of environmental assets, special attention should be paid to rapidly developing **appraisal techniques** basing on questionnaires addressed to the users of coastal assets, including the environmental and ecological ones (also see App. 11).

There are many techniques making possible a relatively impartial quntitative evaluation of various strategies (for flood control and lagoon & coastal management in our case), together with their comparison. The oldest and simplest cost-benefit analysis has been gradually succeeded by more sophisitcated tools (cf. Figs. 11.11-11.12). They can be both monetary and non-monetary, to account for more qualitative assets, such as ecologic ones. Modern decision support techniques stem from systems analysis, wherein a substantial share is taken by multicriterial analysis (Fig. 11.13).

12. In closure, it should be repeated that the Tam Giang - Cau Hai Lagoon is a quite unique, semi-enclosed system, where flooding is a central issue. The physical, biological etc. and socio-economic factors are all lagoon- and flood-oriented and controlled. Climate change factors (SLR!) strongly control the lagoon system and trigger a variety of users-oriented phenomena. Salinity is one of the HUE lagoon system's most important factors. The stability of the lagoon's tidal inlets, and the lagoon morphology are very sensitive components of the lagoon system, are vulnerable to climate change factors, and depend on flood control strategies. Both present and new activities (Ta Trach, Chan May ...) all interact with the lagoon system and flood patterns and flood control measures. Hence Integrated Coastal Zone Management must be harnessed to help planners develop the area in a harmonious manner.

Potential follow-up activities may encompass many various efforts such as (a) Detailed analysis of the lagoon ecosystem and its interactions, including many links skipped in our report; (b) 2-D and 3-D modelling lagoon circulation, salinity and water quality for various development scenarios; (c) Modelling lagoon morphology, including sediment transport (in both rivers, lagoons and the coastal zone) and tidal inlet stability; (d) Upgrading environment protection studies and activities. In terms of potential follow-up, the Hue lagoon system is challenging both socio-economically and scientifically.

# VVA Pilot Study Hue

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# VVA Pilot Study Hue

## SUMMARY

# VVA Pilot Study Hue

**Version 7.1 February 1996**

# 1. Introduction

## 1.1 VVA and Pilot Studies

At all stages of the formulation, inception and implementation of the Vietnam Vulnerability Assessment programme (titled notably as *Vietnam Coastal Zone Vulnerability Assessment and First Steps Towards Integrated Coastal Zone Management (ICZM)*, in line with the requests from Vietnam and the findings of the 1993 Pilot Mission, the VA project has been formulated so as to address a few aims, of which the primary one has been to strengthen the capabilities for performance of ICZM activities in Vietnam.

Although the emphasis in VVA has been placed on specialist assistance to the Vietnamese Government by conducting together with Vietnamese counterparts in working out Vulnerability Assessment to accelerated sea level rise (along the lines of the IPCC Common Methodology), one of the three major outputs formulated in the project documents consists in strengthening the capability (staff and equipment), communication and inter-agency cooperation of Vietnamese counterpart organisations in the context of **ICZM.**

Throughout all project documents it has been stressed that the project must **not** aim, nor is it capable of doing so because of the time and financing constraints, to design and carry on a **full** programme for implementation of Integrated Coastal Zone Management (ICZM) in Vietnam. Instead, the programme of work and the outputs should be seen as providing important **first steps** towards this longer term objective.

Hence, in addition to the basic VA activities, in order to ensure effective interaction with Vietnamese counterparts on addressing short term problems and demonstrating techniques and benefits of integrated approaches and actions, the VA component has been supplemented by **3 short Pilot Studies** on selected local coastal zone problems.

The combination of the long term VA and the short term Pilot Studies should result in strengthening of the technical and management capabilities of the Vietnamese counterparts to deal with the coastal zone management demands imposed by increased development and climate change related impacts on the Vietnamese coastal zone.

There is a strong link between the Pilot Studies and the VA. This enhances the quality of the VA since the feasibility of local application of certain techniques, interactions and adaptive responses is tested in the Pilot Studies and thus not only helps one understand better the local and short-term problems but also sheds light on large-scale long-term processes tackled in VA proper. This will result in the formulation of realistic adaptive responses and recommendations in the VA based on the experiences of the Pilot Studies.

In the Inception Phase I, the Pilot Studies have been formulated as to the ToR, framework and planning. In the Implementation Phase III, aside from the full VA activities in Vietnam, two Pilot Studies have already been carried out --- Pilot Study 1 (PS1) for the Nam Ha Province and Pilot Study 2 (PS2) for the Thua Thien Hue Province. This report describes the latter study.

## 1.2 General Objectives, Approach and Methodology in Pilot Study Hue

The approach adopted for PS1 and PS2 is similar in the sense that certain coastal problem are identified first and then attempts are made to solve them, or outline a solution thereof, in terms of ICZM. The problem for Nam Ha in PS1 was identified as coastal erosion and dike protection within the strategy referred to as *'managed retreat'*. In the course of preparations for PS2 it has become clear that the central issue around which ICZM concepts for Hue should be built consists in the flooding and its impact on the lagoon-oriented life (primarily lagoon salinity), i.e. both human activities and natural processes.

As already stressed in this and other VVA documents, the Pilot Studies (and the whole VVA project itself) do not aim at implementing a full scheme for Integrated Coastal Zone Management (ICZM) but are instead intended as provision of first steps towards ICZM only. The approach and methodology followed throughout PS2 reflect this ideology. The element of CZM is secondary in PS1 but it becomes more conspicuous in PS2 (and perhaps will be expanded in PS3). Yet, because of the time constraints and limited funds provided for PS, the outcome of PS2 illustrated in this report might be below expectations of those who would like to see ready design drawings. However, one should not forget that the problems encountered in Hue are extremely complex, and their complete solution will require an enormous involvement of a good many research institutions, first and foremost Vietnamese ones, perhaps with more guidance and advice from abroad.

Upon implementation of PS2, three **visits** to Hue have been paid, in addition to other travel (Haiphong and HCMC) for the search and retrieval of relevant documents. After the basic second trip to Hue and the field trip of the lagoon system and vicinity, the major occupation of the Study Team consisted of desk studies i.e. extensive reading and translation (almost all documents retrieved are in Vietnamese!), analysis of the lagoon problems, discussions within PO and outside (including visits to institutions and individuals in Hanoi), receiving comments on the findings, and formulation of solutions to the problem, within the scope envisioned for PS2 and with due account of the limited means and time constraints.

**Interviews** with experts during the site visits and elsewhere in Vietnam (Hanoi and Haiphong) have facilitated better and faster understanding of the PS2 problems. The documents made available through such interviews and discussions have proved very valuable sources of information, despite the language barriers.

An element of **integration** has been reached in PS2 through involvement of numerous individuals (perhaps more than 25 people in one way or another) from HMS/MHC and many other Vietnamese institutions, covering the various disciplines embodying both PS2 and ICZM itself, throughout all stages of PS2. Discussions with the Polish PS2 team, and even the translation job alone, have brought about better understanding of coastal and lagoonal phenomena in general and those of Hue in particular.

**Videotaping** of the site visits, Scientific Meeting #2 and other activities centered around PS2 and VVA Mission 3 has assisted the study team in recording important features and events. Hundreds of photographs taken may be invaluable also at later stages of VVA. Some of them are incorporated in this report and some are stored within VVA **GMS**.

Hence the following methodological components of the study have been accomplished:
(a) 3 site trips, including one extensive field trip;
(b) interviews with external experts and institutions;
(c) internal desk studies, including extensive translations from Vietnamese into English, computer work, graphical processing etc by VVA PO team;
(d) analysis of the PS2 problems within the extended study team and during VVA Scientific Meeting #2;
(e) adoption of measures solving some of the problems encountered and preparation of draft report;
(f) reviews and comments by external experts (in Vietnam, Poland and the Netherlands);

(g) revisions and printing of the final report.

The following structure of PS2 has been adopted, and reflected accordingly in this report.
Chapters 2 & 3: description of the Thua Tien Hue Province, as a background to the Hue Lagoon (Tam Giang - Cau Hai) System (Ch.2), together with the description of the study area and its problems, thus making it possible to define the study area problem dealt with throughout this PS2 (Ch.3);

Chapter 4: delineation of the users structure and development features for the study area, with an analysis of possible changes in the lagoon system and their impact on the users

Chapter 5: provision and analysis of environmental boundary conditions for the study area, along with some climate change factors

Chapter 6: description and analysis of flood disasters, flood control measures and flood impact on the lagoon system users

Chapter 7: analysis of lagoon and coastal morphodynamics, including the sediment budget, tidal inlet stability etc

Chapter 8: synthesis of the lagoon ecosystem features and their interaction with the natural and man-controlled processes and developments

Chapter 9: outline of the mathematical modelling of lagoon processes

Chapter 10: summary of the study problem analysis and proposed problem solving measures

Chapter 11: description of integrated coastal zone management (ICZM) needs and potentials for the study area.

The conclusions drawn from the Pilot Study, discussion of possible solutions and strategies are summarized in Chapter 12, which also contains a vision of possible follow-up studies.

For the sake of clarity it should be **noted** that the **drawings** presented in this report have **double** system of **numbering** -- those of more general nature are given roman numbers, consecutively in chapters, e.g Fig.1.I -1.II ..., Fig.2.I, 2.II ... etc. The ones of more specific relation to the individual chapters are given the section number first, followed by subsection number and ordinal number of drawings, e.g. 5.1.4 (denoting Figure 4 in Section 5.1).

It may also be seen that **analysis** of the problems tackled in this PS2 continues in almost all chapters and is summarized in Chapter 10. This way of the presentation of the study seems more appropriate than an extensive analysis in one chapter, mostly because of the variety of the aspects encountered in the lagoon area and the necessity of treating them topic by topic in the context of the state-of-the-art knowledge reflected in respective chapters.

**Figures 1.I and I.II** show general geography of Vietnam and some physical features of Central and North Vietnam.

# 2. Thua Thien Hue Province

## 2.1 Description of the Province as a Background to the Hue Lagoon System

### 2.1.1 General potentials

Thua Thien Hue is located at latitude 16°14'-16°45' North and longitude 107°02' -108°11' East in the narrow strip of Central Vietnam **(Fig.2.I)**. It is 660 km from Hanoi to the North, 1,060 km from Ho Chi Minh City (HCMC) to the South and is the key link of the Vietnamese cultural and tourist system.

Thua Thien Hue has its particular and original features of nature, land, the sky, forests, the sea, lagoons, historic sites, architecture, cultural tradition and human behaviour. Those features are at the same time strong points of the province, which must be paid attention to in the process of mapping out the strategy of socio-economic development of Thua Thien Hue.

The province's capital is Hue City. Vietnam has a lot of famous ancient capitals but up to now it is widely accepted that no capital is as complete, huge and rather intact as Hue ancient.capital. The northern bank of the Perfume River is the area of vestiges with the capital town having a perimeter of 11 km built in the form of a defensive imperial capital. Here still remain over 100 architectural works wholly reflecting the activities of the kings and mandarins of the Nguyen Dynasty. The golden past has thus marked Hue as "a dreamlike urban masterpiece". The complex of vestiges of Hue ancient capital has been affirmed by UNESCO as the cultural heritage of mankind.

With its sea coast of more than 120 km, Thua Thien Hue has a special system of lagoons and marsh of Vietnam including Tam Giang lagoon, connected to Sam and Chuon marsh, to Thuy Tin marsh with Cau Hai lagoon and Lang Co marsh, creating a body of brackish waters covering nearly 22,000 ha. Here is the junction of three estuaries (Thuan An, Tu Hien and Lang Co) with five rivers (O Lau, Bo, Perfume, An Nong and Truoi) flowing from the Truong Son Mountains carrying along with them a lot of algae and plankton, creating conditions for shrimp, crabs, tortoises, fish, moray, conger, eel, snail, gracilaria etc to develop raw materials for a number of products of high economic value such as agar-agar and other valuable aqua produce of the province. **Figure 2.II** shows both Hue and its lagoons.

Another important thing about Thua Thien Hue is that it has a lot ot universities and vocational schools with a large number of skilled technical and scientific staff, writers, literary and artists; an abundant workforce - intelligent, hard-working, professional and sensitive to receiving new ideas and concepts.

### 2.1.2 Mineral resources and industry

The mineral resources of the province encompass nearly 70 mines with more than 25 different kinds of ores and construction materials. The metal group with titan along the coast attains industrial requirements. The iron in Hoa My is of good quality.

All other resources and minerals ot Thua Thien Hue are relatively abundant and diversified. They include gold, ilmenite, iron, peat, pyrite, clay, kaolin, limestone, granite, sand for glass production, mineral water, etc. Limestone is especially important (for cement production), together with multicoloured and pink granite. Other raw materials are sufficient and very tavourable for developing the produdion of construction materials.

In the industrial field, up to now Thua Thien Hue has developed enterprises belonging to such fields as production of construction materials, exploitation ot minerals, mechanical engineering, electronic assemblage, foodstuffs processing, production ot consumer goods, pharmaceutical products, textile, garments, etc. Food processing industry is a substantial component of these activities.

In particular, Song Huong (the Perfume River) Refrigeration Enterprise is the main establishment of the province to process aqua products for exports. It is a refrigeration plant which is perfectly built with a total current capacity of 1,200 T of produce per year. The second establishment is Thua Thien Hue Sea Products Company, established in 1993, which has launched a lot of products, especially dried ones. The traditional exported aqua products of the province are varieties of frozen shrimp and squid and dried squid with an average annual production of 400-500 T/frozen products and 150 T/dried products. Recently the establishments have had such high-class products as SASHIMI squid, boiled AMADA shrimp, and skinned dried squid, all internationally marketed.

### 2.1.3 Aquaculture and sea products

In the province there are 22,000 ha of brackish water lagoons and marshes, over 5,000 ha of lakes and ponds and freshwater rivers and streams which can be used for aquaculture. In recent years the rearing of shrimp, crabs, fish and other special aqua products and the planting of gracilaria have strongly developed in localities along lagoons and marshes. At present the province has 600 ha for shrimp rearing and brackish crabs and 357 ha for planting gracilaria. The rearing of shrimp is now still in the form of extensive farming and semi-intensive farming attaining a capacity of 500-1,000 kg/ha. The fry raised in the form of intensive farming has attained a capacity of 4T/ha. In the coming years Thua Thien Hue province needs investment in expanding the area of aquaculture and applying modern methods increase capacity and efficiency. Illustration of aquaculture (and other users) is given in **Figure 2.III**.

The sea ot Thua Thien Hue lies at the demarcation line between the fishing grounds of the Gulf of Tonkin and those of the Central Sea so it includes the characteristics of the two above-mentioned fishing grounds. The province has 126 km of seacoast opening to the vast East Sea so there is a large shoal of migrating fish like mackerel, tuna, flying fish, etc, which has long been a great source of profit of the locality. To the south of Thua Thien Hue there is the home to black pomfret and the north there are large shrimp grounds. In recent years squid and cuttle-fish have been exploited with increasing production. The production (catch) of sea products attained 10,500 tonnes in 1993. By just using three-layer draw-net, only big squid is caught. In Phu Vang squid catching is highly developed. In the lagoons and marshes of Thua Thien Hue there are also a number of valuable species such as sea-bass, crabs, brill, mullet, etc. In recent years there have been dramatic changes in the activities of processing aqua products for exports.

### 2.1.4 Agriculture

The area under cultivation is about 75,000 ha/year, of which 79.6% is allocated for food crops, 16.6% for food trees and short-termed industrial crnps and 3.6% for perennial trees. The production of corn, sweet potatoes and cassava annually averages over 90,000 tonnes. This is the source of raw materials for production of cattle fodder. There are industrial plants ot export value such as groundnuts, sesame, red pepper and trees giving precious essence like Aquilaria, Herba Ocimi Mentha and cajeput. If investment is made in cultivation and processing of adequate products, high economic value can be achieved from such a production. The herd of cattle in Thua Thien Hue in 1993 totalled 55,500 buffaloes, oxen and cows and 190,000 pigs. The meadows for cattle raising are sufficiently large. Together with hill land, they create favourable conditions for development of the cattle herd.

### 2.1.5 Forestry

Thua Thien Hue has an area of forests and forest land of nearly 330,000 ha, occupying approximately 70% ot the area of natural land. The original feature of the TTH forests is that the convergence of two vegetation types stemming from the north and the south occurs there, with many kinds of precious wood representing the two regions, such as iron-wood, teak, dalbergia bariensis, black sequoia and Aquilaria.

Besides, the forests ot Thua Thien Hue provide other products like rattan, 'dot', etc used as raw materials for the producuon ot fine arts handicratts. There are hundreds ot precious medicine plants like Radix Codonopsis, Amomum xanthioides, Cortex Eucommiae, Strychnos, etc in high mountainsan abundant resource for the production of pharmaceutical products.

The area of afforestation is not large (20,000 ha), including casuarina, eucalyptus, acacia, pine etc. In the whole province there are nearly 166,000 ha of land of shrubs and wood scattered in mountainous areas for cultivation of highly economic species such as rubber tree, pepper, tea, cinnamon, Herba Ocimi etc.

### 2.1.6 Transportation

Thua Thien Hue has a central position in Vietnam with Highway 1A and the national railroad running the whole length ot the province, favourable for the transport of goods between the North and the South. The provincial land and the road system secure the transportation between the districts and cities of the province. By land roads goods are transported trom Laos to the province and vice versa, through Lao Bao International border check point (150 km from the centre ot Hue City). At present the province is mapping out the plan of building a road linking Thua Thien Hue to Saravan Province ot Laos via Aluoi district. To meet the requirements of developing the whole national communications network, the province appeals for toreign capital to upgrade and enlarge Highway 1A.

Thua Thien Hue has a seashore of over 100 km, conditions to develop waterway communications and Thuan An port, 12 km from the centre of the city, with an area of 20,000 sq metres. Formely 5,000-DWT ships could call at the port but because it has not been dredged and repaired, the capacity has been limited. In the days to come, one of the priority objectives ot the province communications branch has been set as upgrading of the Thuan An Port.

### 2.1.7 Tourism

Thua Thien Hue attracts tourists far and wide because it is the cradle of traditional music, the homeland ot savoury royal and popular dishes and the birthplace of age-old, exquisite fine art handicraft works. Spatially speaking, Thua Thien Hue should be understood as a cultural and historic area. The people and the cultural tradition of Thua Thien Hue are great potentials that can increase the strength of Thua Thien Hue tourist market. *Harmony can be found not only between the mountains, the rivers and the architecture, between the nature and the man, but also in the hearts of the natives of Thua Thien Hue* (Anonymous 1995, TTH Potentials and Prospects).

Nowadays in Vietnam it is realized that tourism has become an important economic branch of many developed countries in the world. It is a general economic branch promoting the development of many business and production activities and it has been really regarded as the most efficient branch of bringing foreign exchange to the country Tourism brings not only purely economic profits but also contributes to changing the socio-economic face of a region.

Thua Thien Hue tourism has, over the past few years, made some developments to keep pace with the growth of the national economy in the open door period (doi moi). The province has affirmed tourism as one of the tour economic spearheads to be invested and exploited. The good prospects stem not only from the cultural and historical heritage of the province in general, and Hue in particular, but also in large part from the climate, which bears the transitional quality from sub-equatorial to monsoon type, with the average annual temperature of 26°C.

Recent statistics show over 3,000 beds for tourists, of which about 1,000 beds have standards acceptable to foreign visitors.

## 2.2 General Development Plans for the Region

### 2.2.1 Overall perspectives and plans

The economy of the Thua Thien Hue province still has a lot ot unstable elements. The efticiency of many economic activities is still low, the infrastruture is poor and backward, the invested capital is not heavy, the population increases rapidly, unemployment is high, the exploitation ot the province's potentials is limited, and so on. The policy of Thua Thien Hue authorities (put *expressis verbis* by the People's Committee) in the years to come is then as follows. Upon realization of the potentials and strong points of the province, one should speed up the change of economic mechanisms leading towards industrialisation and modernisation; gradually move from emphasis on industry to agriculture, tourism, and services; expand and increase the efficiency of foreign economic relations; concentrate on building the infrastructure, and the like. Hence concem is to be given to cultural, educational, health, social, scientific and technological problems, taking for granted the political stability.

Thua Thien Hue adopts the policy ot solving the foodstuff problems by combined measures: to develop overall agriculture; to boost the local production of foodstuff; to employ the processing industry of aqua and sea products for boosting the food production and cutting food shortages; handicrafts should be an important supplementary tool in that policy, taking into account the exchange of goods and the overall turnout of goods and services.

The land for crop cultivation in Thua Thien Hue is still large and can be used for planting short and long-termed industrial trees like red pine, rubber, fruit trees, tea, pepper, peanut, pimento, etc serving the food-processing industry and exports. If there is enough capital to build up the infrastructure, to solve the problem of irrigation and to gradually apply modern science and technology aimed at improving the quality ot consumer goods and exports, this can be a tremendous source of the province's protit.

The acrage of forests and hills in Thua Thien Hue occupies nearly 70% ot the natural surface area. Due to the destruction at war and long exploitation by man, forest resources have gradually been exhausted. Up to now there have remained 171,000 ha of natural forests in the whole province, with many kinds of rare wood. In recent years Thua Thien Hue has planted over 20.000 ha of forests and scattered tree enclaves. The remaining area is approximately 150,000 ha of empty land, bald hills and coastal sand banks, offering a vast potential for re- and aforestation of trees and cash crops such as raw materials for paper industry etc.

### 2.2.2 Officially approved projects

Given below are some projects referring to the development of Thua Thien Hue, and bearing impact on our study area in particular, as officially outlined in TTH People's Committee documents.

#### 2.2.2.1 Tourism

**A.** Lang Co tourist area : Reconstruction of the present hotel; the location is a famous coastal area with a beautitul and safe beach.

**B.** Canh Duong sports and tourist area: construction of hotels and sports facilities at a well-known and safe beach.

**C.** Thuan An area: construction of new hotels and seaside resort facilities.

#### 2.2.2.2 Aquaculture

**A.** Growing and processing marine algae: 100% foreign capital. investment aimed at cropping Gracilaria and producing agar-agar. At present there are 500 ha for gracilaria grounds, while the planning goes for another 2,000 ha. The bio-chemical conditions of the area are suitable for gracilaria.

**B.** Shrimp rearing and processing: 100% foreign capital to build shrimp ponds and to process shrimp tor exports. The acrage of lagoons and marshes is very suitable for shrimp farming; at present there are only 800 ha used for this purpose, while the planned area is 4,000 ha.
**C.** Production of breeder shrimp : 100% foreign capital investment into farms producing breeder shrimp with modern technical equipment; 300 million breeder shrimp/year; P15 size. The central area has the capacity to develop the rearing ot shrimp on an area of 5,000 ha.
**D.** Production of shrimp fodder:construction of a plant producing feed for shrimp with a capacity ot 10,000 t/year. It is estimated that the central area has the capacity to develop the rearing of shrimp on an area of 5,000 ha.

**2.2.2.3 Hue City**
Hue is one of the four nuclei of national tourism and recreation areas. Aside from its historical and cultural values, Hue City is attractive to tourists because of such infrastructure as Thuan An Port, Phu Bai airport, Highway 1A, North-South railroad, waterways etc., which all can and will be upgraded in the years to come.

Hue is the convergence place of the two sources ot relations : - The North to South, Central transit relation of the whole country and the East-West forest relation. Hue becomes an inter-regional communications junction and is connected to the outside by air, sea route, and Route 12 running to Laos, Cambodia and Thailand. The Perfume River is the natural link joining the North and South, thus securing the process of urban development in a unified way. --- Apart from its spiritual and traditional values, Hue is also an invaluable source of natural resources and has great capacity to decide the strategy for the economic development of the entire Thua Thien Hue province.

**2.2.2.4 Infrastructure, including flood control and mitigation**
The Hue City and the whole province will undergo a lot of infrastructural change. Here is an outline of some major steps intended for the city alone, with regard to flood control and water supply.
**A.** Rehabilitation and reconstruction of the Hue drainage system. --- Until 1995 and 2010 a study should precede a project on dredging Thuan An Port, the Ke Van river network, the Dong Ba river, the An Hoa and Ngu Ha rivers; including the construction of reservoirs on the Perfume River to solve the flooding problem for the Hue city and its vicinity.
**B.** Attention will be to the drainage system in urban areas. Dirty water must be checked betore being discharged into lakes and rivers.
**C.** Plan ot water supply for the city. At present Hue has two water plants: Gia Vien with a capacity of 10,000 cubic metres/day; Van Nien Quang Te, with 15,500 cubic metres/day. At present the water supply is just 50 litres per person per day for 35% of urban residents. In 2010 the capacity of the plants will be increased to 110,000 cubic metres/day and three 5,000 m' pressure-boosting stations will be built in the Hue citadel district, Thuy Duong and Phu Vang, thus increasing the water consumption standard to 120 litres per person per day, thus satisfying 75% of the water supply in the city and its suburbs.

**2.2.2.5 Mineral resources**
Ilmenite, zircon and rutile ores will be mined and processed under a joint-venture with 100% foreign capital. A plant will be built to exploit 10,000 tonnes of ilmenitel per year and 2,000 tonnes of zircon per year. There are huge reserves of black sand along the seacoast, from which the ores will be extracted. Upon a preliminary survey, the black sand has 54% ot ilmenite, 21% of zircon, and 3.4% of rutile.

White sand, a raw material for glass produce, is also abundant along the coast of Vietnam's central provinces. Yet, mining of white sand and black sand alike should be approached with caution. One must not forget that coastal mining contributes to beach and shore erosion, or sediment deficit in the least. Hence respective shore protection measures should be foreseen in response to the potential erosion, shoreline retreat and all other outcomes of mining activities. These factors must be taken into account in the cost-benefit analysis supporting the mining ventures.

#### 2.2.2.6 Thuan An Port

Reconstruction and upgrading of the Thuan An port is planned under a joint-venture with 100% foreign capital investment. The project aims at accomodating the present Thuan An Port facilities to guarantee the calling ot ships of over 5,000 tonnes. The port site is situated 12 km from Hue Centre; the current surface area is 20 ha.

#### 2.2.2.7 Thac Ong hydroelectric power plant

The plant will be located on an upper branch of the Perfume River (cf. Chapter 5). The investment calls for 100% foreign capital to build a hydroelectric plant with capacity ot 65,000 KW. The project is well substantiated in terms of the availability of hydropower, first and foremost, and systems requirements for flood control and other secondary users of the water to be impounded in the reservoir at Thac Ong.

#### 2.2.2.8 Ta Trach Reservoir

The reservoir is to be constructed on River Ta Trach, a major tributary of the Perfume River (cf. Chapter 5). Vietnamese planners have proved that the construction of the reservoir is well justified in terms of systems requirements for flood control, production of hydropower, water supply for agriculture and secondary users of the water stored in the reservoir. The investment of 100% foreign capital is sought to build the reservoir with a capacity of 500 millions ot cubic metres to secure the operation ot the hydroelectric plant with a capacity of 30,000 KW and to guarantee irrigation for 5,000 ha ot rice fields. Description and substantiation of the project is also given elsewhere in this report.

# 3. Description of the Study Area and Its Problems

## 3.1 Rivers and Their Catchment Area

The **study area** is defined as the Tam Giang - Cau Hai lagoon system, described somehow loosely as below, and with numerous couplings and interactions with other components of the Thua Thien Hue Province, in the broad sense of spatially etc integrated Coastal Zone Management. The Tam Giang - Cau Hai lagoon area so defined encompasses four out of eight districts in Thua Thien Hue. The four districts adjacent to the lagoon are Phong Dien, Quang Dien, Phu Vang and Phu Loc, of which the three encompassing the majority of the lagoonal area are Quang Dien, Phu Vang and Phu Loc, with a total surface area of 154,282 hectares (Quang Dien - 15,896; Phu Vang - 25,386 and Phu Loc - 113,000 ha). Although it is arbitrary, one can follow this delineation, as adopted in quite a few sources, e.g. HP23. **Figure 5.1.3** (see Section 5.1) gives an overview of the TTH river system.

The total yearly solar radiation in the study area is 120 - 140 Kcal/cm$^2$, with the maximum in May, and minimum in December. The yearly average temperature is 24,5°C. The hottest months are June, July, August (over 29°C), the coldest ones --December to February (18 - 21°C). The rainfall is 2.500 - 3.000 mm/year, mainly in September, October and November. The average air humidity is 83.5%. The dry season lasts from February to August, with 56% of easterly winds having the speed of 1 - 7 m/s. Rainstorms occur in August to September, last for 2 - 3 days, and yield 260 mm rain (station Hue).

The study area is controlled by the river system of Thua Thien Hue. The total catchment basin of the Thua Thien Hue rivers is 4,000 sq km. The total runoff discharge to the lagoon is estimated about 6km$^3$/year, stemming from the three rivers O Lau, Huong and Dai Giang. River Bo is the most important tributary of the Huong (Parfume) River, while River Truoi is an important branch of Dai Giang.

The Huong River includes Ta Trach, Huu Trach and Bo with the total basin area of 3,000 sq kilometers, the flow discharge of 5,4 $km^3$/year, river network density of 0,75 km/$km^2$, and the basin's average slope from 11 to 12%. The average sediment concentration is estimated at 150 g/$m^3$. In the flood season, the accumulated discharge amounts to 60 - 80% of the annual volume. The Tieu man flood appears in May - June causing damage to the autumn and summer crop. The tide affects reach Nga Ba Tuan (upstream of Hue). In the dry season, due to flow water levels, the salt wedge forced by tides affects inland areas.

The O Lau basin measures 572 sq km, with the yearly average flow of 0.5 cubic km, and Dai Giang also conveys 0.5 $km^3$.

## 3.2 The Lagoon System

### 3.2.1 Location, topography and morphology

The Tam Giang - Cau Hai lagoon is the largest and most typical lagoon among the twelve brackish tropical water bodies stretching between 11 - 17° North of Central Vietnam, from Thua Thien to Ninh Thuan. It is nearly closed, with two narrow inlets, and is considered a very interesting basic type of lagoon.. It consists of Tam Giang, Sam (An Truyen), Thuy Tu and Cau Hai lagoons.

The Tam Giang - Cau Hai lagoon is about 68 km long, from Vinh Long mountain in SE to the O Lau River mouth at its NW end. It occupies 21,600 hectares i.e. 4,3% of the Thua Thien-Hue Province area or 17,2% of the province's plain area. Tam Giang - Cau Hai lagoon was formed by continental sea inpact and can be divided into four basic structural morphological units: water body, tidal inlets, a subsystem of barriers and dunes, and inland banks ('sheltered shore'; Nguyen Huu Cu 1995).

- The water body

The Tam Giang - Cau Hai lagoon's water body is 216 sq km in area, with 4 different components such as Tam Giang lagoon proper (52 sq km), Sam and Thuy Tu lagoons (60 sq km in total) and Cau Hai lagoon (104 sq km). Tam Giang proper is 24 km long, from O Lau mouth to the mouth of the Huong River, and it is 2.5 km wide and 1.6 m deep on the average or 2 m deep about the Huong River. The Sam - Thuy Tu lagoon measures 33 km from the Huong River to Cau Hai. It is 1.5 - 2.0 m deep, at places 3 m, and its average width is 1.0 km. The depth of water within Cau Hai is 1-1.5 m, or 2 m at places. The lagoon has an average volume of 300 million cubic meters, or over 400 million when flood waters enter the system.

- Tidal inlets

The tidal inlets of Tam Giang - Cau Hai as at present are Thuan An and Tu Hien. The tectonic factors and morphology of both inlets bring about frequent changes. At present the Thuan An inlet is 350 m wide, 5 - 6 m deep on the average, and is oriented NNW-SSE. Tu Hien is 50 m wide, with average edpth of 1 m, and is now aligned from NE to SW. The tidal range at Thuan An and Tu Hien is different -- it has the lowest tidal amplitude at Thuan An and increases towards Tu Hien, with some tidal effects of the adjacent bay of Chan May. The water velocity in Thuan An in the dry season (from February to August) is 1m/s but in the rain season (September to January) may reach 4 - 5m/s. The velocity at Tu Hien is estimated at 0.6 m/s in the dry season and 0.9 m/s during the rain season.

- Subsystem of barriers and dunes

The existence of lagoon depends substantially on its subsystem of barriers and dunes. A system of barriers and dunes attached to Tam Giang - Cau Hai measures 102 km from Viet to Loc Thuy inlet. Its maximum height is 30 m at An Loc, Dong Hai. The subsystem consists of many continuous dunes.

- Lagoon banks

The frontal shore of the barrier subsystem and the lagoon banks have different geological origin and undergo different sedimentation processes. Almost all rivers of Thua Thien Hue (but the Xe Xap River) flow into the Tam Giang - Cau Hai lagoon, with a total average annual discharge about 4 billion $m^3$ and 0.5 million ton of solid sediment, thus constantly shaping the lagoon bank subsystem (Nguyen Huu Cu 1995). The total length of the banks is 183 km, of which granit and gabro occupy 23 km and which include tidal alluvia (2 - 3 m high) and coastal shore alluvia (4 - 6 m high).

The Tam Giang - Cau Hai lagoon was basically formed in Holocene and late Pleistocene, keeping pace with glaciation and changing sea level. In modern geological times it has still been subject to substantial transformations, see Chapter 7.

### 3.2.2 Lagoon and coastal oceanography

The tidal regime outside the lagoon is quite complicated. The tide off the Thuan An inlet is semi-diurnal type with small amplitude (30 - 50 cm). In front of the Tu Hien inlet, the tide is irregular semi-diurnal type with an amplitude of 55 - 110 cm. Tidal waves propagate from south to north, the tidal currents having a celerity of 0.5 - 0.7 m/s at high tide and 1-2 m/s at ebb tide. The velocity of water in the inlets exceeds 50 cm/s.

In winter, easterly waves predominate with the yearly occurrence of 67%, the wave height being 0.5 - 1.5 m, while in summer the southeast direction waves occur over 36% of time, the waves being 0.3-0.5 m high.

The water level in the lagoon changes with time and space. In the dry season, water level in the lagoon is lower by 25-35 cm than the tidal wave crest in front of the Cau Hai lagoon, and 5 - 15 cm off Tam Giang lagoon. In the flood season, the situation is opposite, the water level in lagoon being higher than the sea level, as much as by 70 cm at Cau Hai. The tidal amplitude in the lagoon is smaller than in the sea and the adjacent rivers --- in Tam Giang it is about 30 - 50 cm, and in Cau Hai 10 - 20 cm. The wind waves in the lagoon are about 5 - 10 cm high, or exceptionally 30 - 50 cm when strong winds and typhoons combine.

The circulation in the lagoon is weak but very complicated, and it strongly depends on tides, wind and wind waves. In the dry season, the flow ithrough Thuan An and Tu Hien is 50 - 60 cm/s. In the lagoon the flow is 2 - 8 cm/s, versus that in Song Huong of 4- - 45 cm/s. The wind-induced currents have velocities of 2 - 10 cm/s.

### 3.2.3 Lagoon hydrochemistry, nutrients and pollutants

Because of serious climatic effects, hydrochemical factors play important role and clearly vary in the lagoonal system. The salinity varies from 1 to 33ppth, below 10ppth in the rain season, and above 20ppth in the dry season. In Tam Giang, the surface salinity in the dry season is 9,6ppth, while the bottom layer reaches 29,9ppth (13ppth in other seasons). The salinity exchange patterns due to tides are very complex, bringing about 20 - 27.7ppth in amplitude at the Thuan An inlet, 5.5 - 5.9ppth in Tam Giang, and 1 - 2ppth in Vinh Xuan (Thuy Tu).

pH changes according to salinity, about 7.2 - 7.8. In the rain season, pH is 5.75 in O Lau, 6.4 in the Huong River, while that at Dai Giang and Tu Hien is 7.9. pH is much more higher in the rain season.

Dissolved oxygen in the dry season is 4 - 4.5 ml/l, and during the rain season reaches 5 - 6 ml/l.

Nutrients in the lagoon system display poor and nonuniform distribution because of bad water exchange. $PO_4$ is low in both rainy and dry season, although two times more during rains than in the dry season, about 3.0 - 4.5 mg/l in Tam Giang, An Tuyen, and 4 - 4.5 mg/l in northern Thuy Tu. $NO_2$ is rather poor, rainy season displaying twice as much as in the dry season. $SiO_3$ varies in the range of 500 - 4000 mg/m3, being richer at bottom than in the surface layer, and the poorest in Cau Hai (400 - 1000 mg/m3), while the richest in Tam Giang (1000 - 4000 mg/m3). Nutrients in the bottom layer are fairly rich, nitrogen 0,093% in every area, phosphorus contents being 0,169%, dissolved nitrogen about 2,9mg/100g, dissolved phosphorus at 1.58mg/100g (all data after HP22).

By and large, lagoon nutrients contents are low because of poor lagoon circulation. Seaweed transforms inorganic nutrients into organic ones.

Most lagoon display $Fe^{3+}$, $Fe^{2+} < 1$ without $H_2S$, but in Tam Giang one has $Fe^{2+}$ , $Fe^{3+}$ value >1.6, and that of Thuy Tu is 0.38. The table below shows some typical figures for iron and manganese

| Area | $Fe^{2+}$ (%)) | Fe3+ (%) | $Mn^{2+}$ (%) | $Fe^{2+}$ /$Fe^{3+}$ |
|---|---|---|---|---|
| Tam Giang | 0.42 | 0.61 | 0.0184 | 0.69 |
| Thuy Tu | 0.37 | 0.98 | 0.0136 | 0.38 |
| Cau Hai | 0.90 | 1.49 | 0.0392 | 0.60 |

Some typical process in the lagoon system include stratification, which is caused by features of salinity, temperature, pH, nutrient contents and distribution of pelagic flora. This is caused by harsh climatic conditions and poor nutrient contents, especially in the dry season. Stratification causes saltwater intrusion in the bottom layer far away from the river mouth. In the Bo River (64 km long), salinity instrusion is pronounced some 23 - 25 km. from its mouth. In the Huong River, the tidal return discharge is about 4.7 million m3/ day, discharge from upstream is 3.5 million m3.

Some stratification encountered in the lagoon is owed to the enclosed lagoonal structure and is weakly affected by tides. Reverse stratification is due to a lot of reasons such as pumping of tidal waters from Tu Hien to Thuan An inlet, the supply of underground brackish water and evaporation at the surface layer in the dry season.

### 3.2.4 Biological structure of the lagoon ecosystem

The biological structure of the ecosystem of Tam Giang - Cau Hai is typical of the Tonkin Gulf. It includes 171 species of pelagic plants of 4 types, with both freshwater and saltwater species. Some algae appear in the dry season with high salinity. Pelagic fauna encompasses 31 species, mainly brackish Copepoda, about 3027 per 1 m2. Phytobenthos includes 47 kinds of algae and 12 kinds of higher level. Bottom flora amounts to 33 kinds. Fish is abundant, with 162 species, 57 families and 15 series (all after HP22).

All fauna is of continental origin. Pelagic fauna is more abundant than the biomass, and amounts to about $10^4$ - $10^5$ per 1 $m^3$. In October, when the average temperature is 24°C, the biomass of pelagic flora is 400 - 900, at the daily production of 687 mg/$m^3$, or 130 mgC/$m^3$

Hence flora is reach as to the variety of species (171) but poor as to biomass, while the pelagic fauna is poor in species diversity but rich in biomass.

More details are given in Chapter 8.

### 3.2.5 Natural resources and environmental management problems in the lagoon system

*3.2.5.1 Living resources*
A substantial segment of the lagoon resources stems from aquaculture, which can produce 2500 to 3000 tons/year, of which shrimp amounting to 2,000 tons/year; including 22 kinds of cash fish such *as ciprinus centralis, siganus guttatus, mugil cephalus* etc over the total area of 890 hectares. The annual production of sea plants (algae) is 500 - 1,000 tons. The lagoon can provide jobs for 3,900 households and 7,500 workers (HP22).

More details are presented in Chapter 8.

*3.2.5.2 Economic potentials*
The best value the Tam Giang - Cau Hai lagoon provides is the job opportunity for 300,000 people (of which 195,000 living closely to the lagoon) on 90,000 hectares of which nearly 22,000 ha are the water bodies of the lagoon, 49,000 ha of coastal plains and 19,000 ha of land (dunes etc). Because of the lagoon's regulating works, freshwater can be made available to the population. About 5000 - 7000 boats sail on the lagoon. Obviously, the lagoon can reduce typhoon effects and is also an important means of transportation. My Thuan port can handle 3000-DWT vessels.

At Thuan An, Quang Ngan and Vinh My, moderate amounts of titanium/zircon are available. Besides, there is also Phong Chuong peat.

Tourism can potentially blossom in the lagoon in view of the abundance of freshwater, silent landscapes, sailing opportunities, boat sightseeing, and beautiful beaches on the lagoon barrier etc.

*3.2.5.3 Environmental management problems*
Organic pollution in the lagoon is not felt very much, BOD value remains constant about 0.6 - 1.5 mgO/l, COD being 1 - 3 mgO/l. In the rain season, COD decreases from north to south. Oil pollution amounts to 0.13 - 0.5 mg/l. The radiation pollution is estimated from dozens to 900 R (HP22).

Salt intrusion causes damage to agriculture, industry and water supply but is crucial to the lagoon's ecosystem. Yet one can only provide one crop per year.

It can be concluded that in the lagoon there are some urgent environmental problems, such as petrol pollution because of developing of means of transport. The migration of the Tu Hien and Thuan An inlets (cf. Section 7.2) make the whole ecosystem unbalanced. It is therefore necessary to improve and make priority investments in the Tam Giang - Cau Hai lagoon now, for it plays an increasingly important role; the lagoon system cries for a large-scale and integrated project (HP22).

## 3.3 Flooding and other problems

**Vietnam** is situated in the tropical monsoon area of South-East Asia. Each year, 1800-2500 mm of rainfall is received by Vietnam. Seventy to eighty per cent of this rainfall occurs from July to September in the North and South of the country, and from August to October in the Central Provinces. This severe seasonality of rainfall has meant that floods and typhoons have been a constant threat to the life and property of the Vietnamese people. In the aftermath of the historical flood in August 1971, the Vietnamese Government has enhanced numerous measures for short-term and long-term flood control, such as reforestation and watershed protection; riverbed clearance; flood diversion; reservoir construction; and dyke strengthening, monitoring and repair.

The uneven distribution of rainfall is the main cause of floods in the Vietnamese rivers. The river network in Vietnam has a total length above 25,000 km, concentrated in three rather clearly defined systems of the Red and Thai Binh Rivers in the North, the coastal river system in Central Vietnam, and the Mekong-Dong Nai River system in the South. Due to different topography in every area, each network has its different characteristics. The rivers of Central Vietnam are both short and very steep.

In the **central provinces**, there occurs regular annual flooding. Some of the more tragic events have taken place in 1971? in the Quang Tri Thua Thien Regon, in 1962 in Quang Nam, in 1982 in Binh Dinh, in 1983 in Hue, in 1952 in 16 Eastern Provinces of the South in 1952, and in most Central Provinces in I964. -- Flooding in the Mekong Delta is most notorious throughout the world.. Recent examples of large floods (1961, 1966, 1978, 1984 and 1991) have seen hundreds of thousands of hectares of crops destroyed.

Just slightly *before VVA Mission 3* began in November 1995, the central areas of Vietnam from Quang Binh to Binh Dinh provinces bore the brunt of the loss of life and the damage to property inflicted by three powerfull typhoons, Ted, Yvette and Zack. The three typhoons were all of strength 11 or 12, which occur only once every few years. They were counted as the ninth, tenth and eleventh, by the Vietnamese terminology. The typhoons left in their wake 137 deaths, 199 injuries and 46 missing in one month from October 5 to November 3, 1995. Most of the people reported missing were from Quang Ngai province (Vietnam News #1542).

The typhoons, which developed from tropical convergence in the Eastern Sea, also destroyed nearly 8000 houses, caused damage to or flooded more than a quarter of a million others, damaged 3500 classrooms, and over 450 hospitals and clinics. Tens of thousands of people were made homeless, most of the region's pupils were prevented from attending school and hundreds of hospital patients were evacuated. The typhoons further destroyed or submerged more than 80,000 ha of rice and caused about 1100 boats and vessels to sink or drift away. The estimated loss of property after the three typhoons has reached VND631 billion.

The three storms reported were accompanied by torrential downpours, which caused further damage to vegetable crops and seedlings for afforestation. Thousands of livestock belonging to local farmers were killed. Hundreds of kilometers of highways and roads were severely damaged due to prolonged submersion. Water depths reached two metres on several sections of the roads. In addition, many segments of the north-south railway line were washed away or submerged, thus causing train cancellations for many days, with thousands of passengers forced to postpone their journeys.

Since 1954, there have been 212 typhoons hitting or direclly affecting Vietnam. On the average, there are about 30 typhoons originating in the Western Pacific Ocean each year, of which about 10 are generated in the South China Sea. Of these, an average of 4 to 6 hit or affect Vietnam yearly. There are many years where at least 10 typhoons arrive in Vietnam -- recent events were 1964 (18 typhoons), 1973 (12), 1978 (12), and 1989 (10). The areas most affected by typhoons are the coastal provinces of the North and Central Regions. However, typhoons in the South, though less frequent, can also be extremely damaging. About 60% of the population and 44% of the whole country area are frequently affected by typhoons, which bring about the death toll of some 250 peoplc yearly. The worst in this century were the 1904 typhoon in the South, which caused death and injury to 5000 pcople, and the l985 typhoon in Binh Tri Thien Province, which killed 900 pcople. The losses caused by fioods seem to increase in time as there were three times more people killed between 1985 ans 1989 than those between 1976 and 1979. Typhoons are normally accompanied by storm surges. During the past 30 years, one half of the typhoon population have caused storm surges of over lm, 30% of typhoons over l.5m, and a few typhoons were coupled with a surge exceeding 2.5m. The high water levels so caused frequently destroyed sea dykes, and initiated flooding of lowland coastal areas through overtopping and breaching of dykes. The salinisation of the flooded soil can render farms inoperative for several years

Hence every year typhoons and violent storms strike the coast of Central Vietnam, causing damage to sea dikes and losses to agricultural crops and infrastructure. Typhoon storms are a regular feature of this area of Vietnam. These destructive storms bring intense rainfall accompanied by strong winds. The winds set up the ocean level, with the result that the embankments are overtopped. The overtopping causes two serious problems: the process destroys the embankments and saline water enters the low-lying cultivable land along the coast.

The problem is then further exacerbated by the intense rainfall which accompanies these storms. Rain falls on the large catchment basins in the central highlands and then flows back into the Bo and Huong Rivers which are soon filled to capacity. The water spills over the river banks, flows overland towards the sea coast until it encounters the earthen sea dike. The water builds up behind the dike until the dike is again overtopped.

The greatest danger comes from typhoons, eight to ten of which hit the coast of Vietnam every year. Most of these are accompanied by winds of 70 to 110 kilometres an hour (wind-force 9 to 10). With a frequency of about one in two years however, a typhoon strikes withwinds of 125 to 160 kilometres an hour (wind-force 12). Typhoons areaccompanied by increases in the sea level of 0.5 to 2.5 metres and waves two metres high. The existing dikes around the Tam Giang - Cau Hai Lagoon are inadequate to contain or withstand these forces. In addition to direct damage caused by typhoons, they create a climate of risk which discourages agricultural investment. Since high-yielding varieties of rice are particularly susceptible to salinity, farmers tend to rely on more resistant but lower-yielding traditional varieties. As typhoons normally occur during the summer/autumn period, many farmers simply do not plant during this crop season, and prefer to grow a single crop of rice during the less risky winter-spring season. Given below is an overview (Anonymous, Sea Dike ... 1993) of the losses due to typhoons in 1985 and 1990, respectively:

-- 532 and 425 hectares of rice flooded and completely lost, equivelent to 1520 and 1230 tons of rice;

-- 432 and 342 tons of subsidiary crop (manioc and sweet potato) lost;

-- 532 and 273 tons of rice washed away from storehouses;

-- 225 and 184 buffaloes and oxen washed away;

-- 637 and 422 houses collapsed;

-- 73 and 53 schools and local hospitals collapsed;

-- 19,000 and 25,000 cu m of dikes (eartfill) washed away;

-- total loss estimate: 125,000 and 90,000 USD.

The land around the lower reaches of the Bo River flows is among the lowest in the province. It slopes gently towards the Bo River and towards the coast. As a result, the 7760-meter section of the sea dike which protects this strip of land is the most vulnerable to damage since a high proportion of flood water moves through this area in an effort to escape to the sea. Following the destructive 1990 September and October storms, the sea dike was virtually no longer existent until 1994. Saline water was inundating cultivable land with every high tide.

## 3.4 Definition of Pilot Study #2 Objectives

With its area of 21,600 ha, 31 townships and 4 districts drawing towards the lagoon system, 49,000 ha of adjacent land with a lot of problems in the fields of economy, ecology and environment, 19.000 ha of coastal area, 18% area of the Thua Thien - Hue Province altogether and 300,000 people attached to this area (all data after Tran Duc Thanh & Nguyen Chu Hoi 1995), the Tam Giang - Cau Hai lagoon plays a very important role in the province's economic activities and has a great asset of natural resources. Without any exaggeration it can be said that the lagoon determines the rate and patterns of the socio-economic development of the entire province, and the central Vietnam as well..

However, the knowledge of the ecosystem, natural resources, usage etc of the Tam Giang - Cau Hai lagoon is far from completeness. Moreover, the lagoon undergoes environmental degradation and its resources become depleted. The urgent tasks of environmental control and management stem from frequent flooding, pollution, salinity intrusion, blocked waterways and instability of the tidal inlets (Tran Duc Thanh & Nguyen Chu Hoi 1995). It also becomes urgent to have insight into factors of integrated management of the Tam Giang - Cau Hai lagoon. To solve this problem effectively, it is necessary to acquire basic understanding of the natural environment, ecology and lagoonal resources (Tran Duc Thanh & Nguyen Chu Hoi 1995).

Since the inception of PS2 it has become clear that the whole region suffers from flooding in a variety of ways. Aside from the death penalty and material losses, the floods and nonuniform seasonal patterns of the river discharge create a lot of problems that affect the whole province in general, and the study area in particular. Flood control can bring about changes in the functioning of the emtire lagoon's (study area's) ecosystem. -- **Figures 3.I** and **3.II** provide an overview of the Study Area's physical geography.

Hence the definition of the Pilot Study #2 problems and objectives can be formulated as follows:

*'Given that **flooding** creates most hazards for Thua Thien Hue on a large scale, with the city of Hue as the most conspicuous centre of vulnerability, and the Tam Giang - Cau Hai lagoon system on a regional scale, that the natural lagoon ecosystem attracts various human activities, and that both the natural ecosystem and the population of lagoon system users are equally affected by the flooding, outline as broadly as possible the processes and their interactions in the lagoon system, together with the effects due to climate change and socio-economic developments, and indicate the ICZM methodology applicable to solution of the natural, environmental and socio-economic problems so arising'.*

The intention of PS2 is by no means a solution of the problems defined via this PS2, which are too numerous and complex to be solved within the VVA framework, but instead to outline the possible ways of solving the problems in terms of ICZM, for further exploration in prospective follow-up studies and ultimate solution by the Vietnamese counterparts.

# 4. Study Area Users Structure and Development Features

## 4.1 Users structure

### 4.1.1 General users structure in Thua Thien Hue

Photographs, tables and other material based on **GIS/GMS database** compiled in Hanoi under the **VVA** programme have been available to the Mission staff. Some illustration is provided in this report for the sake of general orientation. **Figures 4.I** and **4.II** show land use and topography.

### 4.1.2 Features of the lagoon system

The total population of the Thua Thien Hue province was counted at 891,350 in 1992 and 995,400 in 1994 (SE1 Report 1995), of which 386,300 lived in 1992 in the districts Quang Dien, Phu Vang and Phu Loc. Hence the average population growth rate anticipated at 2.6% for the whole province (SE1) in the coming years was higher in the two years from 1992 to 1994. The figures predicted for the whole province and the three lagoonal districts, respectively, for the year 2025 are 1,695,000 and 536,000 (SE2), thus less increase being assumed for the lagoon area than for the whole province (roughly 40% versus70%).

#### 4.1.2.1 Natural area and population structure

The Tam Giang - Cau Hai lagoon area encompasses four out of eight districts in Thua Thien Hue and three villages out of 61. The four districts adjacent to the lagoon are Phong Dien, Quang Dien, Phu Vang and Phu Loc, of which the three encompassing the majority of the lagoonal area are Quang Dien, Phu Vang and Phu Loc, with a total surface area of 154,282 hectares (Quang Dien - 15,896; Phu Vang - 25,386 and Phu Loc - 113,000 ha). Although it is somehow arbitrary to delineate which areas belong to the lagoon system (broadly speaking, the whole lagoon catchment basin should be assigned to the lagoon in the ICZM sense), one can follow the definition adopted in quite a few sources, e.g. HP23. Hence, in addition to the lagoonal area of 21,600 ha, the land area of direct linkage to the lagoon measures 68,000 ha of which 49,000 ha belong to the lagoon plain and 19,000 ha of coastal land (HP23).

#### 4.1.2.2. Population and labour distribution

Inhabitants of the three districts attached most directly to the lagoon count nearly 400,000, almost one-half of the Thua Thien - Hue population. The population linked to the lagoon by jobs of their households can be estimated at 195,000, of which most in Phu Loc - 68,000 people/32,000 labourers and Phu Vang - 66,000 people/18000 labourers. Some other estimates are slightly lower, e.g. Vo Van Phu (1995) gives the figure of 120,000 people attached to the lagoon. The population growth rate is determined as 8,6% (HP23). Sea fisheries are mainly concentrated in 17 villages with 7053 households and 12,346 workers.

The main form of business are private firms and cooperatives. In the Phu Vang district, the distribution of households basing on basic occupation (1994) is as in the table below.

| Occupation | Household | % |
|---|---|---|
| Agriculture | 14.966 | 53,02 |
| Forestry | 3 | 0,01 |
| Industry | 608 | 2,15 |
| Aquaculture/fishery | 5.360 | 18,98 |
| Construction | 465 | 1,65 |
| Trading | 2.416 | 8,56 |
| Services | 525 | 1,86 |
| Occupation | Household | % |
| Other jobs | 3.884 | 13,77 |
| Total | 28,227 | 100.00 |

Hence the percentage of agricultural households is 53% and the aquacultural ones nears 19%.

The aquaculture/fisheries on the **coastal** side of the three districts involve the following population

| District | Household | Inhabitants | Labour |
|---|---|---|---|
| Q. Dien | 1006 | 4174 | 2584 |
| P.Vang | 3541 | --- | 8006 |
| P. Loc | 1784 | 10515 | 1756 |

The population busy with aquaculture/fishing on the **lagoon** side of the three districts involves 3867 households, about 22000 inhabitants and 7500 labourers.

| District | Households | Inhabitants | Labour |
|---|---|---|---|
| Q. Dien | 594 | 3206 | 1013 |
| P. Vang | 1819 | 11,000 | 4049 |
| P. Loc | 1454 | 7896 | 2410 |

Temporary land cultivation by wandering hilltribes keeps about 1200 households, with the following distribution over the districts.

| District | Households | Inhabitants | Labour |
|---|---|---|---|
| Q. Dien | 228 | 924 | 307 |
| P. Vang | 600 | --- | --- |
| P. Loc | 413 | 2696 | 871 |

#### 4.1.2.3. Basic occupations

4.1.2.3.1 *Agriculture*
Agriculture is the most important branch of the lagoon economy (over 50%). Hence it suffers severely from natural disasters such as floods, salinity intrusion etc. Irrigation poses problems coupled with agriculture and transportation.

Vietnam has a predominantly agriculture-based economy. The agricultural sector accounted for about 38 percent of GDP in 1989 and provided about 70 percent of employment. With a population of over 70 million, the average availability of arable land per capita is about one tenth of a hectare, among the lowest in the world. Increases in paddy production in recent years have been partly offset by population growth rates averaging 2.3 percent per annum. The nutritional level of the population remains low, particularly outside the Red River delta in the north and the Mekong delta in the south, which are the main fertile rice-producing areas. Approximately **one half** of Vietnam's population and **40 percent** of the national rice-growing area are in the **coastal strip** between the two deltas. Significant increases in agricultural productivity will be needed in these areas to keep pace with population growth. Still greater progress will be needed to help meet the target of the 1991-95 five-year plan for an agricultural growth rate of 3.5 to 4 percent.

Instead of making progress, however, small farmers in central coastal areas are struggling to survive. Paddy-fields along much of the coast have yields of about 1,2 - 2 tons a hectare per crop. Holdings are very small, with an average farm size of 0.2 hectare. As a result, per capita food production is only about 220 kilograms a year (paddy equivalent), in contrast to food requirements of 300 kilograms a year.

Farmers supplement their paddy production with other activities: subsidiary crops such as sweet potato, groundnuts and maize; vegetable gardening, fishing, salt-making, growing of trees for firewood and gathering of firewood for sale, handicrafts and off-farm work. Opportunities for such work are limited, however. Under current conditions, most farmers are unable to satisfy family food requirements from their own farm operations and must rely on off-farm activities. The household deficit is frequently 200 to 300 kilograms of paddy a year. Their situation is precarious and evidence suggests a chronic state of under-nutrition. A UNDP/FAO study - `Agricultural and Food Production Sector Review', ranks Vietnam as one of the most nutritionally deprived countries in Asia. This study describes the coastal region as `the most significant focus of poverty and malnutrition'.

Progress in the coastal areas of the Thua thien Hue Province (and other regions as well) is constrained by frequent sea water flooding. This usually occurs yearly, but can occur twice in a year. The dikes which have to protect the land are too low and suffer from a variety of design deficiencies. Salt water flooding occurs through overtopping or breaching of the dikes. It causes widespread destruction of crops in the field and in stores, as well as infrastructural damage. Soils are salinized and may take several years to recover productivity if salination is severe.

If agriculture is to be improved in the central coastal region and the Hue lagoon area alike, these constraints must be removed. Agricultural intensification in these coastal provinces can be achieved by increasing the number of crops a year to two, and in some cases three; using the best available varieties; improving the use of fertilizers (more fertilizers, better selection of nutrients and improved timing of placement) and extending irrigation systems. Farmers and authorities will not make these changes under current dike conditions. They have, however, indicated a willingness and intention to do so if the dikes can be upgraded.

4.1.2.3.2 *Aquaculture & fisheries*
The total output of aquaculture and fisheries in Thua Thien - Hue is estimated by Tran Duc Thanh & Nguyen Thanh Binh (1994; HP23) at 8,500 tons per year (1992), of which the lagoonal yield is 2000 - 2,500 tons per year, that of Phu Vang and Phu Loc being estimated at 1.500 - 1,800 tons per year, Quang Dien providing 320 tons. According to statistic in October 1994 for the three major districts, the number of working boats was 7195, of which 2202 with engines. There is one boat per 5.5 ha of water area. The motor boats, with 12-13 HP contribute to lagoon pollution. The distribution of boats is given in the table below.

The above figures agree roughly with Vo Van Phu (1995, Hue19), who identifies 1100 motor boats in the lagoon area, out of 2500 in Thua Thien Hue. Phu also confirms there are about 2500 tons caught annually and adds that in 1990 there were 3000 ha available for total aqua/fish (including seaweed?) activities, of which 460 ha for shrimp, with total 100 tons per year, and 80 ha of ponds for fish and crabs.

Phu (1995) estimates that in 2000 there will be 1200 ha for shrimp and fish aquaculture. Yet, already at present, the lagoon is overfished, and small net mesh only increases the deficit between productivity and catch. The aquaculture potentials should be preserved for they are important for sustainable development of the lagoon area.

***Boats in Thua Thien Hue as counted by Tran Duc Thanh & Nguyen Thanh Binh (1994; HP23).***

| Village | Sea | | | Lagoon | | |
|---|---|---|---|---|---|---|
| | Motor boats | Paddle boats | Total | Motor boats | Paddle boats | Total |
| Q. Dien | 224 | 110 | 334 | 196 | 360 | 556 |
| P.Vang | 744 | 1564 | 2308 | 463 | 1438 | 1901 |
| P. Loc | 214 | 411 | 625 | 361 | 1110 | 1471 |
| Total | 1182 | 2085 | 3267 | 1020 | 2908 | 3928 |

Fishery equipment encompasses various kinds of net, string, baskets etc.

Aquaculture was only seaweed in the past, now there are fish and shrimp on the total area of 890 hectares.. In 1994, seaweed was grown on 250 ha in Quang Dien, 237 ha in Phu Vang and 84 ha in Phu Loc.

By and large, aquaculture is an important and expading branch. Aquaculture itself, but also a lot of fishing equipment, and the fishermen bring about water pollution.

4.1.2.3.4 *Transportation*
Lagoonal tranportation is affected by natural floods and inlet migration. The Thuan An port was built 3 years ago making the transportation a bit easier. The Huong River generates a convenient waterway through the lagoon.

4.1.2.3.5 *Other occupations*
Tourism has not yet been fully developed. It is only Tan My hotel and Thuan An bathing beach that have been enhancing tourism. Other factors of development include a Huda brewery in Phu Vang. Carving, husking and small-scale industrial and construction branches mainly concentrate in Phu Vang. In the first nine months of 1994, the turnover was 2.7 billion dongs (USD245,000). Aquaculture processing takes place mainly in Phu Vang. In 1993, the output data was as follows:

| | |
|---|---|
| Fish sauce | 219 thousand liters |
| Cuttle fish | 66.3 tons |
| Shrimp paste | 310 tons |
| Dried fish | 16 tons |

Infrastructure in the lagoon area is very poor, and so are living standards (HP23).

**4.1.2.4. Sociocultural factors**
4.1.2.4.1 *Living standards of population*
In general, living standard are very low and unbalanced between areas. In Phu Thanh, Phu Tan and Thuan An to Vinh Hien, living standards are higher than elsewhere In the lagoon system, people are very poor. They mainly rely on subsistence activities and are often at risk.

The population growth is fast, about 6 - 10 children in every family, and illiteracy is a serious problem all over the lagoon area.

Power and water supply create big difficulties in Phu Vang with 28,227 households of which 6,911 ones can use power (24.5%); 2,281 ones have tap water (7.8%), while water wells are accessible to 23,086 households.

Given below is a list illustrating the education and health care problems in Phu Vang:

| | | |
|---|---|---|
| The number of village with an access road to People's committee | | 19 |
| The number of villages with | a clinic | 21 |
| The number of villages with | a post office | 7 |
| The number of villages with | a radio station | 7 |
| The number of villages with | lower primary school | 21 (20304 pupils) |
| The number of villages with | upper primary school | 13 (4932 pupils) |
| The number of villages with | secondary school | 2 (492 pupils) |
| The number of villages with | kindergarden | 21 (142 classes) |
| The number of villages with | day nursery | 4 |
| The number of village with | transformer station | 9 |

In 1994, there was 1 pupil per 5.9 people, which is considered to be very low.

4.1.2.4.2 *Religion*
In the lagoon area, the majority of population are buddhists and catholics. In Phu Vang there are about 40% buddhists and 20% catholics, and 10 churches and temples. People are said to go to church every fortnight and on holidays such as New Year (HP23).

4.1.2.4.3 *Welfare and immigration*
A large number of people crossing the ocean illegalyy is reported (HP23). In Phu Vang alone, during nine early months of 1994, there were 179 illegal immigrants (boat people).

**Figures 4.III to 4.V** illustrate some present land-use activities as seen during Mission Hue.

## 4.2 Development Features

### 4.2.1 General patterns

Both Vietnam and its central provinces, including the study area, undergo substantial transformations in all socio-economic domains, although the rate of change differs from province to province. Aside from the general trends, spurred so dramatically by the *doi moi* policies, the pilot study problems defined in Section 3.4, accentuated in the study area, add a new dimension to the area's general development features. It is thus reasonable to outline briefly the two major groups of development factors – (1) those stemming from Vietnam's accelerated growth and general socio-economic trends, and (2) the ones typical of the study area, including the context of the flooding and lagoonal problems.

Some general socio-economic transitions and transformations are well reflected in other VVA documents, such as Reports SE1 and SE2 on the existing and anticipated socio-economic factors, VVA analysis spreadsheets etc. They encompass trends in coastal population , employment patterns, land-use structure, land prices and others. Inter alia, the land-use trends predicted for the 30-year scenario all over the coastal regions of Vietnam display the folowing (SE2):

- **aquaculture** will grow by making use of lowland fallow zones, not necessarily at the cost od agricultural land. Although its share in the total acrage of the central provinces is expected to grow only from 0.2% to 0.5%, in thirty years, it still denotes a dramatic growth;
- **rice production** will increase owing to higher productivity per hectare, while the overall rice acrage may decrease by 10-15%, but rather insignificantly in the central provinces, in view of their food deficit;
- vegetables and other field **crop production** should increase through both extension of acrage (form some 5% to 15% of total area in the central provinces) and addition of the third crop;
- orchards, tree- and bush-crops should increase through the use of indigenous forest and barren land; their share in the central provinces should increase from 3% to 8% of total area;
- natural **forest area** is expected to decrease in size (from 23% to 15% in the central provinces) but the production of timber and the acrage of timber forest should increase (from 2.5% to 15% in the central provinces!);
- the acrage occupied by **infractructure**, including special land for irrigation systems, will grow;
- virtually most new activities will take place on the land reclaimed from the present barren areas, although the latter will not be fully transformed in the nearest future – their share in the central provinces should fall down from 42% to 31% of the total area.

<u>Forests</u>, including mangrove ones suffer substantially from human intervention, such as

(a) after-effects of chemical warfare, especially napalm bombing and application of defoliants;

(b) excessive cutting for logs for commercial uses and fuelwood supply; clearing for construction of aquaculture ponds and housing; harvesting of fruit, honey, aromatic oils, and hunting of widelife;
(c) anthropogenic changes in the ecology of forests due to pollution etc.

Increasing deforestation has seriously affected the rainfall runoff characteristics of the catchment area, causing land erosion and denudation, faster flood flows and lower flow rates in the dry season. Vast amounts of earth have been removed from river catchment areas. Exact human impact is unknown but deforestation cannot be rejected as a cause, bringing about large quantities of sand due to land denuadation. In addition, increased siltation from deforested upland areas is changing the nature of estuaries and coastal areas and killing aquatic life and coral reefs.

As a result of the above factors, during the past years the forest area in Vietnam is being reduced by about 100,000 ha/year. Therefore **reforestation** has been promoted, accompanied by aforestation wherever possible and feasible. Protection of mangrove areas is also fostered, for they are important buffer zones against storm surges and typhoon damage, coastal erosion and flood control, as well as play a paramount role as the breeding, feeding and nursery grounds for natural habitats and commercially important coastal organisms. The importance of the ecosystem in economic terms, although not easy to estimate, should not therefore be neglected.

More generally, **integrated watershed management** should encompass not only forestry, as an important component of overall edvelopment, but also multi-purpose utilization of water resources, soil erosion control through appropriate soil stabilization measures, forestry rehabilitaton by large scale reforestation, land use and human settlement planning, waste management, focused on recycling, and flood control measures. Protection of the existing forested watersheds and the rehabilitation of denuded watersheds will require a system of protected areas, enforcement of forestry regulations, fire and disease protection measures, and reforestation.

Of the same dimension, sustainable **coastal zone management** should emphasize *inter alia* the rational utilization of aquatic resources, coastal land use zoning, beach stabilization by vegetation, establishment of wind-breaker forests, control of pollution from both marine and land based sources, oil spill contingency planning and necessary coastal resource conservation measures, including wetland protection.

The importance of **tourism** for Vietnam in general and the central provinces in particular is undeniable. The share of tourism in Vietnam's GDP should grow continuously, at pace with other services, which is a usual pattern for fast developing countries. The tourist attractions of Thua Thien Hue have been emphasized in Chapter 2, and some specific ventures are described in Subsection 4.2.2.

All above activities will interact with **infrastructure**. A large number of projects in the domains of transportation, communications, urban and rural development etc do affect both the province and the study area.

One should not forget that Vietnam is a developing country with limited resources to address **environmental** concerns which may become critical. Vietnam's, and its central provinces' as well, forests, watersheds and waterways, marine resources, land and air are in a degraded state due to years of war, and are currently experiencing severe pressure from a rapidly increasing population. Since the majority of the population depends on these various resources for their livelihood it is imperative that actions be undertaken to promote the **sustainable development**. Through a creative framework which need not be particularly elaborate or expensive, the additional institutional and technical expertise to address these problems can be developed with a minimum level of resources (viet4). All these statements can be made for the Thua Thien Hue province and the Hue lagoon system alike.

**Sustainable development** requires that resources be developed and utilized in an integrated manner. This entails taking into account broader national objectives, regional differences in income and endowment, the effects of one sector, or industry onn another and the impacts of activities in one area on another location. In developing sustainable development strategies it is necessary to ensure that a given strate does not conflict with those of other sectors or industries, and that development strategies serve to reinforce each other and form part of a broad, coordinated program for sustainable development.

## 4.2.2 Regional development features

### 4.2.2.1 General

On top of the general development plans for the Thua Thien Hue province outlined in Chapter 2, one should look into more details of development plans affecting directly the study area. Some projects bearing socio-economic_development features, as enumearated below, deserve special attention.

Leading experts of the Thua thien Hue province (i.a. Professor Ngo Dinh Tuan) set the following priorities in the field of flood control for the province: **afforestation, building reservoirs, construction and conservation of dikes**. Since afforestation and reforestation are self-explanatory, and these measures can be taken in parallel with others, most attention should be devoted to the other two strategies. This is done more closely in **Section 6.2**, where flood control measures are examined. In this subsection reference is made only to flood control, as a kind of addition to other independent development plans, which are nevertheless linked indirectly to and being coupled with the flood control.

### 4.2.2.2 Upgrading of Thuan An Port

Located some 12 km from the centre of Hue, the present harbour at the Thuan An inlet provides an excellent opportunity of cargo handing for the entire region. The present acrage of the harbour is some 20 hectares, which is believed too small for the potentially expanding trade and the region altogether. In view of the sedimentation problems and insufficient dredging, the vessels now calling at the harbour are smaller than necessary, about 2000 DWT.

Expansion of the Thuan An port will consist in enlarging its area and depths, creating new access roads and infrastructure, generating byproducts such as pollution etc. Ships over 5,000 tonnes should be enabled to enter the port through the Tam Giang lagoon, thus a lot of dredging operations have to be carried out, together with subsequent maintenance.

Plans for the expasion of Thuan An Port are not readily available. According to Prof. Ngo Dinh Tuan (private communication), a 3-D model for the Thuan An part of the lagoon has been derived but the obtained results have not been promising. Hence it seems that a reliable new model will be necessary to construct before embarking on details of the expansion.

Port expansion may partly conflict with the recreational use of the Thuan An beach, where new hotels and seaside resort facilities are planned.

### 4.2.2.3 Chan May Harbour project

Chan May Harbour is planned to grow a few kilometres south east of the Tu Hien Inlet, in an embayment sheltered by the Chan May Dong headland. The extent of the construction is under discussion but, if finally decided, the port will be a major one for the Thua Thien Hue province, quite a competition to the Da Nang ports, which are given a leading role in the development strategy for the central provinces' seaports.

A lot of problems affecting the TG-CH lagoon system will arise if the project materializes. Inter alia, together with construction of the Chan May Harbour, a wastewater treatment plant is foreseen to tackle the increasing pollution problem.

#### 4.2.2.4 Oil refinery and oil spills

Plans for a refinery in the Thua Thien Hue area have been formulated at the governmental level, mostly to foster the regioanal economy, a rather political than economic decision. At present these plans seem to be abondoned, perhaps in view of many other development opportunities offered to Vietnam (private communication of Prof. Ngo Dinh Tuan).

Even if the plans for oil refineries in central Vietnam are rejected for long, the problem of oil spills and pollution will be faced in the study area, due to increasing traffic of oil tankers and growing use of the lagoon waters.

#### 4.2.2.5 Tourism

Tourism, including some otherwise unconventional means e.g. floating hostels and other facilities more typical of Vietnam than other regions should be developed to bring investment, provide jobs and improve the users structure. As pointed out by Nguyen Vuc Du (1995, Hue9), the torism potential consists of two parts -- ecosystem and culture + historical heritage. Strategies of tourism building on a larger scale are illustrated by two examples of Dong Ha - Da Nang and A Luoi - Thuan An.

In a smaller scale of the study area, not the entire province, one can specify a few locations where coastal and lagoonal recreation can be further developed: Lang Co tourist area, where a new hotel complex is to be constructed; Canh Duong sports and tourist area (hotels and sports facilities); the Thuan An beach complex, mentioned also on other occasions; and a number of a few other smaller centres.

The lagoon itself provides excellent recreation and tourism opportunities.

Linkage to Laos via the roads leading to Thua Thien Hue, now planned to upgraded together with border facilities, should also have a positive impact on the growth of tourism.

#### 4.2.2.6 Mining

Mining of sand, shell and other sea products is an important activity, connected with many other (construction, tradee, transportation ...). The mining of white sand as intended for the central coast is mentioned in Section 2.2.

#### 4.2.2.7 Agriculture, aquaculture ...

They are self-explanatory important components of the regional development, as elucidated throughout this report. More nature food production can become a regional specialty.

#### 4.2.2.8 Integrated development

Chu Hoi et al. (1994; Hue6) provide recommendations on **integrated use** of the Tam Giang - Cau Hai (TG-CH) lagoon for aquaculture, agriculture and other users. Inter alia, it is concluded that stability of Thuan An ensures effectiveness of Thuan An port now planned for expansion. On the other hand, stability of Tu Hien is crucial to flood control. It is suggested that one should reduce salinity in Cau Hai and increase salinity in Tam Giang to make both water bodies brackish ones. Pollution should be prevented not only for the sake of environmenrtal sanity but also to preserve sustainable development of the lagoon area. Opportunities should be created for agriculture. One should prevent saltwater intrusion into living quarters, in particular in dry season, and into the agricultural areas alike.

Examples of small-scale **development plans** for the study area are available for the district of **Phu Vang,** cf. Anonymous (1995 -- Hue1), with a development programme for new economic areas within Ha Giang-Vinh Ha villages of Phu Vang district and Nguyen Quang Vinh Binh (1995 -- Hue2), with a summary of development features planned for Vinh Ha, Phu Vang district. These plans can be extended in follow-up studies, upon combination with the change factors and patterns envisioned in this report. -- **Figures 4.VI-4.VII** (Mission Hue) illustrate how the living conditions change and are going to evolve.

# 4.3 Analysis of Anticipated Changes in Users Structure

All present and planned **flood control** measures such as construction of reservoirs and upgrading of dykes are discussed in Chapter 6, where they are more appropriate. The discussion centers about i.a. changes in salinity patterns, partly saltwater intrusion but mostly effects in the lagoon proper; positive (irrigation) and negative (salination?..) effects in agriculture; flushing aspects connected with more dredging problems, inlet stability worsening, lagoon users effects; depletion of sediment from the catchment area, sediment deficit in the coastal zone; lagoon system's stability etc.

Analysed briefly in this section are other changes in the users structure, which may but do not have to be linked to or be affected by *flood control.*

The following features can be outlined:

**(a) Urban and rural growth**
The total population of the study area will grow rapidly, perhaps at a rate higher than elsewhere beyond the coastal strip. The growing urban population of Hue will exert more and more pressure on the lagoon system, which will be used in a variety of ways, such as transportation and cargo handling, aquaculture, recreation and tourism, aside from the daily migration of rural workers to the urban areas. On the other hand, the rural population of the lagoon itself will gradually change its occupation structure on the strength of the primary and secondary transformations outlined in this report, such as move to more aquaculture (primary) and increasing construction of dwellings in the wake of improving welfare figures (secondary).

**(b) Growth of aquaculture and high profile of agriculture**
Both the acrage and unit productivity of aquaculture will increase. This stems from the price structure favouring seafood, general governmental strategies aiming at more profitable production, domestic and foreign aid oriented towards better training and dissemination of aquacultural specialties, and a vast potential of lagoonal area adaptable for aquaculture purposes.
At the same time, agriculture will not be disregarded, mainly because the province, and the study area as well, are still considered foci of undernutrition, which can be alleviated primarily by local production. Better varieties of crops will be introduced, rice remaining the major species but vegeatables and fruit gaining impetus. Nature foodstuff is given prority at the provincial authorities' level.

**(c) Infrastructure and services**
As a consequence of other changes discussed in this report, there will be a lot of infrastructure activities, such as roads, communications, wastewater treatment. The sector of services will grow at the cost of other, more 'basic' sectors such as agriculture.

**(d) Chan May effects**
If implemented, the scheme will have a dramatic impact on the lagoon system, not only in physical sense (e.g. coastal morphology) but, first and formost, on the users structure. The scheme would provide a lot of employment during construction of the harbour facilities and their infrastructure (i.a. access roads) after afterwards, through permanent jobs at Chan May. New population centres are likely to arise. Aftereffects can encompass construction of trade centres, hotels and the like.

**(e) Thuan An effects**
These efects can be similar to those of Chan May but their scale will be smaller. On the other hand, in view of the high investment cost, the authorities may decide first on the upgrading of Thuan An, only followed by the huge scheme of Chan May.

**(f) Developments in the tourism sector**
These can be fairly diversified as to scale and services offered. Beach resorts planned will certainly provide employment for some present lagoon population. If more foreign and domestic tourists, now coming mostly for the historic values of Hue City, are attracted by expanding coastal recreation, and if the door to Laos is opened more widely, the effect of tourism and recreation on the users structure may become more conspicuous.

**(g) Pollution, environment and the users structure**
Environmental problems should be given one of priorities. At present, the main source of pollution comes from shrimp farming, and additional use of fertilizers to increase production. As shrimp farming is an important source of income for Vietnam it is of great importance to control the water quality conditions. Some regulations concerning permission for aquaculture are under consideration.

At the moment industry is not the main problem (Ngo Dinh Tuan, priv.comm.). The existing textile factory does not harm environment. As mentioned elsewhere, along with construction of Chan May harbor it is anticipated that a wastewater plant will be built in order to confine the pollution problem.

Note
An outline of the methods for quantification of the above effects and impacts follows in Chapter 11. -- Meanwhile it should not be forgotten that all above effects are correlated with flood impacts and are affected by flood control measures. If the latter undergo modifications, the users structure will be affected accordingly.

# 5. Environmental Boundary Conditions

## 5.0 Some General Characteristics of Central Vietnam's Coastal Lagoons

### 5.0.1. Location and morphology

Central Vietnam's coastline (from Quang Binh to Thuan Hai) is an eroded gulf shaped by waves (from Quy Nhon to Dai Lanh and Ca Na to O Cap), while the coastline is smooth from Ron to Quy Nhon. The difference between the central coastline versus the northern and southern counterparts consists in that the central coastline is well diversified ('rough'), with a lot of embayments, creating lagoons and brackish water areas. The number of rivers in Central Vietnam is limited, and the rivers are rather short and have steep slopes.

The central lagoons and gulfs have smooth bottom and are not deep (2 - 4m on the average). The tidal inlets of the lagoons are not always well developed, and the ratio of the inlet cross-section area to the volume of the tidal wedge is often insufficient to ensure adequate exchange with the sea. The banks of the lagoons are sandy, rocky or semi-cohesive, and are subject to tidal effects. Cau Hai, Cu Mong and Thuy Trieu lagoons are more diversified than other lagoons. The bed alluvium of the central stem from riverine sediments. It can be divided into 3 main varieties: coarse sand, sand and fine silty sand. All contain a lot of organic matter.

For the sake of reference in this chapter (and the report as well), the river system the Thua Thien Hue province and the province's hydrometeo network are depicted in **Figure 5.1.3** (see Section 5.1).

It should also be noted that many **tables and drawings** produced for this chapter are presented in **Appendix 5** (so numbered for the sake of correspondence between Chapters and Appendices, and easy retrieval of the relevant data). Hence a drawing labelled 5.1.6 can be found either in Section 5.1 proper or in Appendix 5. This arrangement has been necessitated by the abundance of tables produced, which would impair the clarity of presentation if placed in the basic body of this report.

### 5.0.2. Hydrological characteristics and their effects in central lagoons

Vietnam's central provinces receive high solar radiation (over 120 Kcal/cm$^2$ per year), which provides energy for the life cycle and organic matter in the coastal area. The annual average air temperature is relatively high (24,9 - 26,4°C), and is the highest in Phan Rang (27,6°C). In Central Vietnam, the impact of winter monsoon is less pronounced than elsewhere, and the temperature regime is rather moderate every year.These characteristics offer a lot of opportunities to shrimp farming, with as much as 2 or 3 catch per year.

The annual average rain range is rather wide (1.000 - 3.000mm); it falls from Hue (2861mm) to Phan Rang (700mm). Phan Rang has the minimum precipitation in the whole country. Duyen Hai area in Central Vietnam has rainy seasons from August to January next year; in September through December the volume of rain is 75 - 80% of the annual amount. Waters in lagoons become diluted, and floods endamger shrimp farming areas. The annual evaporation oscillates between 1,500 and 2,100 mm, the highest figure appearing in dry season from February to April , causing the growth of salinity in ponds up to 40 - 42%.

Wind, typhoon also seriously affect to coastal marine growing. Duyen Hai's provinces in the Centre are impacted by two main monsoons: southeast and winter monsoon. Winter monsoon causes strong wind, diluted water and the lifetime of covering dike system. Typhoon is a very danger climate, can cause serious damage. In annual, the Centre appears 1 - 3 typhoons. The south of Duyen Hai is less impacted than the north. The provinces from Binh Dinh to Binh Thuan have much better condition.

Tides in Central Vietnam change from regular semi-diurnal tide (Thuan An and adjacent area) to irregular semi-diurnal tide (Quang Binh to Thuan An inlet and from south of Thua Thien Hue to north of Quang Nam) and irregular diurnal tide (Quang Nam to Thuan Hai). The tidal range is kept under 2 meters. At Thuan An, the average tide range is 0,4 - 0,5m, in south and north of Thuan An it becomes 0,6 - 1,2m. In the area between Quang Nam and Binh Thuan, the average spring tide is 1,2 - 2m and neap tide is 0,5m. The tidal range inside lagoons and embayments is lower than the above data for open sea.

The depth of lagoons is not large, they are under 3 - 4m deep (below the lowest tide level), and the depth of 5 - 7m appears only in main river mouths and lagoon inlets. Because of the low depth and tidal ranges, the volume of water flowing from the lagoons to the sea is large. In Thi Nai, Nha Phu, Thuy Trieu lagoons, more than a half of water volume is exchanged cyclically. In othe lagoons the exchange is much worse. The nature of water exchange and mixing bears serious implications to hydro-chemistry, hydro-physics and other regimes, thus affecting component and number of hydro-species in the lagoons.

### 5.0.3. Water temperature

Water temperature changes seasonally and during the day alike. In 24 hours, the water temperature increases from the morning value at 5 to 6 o'clock, through its maximum at noon (in January and February) or at 13 to 15 o'lock (April to Jume) to its minimum at 5 to 6a.m. on the next day. The amplitude of temperature oscillations is 4 - 8°C during the day (rainy season) and 6 - 12°C (dry season), or 8 - 10oC on the average. In farming ponds, the minimum temperature is 18°5 (Thua Thien - Hue) and 20 - 24°C (Binh Dinh to Binh Thuan). In dry season, the temperature is 31 - 33°C, sometimes 37 -

38°C (over 2 - 3 hours). The monthly average temperature increases from the North to the South, and the difference is significant in winter.

### 5.0.4. Salinity regime

The salinity in central lagoons undergoes substantial and complex changes, depending on tide regime, amount of rainfall, evaporation, bottom topography and the exchange between lagoon waters and the sea.

The most typical central lagoon, Tam Giang -- Cau Hai has a large water surface area (20.000 ha). It draws from many rivers but since they all pass to the sea through Tu Hien and Thuan An inlets, the mixing ability between of the lagoon is limited. In Tam Giang lagoon, the salinity clearly drops from Thuan An to O Lau River mouth ( about 10 times). The average salinity in dry season (January to July) is about 10‰, while in rain season (August to December) it falls down to about 2‰. In O Lau River mouth, the salinity can be as low as 0,1 - 0,2‰ in rainy season. The lagoons south of Thua Thien Hue have the average salinity in rainy season about 7%, , rising to 15% in dry season. The lagoons in Tri Thien - Hue have brackish water, suitable for many species of shrimp and algae.

Thi Nai, Cu Mong, Nha Phu, Thuy Trieu, Nai occupy a rather small area (under 5,000 ha). The annual average salinity in these lagoons is 23 - 31‰. In dry season, (Jan to Aug) the salinity is maximum and stable, while in rainy season the salinity is lowest. In flood season, the salinity is very low, about 2 - 6‰ on the average. This transition from the previous 15 - 20% lasts for some days.

O Loan lagoon displays very big salinity variation: 0.1 to 41‰ with the average regional values of 35.2 and 1.8‰. The main cause here is the distance between the River and the sea, which is too long to enhance the water exchange ability between the lagoon and the sea. In dry season, the evaporation is very significant, the air temperature and water temperature are very high (in particular, in sand bank areas), the volume of rain is not high, the salinity approaches 40 - 41‰. This situation occurs in marine farming ponds when the tide is very low. On the other hand, on heavy shower days, water flows to the lagoon from rivers and catchment basins, the salinity is quickly reduces, and some lagoons are readily diluted. However, such dilution days are very few and the lack of data does nor permit more accurate estimates.

In the lagoon with widespread aquaculture, the salinity changes seasonally: in dry season it is 25 - 33‰, with the maximum of 38 - 40‰, while in rainy season the salinity is very low, from September to December it becomes 15 - 20‰ ion the average. On heavy shower days, the salinity is 5 - 10‰ on the average. The salinity is pond depends on the salinity in lagoons and river mouth areas. The salinity variation in farming ponds is much bigger than that in lagoons, with serious impacts on aquaculture.

### 5.0.5. Dissolved oxygen regime

The important components of the life cycle, $O_2$ and $CO_2$ , vary in space and time. They both are generated as a result of respiration and photosynthesis proccesses, in which all lagoon species take part by exchanging and cycling $O_2$ and $CO_2$, in the aqueous and atmospheric environments. The volume of free oxygen in lagoons is quite substantial; it varies from 5 to 8mg $O_2$/1. More details are given for the Tam Giang -- Cau Hai Lagoon proper (cf. other sections of this chapter).

## 5.1 Regional Climate and Meteorology

### 5.1.1 Meteorological characteristics

The Tam Giang - Cau Hai lagoon is a tropical lagoon with typical meteorological features given below. The characteristics obviously vary across the province, with its mountains in the west and the lagoon system and the sea in the east. Hence attention must be paid to the location cited (e.g. Hue station in most cases), and local deviations from the province's average values should be taken into account.

**Temperature**

Average temperature in the Thua Thien - Hue province varies from 19.7°C in January to 29.3°C in June (see Tab.5.1.1), the maximum value reaching 40.7°C (see Tab.5.1.2), and the minimum being 10.2°C. The yearly temperature amplitude is 9 - 10°C, while the daily temperature can vary in the range of 7 - 8°C.

**Rainfall**

The rainfall regime sharply changes in rainy and dry season. The monthly average rainfall can vary from approx. 30 mm (February) to approx. 530 mm (November) in case of Thuong Nhat station located upstream the Ta Trach River (see Tab. 5.1.4), and for Hue station the monthly minimum value is approx. 25 mm (March) while the maximum is approx. 740 mm (October) (Tab.5.1.5).

The maximum daily rainfall at Thuong Nhat station can reach 480 mm (see Tab. 5.1.6), while for Hue the maximum measured value was 470 mm (see Tab. 5.1.7).

The average number of days with rain can vary from 8 day in March to 20 days in October at the Thuong Nhat station (see Tab. 5.1.8), and for Hue station 8 days in April and 20 days in November (see Tab.5.1.9).

The mean relative humidity in Hue varies from 72% (July) to 89% (December, January, February) (see Tab 5.1.10). The minimum humidity (30%) has been obseved in June (see Tab. 5.1.11).

**Wind conditions**

The wind conditions measured on land (at Hue Station) are characterized by high occurrence of calm weather, which exceeds 20% in all months of the year and reaches 33% at maximum (being 27.6% on the average). The most frequent winds blow from NE (about 12%) and NW (about 15%), see Table 5.1.12. The average wind speed is low (from 1.4 to 3.2 m/s), and the maximum goes up to 8--14 m/s, see Table 5.1.13.

Some information on wind conditions over the South China Sea can be extracted from Vietnam Hydrometeorological Atlas (1994). **Figure 5.1.1**, borrowed from that source, shows that NE monsoon winds dominate from October to April, while the remaining months are controlled by SW monsoons. The maximum wind speed hardly exceeds 15 m/s.

Other wind data is readily available at the VVA Project Office.

### 5.1.2 Wave characteristics

The data stemming from wave records which would be useful for this study is rather limited. The data from Vietnam Hydrometeorological Atlas (1994), wind roses and wave roses for each month of the year provide some general orientation and guidance.

Wave statistics elaborated for the entire Vietnamese coast (stations in **Fig.5.I**) are illustrated in **Figure 5.II**. The stations located most closely to the study area are those of Son Tra (10-m depth of water) and off-Ouy Nhon (ship measurements at depths of 200 m). -- If wave data are to be computed from wind data, then it seems most reasonable to employ the wind measurements of Bach Long VI (depth h=50 m) for winter and Ouy Nhon for summer, as they seem to provide representative fetches.

Yet one should look for closer *databases measured*, more representative of the study area. Upon discussion with the HMS and VVA Hanoi staff it can be assumed that the Con Co station (107.22E/17.10N) can be used for analysis of waves affecting the study area.

From the VVA data Collection Report A8 one can conclue that the maximum wave height observed in the years 1979--1994 was 9.0 m. The long-term statistics employed the Fisher-Tippet type I distribution for Con Co, with the following figures for respective return periods:

| | |
|---|---|
| 10 years: | 11.6 m |
| 50 years: | 12.8 m |
| 75 years: | 13.9 m |
| 100 years: | 14.5 m |

For the sake of general orientation, Tables 5.1.2.1-4 in **Appendix 5** also contains wave characteristics measured along the Vietnamese coast, including the Con Co station, as processed under VVA, Data Collection Task #7.

### 5.1.3 Currents

The summer circulation close to the Thuan An inlet can be illustrated by the data of measurements carried out at five locations in August 1990. The location of the measuring stations is shown in **Figure 5.1.3**, and the data measured is given in **Figures 5.1.4-5.1.8**.

The results of the measurements show that most summer flows are oriented along the coastline (NW-SE to WNW-ESE. This seems to be independent of depth. The highest velocties measured reached 89 cm/s at statipn V on the depth of 20 m.

### 5.1.4 Typhoons

According to yearly statistics, Thua Tien Hue area is directly impacted by 2 main monsoons, north-east and south-west. Winter monsoon period is from September to March, with the average wind speed 2-4 m/s, the maximum is 40 m/s; the observed wave height is 3.5 - 6.0m.

Monsoons from south-west are observed in the period May - August, with wave heights of 4.0 - 6.0 m. During this period there occur typhoons, when i.a. the Thua Thien Hue area is seriously impacted by very high wind speeds. The occurrence of typhoons and their damage are described elsewhere, i.a. in Chapter 3. To make up this information, some statistics on typhoons is given in Table 5.1.14.

## 5.2 Water Budget of the Lagoon Catchment Area

Tam Giang - Cau Hai lagoon, situated in the central part of Vietnam, stretches from 16°30' till 16°39'N, 107°20' till 107°35'E. Its length is about 68 km, width ranges from 0.6 km till 8 km, and it covers the area of 21600 ha. The total catchment area is about 4000 km$^2$.

Within the catchment area we can distinguish the following main rivers: O Lau, Bo, Huong with its branches: Huu Trach, Ta Trach, and Dai Giang (see. **Fig.5.1.3)**. The Tam Giang -Cau Hai lagoon is supplied with fresh water by a river system, while from the marine side saline water is pumped through two inlets; in the northern part - Thuan An and in the southern part - Tu Hien.

Given below is description of the river system (based on Hue-13).

**O Lau River**

The total catchment area of the river basin is 572 $km^2$. O Lau River has its sources on the altitude of 600 m, in the Kovaladut mountains. There is a lot of rivers flowing from different directions: Rao trang, Thac Ma and Khe Tione, Khe Ba Le, La Sam, Da Krong (flowing on the border between Vietnam and Laos). River flows between the altitudes of 652 m and 787 m in the north-south direction. When O Lau reaches the altitude of 389m it changes direction to east. After merging with the Cao Ban, O Lau River changes direction to north-east. After joining with Cau Nhi and Rao Thac Ma Rivers, O Lau River flows in two branches. The first one flows through the Van Trinh desert, and reaches Tam Giang lagoon. It forms the border of two districts Huong Dien and Phong Dien. The second branch flows through the system of canals, and flows to the Thach Han through Luong Chanh field.

The measuring station is located in Cau Nhi village, far from the main road (2 km). Table 5.2.1 shows variation of river discharge, depth, pH and salinity of O Lau River within a year.
The maximum salinity is observed in March (the first month of spring). The annual discharge of O Lau River is $5*10^8$ $m^3$. In each cubic meter there is 80 g of alluvium which is used to form Tri Thien plain. O Lau River is the main factor to form Phong Dien and Hai Lang. One part of the O Lau River basin is located on the lowland and the other is on the highland. A lot of rice is floating to Tam Giang lagoon because alluvium is not consolidated.

**Bo River**

Central part of this river is called Co bi or An Lo. It is 80 km long and its catchment area is about 800 $km^2$. It has the sources on the altitude of 900 m. The upstream part, called Rao Nai, is not very wide i.e. 8 m. About 30 km to the south there is the Rao Nho basin. Here the river is inflowing into Rao Trang basin. From Nho village the river flows between right and left banks very roughly. Starting from A La, the river flows in a wide valley. In the downstream part there is a lot of silicate. On the right bank river is very calm. Flow is directed north-east towards Co Bi. Next Bo River flows to Co Bi directed north - south passing two plains and a lot of villages such as Co Bin, Lai Bang, Son Cong, Hien Si, Lai Thanh, Phan Sa. After this it passes road no.1 under the bridge An Lo. Here it divides into two branches: Tan Thanh An Xuan and Huong River.

The measuring station is located on the An Lo bridge, 17 km from the road no.1. (116E82/18N36). The discharge of Bo River is changeable in the rainy season, monthly average discharge is 500 $m^3/s$. The maximum salinity in the downstream part is observed in April. In the dry season salinity intrusion reaches the city of Phu Le. Bo River plays an important role for the Thua Thien plain. Its yearly discharge is 1.7 $10^6$ $m^3$, with 80 g of alluvium per one cubic meter. Co Bi, Hien Si, and Van Sa plains are richer and richer in alluvium each year. Table 5.2.2 shows features of Bo River.

**Huong River**

Huong River plays an important role for the southern part of Tri Thien province. The catchment area of the Huong River is 1532 $km^2$. In the wet season it contains a lot of sediment, while in dry season it is clean. There is a very high erosion upstream.

The Huong River has two branches. The first one (the right branch) has its sources in the Tha Thien - Quang Nam and Ai Lao, on the altitude of 900 m. The main direction is north-south. The river is very narrow and very long. In the upstream part the bottom has a steep slop; on the distance of 30 km it reaches the altitude of 100 m.

The Ta Trach River changes according to Ta Vo mountains until it reaches the Rao Tra Ve (source of Ba Rang). After that it flows along the Chuc Mao mountain foot. From Bihn Dien Thon, Ta Trach changes the direction to Nam Hoa - A Luoi and joints the left branch in Bang Lang. In dry season water level is very low. In Bang Lang this river is only 30 m above the mean sea level. The left branch (Huu Trach) has its sources in the mountains on the altitude of 600 m (Bon Don mountains - area of Ta Lo). That river is formed by a lot of small streams. The flow changes from north to the south-east while reaching the altitude of 100 m. From Li Hi (on the distance of 20 km) the river expands to 3.5 km width. When the river flows into the Bang Lang it goes through warm streams. It is one of 20 beauty spots in Vietname. Huong River is formed by left and right branches in Bang Lang on the altitude of 33 m, and slowly flows down. Later Huong River flows through Cu Chanh, Suoc Du. The left branch is formed by limestone while the right by stone. In Long Tho and Nguyet Bieu the altitude is only 10 m above sea level. In Hue the altitude is 6 m, and in Tan My is only 0.6 m above mean sea level. There is a lot of sediment along the river.

Under the Gia Vien bridge Huong River flows to Phu Cam. After that it merges the Cau Hai lagoon through complicated system of canals. Close to Vi Da village the Huong River has been divided by a dam to form a branch which is used for protection of Tho Loc village against salinity intrusion. Thanks to this dam the transportation is easy between Phu Vang district and Thuan An inlet. In case of big discharge of Huong River, fresh water flows over dam. In periods of low discharge this dam protects against salinity intrusion. After passing through Hen Dune, the Huong River joins Bo River and both flow through the Thuan An inlet in Tan My.

The measuring station is located in Nguyet Bieu village (126E89/18N28).The minimum water levels are observed in August (i.e. 0.89 m above mean sea level), while the maximum values reaching 3m above mean sea level are observed in October. Rain is the most important source of water supply. The highest discharges are observed in autumn.

In January, February and March the salinity concentration is 0.020 g/l, but in April concentration increases till 0.14 g/l. It keeps high concentration until August; later it starts to reduce. As the Huong River is important for the system it is necessary to have several measuring stations along the river. They are located starting from 3 m above mean sea level. From Dap Da to Bao Vinh salinity quickly increases (from 100 mg/l till 3 g/l in the surface). Discharge of Huang River is finally formed in the Tri Thien plain. About $5*10^{10}$ $m^3$ is discharged annually to the lagoon. There is 150 g of alluvia in each cubic meter. Table 5.2.3 shows characteristic features Huong River.

**Song Nong**

This is a small river in the southern part of the province. Its sources are in the Lihi mountains on the altitude of 188 m. It flows through Huong Thuy and Phu Loc districts and joins the Dai Giang. The catchment area is 85 $km^2$. It is rather deep river. The measuring station is located 200 m from the main road (0.562 m above mean sea level). The value pH does not change much within the year. The maximum salinity is from March to June (dry season), but it never reaches 1 g/l (Tab.5.2.4).

Tables 5.2.1 - 5.2.4 are based on A.A.Branch, 1967

**Tam Giang - Cau Hai Lagoon**

The area of the lagoon is about 217 $km^2$. It is customarily divided in various ways, as readily seen in this report and its drawings. One of the simplest division encompasses three areas : Tam Giang - 49 $km^2$, Thuan An - 54 $km^2$, and Cau Hai - 114 $km^2$

*Cau Hai lagoon*

It is the largest part of the lagoon system, located 40 km from Hue. This lagoon is formed by Dai, Phu Bai, An Nong, Truoi and Phu Loc Rivers. Only Dai Giang discharges to the lagoon $5*10^8$ $m^3$/year. In each cubic meter there is 70 g of alluvia. The total amount of alluvia from Dai Giang is $35*10^6$ kg/year, while the total amount of alluvia is $50*10^6$ kg/year.

*Thuan An and Tam Giang lagoons*

The area of both lagoons is about 100 $km^2$. Tam Giang is on the territory of the Huong Dien and Quang Dien districts, and is formed by alluvia from O Lau River. The direction of this lagoon is north-west to south-east. The distance from O Lau River to Kim Doi is 17 km. Alluvium is mainly concentrated in the O Lau River mouth. The depth is only 1 m in the river mouth.
Dunes are on both banks of Thuan An inlet. The salinity of Thuan An inlet in August is 25 g/l, the maximum value reaches 33 g/l. There was a plan to build a dam in Tan My. In case this project is successful, water in Tam Giang Lagoon will become fresh.
(all data based on Hue -13)

The water budget in the catchment area can be described roughly based on different sources of data. To have a general picture of water bugdet we can use data published in Vietnam Hydrometeorlogical Atlas (1994), (see Tab. 5.2.5). From them we can estimate the annual run-off as 6.3 $km^3$/year.

This estimate is in agreement with the annual water budget estimated by Thanh and Chu Hoi (1994) as: 5.4 $km^3$/year for Huong River system, 0.5 $km^3$/year for O Lau River and 0.5 $km^3$/year for Dai Giang River system.

Some estimates of the annual discharge for a part of the system has been published by Kahn (Hue -9) based on measurements (see Tab. 5.2.6). He also published average discharge in chosen months for Huong River (Tab. 5.2.10), some extreme values for May and June for chosen years (Tab. 5.2.11), and the maximum discharge for Huong River in chosen years (Tab.5.2.12) (Hue - 9). Comparison of these two tables shows that summer flood is less severe than the autumn flood season. The maximum values of discharges in June are much lower than the absolute maximum (eg. years 1983, 1985).

Some conclusions on the average discharge for the Huong River catchment area can be drawn by comparison with other catchment areas. Here we can use the Thu Bon River system, as it seems to be the most similar system in character. The Thu Bon catchment area has 10350 $km^2$ while the annual run-off is about 19 $km^3$/year. Comparison of the monthly flow distribution within a year for two stations located on the Thu Bon River Nongson and ThanMy (**Figs. 5.2.1, 5.2.2**) with the similar distribution for the Thuan Nhat station on Ta Trach (**Fig. 5.2.3**) shows general similarity. From those figures it is clear that 60-80% of the total discharge comes from wet season. Additional information on mean, minimum and maximum discharge for Thuan Nhat station are shown in Tabs 5.2.7-5.2.9.

When we look on data shown in Tab.5.2.9 we can notice that in most cases the maximum discharge is observed in October with possible shift to September or November. When we look on the average discharges in months (Tab.5.2.7) we find that these values are relatively low in comparison to absolute maximum in months.

Comparison between discharges published by Branch (1967) and Kahn (1995) for Bo River show substantail differeneces for March and April. These differences can come from the fact that Branch estimated discharges, while data shown by Kahn come from measurements taken only for 6 years (1979-1985).

From the marine side Tam Giang - Cau Hai lagoon has connection with the South China Sea through two inlets. Thuan An in the northern part, and Tu Hien in the Southern part. The Thuan An inlet is 300 - 350 m wide and 4 - 6 m deep. The tidal regime for each of the inlets is different. In the area of the Thuan An inlet tide is regular semi-diurnal, with the amplitude of 30-50 cm, while in the area of Tu Hien inlet tide is irregular semi-diurnal with amplitudes of 50-110 cm.

In Chapter 5.5 analysis of the existing components for water budget together with description of mechanisms by which water is redistributed will be shown.

Table 5.2.1 Characteristic features of O Lau River (Hue -13)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| discharge ($m^3/s$) | 69 | 30 | 60 | 40 | 19 | 20 | 25 | 30 | 60 | 240 | 260 | 90 |
| depth (m) | 1.50 | 1.00 | 1.35 | 1.15 | 0.85 | 0.90 | 1.00 | 1.10 | 1.50 | 2.90 | 2.95 | 1.70 |
| pH | 5.80 | | 6.00 | 5.50 | 5.50 | 5.50 | 5.50 | 5.00 | 5.50 | 5.50 | | |
| salinity (g/l) | 0.015 | 0.020 | 0.720 | 0.09 | 0.09 | 0.100 | 0.110 | 0.09 | 0.02 | 0.031 | 0.027 | 0.027 |

Table 5.2.2 Characteristic features of Bo River (Hue - 13)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| discharge ($m^3/s$) | 5.5 | 41.25 | 41.75 | 28. | 45. | 35. | 15. | 13. | 215. | 475. | 315. | 250. |
| depth (m) | 0.75 | 0.65 | 0.65 | 0.50 | 0.60 | 0.25 | 0.10 | 0.10 | 2.30 | 5.20 | 3.50 | 2.90 |
| pH | 5.20 | 5.00 | 5.50 | 5.50 | 6.00 | 6.00 | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 | 5.50 |
| salinity (g/l) | 0.015 | 0.020 | 0.080 | 0.10 | 0.09 | 0.08 | 0.03 | 0.035 | 0.035 | 0.037 | 0.30 | 0.017 |

Table 5.2.3 Characteristic features of Huong River (Hue - 13)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| discharge ($m^3/s$) | 156 | 90 | 120 | 75 | 75 | 75 | 110 | 60 | 75 | 700 | 430 | 405 |
| depth (m) | 1.4 | 1.15 | 1.30 | 1.05 | 1.05 | 1.05 | 1.23 | 0.90 | 1.02 | 3.00 | 2.20 | 2.00 |
| pH | 5.5 | 5.5 | 5.2 | 5.5 | 5.5 | 5.5 | 6.0 | 5.5 | 5.0 | 5.0 | 5.0 | 5.0 |
| salinity (g/l) | 0.020 | 0.020 | 0.020 | 0.14 | | 0.09 | 0.08 | 0.12 | 0.040 | | | |

Table 5.2.4 Characteristic features of Nong River (Hue -13)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| discharge ($m^3/s$) | 22 | 14 | 11 | 24 | 47 | 29 | 27 | 27 | 75 | 48 | 37 | 83 |
| pH | 5.5 | 5.5 | 5.0 | 5.5 | 6.0 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 |
| salinity (g/l) | 0.020 | 0.030 | 0.100 | 0.215 | 0.250 | 0.120 | 0.07 | 0.038 | 0.60 | 0.017 | 0.019 | 0.028 |

Table 5.2.5 General characteristics of the water budget in the catchment area. (catchment area - 4000 $km^2$) (based on Vietnam Hydrometeorological Atlas, 1994)

| | discharge/$km^2$ | value for the catchment area |
|---|---|---|
| annual run-off<br><br>surface run-off<br>ground water run-off | 50 l/s<br><br>40 l/s<br>10 l/s | 6.3 $km^3$/year<br><br>4.94 $km^3$/year<br>1.36 $km^3$/year |
| maximum 3 months flood flow | 150 l/s | 4.7 $km^3$ |
| maximum montly flood flow | 220 l/s | 2.2 $km^3$ |
| minimum 3 months flow | 15 l/s | 0.47 $km^3$ |
| minimum 30 days flow | 5-10 l/s | 0.05-0.10 $km^3$ |
| minimum daily flow | 5 - 7.5 l/s | 20 - 30 $m^3/s$ |
| highest peak flood flow | 4000 l/s | 16000 $m^3/s$ |

Tab.5.2.6 Characteristic of discharge based on measurements done by Kahn

| | Ta Trach | Huu Trach | Bo | Huong |
|---|---|---|---|---|
| annual discharge ($km^3$/year) | 1.58 | 1.18 | 1.42 | |
| discharge (dry season) ($m^3/s$) | 14.3 | 12.9 | 16.3 | 48.5 |
| absolute minimum discharge ($m^3/s$) | 9.52 | 8.56 | 10.8 | 32.2 |

Tab.5.2.7 Mean flow (m$^3$/s) in Huong River - station Thoung Nhat (Ta Trach) (Hanoi 1)

| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 7.69 | 5.29 | 3.35 | 3.88 | 11.6 | 12.2 | 9.07 | 4.93 | 6.32 | 78.8 | 70.3 | 25.6 | 19.9 |
| 1982 | 9.02 | 5.03 | 3.44 | 5.07 | 5.49 | 6.56 | 4.95 | 4.65 | 25.2 | 10.7 | 14.7 | 12.8 | 8.96 |
| 1983 | 12.0 | 7.57 | 4.43 | 3.13 | 3.11 | 13.0 | 6.62 | 6.86 | 7.70 | 70.3 | 47.9 | 13.3 | 16.4 |
| 1984 | 7.32 | 5.96 | 3.52 | 3.29 | 9.06 | 12.8 | 6.42 | 7.77 | 5.20 | 54.5 | 49.7 | 24.0 | 15.8 |
| 1985 | 10.1 | 7.68 | 5.45 | 6.30 | 11.2 | 18.5 | 5.74 | 3.97 | 8.73 | 32.7 | 49.5 | 38.7 | 16.6 |
| 1986 | 12.2 | 6.12 | 4.76 | 2.82 | 13.6 | 5.85 | 3.70 | 4.90 | 3.76 | 65.5 | 29.4 | 24.7 | 14.9 |
| 1987 | 6.36 | 3.21 | 2.62 | 2.60 | 2.51 | 4.62 | 1.96 | 14.2 | 23.2 | 6.54 | 30.8 | 19.6 | 9.85 |
| 1988 | 6.35 | 3.67 | 3.03 | 2.65. | 3.50 | 4.80 | 5.26 | 4.14 | 5.71 | 75.5 | 37.2 | 19.0 | 14.3 |
| 1989 | 14.7 | 6.89 | 5.06 | 3.69 | 29.4 | 12.6 | 10.5 | 8.19 | 7.46 | 12.1 | 10.0 | 9.70 | 10.9 |
| 1990 | 6.08 | 5.32 | 5.10 | 3.71 | 8.51 | 5.38 | 4.27 | 8.83 | 31.4 | 77.3 | 57.9 | 16.1 | 19.2 |
| 1991 | 10.1 | 5.71 | 3.58 | 2.79 | 5.23 | 15.0 | 7.0 | 11.1 | 11.7 | 98.2 | 43.9 | 16.8 | 19.3 |
| 1992 | 10.2 | 5.61 | 4.08 | 3.41 | 4.87 | 4.57 | 7.07 | 3.52 | 4.85 | 49.8 | 34.3 | 55.7 | 15.8 |
| mean | 9.08 | 5.56 | 3.98 | 3.70 | 8.77 | 9.19 | 5.81 | 6.73 | 11.18 | 50.4 | 37.4 | 19.1 | 14.5 |

Tab.5.2.8 Minimum flow (m$^3$/s) in Huong River - station Thoung Nhat (Ta Trach) (Hanoi -1)

| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 5.89 | 4.17 | 2.79 | 2.58 | 3.00 | 7.18 | 5.89 | 3.42 | 3.21 | 4.44 | 18.6 | 13.8 | 2.58 |
| 1982 | 6.40 | 4.10 | 2.95 | 2.95 | 2.95 | 2.75 | 3.35 | 2.95 | 5.10 | 6.40 | 7.90 | 8.50 | 2.75 |
| 1983 | 8.43 | 5.57 | 3.49 | 2.34 | 2.05 | 1.76 | 3.20 | 4.36 | 4.36 | 4.96 | 18.6 | 10.4 | 1.76 |
| 1984 | 5.83 | 4.30 | 2.80 | 2.40 | 2.57 | 4.90 | 3.13 | 3.86 | .80 | 4.05 | 14.1 | 14.1 | 2.40 |
| 1985 | 7.38 | 5.65 | 3.70 | 3.70 | 5.04 | 3.96 | 3.44 | 2.41 | 2.26 | 7.76 | 11.3 | 13.2 | 2.26 |
| 1986 | 6.90 | 4.59 | 3.30 | 2.18 | 2.30 | 3.50 | 2.30 | 2.30 | 2.18 | 7.25 | 14.2 | 8.36 | 2.18 |
| 1987 | 4.30 | 2.55 | 1.90 | 1.74 | 1.66 | 2.03 | 1.46 | 1.46 | 2.74 | 3.50 | 3.50 | 8.83 | 1.46 |
| 1988 | 4.15 | 3.13 | 2.50 | 2.27 | 2.06 | 2.62 | 2.62 | 2.62 | 2.50 | 9.67 | 17.8 | 9.31 | 2.06 |
| 1989 | 8.21 | 4.77 | 4.15 | 3.35 | 3.40 | 6.10 | 4.46 | 4.62 | 4.98 | 5.18 | 4.98 | 5.80 | 3.35 |
| 1990 | 4.72 | 4.54 | 4.21 | 3.25 | 3.17 | 3.60 | 3.36 | 3.47 | 4.93 | 11.3 | 15.5 | 7.33 | 3.17 |
| 1991 | 4.60 | 3.63 | 2.61 | 2.61 | 3.45 | 2.61 | 2.32 | 2.20 | 2.94 | 3.99 | 5.26 | 6.65 | 2.20 |
| 1992 | 6.35 | 4.75 | 2.64 | 2.11 | 2.23 | 3.99 | 3.77 | 4.7 | 5.36 | 11.5 | 21.0 | 12.5 | 2.11 |
| 1993 | 7.71 | 4.35 | 3.28 | 3.03 | 3.03 | 3.28 | 3.28 | 3.03 | 3.16 | 4.16 | 12.6 | 27.3 | 3.03 |
| MIN | 41.5 | 25.5 | 19.0 | 17.4 | 1.66 | 1.76 | 1.46 | 1.46 | 2.18 | 3.50 | 3.50 | 6.65 | 1.46 |

Tab.5.2.9 Maximum flow ($m^3/s$) in Huong River - station Thoung Nhat (Ta Trach)(Hanoi-1)

| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | max year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 23.6 | 10.2 | 4.17 | 41.2 | 76.0 | 73.7 | 78.5 | 13.0 | 78.5 | 60.0 | 844.0 | 47.7 | 844. |
| 1982 | 18.5 | 6.40 | 4.60 | 81.0 | 84.9 | 119.0 | 50.7 | 66.6 | 540.0 | 64.9 | 84.9 | 35.7 | 540. |
| 1983 | 37.8 | 10.8 | 6.18 | 10.1 | 13.9 | 592.0 | 41.2 | 25.0 | 97.6 | 1250.0 | 726. | 18.6 | 1250. |
| 1984 | 11.7 | 10.2 | 4.90 | 39.9 | 87.7 | 25.3 | 91.0 | 91.0 | 57.2 | 1330.0 | 427.0 | 72.0 | 1330. |
| 1985 | 17.1 | 13.8 | 29.6 | 78.2 | 83.0 | 556.0 | 17.1 | 19.5 | 142.0 | 892.0 | 489.0 | 384.0 | 892. |
| 1986 | 26.1 | 9.88 | 9.46 | 3.92 | 196.0 | 15.2 | 108.0 | 123.0 | 60. | 638.0 | 77.0 | 190.0 | 638. |
| 1987 | 10.6 | 4.04 | 5.84 | 27.5 | 14.2 | 300 | 9.66 | 480.0 | 618.0 | 35.4 | 172.0 | 51.1 | 618. |
| 1988 | 9.31 | 4.35 | 3.96 | 3.96 | 40.9 | 198.0 | 281.0 | 29.0 | 65.4 | 775.0 | 103.0 | 112.0 | 775. |
| 1989 | 59.6 | 10.5 | 55.6 | 8.21 | 7.21 | 31.5 | 423.0 | 146.0 | 41.3 | 277.0 | 143.0 | 22.1 | 423. |
| 1990 | 18.4 | 12.6 | 38.2 | 5.37 | 74.4 | 13.4 | 20.6 | 268.0 | 745.0 | 729.0 | 454.0 | 63.1 | 745. |
| 1991 | 12.4 | 5.51 | 11.6 | 15.2 | 38.5 | 12.4 | 14.4 | 186.0 | 8.02 | 371.0 | 84.0 | 14.8 | 371. |
| 1992 | 32.2 | 7.10 | 6.35 | 7.85 | 81.0 | 107.0 | 294.0 | 76.0 | 238.0 | 788.0 | 125.0 | 50.2 | 788. |
| 1993 | 16.2 | 7.71 | 5.85 | 5.85 | 49.5 | 8.70 | 54.6 | 5.25 | 19.2 | 462.0 | 176.0 | 201.0 | 462. |
| MAX | 59.6 | 13.8 | 55.6 | 81.0 | 196.0 | 592.0 | 432.0 | 480.0 | 745.0 | 1330.0 | 844.0 | 384.0 | 1330. |

Tab. 5.2.10 The average discharge ($m^3/s$) in chosen months for Huong River system (Hue 9 - paper 2 - Kahn)

| River | station | march | april | july | august | absolute min | date |
|---|---|---|---|---|---|---|---|
| Bo | Co bin | 15.73 | 14.65 | 11.59 | 13.74 | 4.00 | 8/86 |
| Ta Trach | Thoung Nhat | 3.76 | 3.71 | 6.08 | 6.63 | 1.42 | 8/87 |
| Huu Trach | Bihn Dien | 15.04 | 13.40 | 14.30 | 14.90 | 4.53 | 8/82 |

Table 5.2.11 The maximum discharge in May and June for Huong River system (years 1979-1985) (Hue -9, paper II - Kahn)

| | Bo River in Co bin | | Huu Trach in Binh Dien | | Ta Trach in Thuang Nhat | |
|---|---|---|---|---|---|---|
| year | Qmax (m3/s) | Date | Qmax (m3/s) | Date | Qmax (m3/s) | Date |
| 1979 | 399 | 22-6 | 324 | 22-6 | - | - |
| 1983 | 468 | 26-6 | 1263 | 25-6 | 592 | 25-6 |
| 1984 | 696 | 10-6 | 299 | 27-5 | 253 | 12-6 |
| 1985 | 1060 | 19-6 | 2030 | 18-6 | 404 | 18-6 |

Tab.5.2.12 Maximum discharges for the Huong River system in years 1953, 1983, 1985, 1990 (Hue-9 - paper 2 - Kahn)

| | Ta Trach in Thuong Nhat ($m^3/s$) | Huu Trach in Binh Dien ($m^3/s$) | Bo River in Co bin ($m^3/s$) | Huong River in Hue ($m^3/s$) |
|---|---|---|---|---|
| 1953 | 8000 | 4000 | 4000 | 12500 |
| 1983 | 1250 | 4020 | 2850 | - |
| 1985 | 892 | 1655 | 2120 | - |
| 1990 | 745 | - | - | |

## 5.3 Physiographic Features of the Lagoon

### 5.3.1 Circulation patterns in the Tam Giang - Cau Hai lagoon

The circulation patterns of the Tam Giang - Cau Hai lagoon are rather complicated. There are three main hydrological - meteorological factors that play the major role: tides, river discharges and wind conditions. Additionally the lagoon's topography, bathymetry, salinity and temperature also affect the circulation patterns.

The knowledge of the lagoon's circulation patterns is limited, and the available data is quite scarce. Some basic knowledge can be extracted from the measurements carried out in March and November 1993 (HP10). The measurements have been carried out at some specific locations inside the lagoon system (see Tables 5.3.1.1 - 5.3.1.3). From those data we can conclude that in Tam Giang water velocities are rather uni-directional and relatively small. Yet it is too early to draw far-reaching conclusions -- the data is limited, more measurements are planned these months, and some modelling can be helpful (cf. Chapter 9).

A part of the measurements carried out in the TG-CH system encompassed the tidal inlets of Thaun An and Tu Hien. On the basis of those surveys one finds out that the maximum velocities in the surface layer can reach about 0.9 m/s in the Thuan An inlet, while at Tu Hien the velocities can reach approx. 0.7 m/s (Tables 5.5.1, 5.5.3, 5.5.5, 5.5.7). As water flow is induced by tides, it is two-directional at the inlets.

Table 5.3.1.1 shows some representative measurements in Tam Giang, with the following orientation figures for the measuring conditions:

max. level amplitude - 0.28 m
max. water level - 0.98 m
min. water level - 0.70 m
average water level - 0.82 m

(correction according to Kim Lang)

Table 5.3.1.1 Measurements in Tam Giang lagoon (Quang Loi) (15-16/3/1993) (HP10)

| | Surface | | Bottom | | Water level (m) | Depth (m) |
|---|---|---|---|---|---|---|
| Time | vel (m/s) | dir (deg) | vel (m/s) | dir (deg) | | |
| 16 | 0.35 | 300 | 0.36 | 300 | 0.98 | 4.0 |
| 18 | 0.22 | - | 0.12 | - | 0.95 | 3.9 |
| 20 | 0.15 | 120 | 0.13 | 120 | 0.92 | 4.0 |
| 22 | 0.24 | - | 0.18 | - | 0.83 | 4.25 |
| 24 | 0.27 | - | 0.22 | - | 0.70 | 3.98 |
| 02 | 0.13 | - | 0.06 | - | 0.70 | 3.98 |
| 04 | 0.29 | 300 | 0.27 | 300 | 0.77 | 4.40 |
| 06 | 0.45 | - | 0.40 | - | 0.86 | 4.10 |
| 08 | 0.00 | | 0.00 | | 0.91 | 4.40 |
| 10 | 0.39 | 120 | 0.24 | 120 | 0.83 | 3.40 |
| 12 | 0.27 | - | 0.17 | - | 0.73 | 3.70 |
| 16 | 0.44 | 300 | 0.26 | 300 | 0.80 | 4.00 |

Table 5.3.1.2 Measurements at the mouth of the Huong River (17-18/3/1993 (HP10)

| | Surface | | Bottom | | Water level (m) | Depth (m) |
|---|---|---|---|---|---|---|
| Time | vel (m/s) | dir (deg) | vel (m/s) | dir (deg) | | |
| 10 | 0.11 | 90 | 0.00 | | 0.93 | 4.0 |
| 12 | 0.21 | - | 0.11 | 90 | 0.86 | 3.4 |
| 14 | 0.45 | - | 0.20 | - | 0.80 | 3.2 |
| 16 | 0.20 | - | | | 0.79 | 4.0 |
| 18 | 0.26 | 270 | 0.26 | 270 | 0.86 | 4.0 |
| 20 | 0.00 | 90 | | | 0.93 | 4.5 |
| 22 | 0.00 | | 0.00 | | 0.93 | 4.5 |
| 02 | 0.33 | 90 | 0.17 | 90 | 0.84 | 4.0 |
| 04 | 0.00 | | 0.00 | | 0.79 | 4.0 |
| 06 | 0.11 | 270 | 0.30 | 270 | 0.84 | 4.0 |
| 10 | 0.24 | - | 0.33 | - | 1.03 | 4.2 |

max. level amplitude - 0.24 m
max. water level - 1.03 m
min. water level - 0.79 m
average water level - 0.81 m
(correction according to Kim Lang)

Table 5.3.1.3 Measurements at Thuy Tu (Vinh Xuan) (15-16/3/1993) (HP10)

| | Surface | | Bottom | | Water level (m) | Depth (m) |
|---|---|---|---|---|---|---|
| Time | vel (m/s) | dir (deg) | vel (m/s) | dir (deg) | | |
| 16 | 0.00 | 320 | | | 1.0 | 4.4 |
| 18 | | | | | 0.9 | 4.4 |
| 20 | 0.00 | | 0.00 | | 0.6 | 4.4 |
| 22 | 0.00 | 140 | | | 0.5 | 4.15 |
| 24 | 0.08 | 320 | | | 0.6 | 4.05 |
| 02 | 0.08 | 320 | | | 0.6 | 4.05 |
| 04 | 0.10 | - | | | 0.7 | 4.15 |
| 06 | 0.00 | | | | 0.7 | 4.15 |
| 08 | 0.17 | 120 | | | 0.8 | 4.25 |
| 10 | 0.27 | 160 | | | 0.8 | 4.25 |
| 14 | 0.22 | 300 | 0.13 | 300 | 1.0 | 4.45 |
| 16 | 0.11 | - | | | 1.0 | 4.40 |

max. level amplitude - 0.75 m
max. water level - 0.50 m
min. water level - 1.00 m
average water level - 0.50 m

### 5.3.2 Salinity and temperature

Spatial distributions of salinity and temperature are two of the most important features of the entire lagoon system, as they influence the activities in the area. For this reason they are relatively well explored, as based on in situ measurements. **Figure 5.3.2.1** shows a range of salinity variation. The area of lagoon has been divided into four zone types. The first type, represented in the northern end of the lagoon, is characterized by low salinity concentration (0-5 ppt). In the second zone salinity does not exceed 17 ppt, while in the third type of zone, salinity does not exceed 30 ppt. In the second and third type of zone concentration can reach the minimum value of 0 ppt. The forth zone type, typical for inlets, is characterized by the highest concentration reaching the maximum value over 30 ppt. In zone of fourth type the minimum concentration is always over zero.

Based on in situ measurements carried out in 1993 we can show two typical cases for the lagoon system, i.e. dry and wet season. In wet season, when rivers discharge tens of cubic meters per second the lagoon in mainly filled with fresh and brackish water (see **Fig.5.3.2.2a**). In the dry season rivers discharge much smaller amount of water, so saline water from South China Sea is going easily to the lagoon **(Fig.5.3.2.2b)**. In that period the majority of the lagoon is filled with brackish and saline water.

The process of salt water intrusion through inlets to the lagoon can be observed based on measurements done in March and November 1993.

In the dry season salinity concentration in the bottom and surface layers do not differ significantly within a day in both inlets **(Fig. 5.3.2.3a,c)**. In the Tu Hien inlet, measurements have shown even reverse salinity distribution. In the wet season salinity concentration can vary substantially in vertical **(Fig. 5.3.2.3b,d)**. This is well pronounced in case of Thuan An inlet. This can be easily explained as this inlet is under strong influence of the Huong river. We can also notice relation between salinity concentration and water level in the inlet.

Water temperature is relatively uniform over the whole lagoon system. This is connected with relatively small dimensions in horizontal plane, and small depths of this water body. Yet the water temperature in the lagoon varies, depending on air temperature. The lowest temperatures are measured in December - about 20°C on the average (Tab.5.3.2.6). Temperature increases in January to about 25°C (Tab.5.3.2.1), in March to about 30°C (Tab.5.3.2.2), June - approx. 32°C (Tab.5.3.2.3). In July is slowly deceases to approx. 31°C (Tab.5.3.2.4), and in October - 30°C (Tab.5.3.2.5).

In the dry season saline water is observed not only in the lagoon itself, but also salinity intrusions are observed in the downstream parts of rivers merging into lagoon.

Some data from measurements has been published by Kahn (Tabs. 5.3.2.7, 5.3.2.8- Hue -9). From those data it is quite clear that the system is very sensitive to tidal changes. For the same station we can have salinity gradient over 10 ppt, eg. station Sinh (Tab.5.3.2.8).

The maximum salinity intrusion, about 30 km, has been observed on the Huong river. In January, February and March the salinity concentration is 0.020 g/l, but in April it increases till 0.14 g/l. It keeps high concentration until August; later it starts to decrease due to increase of discharge. There have been several measuring stations along the river, the maximum altitude of which was 3 m above the mean sea level. Data from measurements are as follows:

- Ta Trach (left bank) in Bang Lang - salinity below 100 mg/l;
- Huu Trach (right bank) in Bang Lang - salinity below 100 mg/l;
- Huong river in Bang Lang - below 100 mg/l;
- Huong river (old pumping station) - below 100 mg/l
- Dap Da - below 100 mg/l
- Bao Vinh - surface 3 g/l; 3 m depth - 33 g/l
- Bo (in confluence with Huong) - surface 8 g/l; depth of 3m - 33 g/l
- Thuan Hoa church - surface 8 g/l, bottom - 33 g/l
- Tan My - surface 13 g/l, bottom 33 g/l
- Thuan An inlet - surface 25 g/l, bottom 35 g/l.

(data from Hue - 13)

Tables 5.3.2.1-5.3.2.8 in **Appendix 5** provide additional information and insight.

### 5.3.3 Water Quality

Together with salinity and temperature, chemical parameters have been measured in dry and wet season in 1993. Some measuerements were also carried out in 1987 (see Tabs 5.3.2.1 - 5.3.2.6). Given below are characteristic water quality parameters (HP - 5).

#### pH

The spatial distribution of pH in dry and wet season of 1993 is shown in **Fig.5.3.3.1 a,b**. As we can notice pH value in the dry season (Fig.5.3.3.1 a) reaches its maximum in the vicinity of Thuan An (8.02) and Tu Hien (7.90) inlets. In those parts of the lagoon which are under influence of fresh water pH value is lower. The minimum value observed in dry season is 7.28. In wet season (see **Fig. 5.3.3.1 b)** the minimum value does not exceed 6.0 (Tam Giang), while the maximum value exceeds 8.0. The pH value in the inlets differs due to tides.

The data from measurements in 1987 (Tabs 5.3.2.1-5.3.2.6) show values of pH in the similar range as those in 1993.

**Figure 5.3.3.2** represents daily variation of pH in Thuan An (a) and Tu Hien (b) inlets in dry season (13-14/3/1993) in the surface and bottom layers. In Thuan An variation between minimum and maximum values is very small (about 0.05). In Tu Hien differences between surface and bottom are relatively small, but variation within a day can reach value of about 0.4 (see **Fig.5.3.3.2**).

The pH concentration in rivers has been given by (Hue-13) (see Tabs. 5.2.1-5.2.4) for O Lau, Bo, Huong and Nong being in the range 5.0-6.0. According to (HP-22) in wet season the pH concentration in rivers is as follows: O Lau - 5.75, Huong - 6.4, Dai Giang - 7.9.

**$PO_4$**

The concentration of phosphates in the Tam Giang - Cau Hai lagoon depends on season. In dry season (**Fig.5.3.3.3a**) it is in the range 3 - 4.5 $mgP/m^3$, and concentration increases from north to south. In the O Lau river mouth it is below 3.5 $mgP/m^3$, in the central part is in the range 3.5 - 4.0 $mgP/m^3$, in Sam over 4 $mgP/m^3$, in Thuy Tu below 3.5 $mgP/m^3$, and in Cau Hai below 4 $mgP/m^3$.

In the wet season the concentration is approx. 3 times higher than in dry season (see **Fig.5.3.3.3b**). The highest concentration is observed in the vicinity of the inlets (over 8 $mgP/m^3$), in the remaining parts of lagoon is below 5 $mgP/m^3$.

**$SiO_3$**

The concentration of silicates varies from 400 to 4000 $mgSi/m^3$ within a year. Its concentration in Tam Giang, Sam and An Truyen is higher than in Thuy Tu and Cau Hai (see **Fig.5.3.3.4** only for dry season). In the Tam Giang it ranges from 1000 till 4000 $mgSi/m^3$. In the river mouths of O Lau and Huong it exceeds 2000 $mgSi/m^3$.

**$NO_3$, $NO_2$ and $NH_3$**

The concentration of $NO_3$ is very high only in Sam (0.028 - 0.143 mgN/l), in the remaining parts of lagoon is much lower.

The concentraction of $NO_2$ depends on season, in dry season it varies in the range 0.5 - 1.5 $mgN/m^3$, while in the wet season is higher (1.6-4.0 $mgN/m^3$). Ammonia concentration varies in the range 0.01-0.79 mgN/l, with the highest concentration in Sam (0.04-0.79 mgN/l).

**Dissolved oxygen**

Concentration of dissolved oxygen is usually lower in dry season than in the wet season. This conclusion can be drawn from data shown in Tab.5.3.3.1, where ranges of variation depending on season and location are given. This information is in general agreement (the same order of magnitude) with data from 1987 published by (Hue-7) (see Tabs 5.3.2.1-6). Detailed comparison of data from two years (1987 - Hue 7, 1993 - Hue 10) is quite difficult because they are presented in a different for, i.e. either as averaged values (Tab.5.3.3.1) or as data from specific measuring campaigns (Tabs 5.3.2.1-6). Concentration of dissolved oxygen in O Lau in dry season is about 6.0 mg/l (HP-5).

### COD

According to (HP-5) COD concentration in wet season is in the range 2-3 mgO/l, while in dry season 1.0-2.5 mgO/l. The maximum value of COD in Huong river was 6 mgO/l. These values are in agreement with data from other publications (HP-22).

### $BOD_5$

On the average, $BOD_5$ is equal 1.0 mgO/l. In Tam Giang is lower - 0.7 mgO/l, in Thuy Tu - 0.8 mg/l, and in Cau Hai is 1.5 mgO/l (HP-5). This range of variation is in agreement with information published in (HP-22).

#### Lagoon bottom layer

For the lagoon bottom layer, the following concentrations have been mentioned in (HP-22): dissolved $NO_2$ - 2.9 mg/100g and dissolved $PO_4$ - 1.58 mg/100g.

#### Metal pollutants

Not much data on pollution by metals is available for the area of interest. Only measurements for two successive years for Huong river have been published by Kahn (1995) (Hue - 9). From them it seems that concentration of metals increases. In case of rivers it is always more appropriate to compare loads than concentration. In a moment river discharge for July 1994 and July 1995 is not known.

Tab. 5.3.3.1 Concentration of dissolved oxygen (mg/l) (Hue - 10)

| | dry season | | wet season | |
|---|---|---|---|---|
| | surface | bottom | surface | bottom |
| Tam Giang | 8.16 - 9.89 | 3.52 - 5.45 | 7.0 - 7.04 | 4.75 - 5.10 |
| Sam | 6.05 | 5.26 | 7.70 | 6.47 |
| Thuy Tu | 6.86 | 3.34 | 7.40 | 4.34 |
| Cau Hai | 6.60 | 5.04 | 7.60 | 6.0 |

Table 5.3.3.2 Pollution by metals in Huong river $\mu$ g/l (Kahn, 1995) (Hue-9)

| | Pb | Cd | Cu | Zn |
|---|---|---|---|---|
| 7/1994 | 0.325 | 0.953 | 1.516 | 9.325 |
| 7/1995 | 0.340 | 0.962 | 1.924 | 12.320 |

## 5.4 Analysis of Climate Change Impact

### 5.4.1 Climate Change Predictions Applicable to Thua Thien Hue

From the studies carried out recently for general flood control planning, and based on hydro-meteorological observations within the Thua Thien Hue province, the following conclusions are drawn (private communication from Professor Ngo Dinh Tuan):

- annual rainfall decreases,
- the frequency of typhoons and the strength of floods increases,
- sea water level increases at a rate of 2mm/annum (based on data from Da Nang),
- increase in temperature of 0.1°C/10 years is felt.

This belief of specialists involved in long-term planning is shared by many others in Vietnam. *Inter alia*, the annual water-balance equation, making use of predicted component values provides Dao Van Le (1993) with a useful method for assessing the sensitivity of water resources to climate change up to the year 2030 in different regions of Vietnam: small increase in the North and substantial decrease in the South in annual mean runoff.

In the northern region of central Vietnam the increase in annual runoff would be roughly 6-15% and would result from an intensification of typhoon activities and the severity of floods. In the middle and southern parts of the central region, annual runoff would decrease by 9-19%, particularly in the Thuanhai province by 16-33%. The vulnerability to drought would increase and desertification would be the most serious problem (Dao Van Le 1993).

From extreme events in the past, scientists have gained experience to deal with short-term variability: change in the existing reservoir operation rules, and flood and drought preparedness. But for long-term variation and change in water resources, more studies need to be made in order to have reliable assessments from which water resource managers and planners will derive policies for the future.

### 5.4.2 Climate Change Impact on the Study Area

In the context of the predicted changes in annual mean runoff, flood seasonality, the respective changes in vulnerability to drought due to climate change, and the construction of water reservoirs to alleviate the flood and climate change hazards, some problems arise:

1. The **reservoir operation** rules need to be reviewed and made more flexible to control flooding in high areas of the flood plain, at the same time to avoid the risk of filling the reservoirs too soon in the summer and the risk of not filling the reservoir in the autumn.

2. Aside from the **drought** problem which may appear locally or regionally due to climate change, the lagoon and coastal areas also suffer from **acid sulphate soils** and **salt intrusion**, which would be aggravated by the predicted sea level rise. The construction of reservoirs upstream can repel the advance of salt water far upstream but may aggravate the saltwater intrusion problem by prolonged deficit of water in the downstream river stretches and branches, as compared with the present situation without reservoirs.

3. The entrapment of sediment due to changing surface run-off patterns would accelerate the flooding of coastal areas and the reduction of the lagoon and coastal vegetation (such as mangroves etc).

Changes in demand for water resources induced by climate change also need to be studied. For regions where rainfall decreases and temperature increases, this concerns increasing demand for irrigation, industrial use such as cooling, etc. All these factors play an important role in long-term planning.

## 5.5 Analysis of Prototype Data and Synthesis of Findings

The set of collected data of hydrological and meteorological conditions in the Thua Thien - Hue area has been presented in Sections 5.1-5.4. Some additional tables showing the exchange through inlets in dry and wet seasons are shown in Tabs 5.5.1-5.5.8. In this section we will try to look on the system in a more gereral way by taking into account two aspects: (1) water budget and (2) water quality in comparison with the existing standards.

### 5.5.1 Water budget

The basic objective in an investigation of the water budget of a coastal lagoon is an analysis of the gains and losses of water for a lagoon as a whole, or for some sub-areas of special interest, together with the description of the mechanism by which water is redistributed within the lagoon. A study of water budget evaluates all the processes which supply or remove water from the system. These processes are represented by terms in the hydrological equation referred to as the storage equation. This is a continuity equation explaining the volume changes in terms of processes that involve both salt water and fresh water:

$$\frac{\Delta V}{\Delta t} = P - E + R + G \pm A$$

where:

| | |
|---|---|
| V | - volume of the lagoon, |
| P,E | - spatially integrated precipitation and evaporation, respectively, |
| R | - surface run-off, |
| G | - groundwater run-off, |
| A | - advective gain or loss of water, |
| t | - time. |

All terms are expressed in $m^3/s$.

In case of Tam Giang - Cau Hai lagoon we can try to establish the water budget, as based on data collected in previous chapters.

The *surface* of the lagoon is as follows:

| | | | |
|---|---|---|---|
| | Cau Hai | - | 114 $km^2$ |
| | Tam Giang | - | 49 $km^2$ |
| | Thuan An | - | 54 $km^2$ |
| total area | | | 217 $km^2$ |
| average depth | | | 1.5 m |

*volume of the system:*

$217\ km^2 * 1.5m = 325.5*10^6\ m^3$

*precipitation:* 2800 mm

$217\ km^2 * 2800\ mm = 607.6 * 10^6\ m^3$

*evaporation:* 1000 mm

$217\ km^2 * 1000\ mm = 217.0 * 10^6\ m^3$

Annual run-off can be based on different sources of information

1. Annual run-off (Vietnam Hydrometeorlogical Atlas of Vietnam, 1994)

   catchment area: 4000 $km^2$; average annual run-off: 50 $l/s/km^2$

   200 $m^3/s$ which is equivalent to $6.3*10^9\ m^3/year$

2. Indirect estimates as done by Dr Chu Hoi (1994): $6.4*10^9$ m$^3$/year

3. Comparison with other catchment areas:

   This latter estimate has been done by comparison of two catchment areas, which are similar in character i.e. ThuBon catchment area and the catchment area of our interest. When we compare distribution of average flow in months from two measuring stations Thuan Nhat (Ta Trach) and Nongson (ThuBon) we can conclude that there are similarities. In both cases discharge in wet season (September - December) is about 70% of total annual discharge. From this we can conclude that the same monthly distribution holds true for the whole catchment area.

Hence one arrives at annual run-off estimates in the range of 6.3 to 7.3 billion cu m.
Based on characteristics of two catchment areas:

| *ThuBon*: | | *Tam Giang-Cau Hai*: | |
|---|---|---|---|
| catchment area: | 10350 km$^2$, | catchment area: | 4000 km$^2$ |
| discharge: | $19*10^9$ m$^3$/year | discharge: | 7.3*109 m$^3$/year |

*Exchange through tidal inlets*

Measurements done at two inlets during dry and wet season (see Tabs 5.5.1-5.5.8) enable us to assess the exchange through the inlets. The measurements presented come from one day only. From them we can see that in this system we have inflow of water to the lagoon through Tu Hien inlet, while there is always outflow through Thuan An inlet. On that particular day the net outflow from lagoon was:

| | | |
|---|---|---|
| 13-14/3/95 | (dry season) | $-5.8*10^6$ m$^3$/day |
| 23-24/11/95 | (wet season) | $-30.36*10^6$ m$^3$/day |

Measurements in the inlets may be not very accurate, but give an idea on the possible direction (and volume) of water exchange through the tidal inlets of thuan An and Tu Hien in both seasons.

### 5.5.2 Water quality of Tam Giang - Cau Hai in comparison with water quality standards

According to Vietnamese legislation water quality standards are divided into several classes depending on the purpose of use:

- supply water for daily-life in the urban and rural settings
- supply water for specific industrial areas,
- supply water for plantation and irrigation in agriculture
- supply water for entertainment, physical training, sports and aquaculture.

The Vietnamese water quality standards for daily supply are shown in Tab. 5.5.9 together with comparison with standards for other countries. Given in Tab.5.5.10 are standards for Polish freshwater bodies (depending on class). Comparison of the data shown in 5.3.3 with the standards mentioned above shows that at present most parameters of the study area are in the first class (according to Polish standards), so we can conclude that waters may be regarded fairly clean.

It can be expected that, because of intensive use of Tam Giang - Cau Hai for aquaculture and development of infrastructure in this area, the improvement of living standards in the Thua Thien Hue province will bring about deterioration of water quality, as many experts fear. One of symptoms can be seen in the change in metal concentration in Huong River during two successive years (see Tab.5.3.3.2).

Tables 5.5.1 to 5.5.10 illustrate the above discussion and arguments, cf. Appendix 5.

# 6. Flood Disasters and Flood Control

## 6.1 Flood Scenarios, Events, Statistics ...

The **main sources** of flooding in Vietnam:

- heavy rains,
- storm surges,
- strong winds.

There are two **main types** of flood hazard: *river floods* and *coastal floods*. Both are linked to the prevailing weather system and the geomorphological & topographical features of a given site. In addition, coastal flooding can be caused by cyclones leading to storm surges, and sometimes by offshore earthquakes (tsunamis). The basic cause of river flooding is the incidence of heavy rainfall.

Rainfall associated with a tropical cyclone can be intensive over a lengthy period. The damage that results as a direct consequence of rainfall, and not in the form of floods can be enormous. Rain seeping into homes and buildings and attacking foundations may cause severe damage. Drainage which is not sufficient will often lead to local floods, and riverine flooding may result under extreme conditions.

Storm surges caused by cyclones often result in coastal flooding. The factors which combine to cause a storm surge are partly meteorological and partly hydrographic, including the state and nature of thc tide and the topography of the sea bed in the vicinity of the coast.

Hazards caused directly by rain and wind are less tangible flood hazards. This is because their impact is not restricted by topography or geological qualities to certain areas. If a settlement is located in a region where cyclones occur, every square metre may be exposed to their maximum impact. Thus, small-scale variations in mitigation measures cannot be expected as far as the direct impact (rain and wind) of cyclones is concerned. For the mitigation and prevention of disasters, frequencies of wind strengths, expected direction of propagation of the cyclone and maximum rainfall frequencies are of importance while the warning system is of vital importance !or preparedness as the warning period may have consequences for the planning of evacuation routes and the number of protectivc shelters.

Flooding in **Vietnam** ranks as the worst of all natural disasters. In addition to loss of life and human misery, floods inflict severe damage to agriculture, infrastructure, public buildings, private houses and propery. The Thua Thien - Hue province belongs to those severely flooded in Vietnam (**Figure 6.1.1**). Floods are mostly caused by heavy rains induced by monsoon, storm surges associated with typhoons or by combination of both (**Fig. 6.1.2**). Typhoons are particularly severe in the central and northern regions of Vietnam during the rainy season. The extent of TTH flooding is seen in **Figures 6.1.3-6.1.4.**

In the **Thua Thien - Hue** one can distinguish two flood seasons. The first one is in May-June, which is less severe than the second flood season (September - November). According to statistics, there are 3-4 floods per year (sometimes 7-8), lasting 1-3 days. Statistics also show that Thua Tien Hue area is directly impacted by 2 main monsoons, north-east and south-west, especially when typhoon occurs. The winter monsoon period is from September to March, with the average wind speed 2-4 m/s, the maximum wind speed being 40 m/s; the observed wave height reaching is 3.5 - 6.0 m close to shore.

Monsoons from south-west are observed in the period May - August, when the wave height is 4.0-6.0 m. (Tab. 6.1.1 and 5.1.14).

In Tab.6.1.2 alarm water levels are shown for two stations: Phu Oc and Hue.

Comparison between alarm level I (see Tab.6.1.2) with mean monthly water levels for Phu Oc (Tab.6.1.5) and Hue (Tab.6.1.11) shows that every year at least in one month the average water level exceeds the alarm datum. Some more statistical data on water levels is shown in Tabs. 6.1.5-7 for Phu Oc, in Tabs. 6.1.8 -6.1.10 for Thuong Nhat, and in Tabs. 6.1.11 - 6.1.13 for Hue.

Some additional data for extreme floods are shown in Tab. 6.1.3 for Huong and in Tab.6.1.4 for Bo River.

Tables 6.1.5 to 6.1.13, as less synthetic and more specific water levels at particular stations, are collated in **Appendix 6**.

Table 6.1.1 The most severe typhoons in years 1983 - 1993 (VVA - A7)

| Name of typhoon | station near the typhoon | wind dir | wind speed | wave dir | wave height (m) | water level (cm) | tidal level (cm) | losses |
|---|---|---|---|---|---|---|---|---|
| LEX<br>26 X 1983 | Con Co | SW | 38 | S,<br>NW | 9.0 | coastal storm surge | | 2000 ha of rice flooded |
| CECIL<br>15 X 1985 | Con Co | NE | 34-35 | NE | 8.0 | 227 | | 769 persons dead,<br>128 persons missing,<br>50000 persons injured<br>80000 houses destroyed |
| DOM<br>12 X 1986 | Hong Ngu<br>Con Co<br>Son Tra | NE<br><br>SE | 16<br><24<br>16 | NE<br>E<br>SE | 2.0<br>4.0<br>2.0 | 242<br>132<br>142 | 205<br>100 | |
| SKIP<br>12 X<br>1988 | Con Co | | | N<br>NW | 4.0<br>3.0 | | 105 | |
| ANGELA<br>11 X 1989 | Con Co<br>Son Tra | W<br>NW | 36<br>28 | NW<br>NW | 5.0<br>3.5 | 128<br>156 | 105<br>105 | |
| ED<br>20 IX<br>1990 | Hon Ngu<br>Con Co<br>Son Tra | NNW<br>NNE<br>NW | 17<br>35<br>36 | N<br>NW<br>NW | 1.5<br>4.0<br>6.0 | 250<br>122<br>182(18/IX)<br>122\(19IX)<br>109(10/IX) | 190<br>85<br>100<br>(18/IX) | |
| FRED<br>19 VIII<br>1991 | Hon Ngu<br>Con Co | NNW<br>N<br>SW | 28<br>27<br>16 | NNW<br>N<br>SW | 6.0<br>2.4<br>2.5 | | 165 Cua Hoi<br>65 Cua Tung | |
| LEWIS<br>11/VII<br>1993 | Con Co | NW | 12 | SW | 1.5 | 64 | 60 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| WINONA 29/VIII 1993 | Con Co | SW | 12 | SW | 2.5 | 76<br>96 | 60<br>85 | |

Additional data for Table 6.1.1:

LEX - Vmax - 32-34 m/s; Pmin 980.5 hPa; ships and boats sank and broken down 292; 300 m of rain riffled, 2000 ha of rice flooded, coastal storm surge 2.5 - 3.0 m

CECIL - 7 days, Vmax - 41 m/s, Pmin - 960 hPa, 769 persons dead, 128 persons missing, 50 thousand persons injured, 80,000 houses destroyed,

DOM - 7 days, Vmax-25 m/s, 993 hPa - Pmin,

SKIP - 10 days, 51 m/s, 950 hPa,

ANGELA - 14 days, 59 m/s, 920 hPa,

ED - 7 days, 32 m/s

(Sources: Vietnam Coastal Zone Vulerability Assessment, Data Collection Report A7, and Storm characteristics by Nguyen Doan Toan, Tran Hong Lam, Nguyen Thi Hai, Hanoi - 1995, VVA-DC7)

Tab.6.1.2 Historical flood record: (Tran Nhon, Mitigation, emergency ..., 1992, Hanoi)

| location | alarm level I (cm) | alarm level II (cm) | alarm level III (cm) | max. level | Date of max. level |
|---|---|---|---|---|---|
| Phu Oc (Bo) | 200 | 400 | 550 | 650 | 1964 |
| Hue (Huong) | 150 | 300 | 400 | 585 | 30/10/1983 |

Tab.6.1.3 Water levels during floods on Huong (cm)

| | Khelu | Tuan | Nham Bieu | Kim Long | Phu Cam | Dag Da | La Y | Sihn | T.Long |
|---|---|---|---|---|---|---|---|---|---|
| 1953 | | 9.40 | 7.07 | 5.50 | | | | 2.30 | |
| 1975 | 11.80 | 7.82 | | 4.32 | | | | 2.32 | 2.0 |
| 1983 | 13.80 | 8.50 | 6.60 | 4.90 | 4.72 | 4.43 | 4.13 | 2.50 | 2.4 |
| 1985 | | | | 4.72 | | | | | |
| 1990 | | | 4.53 | 4.53 | | | | 2.10 | |

Tab.6.1.4 Water levels during floods on Bo (cm)

| | Co bin | An Lo | Phu Oc | T. Ha |
|---|---|---|---|---|
| 1983 | 8.96 | 6.00 | 5.50 | 2.80 |
| 1985 | 6.734 | | | |
| 1990 | | | | 4.77 |

## 6.2 Flood Control and Protection Measures

### 6.2.1 General

The <u>strategies</u> to deal with floods can be grouped as follows:

(1) **Flood mitigation**, which encompasses a range of measures which can reduce the frequency and severity of flooding; such as flood prediction, non-structural measures to reduce runoff, and structural measures which can be taken to protect low-lying land and coastal areas;
(2) **Emergency preparedness**, by which one means steps aimed at foreseeing the impact of flooding;
(3) **Disaster management**, which aims at best tackling situations as they arise, mobilization of the emergency services and the provision of commands for decision-making and the coordination

Although natural disasters are part of our environment, no disaster is entirely natural, since human activity invariable aggravates the risks through insufficiently paying attention to where and how settlements are built or natural resources are exploited. Effective **mitigation** of disasters entails *risk assessment, planning and decision making and implementation*, all within a given administrative framework. Flood hazards are linked to the prevailing weather and geographical systems, but flood phenomena can be aggravated by other natural or man-made factors. Once the characteristics of the flooding are understood, determination can be made about the most effective combination of strategies to mitigate the flooding. Some general illustration can be found *inter alia* in Fosse (1992), who described examples in Nepal, Bangladesh, the Philippines and Colombia.

### 6.2.2 Historical perspective and present situation

Since flooding and typhoons have always been a permanent threat to the people of Vietnam, the struggle to prepare for these inevitable events has occupied an imporlant position in the thousands of years of Vietnam's history. The first dyke of Vietnam was constructed in the first century under the Hai Ba Trung Dynasty. Early in the eleventh century, under the Ly Dynasty, dykes were conslructed to protect against the Red River the Dai La Kings' town (later named Hanoi). In the thirteenth century, under the Tran Dynasty, dyke systems were built from Vict Tri (upstream of Hanoi) down to the sea, and the construction of sea dykes also began. Since then onwards, the capacity of dykes in Vietnam have been constantly strengthened by widening and raising at an accelerated rate. From 1884 to 1945, the Victnamese people placed 87 million m3 of earthfill, while since 1945, 255 million m3 of earthfill and 4.2 million m3 of rock revetment were employed.

Since the historical flood in August 1971, the Vietnamese Government has applied **six general measures** for short-term and long-term flood control:

1. Reforestation and watershed protection;
2. Constructiun of medium and large-scale reservoirs in the upstream areas;
3. Strengthening of dyke systems;
4. Flood diversion whenever necessary;
5. River dredging and clearance to provide discharge channels;
6. Dyke monitoring, repair and upgrading.

During the past years, although ref<u>orestation</u> has been promoted, the forest area is being reduced by about 100,000 ha/year. Increasing deforestation has seriously affected the rainfall runoff characteristics of the catchment area, causing land erosion and denudation, faster flood flows and lower flow rates in the dry season. In the <u>watershed</u> domain, millions of m3 of earth have been removed from high river banks, and a number of fallen bridges and sunken ships have been removed. However, in recent years, the situation has again worsened. Construction materials are being dropped in the waterways, new residential areas have been established on the riverlands, and sand bars along the rivers and in the estuaries have been dredged because of the lack of other funds.

<u>Flood diversion</u> works have not always been able to perform at their design capacity. For example, the Day River channel had been planned to divert floodwaters from the Red River wilhout endangering the Day River dykes. However, only 60% of the waters is possible to evacuate because new areas within

the floodplain have been settled for agriculture during the long period since the last flood. The most diffcult problems in many coastal regions is that too many people settle as the coastal areas expand around new sedimentation zones -- they have to be taken care for in the case of flooding and then eventually resettled after the hazard escapes.

Upstream reservoirs serve many beneficial purposes but by holding back sediment are inducing erosion in the lower basin, and are extending the period of flooding. The former effect increases the danger to the dykes while the latter stretches tbe resources of the dyke management and repair claims during flooding.

The extent of the present dyke system, aimed at both flood mitigation and control of saltwater intrusion, has been clearly documented in the database collected for VVA, cf. **Figure 6.1.5**. An extensive description of the dyke system given in the VVA Data Collection Report A2 should be consulted for details. Some illustration of the present flood control, as seen in Mission Hue, is given in **Figure 6.1.6.**

The Vietnamese experience of dyke monitoring, reapair and upgrading has shown that dykes are the most important structural measure for flood mitigation and control of damage from typhoons. Ho Chi Minh once said: *"All people must take care of tbe dykes"*. Even when otber measures are implemented, dykes will remain an essential and indispensable structural measure to protect life and ensure continued agricultural production. However, during large floods, dyke monitoring and repair needs to be undertaken quickly and reliably. Vietnam now has nearly 8000 km of dykes, including 6000 km of river-dykes and 2000 km of sea-dykes. There are 3000 km of dykes along larger rivers and 1000 km of major sea-dykes. About 600 revetments of various types and 3000 under-dyke sluices have been built. In addition, there are 500 km of embankments for controlling nuisance floods and preventing salinity in the Mekong Delta.

Over the last two thousand years, techniques for combatting **failures in** the **dyke systems** have been developed. In particular since 1971, new strategies have been worked out for detecting zones of weakness, for strengthening crucial areas of tbe dyke system, and for more effedively responding to alarms. However, one still faces a number of serious problems:

1. There can be many causes of dyke failures, induced by geotechnical, hydrological and other factors. Among the latter, there are termite nests and not so untypical rodent pipes.
2. Changes in the river channels during floods can cause bank erosion, threatening the safety of the dykes. Bank protection by revetments and groins is very costly, and sometimes difticult to construct to a satisfactory standard.
3. Most sluices which allow.water to pass through the dykes are out of date and seriously damaged, though they remain operational. In the flood season, many sluices have to be rendered inoperative in order to maintain the security of tbe dykes.
4. The sea-dyke systems, especially in the Central Provinces, are very low and are overtopped frequently and washed away. Sea-dyke systems in tbe North, although larger and able to withstand typhoons up to level 10 at mean sea level, are also to remain operational when typboons and storm-surges combine.
5. Resources and equipment for dyke monitoring and repair have been kept minimal and are most often insufficient. Dyke monitoring has been mainly visual, even though most defects are located inside the dyke or in tbe foundations anl are tbus diffcult to discover. Fortunately, this situation is set to improve substantially witb the new dyke monitoring and repair technology being introduced under the UNDP's Project VIE/88/015.
6. Although the Council of the State of Vietnam has promulgated an ordinance to proted dykes, violations of fhis ordinance are increasing, especially where the dykes pass through densely-populated areas. In an attempt to maximize the use of its own resources, Vetnam also applies structural and non-structural measures for mitigating floods, such as:
(a) establishment of operation plans for flood mitigation and typhoon emergency action;

(b)promulgating laws, ordinances and regulations for flood control;
(c) improving the forecast and warning systems;
(d) promulgation of design standards. However, the science and technology facilities in meteorology, hydrology, communications, and operation of flood control activities remain at low levels. Furthermore, a subsidy system for flood-preparedness at the village level, which worked well in the gast, is no longer appropriate in Vietnam's increasingly market-oriented economy.

### 6.2.3 Planned flood control measures

On top of the present flood control system, which is to be well maintained and has to be upgraded according to new challenges and demands, there will be new measures and initiatives, as already mentioned on other occasions in this report. The major directions of those developments can be outlined as follows:
(a) construction of **new dykes** and rehabilitation of the present dyke system;
(b) construction of **new reservoirs** in the catchment basin of the study area;
(c) **diversion** of some river branches.

Aside from those major steps, some common protective measures to reduce flood from **reaching settlements** are:
*- Improving channels; - Construction or strengthening of existing dikes; - Increasing pumping capacities.*

However, options to improve the site do not obstruct the hazard itself; their main aim is to reduce the risk at a specific site. There are two main options for improvement of sites exposed to floods: elevation of sites and prevention from erosion. Erosion control is most urgent where stream velocities are high.

Reducing the vulnerability of structures in flood-prone areas can be a successful option, especially when combined with other options. There are two parameters that determine the vulnerability of buildings to water force and its material characteristics when immersed in water. Reducing vulnerability requires attention to both parameters. Special attention must be given to the foundation: inundation may give rise to erosion around the foundation of structures.

The flood resistance of components of infrastructure is in many cases adequate. Despite this, much damage is caused by erosion, mainly due to foundation failures caused by erosion.

Flood damage to infrastructure can be caused by direct water forces, by erosion, or by a combination of both. For other infrastructure elements, such as roads, tracks, pipelines and electricity poles, the main cause of damage is erosion. Land-use regulations for the mitigation of flood disaster serves to implement patterns of land-use to life, property and development when the inevitable inundations occur. One of lhc most important functions of land-use regulalinns against flooding is to ensure that flood hazards are made no worsc by ill-conceived new land use. Especially where urban and induslrial development is rapid, there is a strong possibility that risk will increase.

Accordingly, some indirect measures of flood mitigation can be used in particular for the *regulation* of **urban** *expansion*, and the following forms are especially relevant for such flood **mitigation**:
- Reduction of population densities; - Relocation of elements that block the floodway; - Regulation of building materials; - Provision of escape routes.

Hence, in practice some moves for the future are already made:

**(1) Dykes**. Central provinces, including Thua Thien Hue, have already been targeted for dyke upgrading and expansion, so it semms to be only a matter of time when such activities are undertaken under inter national aid programmes. In May 1992, the World Food Programme (WFP/PAM) decided to fund the rehabilitation and upgrading of 554 km of sea dikes in Central Vietnam, including 96.5 km in Thua Thuen Hue. A good beginning is marked by the presence of Dutch aid, complementing the WFP initiative. The Dutch stretched their hands under the Tam Giang Lagoon dike repair and Nam Thach Han irrigation scheme programme initiated in 1993 and nearly completed in 1995.

Along the lagoon, the existing dikes are used for two purposes: (1) to prevent against salinity intrusion (2) for flooding period. In the past dikes were built by inhabitants of the area, while now they are financed by international funds, although the financing is felt to be low. The two purposes are expected to guide the designers also in future construction.

**(2) Construction of reservoirs.** The planning and preparations for the construction of Ta Trach (Xa Dua; 500 mil cu m, 30 MW...) + Bihn Dien (Huu Trach) and Co Bin (Bo) + Thac Ong Lake (?) + other minopr reservoirs are well advanced (as confirmed at various reliable sources during the Hue Mission).

It is expected that the first reservoir, on Ta Trach will be ready by the year 2000! Its working capacity will be $500*10^6$ $m^3$. This reservoir should be able to reduce flooding only 1 per 20 years. During the dry season fresh water will be discharged in the quantity of about 40-50$m^3$/s, so as to reduce salinity intrusion to $1^\circ/_{\circ\circ}$. Also water will be used for production of energy. It is predicted that the maximum discharge in flood season will not exceed 5000$m^3$/s. It is estimated that construction of this reservoir will coast about 100 ml US$ (Ngo Dinh Tuan, priv.comm.)

The construction of reservoir will have the following advantages:
- yearly 5 ml US$ will be saved due to flood reduction,
- construction will be positive to environmental protection,
- source of fresh water for irrigation,
- source of fresh water for domestic usage,
- positive influence on shrimp farming,
- increase of production in agriculture.

Some disadvantages of this construction are also expected, such as
- decrease of downstream siltation,
- changes in rivers' bottom, river mouths' changes,
- deposition of sediment in reservoir.

The two additional reservoirs are planned for construction after year 2010. Both of them will be smaller and less profitable in financial terms, mainly because of less favorable natural conditions.

**(3) Diversion** plans have materialized to a lesser extent. One of the options considered in the search for minimum flooding of the Hue area consists in swift passage of huge amounts of riverine flood waters towards the sea, by constructing high dykes nad embankments preventing the overflows into lower land zones. This should be connected with construction of efficient means for drainage, i.e. the whole infrastructure of secondary dykes, pumping stations etc. A version within that option can encompass river diversion i.e. directing of Song Huong waters towards Cau Hai, through enlarged river channels of Lui Nong and Dai Giang.

Flood control and drainage systems must be so designed as to take into account that salinity intrusion in the dry season can be a very serious problem. In 1990 in dry season salinity intrusion was observed 30 km from the mouth of Huong River, on Bo River at the station Phu Oc (about 25 km upstream), and in O Lau River some 30-35 km from Thuan An inlet.

To mitigate the salinity intrusion, a project on irrigation and drainage paid by the Vietnamese Government (about 200 000 US$) was initiated in 1995.. This is a 3-year project (1995-1997), within which some dredging works around the old city of Hue are done. Also within this project navigation on the Huong River is under consideration. In fact, the Huong River is nearly ready for navigation, only a small part close to Hue needs more dredging works.

## 6.3 Analysis of Flood Impact and Control on the Lagoon System Users

Flooding, stemming from both atmospheric,inland and seaborne factors, exerts a number of impacts on the flooded area, or the lagoon system in the case of our study area. Very schematically, in the context of the study area, these impacts include:

(1) loss of life and health and material losses due to inundation of land;
(2) aftereffects in agriculture and other branches of economy;
(3) seasonal and/or short-term changes in salinity and water quality of the lagoon system, coupled with water exchange and flushing patterns;
(4) seasonality of sedimentation processes in the lagoons system and its catchmnet basin;
(5) seasonal, short-term and long-term changes in the morphology of the lagoon system, in particular its tidal inlets and river mouth sections;
(6) seasonal and other changes in the lagoon ecosystem, including migration of species, local transformations of habitats etc;
(7) seasonal and other changes in land use and socio-economic features associated with all above changes;
(8) many secondary and indirect effects.

The above impacts should be analysed vis-a-vis the present flood control practices and the measures planned for the future. Some impacts are both positive and negative, so a delicate balance should be sought in planning of flood control strategies. A few immediate examples are as follows.

Agriculture is affected positively by riverine flooding in the sense of irrigation, fertilization and nutrification but intrusion of saltwater due to sea-induced flooding is detrimental.

Aquaculture requires salinity ranges and other water qaulity parameters to be kept under control. This can be impaired by excessive freshwater flooding. On the other hand, flushing of the lagoon is positive with respect to renewal of nutrients etc.

The amounts of riverine flood waters entering individual parts of the lagoon network, and the flushing connected with the passage of such substantial amounts have direct bearings on dredging, sedimentation, morhology and stability of the lagoon and its inlets. Less flushing means more dredging works and problems, worse inlet stability and other problems to the lagoon users. Less flushing, i.e. smaller amounts of water passed by, means less sediment from the catchment area, sediment deficit in the coastal zone, and the system's sedimentological instability. On the other hand, excessive amounts of riverine flood waters can cause excessive accumulation of sediment in some unwanted areas, excessive deepening of waterways, less retention in some other areas etc.

In planning of flood control for the future, a reasonable blend of different measures must be offered to a growing variety of the lagoon users, and the advantages and shortcomings of those measures must be *compromised by* the use of *integrated management techniques* (cf. Chapter 11). It is quite likely that

that blend will consist of dyke construction and upgrading; construction of reservoirs; some diversion schemes; drainage measures; and respective infrastructure.

The effect of *dykes* on the lagoon users structure is rather passive at present -- the dyke system is intended to protect the enclosed areas from either saltwater or freshwater. In future dykes may become a more active tool of flood control if a huge scheme of river endikement is implemented and the river waters are conveyed striaght and fast towards the sea, without meandering and overflowing to the lagoon. Such a choice is however less conceivable having in view the loss of the function of lagoon flushing, very essential to that ecosystem.

The construction of *reservoirs* will lead to flood reduction and environmental protection, will make more reasonable use of frsh water for irrigation etc and will not impair aquaculture by not affecting the desired salinity regime. Yet one should not forget the most conspicuous 'byproduct' of reservoirs, i.e enforced sedimentation on their bottoms and the subsequent reduction of downstream sediment transport and overall sediment deficit in the lagoon system.

*Diversion* of Song Huong waters towards Cau Hai can have one important advantage of flushing the lagoon, thus helping its water quality and ecosystem; the intrinsic instability of Tu Hien can only be remedied by allowing more water into Cau Hai.

Mitigation of salinity intrusion, efficient drainage and other infrastructural activities will be necessary to accompany the major efforts of dyke and reservoir construction.

Whatever the flood control schemes decided for the study area, the users structure will change accordingly; e.g. less salinity intrusion will foster agriculture; more reservoirs and sediment entrapment will impair beaches and tourism etc.

# 7. Lagoon and Coastal Morphodynamics and Tidal Inlet Stability

## 7.1 Sediment Budget and Transport

Table 7.1.1 provides a summary of sediment load and budget figures derived from various sources and partly computed by the mission staff.

**Table 7.1.1 Sediment data for the study area**

**I. SEDIMENT LOAD & BUDGET**

**Sediment input:**

**Song BO: 192,000 tons/year**

**Song HUONG: 450,000 tons/year**

**Song O LAU: 40, 000 tons/year**

**Dai GIANG: 35,000 tons/year**

**thus total → 270,000 cu m per year**

**(after Nguyen Duc Vu 1995, Khoa Hoc 3:49-53)**

**Sediment sinks:**

**(1) estimated (rbZ) 60,000 cu m per year**

**due to sand and gravel mining**

**(2) + Ta Trach Reservoir ...+ other reservoirs when implemented ++ ...**

**(up to 200,000 cu m yearly?)**

**Sediment output (from the lagoon to the sea): to be estimated:**

**Av concentration in the rain season: 50 mg/l**

**Av inlet flow velocity: 4-5 m/s in the rain season, below 1 m/s otherwise**

**Sedimentation patterns (circulation, grain distribution ...) to be explored**

**II. COASTAL EFFECTS**

**Littoral drift estimates: 300-400-500,000 cu m per annum net NW → SE**

The following comments should supplement Table 7.1.1.
(1) Sediment transport estimates have been based on rough computations by Unibest, a Dutch software package. The wave data and sediment properties intervening in the computations have been borrowed from the approximate data in possession of the VVA staff (cf. reservations on the wave dataset in Chapter 5). More accurate computations should rely more heavily on improved wave figures, typical of at least the two predominant wave regimes in winter and summer; refined refraction plans for the study area; corrected data on coastal circulation (nonwave-induced currents such as tidal, inertial and wind-induced); refined data for bedforms and bed roughness...
It is noted that some other sources (HP22, Hue6) cite longshore sediment transport rate in the order of 3 million cu m per year (3.5 from NW and 0.5 from SE), which seems to be an exaggerated figure. Other computations using the CERC formula yield 2.012.000 m3/year to SE and 1.490.000 m3/year to NW (HP22)
(2) Sediment concentration in the river system is known only roughly. It remains to be checked if the figures cited are basically bedload only and how bedload relates to suspended load in a variety od circumastances likely to be encountered in the river and lagoon system if various flood control strategies are adopted.

## 7.2 Lagoon Morphodynamics and Tidal Inlet Stability

### 7.2.1 Morphodynamic Features

This is an interesting complex of phenomena, will should be dealt with in detail, not only beacause of its scientific and ecological importance but also on account of its socio-economic implications.

The Tam Giang - Cau Hai Lagoon is situated next to the Thua Thuen Hue Plain. The plain consists of Quaternary alluvium (stemming from Neogene) filling up low-lying Kenozoic strata. Neotectonic movements brought about complicated patterns of sedimentary stratification. The formation of the TG-CH lagoon is connected with the development of the Hue Plain, especially during the Holocene, not untypical for many lagoons some 6000-8000 years ago.

At the beginning of Holocene, the lagoon formation was affected by the sea level rise due to Flandrian transgression. Until mid-Holocene, the Trieu Phong - Hai Lang lagoon so formed was confined by a barrier dune ridge on the sea side. Pha Trach - Phong Chuong foredunes included marshes which later became a peat basin.

It was in late Holocene that the Tam Giang - Cau Hai Lagoon in its present shape was formed. The system of dunes developed along the Viet mouth. Where the tidal effects were minor, the dunes were mostly controlled by wind.

At the beginning, the TH-CH lagoon was larger than at present. The progression of the Hue Plain was connected with advancement of its alluvia and subsequent confinement of the lagoon. This process continued until the balance was reached between the amount of water flowing out during the flood season and the carrying capacity of the outlet to the sea, i.e. when the Thuan An inlet was generated (after Tu Hien). A certain role in the formation of Thuan An was played by thixotropy of the alluvian fan.

As the Perfume River continued to play a crucial role in the lagoon morphodynamics, substantial amounts of sediment were conveyed to Thuan An. No major erosion events were noted, and the inlet of Thuan An has moved continupusly to the North, at an estimated rate of 40 m per year during the recent century (Nguyen Huu Cu 1994, HP1).

Nguyen Huu Cu (1994, Hue6) provides the following conclusions regarding the structure, morphology and evolution of TG-CH. Tam Giang emerged as a typical lagoon, Huong mouth is deltaic; Thuy Tu developed in Pleistocene as an old river, while Cau Hai emerged as a recent tectonic body. All this brings about structural, morphological etc differences.

The <u>sediment budget</u> of the TG-CH lagoon system can be split up in four basic components (Nguyen Huu Cu 1994):
(1) riverine input; (2) marine input through the inlets of Thuan An and Tu Hien; (3) local sedimentation within the lagoon; and (4) exchnge products due to regional transformation of the topography by wind, waves, surges, surface run-off, flood waters etc.

Nguyen Chu Hoi & Tran Duc Thanh (1995, HP5) provide a summary of **<u>sediment characteristics</u>**, mostly granulometric, for the TG-CH lagoon. They make distinction between the barrier dune and inner lagoon sediment. For the former, stretching some 60 km along shore and measuring 2.5 km at the widest transect, the overall distribution of sediment is as follows:
-- gravel and coarse sand on beaches of Thuan An;
-- medium sand at barrier dunes of Dien Loc - Tu Hien.

Tables 7.2.1-7.2.5 (cf. Appendix 7) contain illustration of TG-CH sediment data. In particular, Table 7.2.1 shows basic granulometric data for beach and dune of the Tam Giang - Cau Hai Lagoon.

The sediment of the lagoon proper consists of coarse to fine sand, silt and clay. Samples with coarser silt and silty clay are found in shallow water of the lagoon while finer silt and clay are sampled in deeper water. Tables 7.2.2-7.2.5 provide respective data for the various samples (some figures have been rounded up as the original data by Nguyen Chu Hoi & Tran Duc Thanh (1995, HP5) has been inconsistent. -- In particular, Table 7.2.2 presents granulometric characteristics of sand samples inside the Tam Giang - Cau Hai Lagoon; Table 7.2.3 granulometry of sandy silt samples in the Tam Giang - Cau Hai Lagoon; Table 7.2.4 granulometric characteristics of coarse silt samples in the Tam Giang - Cau Hai Lagoon; and Table 7.2.5 the same for fine silt samples in the lagoon.

Nguyen Chu Hoi & Tran Duc Thanh (1995, HP5) claim there is no proper clay in the lagoon.

Having analyzed the granulometric distribution of the lagoon sediment in space and over depth, its mineralogic composition , and some other characteristics, Tran Dinh Lan (1992, HP6) come to the following conclusions on classification of the lagoon:
-- Mouths of O Lau and Truoi Rivers are characterized by fine dark grey sediment, rich in organic matter; these subareas do not encounter any substantial exchange of water or sediment;
-- Dam Sam bottom consists of dark grey fine sand and aleurite, affected by tidal motions and thus belonging to lagoon-type tidal flats;
-- Thuan An and Tu Hien tidal inlets are built of coarse to fine sand with shell debris, grey brown and yellow in colour, typical of tidal inlets affected by tides, waves and currents;
-- Tam Giang and Thuy Tu are characterized by sediment grain size decreasing with depth, greyish brown or brown, affected seasonally by riverine water;
-- Cau Hai contains dark grey aleurite and is subject to substantial exchange of water due to internal circulation.

On the other hand, the bed alluvia are arranged in five distinctive areas by Tran Duc Thanh & Nguyen Chu Hoi (1995):
1. O Lau - Truoi - Cong Quan with greyish black fine mud
2. Dam San characterized by greyish black fine mud
3. Tu Hien and Thuan An inlets with yellow sand
4. Tam Giang, Thuy Tu and tidal flats encompassing brown- yellow and greyish brown mud
5. Cau Hai with greyish blue mud.

Types 1 and 2 are typical of deltaic sediments, type 3 characterizes tidal inlet environments, while type 4 appears in tidal environments, and type 5 is typical of lagoon deposits.

### 7.2.2 Tidal Inlets and Generation of Beaches

The beach processes and migration of the lagoon's tidal inlets form an important component of the lagoon morphodynamics.

In addition to the general overview of the lagoon's history, the following description from HP9 sheds light on the generation of the lagoon edges.

During the Quaternary the beaches of Thuan Thien Hue were generated by the system of Rivers Huong, Bo, O Lau, which brought in sediment into the earlier gulf.

1st stage (unknown duration): generation of the river bed. The coastline at that time was not influenced.

2nd stage (medium Holocene): a system of dunes appeared in Phong Dien and Phu Vang, consisting of a sequence of dunes 7--8 m high. At that time the sea level was higher by 4-5 m (4500 years ago) than at present, while 2--3 m higher 3000 years ago.

Together with a system of dunes there was an ancient lagoon, which was later filled up with alluvial sediments to create the present day Hue plain.

3d stage (late Holocene): a system of very high dunes was generated from Quang Tri to Tu Hien inlet. That was in the period of Bau Tro and Sa Huynh i.e. 2300 years ago when the sea level was higher by 1-2 m than at present. The Tam Giang - Cau Hai lagoon system was created at that time. At the beginning that system stretched to the north up to Hai Lang (Quang Tri) and it had only the Tu Hien in let. The process of lagoon filling became at the mouths of O Lau and S ong Huong. The system gradually narrowed. After the huge flood of 1467 the inlet Thuan An appeared and tu Hien lost its importance, and was subject to many changes afterwards. Thuan An inlet had the tendency of moving northwards.

The morphological transformation of the lagoon edges can be tracked back from the stratigraphy of the lagoonal sediments, cf. **Figure 7.1**.

### 7.2.3 Inlet Stability and Migration

Nguyen Khoa Lanh (1994, Hue9) gives the following description and explanation for changes and causes of Tu Hien migration in longer historical perspectives. The book titled 'Great Vietnam Re-united' says that '1000 years ago the inlet was very wide and deep enough for navigation. When the Gia Lay kings came to power it gradually narrowed. In the tenth reign of Gia Lay the inlet was open but narrow'. Until 1953 navigation was not difficult. At the end of 1953 after a severe flood a northern inlet was opened. In 1979 it was filled up. Then the Binh Tri province opened the inlet in the south. in 1990 the N inlet was re-opened due to flooding but in 1994 it was filled up again.

The inlet opening and closing process is linked to unequal water levels in the lagoon and the sea. From surveys in rain seasons it appears that the water level in Cau Hai was higher than at sea, e.g. the superelevation at Cau Hai station reached 70 cm - 1m a few times in the past.

As NE waves prevail from December to April, creating 90 degress with the shore normal, they bring sand to the shore. Higher water level in the lagoon conveys sediment transport away from the lagoon. In the dry season accretion evolves quickly, and the inlet closes up, in many cases overnight.

In recent forty years, the tidal inlet of Tu Hien was closed 3 times -- in 1953, 1979, 1994. In 1979, the salinity in Cau Hai was measured at 9 - 33ppth before closure and 11ppth after, thus proving the importance of lagoon flushing through the inlets. The last series of closing and opening events was initiated in 1989, with dramatic migration of Tu Hien in November 1994. Tu Hien is felt responsible for inundation, fertilization and flushing of the entire Cau Hai lagoon.

The migration is also an inherent feature of the other inlet, Thuan An. During this century, Thuan An has been moving 40 m/year to the north. At present the migration is slow and the old inlet at Phu Thuan. is approached. Thuan An is directly affected by the Perfume River waters, which are flowing to the sea very dynamically, especially during the flood season.

The history of the migration of both inlets, Thuan An and Tu Hien, from 1404 to date is illustrated in **Figure 7.2**.

Hence Tu Hien should be investigated in terms of both technical means and general regional geography. It is quite obvious that, for the sake of the lagoon sanity, Tu Hien should be opened and measures should be taken to avoid its closure.

The stability of both tidal inlets of the lagoon can be discussed in terms of the tidal prism volume and inlet cross-section, cf. Shore Protection Manual (1984). From the sketch in **Figure 7.3** it may be seen that the present cross-section area of both Tu Hien and Thuan An is too small to comply with the requirements of morphological stability. This is particularly true for Tu Hien, with its present cross-section area of 50 sq.m, versus tens of thousands sq.m required. The situation with Thuan An is not so dramatic because the inlet is not only tidal but also riverine, and is controlled by the Perfume River waters to a large extent.

A more detailed analysis is necessary to support dredging operations etc, especially in view of the planned flood control measures and subsequent lagoon transformations, cf. **Figures 7.4** and **7.5** for present picture of the Tu Hien inlet, as seen during Mission Hue.

# 8. Analysis of Lagoon Ecosystem

## 8.1 General

**Estuarine, lagoonal and coastal ecosystems**

Estuaries and lagoons along the coastline of Vietnam are controlled by the mixing of sea water and freshwater discharged from the river systems, including the Pefume River in our study area. The coastal regions with estuaries and lagoons play a very important role in various economic fields, in the exploitation of biological resources and minerals, in transportation and in the expansion of new land for cultivation.

Estuaries, lagoons and shallow sea waters are the spawning and breeding ground of many species of marine organisms of commercial importance. In these regions are distributed rich coral reefs and mangrove forests where a wide range of fishes, shrimp, oysters, birds, and terrestrial animals is concentrated.

Estuaries and lagoons in Vietnam suffer from changes induced by both natural processes and human activities. The main factors which have an impact are the following:

- Fishing, which is chiefly concentrated in estuaries, lagoons and shallow coastal waters;

- Main spawning and breeding grounds of many commercial species and home of the young larvae;

- Fishing technology, which is basically manual -- fishing tools used are over-destructive e.g. the use of fishnets of small mesh and the use of explosives. Because of these effects, catch per fishing unit does not increase, but is, in fact decreasing. Fishing intensity is now rapidly increasing in comparison with what it was some years ago, but the total catch only increases slightly. Owing to over-fishing over several decades, many economic species of marine organisms have decreased or now are threatened. These include Dorosoma nasus in Central Vietnam's sea, Mytilus smaragdinus in the lagoons of Central Vietnam and diversicolor in Bach Long Vi island and Panilurus s. in the coral reefs.

- Mangrove forests, the surface of which in estuaries is about 300,000 ha, including 140,000 ha of Melaleuca forest. This area is now greatly reduced by napalm bombing and herbicide spraying by the US military during the war against Vietnam, and by the destruction of mangrove forests for other economic uses, such as expanding brackish fishpond; cutting of firewood and building materials and the burning Melaleuca forests for hunting purposes.

- Exploitation of coral reefs for making quick lime is very wasteful use of these productive living resources, especially that extensive alternative sources of quick lime are available in the karst limestone hills of Vietnam.

- Loss of coastline tree cover increases the incidence of storm damage by tidal waves and typhoons in populated coastal areas and leads to sand blowing on to agricultural lands.

Estuaries, lagoons and shallow waters suffer pollution by wastewater from the populous cities and industrial plants, by exploration of oil and gas on the continental shelf and by loading and unloading of goods, especially petroleum products in the sea ports. In addition, increased siltation from deforested upland areas is changing the nature of estuaries and coastal areas and killing aquatic life and coral reefs. In many estuarine regions people are also expanding the cultivation of new land by building dykes seaward. Many hydro-electric stations, reservoirs, dams, etc. are built on the upper streams and water courses. These activities affect the life of organisms and biological productivity of estuarine ecosystems by changing the flow of freshwater downstream. The balance of freshwater with salt water which determines the distribution of species in the coastal zones in thus affected.

Estuaries and lagoons are important areas and are subject to profound changes from both natural and artificial factors, yet they have not been fully studied.

**Mangrove forests, seagrass and other coastal vegetation**

Mangrove forests grow luxuriantly in Vietnam, especially its southern coast, and because of the attention received from scientists from time to time, some baseline data is available that can be of help in planning theirsustainable development. Mangrove forests suffer, among other things, from:

i) clearing for construction of aquaculture ponds and housing;

ii) cutting for logs for commercial uses and fuelwood supply;

iii) after-effects of chemical warfare, especially napalm bombing and application of defoliants (agent orange);

iv) harvesting of Nipa fruits and hunting;

v) felling for extraction of aromatic oils and honey; and

vi) changes in the ecology of the mudflats from sedimentation, oil pollution and land-based pollution, especially garbage.

Protection of mangrove areas should always be planned, keeping in mind their importance as buffer zones against storm surges and typhoon damage, coastal erosion and flood control, as well as their prime role as the breeding, feeding and nursery grounds for commercially important coastal organisms. The importance of the ecosystem in economic terms, although noteasy to estimate, should not therefore be neglected.

**Seagrass beds** usually occur in close association with coral reefs and mangrove swamps, and although not a specifically significant habitat/ecosystem as such, their significance should be evaluated from the point of view of their importance for marine turtles and as the nursery ground for other commercial species. Although almost nothing is known about the extent of sea-grass beds in Vietnamese waters, increasing sedimentation from land sources is badly affecting their distribution.

**Coral reefs**

Although no estimate has so far been attempted of the extent of coral reefs in Vietnamese waters, considering that fringe reefs on an average extend only 100-200 m from the coastline and around the offshore islands, the country's coral resources are not extensive. There are no coral atolls and the fringe reefs are most abundant along the central coastline and around the southern coast. Among them one encounters the corals in the vicinity of Chan May, which can principally be affected by activities and measures taken in our study area of Tam giang -- Cau Hai Lagoon. --- About 70 genera and 200 species of corals have so far been identified, some of which are already becoming rare and are threatened.

## 8.2 Primary Production and Nutrients

Doan Bo & Nguyen Duc Cu (1995, HP7) devised a method for calculation of primary production of phytoplankton and ecological effectiveness of autotrophic hierarchy, basing on the contents of phosphorus consumed in photosynthesis. The method has been employed to determine characteristics of the Tam Giang - Cau Hai Lagoon. It has been shown that the lagoon is a typical tropical water body with a high primary production. Although the water temperature is not very high, only 22 - 24°C in the summer, the primary production of phytoplankton reaches 70 to 130 mgC/m^3 per day, the P/B daily effectivenes is 1.6--1.7 while the autotrophic one approaches 2.1--2.2. Should the water temperature be higher (say 28°C) and the environmental conditions be more suitable, the primary production may go up to 200-250 mgC/m^3.

The principal hydrophysical and hydrochemical characteristics of the Tam Giang - Cau Hai Lagoon are given in Chapter 5 and elsewhere in this report, and are summarized by our Vietnamese partners in **Appendix 8** (Part II). What is worthwhile to emphasize in the context of that summary, the salinity and its changes play essential and delicate role in the behaviour of the lagoon ecosystem.

A few remarks should be made on the hydrochemical background of the primary production in the lagoon.

a. **Salinity** changes **in space**

In Tam Giang - north of Thuan An inlet, salinity gradually increases from north to south. From O Lau river mouth to Ro market (point 32.31) salinity is 0 - 2°/₀₀ in wet season, and is below 5°/₀₀ in dry season. From Dam market to An Gia (point 30.29), salinity is 0 - 3°/₀₀ in wet season, and 6 - 12°/₀₀ in dry season. From Mai Duong to Thuan An salinity is 0 - 7°/₀₀ in wet season, and 16 - 30°/₀₀ in dry season. In Sam - An Truyen salinity is 0 -1°/₀₀ in wet season, and 25 - 30°/₀₀ in dry season. Thuy Tu lagoon receives fresh water from the Huong River and sea water through Thuan An inlet. So salinity in this area falls from north to south. At point 14, salinity is 0 - 5°/₀₀ in wet season and 16 - 30°/₀₀ in dry season. At point 13, Vinh Xuan area, salinity is 17 - 25°/₀₀ in dry season, and 10 - 22°/₀₀ in wet season in Vinh Hung next to Cau Hai (point 12).
In Cau Hai, salinity reduces from east to south-west. In Truoi River, salinity is minimum in wet season (0 - 5°/₀₀), and 15 - 25°/₀₀ (dry season). Tu Hien inlet has salinity 25 - 30°/₀₀ in dry season. From Da Bac (point 4) to Tuy Van (point 6), salinity is 17 - 25°/₀₀.

b. **Seasonal salinity** changes

In Thua Thien - Hue, wet season is from November to February, dry season is from March to August. October and November have a majority of rainfall of the whole year, so the lagoon becomes nearly fresh water (salinity is 0°/₀₀). In December and January the rainfall reduces, so salinity in lagoon is 5 -1O°/₀₀. In February and March the rainfall is minimum, so salinity is over 20°/₀₀ in areas near river mouths. From April to August, salinity in lagoon is over 30°/₀₀ even at river mouths. In short, salinity in Tam Giang lagoon changes according to two seasons; fresh water period (in October and November) is shorter than the salt water period (in January and February).
Basing on the Venice formula (1958), one can distinguish:

- fresh water: salinity is below 0.5°/₀₀,
- fresh brackish water: salinity is 5 - 0.5°/₀₀,
- medium brackish water: salinity is 18 - 5°/₀₀,
- salt brackish water: salinity is 30 -18°/₀₀,
- salt water: salinity is over 30°/₀₀ but it is below the salinity in the next river mouth.

According to the above division, the surface waters of Tam Giang can be split up in 4 areas as follows:

- 1st area: changing from fresh to fresh brackish water (close to O Lau River mouth),
- 2nd area: changing from fresh to fresh brackish and medium brackish water (Dam market to An Gia),
- 3rd area: variable in time, from fresh brackish, medium brackish water to salt brackish water (Mai Duong to An Xuan, Vinh Hung to Da Bac, Phu Loc to Tuy Van),
- 4th area: variable in time, from fresh water to fresh brackish, medium brackish, salt brackish and salt water (close to Thuan An inlet).

Hence, in a very brief resume, the salinity in the Tam Giang lagoon is 15 - 30°/₀₀ depending on time and region. The pH value is stable but mainly stays alkaline. In the north of the lagoon, nitrate, silicon and phosphate concentrations are high, especially at the O Lau mouth. Dissolved oxygen content is high and differs in two seasons. These environmental conditions make a large area of lagoon favorable for marine production (cf. **Appendix 8** for details)

## 8.3 Flora

The following excerpts from Appendix 8 elucidate the flora structure in the lagoon.

1. Phytoplankton with 171 species, of which Chrysophyta are abundant ( 119 species). Marine species componentspredominate (78.36% of total), the freshwater species being 19.29% of the total. Freshwater phytoplankton grows in the wet season (October to December by 6.69%), while the marine one increases in dry season (April to June, by 18.32% of total).

2. There are 59 species of bottom plants, most of them being marine and/or Bacillariophyceae. Their bulk does not change with time.

3. Big-size plants include 40 kinds of sea algae and 11 kinds of seagrass. Sea algae develop with high biomass over large areas. Seagrass develops on sand and clayey sand, and its quantity is also substantial.

- *Distribution in space*

The number of branches and species of phytoplankton increases near inlets and falls far from them. At Tu Hien inlet, there are 117 species (of which 68.42% phytoplankton). There is only 2.33 - 0.49% phytoplankton at the distance of 8 - 10 km from Tu Hien inlet. At Thuan An inlet, there are 120 species (70.17% of total) while 8 km to the north from Thuan An inlet, there are 73 species (42.69%), 12 km to the north from Thuan An inlet, there are 53 species (30.99%), and 19 km to the north from Thuan An inlet, there are only 6 species (3.50%), 10 -12 km from that, there are 44 species (9.94%) and 32 km from that, there are only 4 species (2.33%).

One can see that the quantity of phytoplankton at Thuan An inlet is much higher than at Tu Hien. The distribution of marine phytoplankton mainly depends on the impact of tidal currents. Freshwater phytoplankton mainly concentrates in lagoon in wet season. At O Lau mouth there are 32 species. The distribution of freshwater phytoplankton depends on two main factors: frequency of river phytoplankton inflows into lagoon and freshwater level.

- *Distribution by depth*

The depth in Tam Giang is 1- 2.5 m, so the difference between the surface and the bed layer is not big.

- ***Adaptation to salinity***

Most phytoplankton concentrates in the area with salinity over 30°/₀₀, and decreases with decrease in salinity. For 15°/₀₀ salinity there are 36 species, at 10°/₀₀ - 25 species, and at 5°/₀₀ - 6 species. Freshwater phytoplankton adapts very badly to salinity. There are very few species in Bacillariophyceae rank in area of 15°/₀₀ salinity.

*Change in flora species composition in time*

As the salinity in Tam Giang lagoon varies seasonally, it causes the change in species composition of marine phytoplankton throughout the year. In October and November, there is a lot of freshwater phytoplankton in lagoon, the marine phytoplankton almost disappears or it is represented by a very few species (9.63% of total phytoplankton). The main component is Bacillariophyceae rank of Chrysophyta group. On the contrary, the freshwater phytoplankton is very abundant. From February to March, the salinity in the lagoon gradually increases, and marine phytoplankton appears in the lagoon. From April to June, the number of species is maximum, and becomes 18.32% of total phytoplankton. In July, August and September, the quantity of marine phytoplankton species in lagoon falls down (11.30% of total phytoplankton).

## 8.4 Fauna

In the Thua Thien - Hue lagoon system, there are 30 **zoo-plankton** species and 32 zoo-benthos species; brackish, fresh and seawater ones. The distribution of zoo-plankton and zoo-benthos depends mainly on salinity concentration. The average quantity of zoo-plankton is estimated at 1950 pieces/$m^3$ and that of zoo-benthos at 570 ones/$m^3$. By and large, the Thua Thien - Hue lagoon is poor in zoo-plankton and zoo-benthos.

The distribution of zooplankton depends on a lot of factors, of which salt concentration is the most important. In Tam Giang lagoon, to the north of the Huong River, salinity falls down from Thuan An to O Lau. A number of species living at high salinities appear between Thuan An and An Xuan. Vinh Tu pier and Dam market are brackish water species areas, while Moi market and O Lau are occupied by freshwater species. The lagoons and marshlands south of the Huong River (Sam, Chuon, Thuy Tu, Cau Hai) are characterized by a lot of brackish water and marine species, and the impact of seawater is felt at the vicinity of the inlets of Tu Hien and Thuan An. At Truoi and Loi Nong, freshwater species gain in importance.

Among **fish**, typical brackish water fish species are the largest community of the lagoon system. The different kinds of such fish (Clupeidea, Engranlidae, Atherinidae, Belonidae, Hemirhamphidae, Mugilidae, Serranidae, Theraponidae, Apogonidae, Leignathidae, Lutianidae, Gobiidae, Siganidae, Bothidae, Soleidae) have accomodated to the seasonally varying salinity in the lagoon.

Typical seawater fish species live close to the inlets of Thuan An and Tu Hien, and appear in the body of the lagoon only in dry season (April to August); such typical fish is Perciformes. The distribution of them depends on salinity of lagoon. There are 80 representatives of these kinds such as : Synodontidae Muraenidae, Muraenesocidae, Centropomidae, Priacanthidae, Carangidae, Pomadasyidae, Sparidae, Mullidae, Psettidae, Trichiaridae, Platycephalidae and Trentrodontidae. This fish is highly productive in terms of fisheries.

Typical freshwater species develop in river mouth areas. There are 60 species of such fish, of which Cyprinidae, Clariidae, Symbranchidae, Anabantidae, Ophiocephalidae families are most representative. In Cau Hai lagoon, because of the partially closed Tu Hien inlet, water in the lagoon becomes fresh, so typical freshwater species can develop there in both volume and quantity, mainly as Cyprinus sp. -- It is appropriate to note that the fish system structure in the TG-CH lagoon has both tropical and temperate zone features at the same time.

Seasonal variability of fish species is notable. In short, in dry season marine fish prevails while from October to December freshwater species are more pronounced. This bears witness of seasonal fish migration.

## 8.5 Aquaculture

In the domain of aquaculture, **algae** (Gracillaria) are the main type and the major source of foreign currency. The natural alga productivity is 1-2 kg/m$^2$, but on farms the average productivity reaches 1.5-2.0 t/year/ha. In the neighbourhood of river banks, where salinity is 7-15 °/₀₀, algae can be farmed most conveniently. In the past the highest production of algae was at Phu Thuan, Hung Hai and Thuan An. At present, the salinity there is higher (15-25 °/₀₀) and algae productivity decreases, while crab and shrimp productivity is on the growth. The total acrage used for farming in Sam, An Truyen and Cau Hai is 470 ha. This area can increase by 20% in the coming years. Eucheuma algae will grow in areas where salinity is 34-35 °/₀₀.

Among aquacultural **invertebrates**, shrimp, crab and lobster are the most attractive and productive species. In lagoon proper, Penaecidae shrimp is the most common; it can live only 1-2 years and secures high productivity. One can distinguish 11 shrimp species, three of which are most common: Penaeus mondon, P.mehuiensis, Metapenaeuns ensis, concentrated mainly at Thuan An inlet. The total area of shrimp farming is 460 ha. In future, this area will be doubled at Tan My and An Truyen, where salinity is 15-25°/₀₀. It is expected that in the year 2000 the total area will be 1500 ha. The present production covers only 50% of demand. The present crab species in the lagoon is sea crab (Seylla serrata). Crab farming began in 1993. The area farmed for crab production is 16 ha at Thuan An.

**Fish** farming in brackish water of the Thua Thien Hue lagoon began in 1993. The most common fish species are Epinephelus, Siganus and Gobius. The Aquaculture Institute at Thuan An keeps nearly 1 million of young fish in ponds covering 6 ha, in 165 cages. At present the average productivity is 150-200 kg/ha. With more investment, the farming area will increase to 3000 ha, three times more than at present.

In the eighties, the average fish productivity was 2287 tons/year, with the peak in 1984 and 1988; the problem being coupled with the migration of the Tu Hien inlet and changing fishery technologies. In 1979, when Tu Hien was closed, lagoon became freshwater type, seafish partly disappeared, and freshwater species slowly entered. In 1984 and 1985, fish productivity mainly relied on freshwater species. When Tu Hien inlet was re-opened in 1988, fish productivity became again the sea type. In early nineties, exploitation and farming developed, and productivity increased accordingly (cf. **Appendix 8)**

## 8.6 Biodiversity

Information on the Tam Giang - Cau Hai lagoon ecosytem, with emphasis on its biological life can be extracted from Vo Van Phu (1995; Hue19) and Nguyen Nhat Thi (1995, Hue6).
Vo Van Phu (1995; Hue19) assesses the level of the lagoon bioproductivity at 1000-100,000 cells per cu m, with the maximum of 1,000,000 at Tam Giang. During the dry season one encounters 350 billion cells in the entire lagoon. Phu counts 3068 flora units per cu m, along with benthic fauna of 725 pieces = 108 g / sq m.

According to Nguyen Nhat Thi (1995, Hue6), basic characteristics of the Thua Thien Hue lagoon ecosys tem can be summarized as follows:

- Suspended flora : 170 species
  - Bacillariophyta : 69,6%
  - Chlorophyta : 12,3%
  - Pyrrophyta : 9,3%
  - Cyanophyta : 8,7%
- Water plants : 40 species
  - Chlorophyta : 21 species
  - Cyanophyta : 13 species
  - Rhodophyta : 5 species
  - Phacophyta : 1 species
- Higher flora : 12 species
- Suspended fauna : 31 species
  - Copepoda : 26 species (84% of total)
- Bottom fauna : 33 species
  - Molluscs : 9 species
  - Polychacta : 8 species
  - Amphipoda : 9 species
- Fish : 223 species
  - Sea fish : 145 species (65%)
  - Brackish water fish : 43 species (19,2%)
  - Fresh water fish : 35 species (15,7%)
- Besides, in the Tam Giang lagoon there appear a lot of phytobenthos.

There are four main components of the lagoon life: brackish, marine, freshwater and migratory. The migratory species of the lagoon can be arranged in three groups:
- Sea group, migrating from the sea, mainly during the dry season;
- Freshwater group, stemming from rivers and appearing in the lagoon during rain season;
- Brackish water group, the basic group maintained in the lagoon all year round.

The spatial distribution of suspended flora and bottom fauna alike display some general trends such as concentration of the sea group at the Thuan An and Tu Hien inlets, of the freshwater group in the other parts of the lagoon and of the brackish group everywhere in the lagoon.

By and large, the Tam Giang - Cau Hai lagoon system is a fairly typical tropical ecosystem, although with a certain tendency to temperate features. The lagoon is well fit for aquaculture, especially in view of diversified nutrients structure, which must be preserved if the lagoon ecosystem is to remain undamaged. Since the lagoon is semi-enclosed, salinity plays a paramount role. Stratification of the lagoon waters, in both vertical and horizontal, controls heavily the living conditions of various species. The latter include 235 water flora species, 86 invertebrates, and 21 shrimp and crab species. 163 fish species breed in the lagoon, of which 22 are highly productive.

## 8.7 Biological productivity

Potential exploitation of biological resources encompasses the following four main groups of water plants:

- Industrial purposes: *Glacilaria*, with average productivity of 700 - 800 kg/ha/year, some times 1 ton/ha/year
- Drug production: *Caloglorra*, of limited productivity

- Livestock fodder: *Enteromorpha, Valisneria, Ceratophyllum*
- Fertilizers: *Enteromophorpha, Cymodocea, Blyxa, Najas.*

General productivity in the aquaculture sector of the Tam Giang - Cau Hai lagoon is outlined by Nguyen Nhat Thi (1995, Hue6) as shown in the table below:

| Year | Species | Phu Vang district | | Phu Loc district | | Total yearly productivity |
|---|---|---|---|---|---|---|
| | | yearly productivity | by species | yearly productivity | by species | 2 districts |
| 1990 | Shrimp | | | 815 t | 230 t | 815 t |
| | Crab | | | | 28 t | |
| | Fish | | | | 557 t | |
| | Water plant | | | | 10 t | |
| 1991 | Shrimp | 636 t | 157 t | 820 t | 213 t | 1,456 t |
| | Crab | | – | | 25 t | |
| | Fish | | 415 t | | 582 t | |
| | Water plants | | – | | 6 t | |
| 1992 | Shrimp | 996 t | 236 t | 830 t | 218 t | 1,826 t |
| | Crab | | 21 t | | 23 t | |
| | Fish | | 506 t | | 589 t | |
| | Water plants | | – | | 2 t | |
| 1993 | Shrimp | 920 t | 276 t | 770 t | 195 t | 1,690 t |
| | Crab | | 32 t | | 22 t | |
| | Fish | | 576 t | | 553 t | |
| | Water plants | | – | | 1 t | |
| 1994 | Shrimp | 699 t | 168 t | 750 t | 185 t | 1,449 t |
| | Crab | | 36 t | | 20 t | |
| | Fish | | 438 t | | 495 t | |
| | Water plants | | – | | – | |

The aquacultural production in the lagoon system is characterized by the following figures (Nguyen Nhat Thi 1995, Hue6):

*+ In Quang Dien :*
Shrimp production area : 250 ha
Productivity of shrimp : 27 tons/season
small shrimp : 21 - 23 tons/season
crab and shrimp : 20 tons/season
average : 280 kg/season.

*+ In Phu Vang :*
Natural fishing area : 237 ha
Total production : 185 tons
Average productivity : 780 kg/ha
Feeding area: 320 ha
Total catch of all species : 32,174 kg
Average productivity: 100 kg/ha.

In general, aquacultural productivity is still estimated as very low compared with other branches (Nguyen Nhat Thi , 1995, Hue6).

Vo Van Phu (1995; Hue19) focuses attention on fish and lagoon productivity. *Inter alia*, Phu describes the role of fish in aquaculture (Sec.2.2.3), determines the life cycle of 10 fish species, specifies natural conditions of the lagoon (Ch.3), enumerates components of fish species (Ch.4), biological features of 10 economic fish (Ch.5) and draws conclusions on the aquacultural potentials of the lagoon system.

More specifically, Vo Van Phu (1995) distinguishes fish species breeding on (a) flora & organic matter; (b) breeding on invertebrates and othe fauna, including pelagic fish (Stolephorus etc); (c) economic fish feeding on big size flora (benthic fish). Out of 163 fish species described by Phu there are 23 species which are important economically (16 a-type & 7 b- and c-type). Phu provides relationships between weight and length for various fish species, which are less relevant to this study. What can be important, though, is the length of the spawning season given below (Phu's original Table 8).

23 fish species secure 2-5% of the overall product. The aquacultural production in the lagoon is given by Phu (1995) as 2287 ton/yr in the 80ties (of which 85% fish) and 3296 ton in the 90ties (with 80% of fish). More figures may be consulted in **Appendix 8**.

# 9. Mathematical Modelling of Lagoon Processes

## 9.1 Basic Aspects of Modelling

Upon embarking on modelling one has to consider certain elements that will affect subsequent steps. Hence one has to answer some basic questions such as: what is understood by modelling, what is the aim of our model we want to set-up, which natural processes are dominant and how one should reproduce them. One possible definition of a model can be as follows:

*A model is the structure of interacting equations describing quantitatively certain aspects of the behavior of a natural system:*

One has to be aware that any model is only an approximation of reality. The amount of details is always limited, depending on spatial and temporal discretization. For this reason one has to accept certain ' inaccuracy' of the obtained results. Depending on the final use of the model (research and/or management) one should include those processes which are the most relevant for the main goal.

The aim of modelling is to find relations between different features (eg. in hydrodynamic models - relations between meteorology, water levels, and water currents; in water quality models - relations between loads and concentration). Numerical models can help us to fill in gaps in the knowledge and understanding of different processes observed in nature. Managers can use models to predict the effectiveness of proposed measures (eg. reduction of loads).

To define the model one should start from systems analysis i.e. one has to define the main problems to be solved. Then one formulates the concept of the model and determines the required amount of details to secure solution of the defined problem. As the next step one chooses the system of equations, and select the appropriate method of solution.

Additionally, at the stage of model preparation one has to consider model inputs and outputs. In hydrodynamic as well as in water quality models we need the following input data: bathymetry, forcing functions, boundary and initial conditions. The outputs can be shown in different forms: maps of flow fields, maps of concentration, fraction of pollutants related to sources, absolute and relative violation of standards. As the final step one should consider model accuracy, taking into account different simplifications and model limitations.

## 9.2 Circulation Models for Lagoon Systems

Coastal lagoons are ecologically and economically important because of their high productivity and intensive use for aquaculture, recreation and waste disposal. Since a lagoon is usually a retention basin, it is very productive. On the other hand, this retentive capacity can result in poor flushing and large pollution loads to the system. As a consequence it causes degradation of natural environment.
A typical inlet-lagoon system consists of one or more relatively narrow channels connecting one or several basins to the ocean. The seaward side of the lagoon is typically formed by a barrier beach or a narrow strip of land.

In this chapter an overview of different models of the circulation and mixing dynamics of lagoon system will be given.

### *One - dimensional modelling*

The simplest models for lagoon systems concentrate on inlet channels, which usually control the transport of water, salt and other substances between lagoon and the ocean. The lagoon is typically treated as a water storage basin in these models, and the surface elevation is assumed to vary uniformly in a pumping mode.
The equation for one-dimensional inlet can be written as:

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}=-g\frac{\partial h}{\partial x}-\frac{\gamma}{h}U\,|U| \tag{9.1}$$

where U is the cross-sectionally averaged along channel velocity, g - acceleration due to gravity, h is the water depth in the inlet and g is the bottom friction coefficient.
The bottom friction losses are expressed by a quadratic law, where the absolute value sign is used to assure the appropriate sign of the friction.

Integration of equation (9.1) along the channel axis yields an expression relating the sea surface level to that in the basin. Assuming the inlet is finite in length, L, equation (9.1) can be integrated to yield

$$h_o=h_b+\frac{\partial U}{\partial t}\frac{L}{g}+(k+\frac{\gamma}{h}L)\frac{U\,|U|}{g} \tag{9.2}$$

where $h_o$ and $h_b$ are the surface elevations in the ocean and basin (see Fig. 9.3.1), respectively, and k represents the combined entrance, $k_{en}$, and exit, $k_{ex}$, losses as the flow enters and leaves the channel ($k = k_{en} + k_{ex}$). Assuming that the basin oscillates in a pumping mode the mass conservation equation for the basin becomes:

$$UA_c=A_b\frac{dh_b}{dt} \tag{9.3}$$

where $A_c$ is the cross-sectional area of the inlet and $A_b$ the surface area of the basin. Equation 9.3 assumes that changes in $A_b$ and $A_c$ due to depth variation are small over a tidal cycle. Eliminating U in eq.9.2 by the use of eq. 9.3 we obtain

$$h_0 = h_b + (\frac{A_b}{A_c})\frac{L}{g}\frac{d^2 h_b}{dt^2} + (k + \frac{\gamma}{h}L)\frac{1}{g}(\frac{A_b}{A_c})^2\frac{dh_b}{dt}|\frac{dh_b}{dt}| \quad (9.4)$$

Equation 9.4 can be non-dimensionalized to determine the parameters characterizing inlet behavior:

$$t^* = \frac{t}{T}; \quad h_b^* = \frac{h_b}{a_0}; \quad h_0^* = \frac{h_0}{a_a} \quad (9.5)$$

where T is the forcing period, $a_o$ is the sea level range in the ocean. By incorporating eq. 9.5 into eq.9.4 one has

$$h_0^* = h_b^* + (\frac{A_b}{A_c})\frac{L}{gT^2}\frac{d^2 h_b}{dt^{*2}} + (k + \gamma\frac{L}{h})(\frac{A_b}{A_c})^2 \; \frac{a_0}{gT^2}\frac{dh_b^*}{dt^*}|\frac{dh_b^*}{dt^*}| \quad (9.6)$$

In Equation.9.6 one can distinguish three dimensionless parameters:

$$G_1 = (\frac{A_b}{A_c}), \quad G_2 = (\frac{A_b}{A_c})^2, \quad G_3 = \frac{L}{h}(\frac{A_b}{A_c})^2\frac{a_0}{gT^2}$$

$G_1$, $G_2$ and $G_3$ characterize the temporal acceleration, convective acceleration, and frictional dissipation terms in the governing Equation 9.1.
Based on the analysis for typical inlet-lagoon systems the frictional loss term normally is large compared to the temporal or convective terms. $G_3$ is therefore an appropriate choice for inlet-lagoon analysis.
An additional parameter G, being the inverse square root of $G_3$ is often used in analysis. For small values of G the inlet acts as a filter, decreasing the amplitude response and increasing the phase shift between the ocean surface elevation and that in the lagoon. As G increases, the filtering effectiveness of the inlet decreases. When G reaches or exceeds 1, the surface elevation perturbations in the ocean pass the inlet without disturbance.

### *Two - dimensional modelling*

Most lagoon systems are shallow and well mixed water bodies. It is a common practice to represent flow by the use of two - dimensional, vertically averaged equations in the following form:

- conservation of mass:

$$\frac{\partial\eta}{\partial t} + \frac{\partial HU}{\partial x} + \frac{\partial HV}{\partial y} = 0 \quad (9.7)$$

- conservation of momentum:

$$\frac{\partial HU}{\partial t}+\frac{\partial HU^2}{\partial x}+\frac{\partial HUV}{\partial y}-fV=-g\frac{\partial \eta}{\partial x}+\frac{1}{\rho}(\tau_{sx}+\tau_{bx}) \tag{9.8}$$

$$\frac{\partial HV}{\partial t}+\frac{\partial HUV}{\partial x}+\frac{\partial HV^2}{\partial y}-fU=-g\frac{\partial \eta}{\partial y}+\frac{1}{\rho}(\tau_{sy}+\tau_{by}) \tag{9.9}$$

where U, V are the vertically averaged velocities in the x and y directions, respectively, f is the Coriolis parameter, h is the free surface elevation, H is the total water column, $t_s$ and $t_b$ are the surface and bottom stresses, respectively.
The surface and bottom stresses are approximated by quadratic formulations in the forcing velocity with a drag and Chezy (or Manning) coefficients to parametrize the appropriate constants.
As the governing equations are non-linear and as most lagoon systems have complex geometry and bathymetry, it is a common practice to solve them by numerical methods.
In literature we come across two types of approaches: solution by finite differences and finite elements using different numerical schemes in time domain (explicit, implicit, semi-implicit) (see Leenderste, 1967; Stelling, 1984; Kowalik and Murty, 1993).

### *Three - dimensional modelling*

The progress in computer hardware and software enables application of three-dimensional modelling, mainly layered models for practical cases.

In this approach a set of governing equations can be written as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{9.10}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=fv-\frac{1}{\rho_0}\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}(\varepsilon_x\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(\varepsilon_y\frac{\partial u}{\partial y})+\frac{\partial}{\partial z}(\varepsilon_z\frac{\partial u}{\partial z}) \tag{9.11}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-fu-\frac{1}{\rho_0}\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}(\varepsilon_x\frac{\partial v}{\partial x})+\frac{\partial}{\partial y}(\varepsilon_y\frac{\partial v}{\partial y})+\frac{\partial}{\partial z}(\varepsilon_z\frac{\partial v}{\partial z}) \tag{9.12}$$

$$\frac{\partial p}{\partial z}=-\rho g \tag{9.13}$$

where u, v and w are velocities in x, y and z directions, respectively, p is the pressure, $r_0$ is the reference density, f is the Coriolis parameter, t is time, g is acceleration due to gravity, r is density, and $e_x$, $e_y$, $e_z$ are the eddy viscosity coefficients in x, y, and z directions, respectively.

Similarly as for depth averaged case solution of these equations is carried out by numerical methods. There are two general approaches known in literature concerning vertical discretization: (1) layers of fixed thickness, (2) layers of thickness proportional to water column (eg. sigma coordinates). In horizontal it is possible to introduce regular, irregular, curvilinear, nested grids.

### Comparison between 2D and 3D models

The ideal model is three dimensional with an infinitely variable grid able to resolve detail in-plan and in the water column. The model should include interaction of tidal currents and wind-field. Such a model should be able to simulate seasonal variations and the fate of pollutants in the long term.
In reality, in engineering applications we use simpler models. It requires experience and skill to decide which processes may be ignored or simplified, and secondly to choose a model to the best possible advantage.
Waste water disposal models often have been 2D depth-averaged models. However, these models are basically unsatisfactory for simulating wind driven circulations, especially in those cases with existence of salinity or temperature stratification or if there are significant lateral density gradients at depth, which generate density currents. Even in vertically well-mixed conditions in the absence of density effects it is important to take into account the shearing effects of the velocity profile by predicting 3D movement.

2D models fail to simulate:

- 3D wind driven currents,
- buoyancy and stratification effect,
- gravitational and geostrophic currents.

Generally it is easier to calibrate and interpret the predictions from 3D model than 2D model.

## 9.3 Circulation model for Tam Giang - Cau Hai lagoon

### 9.3.1 Present Vietnamese approach

From the Hue Mission contacts with Doctors Ngo Dinh Tuan (Center for Applied Hydrology and Environment in Hanoi) and Pham Van Huan (Hanoi University - Department of Oceanography) one can conclude that there is only one mathematical model for Tam Giang - Cau Hai lagoon, as a system. The existing model, prepared by Dr Pham Van Huan, is a 2D wind driven model. There has been an attempt at 3D modelling for a part of the lagoon (region of Thuan An inlet), but no publications are available. According to Professor Tuan, the obtained results have not been acceptable.

Description of the existing 2D model has been given by Pham Van Huan (see **Appendix 9**). In this approach, the lagoon is covered by a regular grid 500x500m. The governing equations are solved by finite differences, probably using explicit scheme (time step 30s).

The only forcing function introduced is wind. Introduction of river discharge and water level variation due to tides was mentioned, but none of these effects has been incorporated in the working version of this model. The density problem has not been taken into account. Calculations carried out concentrated on steady state cases. Examples of the results are shown in Fig.9.3 and in Figs 1-4 of Appendix 9.

Unfortunately, Pham Van Huan did not make any comparison between model results and real conditions. This model can be treated as the starting point for further works. The intention of Dr Pham Van Huan is to continue with modelling by taking into account the forcing functions mentioned above.

The present state of modelling in Hanoi is not detailed enough to represent real conditions. Some data measured over the lagoon system (mostly 1993) are already available, and some other field campaigns are under way, so obviously this database can be helpful in modeling validation.

Other modelling attemptsat MHC and the Institute of Oceanology, Hanoi, seem to be immature.

### 9.3.2 Possible approaches to reasonable modelling of circulation in Tam Giang - Cau Hai

Basing on the knowledge of the lagoon system, one can distinguish the main forcing functions: wind conditions, water level variation in two inlets due to tides, discharge of rivers, density differences due to spatial and temporal variation of salinity and temperature.

One can suggest the following two-step approach for modelling of this system.

As the *first step* one can propose to set-up 2D model (depth averaged). This model should incorporate the main rivers: Huong (and Bo), O Lau and Dai Giang. We should try to model the downstream part of those rivers (parts where salt water intrusion is observed in dry season). The lagoon itself should be covered with relatively fine grid to enable reproduction of inlets quite accurately. In such areas as Tam Giang - Cau Hai it is recommended to introduce non-uniform grid, eg. curvilinear grid, which enables refinement in areas of special interest (like inlets).
With 2D model it is possible to incorporate salinity and temperature variation in horizontal plane, wind field over the area, and water level variation due to tides. As a result we get changes in water levels, depth averaged velocity patterns, spatial and temporal distribution of salinity, temperature, water density. Two-dimensional models are commonly used for water level prediction. If we intend to use model only for water level prediction we can exclude the density problem.

In the *second step* one can propose an extension of 2D model to 3D (layered) model. In that case we get detailed information on velocity patterns and other phenomena like salinity intrusion. These types of models are very useful for detailed studies, but they are more demanding with respect to data collection.

*Basic problems*

1. The model grid must be able to resolve the essential details of the bathymetry, tidal currents, salinity or thermal fronts and pollution distributions. It is not always possible to determine in advance where a coarse grid may be adequate.

2. A basic requirement for satisfactory model is high quality bathymetric survey data, which should contain sufficient detail in shallow inter-tidal areas, which are sometimes difficult to survey. Ideally, the survey should include sections orthogonal to channels at a spacing not exceeding more than one or two channel width. The spacing might vary between 0.3 and 0.2 times the proposed model grid size. Special care should be taken in interpolation the sounding onto a model grid.

3. Many models have failed as a result of poorly posed offshore boundary conditions. In tidal waters the boundaries should be located as well aligned with co-tidal lines, peak flood and ebb currents. Results from a coarse grid regional model are much help in selecting the optimum boundaries of a more detailed local model. It is also important to specify the correct mix of boundary conditions in terms of water level, velocity or discharge.

4. In order to assess the diagnostic capability of a mathematical model the simulated results must be compared to observations made in the region of interest. Formulation of an objective method of comparison with observations is essential to successful calibration of any model.
The calibration procedure implies the adjustment of inexactly known factors (eg. bed roughness, boundary conditions, etc) to achieve an acceptable level of agreement with field data. Once a model has been calibrated it is usually validated against another set of data to ensure the model can be used to represent a variety of different conditions. A model can only be calibrated effectively with a representative data set of field measurements.

### 9.3.3 Example of possible approach to 2D modelling

Shown below is an example of possible approach for the Tam Giang - Cau Hai lagoon. This is not a real 2D model for this lagoon, but only illustration of the strategy that can be proposed.
The area of lagoon can be covered by a regular grid 500 * 500 m (see Fig.9.3.3 a). The bathymetry of the lagoon can be discretized in the proposed grid as shown in Fig.9.3.3 b. In the first draft, rivers are not represented in the appropriate way. Here we have only one river (representing the Huong River system) and two inlets (see Fig.9.3.3 b). In case of inlets we prescribe water level variations according to tidal forcing (see Fig.9.3.4). In two inlets and for river discharge we incorporate salinity and temperature as well.
To observe the possible 'seasonal behavior' of the lagoon one can carry out very simplified runs:

1. Supposing during the dry season the whole lagoon is filled with saline water (from the South - China sea) and additionally we have only one river (Huong) that enters this water body. For this simplified approach we can notice the behavior of fresh water spreading in the lagoon. From Fig.9.3.5, where salinity distribution in the Lagoon is shown, one can note that spreading of fresh water in the lagoon water body proceeds slowly. The process of spreading also depends on the phase of the tidal motion in the lagoon (see Fig.9.3.6).

2. Supposing during the wet season the whole lagoon is filled with fresh water and again one has only one river merging to this lagoon. Here we can try to examine two cases: (a) two inlets are active; (b) only one inlet (Thuan An) is active. In nature those two cases are rather common, so this example can give an idea of possible intrusion of saline water to lagoon due to tidal motion in inlets. In case of one active inlet (Thuan An) spreading of saline water proceeds from the inlet in the direction to Tam Giang and Cau Hai (Fig.9.3.7). As in the previous case, the spreading is closely related to velocities induced by tide (Fig.9.3.8). This result can be compared with the second case where spreading of saline water is forced by tidal motion in two inlets (Fig.9.3.9). Similarly to earlier examples, the process of spreading is closely related to velocity patterns (Fig.9.3.10).

This example shows the importance of tidal forcing, and spreading of saline water in a fresh water system. The real model for this area will be more complex but it can ensure the prediction of water levels and spatial distribution of salinity (temperature)in Tam Giang - Cau Hai.

## 9.4 Water Quality Modelling

In recent years there has been a worldwide expansion of mathematical models of coastal pollution. Here we will try to shed light on this problem only.

The coastal environment is the zone where oceanic phenomena overlap with tidal and fluvial phenomena. Pollution of this zone means degradation of water quality making it offensive and harmful to human, animal and plant life. Water quality variables include temperature, turbidity, salinity, dissolved oxygen, BOD, nutrients, coliform, chlorophyll, heavy metals, hydrocarbonates, PCB's, toxic chemicals, floating debris, oil and grease. A mathematical model for pollution consist in systematic calculation of the movement of water, solutes and suspended matter, element by element, throughout the modelled area, at successive time intervals.

Computer-aided modelling is usually based on the conservation of water, conservation of a dissolved passive matter (eg. salinity) and any dissolved reactive substances. Calculation of the concentrations of pollutants is based on the advection-diffusion equation, which for three-dimensional cases can be written as follows:

$$\frac{\delta C}{\delta t} = -V_x \frac{\delta C}{\delta x} + D_x \frac{\delta^2 C}{\delta x^2} - V_y \frac{\delta C}{\delta y} + D_y \frac{\delta^2 C}{\delta y^2} - V_z \frac{\delta C}{\delta z} + D_z \frac{\delta^2 C}{\delta z^2} + L + P \quad (9.14$$

where: C - concentration ($g/m^3$); t - time (s); $V_x$, $V_y$, $V_z$ - velocities in x, y, z directions (m/s), respectively; x, y, z - distances in x, y, z directions, respectively (m); $D_x$, $D_y$, $D_z$ dispersion coefficients in x, y, z directions ($m^2/s$), respectively; L - loads ($g/m^3/s$); P -processes ($g/m^3/s$).

An example of possible representation of eutrophication is shown in Tab.9.3.1 and Fig.9.3.11. Table 9.3.1 shows all substances related to eutrophication and processes acting on each substance. The column called 'status' indicates whether the process produces or consumes the considered substance. In case process can work in both directions this column is left empty.

In this approach four main nutrients are considered: carbon, nitrogen, phosphorous and silicon. Each nutrient occurs in a system of several pools:

- inorganic dissolved,
- algae,
- detritus (relatively fast decomposing dead algae),
- other organics (relatively slow decomposing algae),
- algae in sediment,
- detritus in sediment,
- other organics in sediment.

Figure 9.3.11 presents a diagram of several polls of nutrients and their interaction by processes.

**Basic problems**

- For water quality modeling water transport has to be supplied from a hydrodynamic model. Depending on dimensions of this model, the flow has to be delivered as 1D, 2D or 3D. The difference between dimensions of both models introduces additional problems.

- To run the model the following data has to be incorporated:

    * hydro-meteorological conditions: wind direction and velocity, radiation, water temperature,
    * concentration of analyzed parameters on boundaries and loads from all sources (rivers, streams, industry, agriculture, atmosphere) during the period of calculation,

- In the process of calibration/validation, the concentration of the analyzed quantities has to be available. The calibration/validation procedure should cover seasonal changes.

**Table 9.3.1 Substances and processess vs. eutrophication**

Tab.9.3.1 Substances and processes related to eutrophication (status indicates whether process produces (+) or consumes (-) a considered substance)

| substance | process | status |
|---|---|---|
| oxygen | reaeration | - |
| | nitrification | - |
| | mineralization of organic material | + |
| | uptake of nitrate by algae | + |
| nitrate | denitrification | - |
| | nitrification | + |
| | uptake by algae | - |
| dissolved phosphate | adsorption/desorption to particulate matter | |
| | mineralization of organic material | + |
| | uptake by algae | - |
| | autolysis by algae | + |
| nutrients in detritus and other organics | mortality of algae | + |
| | mineralization | - |
| | sedimentation | - |
| | resuspension | + |
| adsorbed phosphates in sediment | sedimentation | + |
| | resuspension | - |
| | burial | - |
| nutrients in other organics in sediment | mineralization | - |
| | sedimentation | + |
| | resuspension | - |
| | burial | - |

| substance | process | status |
|---|---|---|
| ammonium | nitrification | - |
| | mineralization of organic material | + |
| | uptake by algae | - |
| | autolysis of algae | + |
| adsorbed phosphates | adsorption/desorption to particular matter | |
| | sedimentation | |
| | resuspension | + |
| dissolved silicates | mineralization of organic material | + |
| | uptake by algae | - |
| | autolysis of algae | + |
| organic carbon from wastes | mineralization | - |
| algae | production | + |
| | mortality | - |
| | sedimentation | - |
| | resuspension | + |
| nutrients in detritus in sediment | mineralization | - |
| | sedimentation | + |
| | resuspension | - |
| | mortality of algae | + |
| algae in sediment | sedimentation | + |
| | resuspension | - |
| | mortality | - |
| | burial | - |

# 10 Summary of Problem Analysis and Proposed Measures

## 10.1 Synthesis of Problems Analyzed in Pilot Study

### 10.1.1 Scope of synthesis and procedural achievements

As mentioned in Chapter 1, Pilot Study #2 has been so structured as to achieve the major goals stipulated in the project documents, i.a. strengthening of co-operation and interaction with the Vietnamese counterparts, their capabilities, and upgrading of the ICZM dimension. To this end, PS2 encompassed 3 site trips, including one extensive field trip; interviews with external experts and institutions; internal desk studies, including extensive translations from Vietnamese into English, computer work, graphical processing etc by VVA PO team; analysis of the PS2 problems within the extended study team and presentation of tentative findings during VVA Scientific Meeting #2; adoption of measures solving some of the problems encountered and preparation of draft report; and reviews and comments by external experts (in Vietnam, Poland and the Netherlands), thus stepping the interaction and knowledge of the PS2 problem.
(g) revisions and printing of the final report.

The identification and analysis of the problems arising in PS2 context have been pursued in respective Chapters 1-9. The **synthesis** itself, presented herein should be regarded as an achievement *per se*, for it results from a lot of interaction with the Vietnamese partners, stems from an analysis of various purely Vietnamese sources, cross-checking etc. and is written in English, whereas an overwhelming majority of source references has been in Vietnamese. Thus an additional advantage of this report is its English, ensuring dissemination of the PS2 problems. Hence the report may be useful for both those Vietnamese and foreign readers who already are somehow familiar with the problem or some its aspects, but welcome the synthesis, and the primarily foreign readers who might continue with the research and its implementation, e.g. mathematical modelling.

Given below is a summary of the results and findings reflected in previous chapters (10.1.2), followed by a discussion of the problem solving measures (10.2).

### 10.1.2 Synthesis of findings

In analysis of anticipated changes in the lagoon users structure, emphasis is placed on the features enumerated below, while all present and planned ***flood control*** are discussed later (Chapter 6), when they are more appropriate. The discussion centers about i.a. changes in salinity patterns, partly saltwater intrusion but mostly effects in the lagoon proper; positive (irrigation) and negative (salination?..) effects in agriculture; flushing aspects connected with more dredging problems, inlet stability worsening, lagoon users effects; depletion of sediment from the catchment area, sediment deficit in the coastal zone; lagoon system's stability etc.

*Inter alia*, it is noted that the total **population** of the study area will grow rapidly, perhaps at a rate higher than elsewhere beyond the coastal strip. The growing *urban population* of Hue will exert more and more pressure on the lagoon system, such as transportation and cargo handling, aquaculture etc. The *rural population* of the lagoon itself will gradually change its occupation structure on the strength of the primary and secondary transformations, such as a move to more aquaculture (primary) and increasing construction of dwellings in the wake of improving welfare figures (secondary).

Both the acrage and unit productivity of **aquaculture** will increase. This stems from the price structure favouring seafood, general governmental strategies etc.

As a consequence of other changes discussed, there will be a lot of **infrastructure** activities, such as roads, communications, wastewater treatment. The sector of **services** will grow at the cost of other, more `basic' sectors such as agriculture.

If implemented, the **Chan May** Harbour scheme will have a dramatic impact on the lagoon system, not only in physical sense (e.g. coastal morphology) but, first and foremost, on the users structure. The scheme would provide a lot of employment during construction of the harbour facilities and their infrastructure (i.a. access roads) after afterwards, through permanent jobs at Chan May. New population centres are likely to arise. Aftereffects can encompass construction of trade centres, hotels and the like.

**Thuan An** efects can be similar to those of Chan May but their scale will be smaller. On the other hand, in view of the high investment cost, the authorities may decide first on the upgrading of Thuan An, only followed by the huge scheme of Chan May.

Developments in the **tourism** sector can be fairly diversified as to scale and services offered. Beach resorts planned will certainly provide employment for some present lagoon population. If more foreign and domestic tourists, now coming mostly for the historic values of Hue City, are attracted by expanding coastal recreation, and if the door to Laos is opened more widely, the effect of tourism and recreation on the users structure may become more conspicuous.

**Pollution and environment** problems should be given one of the highest priorities. Industry does not seem to create major pollution hazards but aquaculture and agriculture may become become bottlenecks of further growth in uncontrolled ecologically.

An analysis of **climate change impact** on the study area, in terms of its *boundary conditions*, shows that special actions must be taken in advance with regard to *reservoir operation rules; drought control; prevention of acid soil and salt intrusion; and entrapment of sediments* in reservoirs due to denudation processes (prevention of sediment deficit in the coastal strip). All other actions due to accelerated sea level rise are self-explanatory in the context of our extensive VVA programme.

Our **analysis of flood impact** and control on the lagoon system users has shown the following. Flooding, stemming from both atmospheric,inland and seaborne factors, exerts a number of impacts on the flooded area i.e. our lagoon system; these impacts including

(1) loss of life and health and material losses due to inundation of land;
(2) aftereffects in agriculture and other branches of economy;
(3) seasonal and/or short-term changes in salinity and water quality of the lagoon system, coupled with water exchange and flushing patterns;
(4) seasonality of sedimentation processes in the lagoons system and its catchmnet basin;
(5) seasonal, short-term and long-term changes in the morphology of the lagoon system, in particular its tidal inlets and river mouth sections;
(6) seasonal and other changes in the lagoon ecosystem, including migration of species, local transformations of habitats etc;
(7) seasonal and other changes in land use and socio-economic features associated with all above changes;
(8) many secondary and indirect effects.

The above impacts should be analysed vis-a-vis the present flood control practices and the measures planned for the future. Some impacts are both positive and negative, so a delicate balance should be sought in planning of flood control strategies.

In **planning of flood control** for the future, a reasonable blend of different measures must be offered to a growing variety of the lagoon users, and the advantages and shortcomings of those measures must be *compromised by* the use of *integrated management techniques* (cf. Chapter 11). It is quite likely that that blend will consist of dyke construction and upgrading; construction of reservoirs; some diversion schemes; drainage measures; and respective infrastructure.

The effect of *dykes* on the lagoon users structure is rather passive at present -- the dyke system is intended to protect the enclosed areas from either saltwater or freshwater. In future dykes may become a more active tool of flood control if a huge scheme of river endikement is implemented and the river waters are conveyed straight and fast towards the sea, without meandering and overflowing to the lagoon. Such a choice is however less conceivable having in view the loss of the function of lagoon flushing, very essential to that ecosystem.

The construction of *reservoirs* will lead to flood reduction and environmental protection, will make more reasonable use of frsh water for irrigation etc and will not impair aquaculture by not affecting the desired salinity regime. Yet one should not forget the most conspicuous `byproduct' of reservoirs, i.e enforced sedimentation on their bottoms and the subsequent reduction of downstream sediment transport and overall sediment deficit in the lagoon system.

*Diversion* of Song Huong waters towards Cau Hai can have one important advantage of flushing the lagoon, thus helping its water quality and ecosystem; the intrinsic instability of Tu Hien can only be remedied by allowing more water into Cau Hai.

Mitigation of salinity intrusion, efficient drainage and other infrastructural activities will be necessary to accompany the major efforts of dyke and reservoir construction.

Whatever the flood control schemes decided for the study area, the users structure will change accordingly; e.g. less salinity intrusion will foster agriculture; more reservoirs and sediment entrapment will impair beaches and tourism etc.

The **lagoon and coastal morphodynamics** is inherently coupled with the stability of the TTH tidal inlets. The sediment budget data (computed, estimated and/or retrieved otherwise) are as follows.
Sediment input from rivers: Song BO: 192,000 tons/year; Song HUONG: 450,000 tons/year; Song O LAU: 40,000 tons/year; Dai GIANG: 35,000 tons/year; thus total → 270,000 cu m per year.
Sediment sinks: 60,000 cu m per year due to sand and gravel mining + unknown quantities to be estimated for Ta Trach Reservoir ... & other reservoirs when implemented ++ ... (up to 200,000 cu m yearly?)
Sediment output (from the lagoon to the sea): to be estimated (more precise data needed)
Av concentration in the rain season: 50 mg/l
Av inlet flow velocity: 4-5 m/s in the rain season, below 1 m/s otherwise
Sedimentation patterns (circulation, grain distribution ...) to be explored

On the coastal side one has the littoral drift estimates: 300-400-500,000 cu m per annum net NW → SE Sediment transport estimates have been based on rough computations by Unibest, a Dutch software. More accurate computations should rely more heavily on improved wave figures, typical of at least the two predominant wave regimes in winter and summer; refined refraction plans for the study area; corrected data on coastal circulation (nonwave-induced currents such as tidal, inertial and wind-induced); refined data for bedforms and bed roughness.

It is quite obvious that, for the sake of the lagoon sanity, **Tu Hien** should be opened and measures should be taken to avoid its closure. Hence Tu Hien should be investigated in terms of both technical means and general regional geography. The stability of both tidal inlets of the lagoon can be discussed in terms of the tidal prism volume and inlet cross-section, cf. Shore Protection Manual (1984). From our sketch (Fig. 7.3) it may be seen that the present cross-section area of both Tu Hien and Thuan An is too small to comply with the requirements of morphological stability. This is particularly true for Tu Hien, with its present cross-section area of 50 sq.m, versus tens of thousands sq.m required. The situation with Thuan An is not so dramatic because the inlet is not only tidal but also riverine, and is controlled by the Perfume River waters to a large extent. -- A more detailed analysis is necessary to support dredging operations etc, especially in view of the planned flood control measures and subsequent lagoon transformations.

Our analysis of the **lagoon ecosystem** is focused on the nutrients and primary production, followed by flora anf fauna, biodiversity and bioproductivity, linking to the lagoon's economic value. In terms of *hydrochemistry*, the surface waters of Tam Giang can be split up in 4 areas as follows:

- 1st area: changing from fresh to fresh brackish water (close to O Lau River mouth),
- 2nd area: changing from fresh to fresh brackish and medium brackish water (Dam market to An Gia),
- 3rd area: variable in time, from fresh brackish, medium brackish water to salt brackish water (Mai Duong to An Xuan, Vinh Hung to Da Bac, Phu Loc to Tuy Van),
- 4th area: variable in time, from fresh water to fresh brackish, medium brackish, salt brackish and salt water (close to Thuan An inlet).

In the domain of *aquaculture*, *algae* (Gracillaria) are the main type and the major source of foreign currency. The natural alga productivity is 1-2 kg/m$^2$, but on farms the average productivity reaches 1.5-2.0 t/year/ha. In the neighbourhood of river banks, where salinity is 7-15 $^{o}/_{oo}$, algae can be farmed most conveniently

Among aquacultural *invertebrates*, shrimp, crab and lobster are the most attractive and productive species. In lagoon proper, Penaecidae shrimp is the most common; it can live only 1-2 years and secures high productivity. The total area of shrimp farming is 460 ha. In future, this area will be doubled at Tan My and An Truyen, where salinity is 15-25$^{o}/_{oo}$. It is expected that in the year 2000 the total area will be 1500 ha. The present production covers only 50% of demand. Crab farming began in 1993; its area is now 16 ha at Thuan An.

*Fish* farming in brackish water of the Thua Thien Hue lagoon began in 1993. The most common fish species are Epinephelus, Siganus and Gobius. In the eighties, the average fish productivity was 2287 tons/year, with the peak in 1984 and 1988; the problem being coupled with the migration of the Tu Hien inlet and changing fishery technologies.

In terms of *biodiversity*, the Tam Giang - Cau Hai lagoon system is a fairly typical tropical ecosystem, although with a certain tendency to temperate features. The lagoon is well fit for aquaculture, especially in view of diversified nutrients structure, which must be preserved if the lagoon ecosystem is to remain undamaged.

Diversification of the lagoon waters, both vertical and horizontal, controls heavily the living conditions of various species. The latter include 235 water flora species, 86 invertebrates, and 21 shrimp and crab species. 163 fish species breed in the lagoon, of which 22 are highly productive.

Potential exploitation of *biological resources* encompasses the following four main groups of *water plants:*

- Industrial purposes: *Glacilaria*, with average productivity of 700 - 800 kg/ha/year, at times 1 ton/ha/year

- Drug production: *Caloglorra*, of limited productivity
- Livestock fodder: *Enteromorpha, Valisneria, Ceratophyllum*
- Fertilizers: *Enteromophorpha, Cymodocea, Blyxa, Najas.*

In general, *aquacultural productivity* is still estimated as very low compared with other branches. -- 23 fish species secure 2-5% of the overall product. The aquacultural production in the lagoon is given by Phu (1995) as 2287 ton/yr in the 80ties (of which 85% fish) and 3296 ton in the 90ties (with 80% of fish); cf. Appendix 8.

Upon analysis of various requirements imposed on the **modelling of lagoon processes** it is concluded that the state of the art of lagoon modelling in Vietnam is far from satisfying the growing demand, to the best of the Mission staff's knowledge; nor ist it detailed enough to represent real conditions. Some data measured over the lagoon system (mostly 1993) are already available, and some other field campaigns are under way, so obviously this database can be helpful in modeling validation. The only existing model, prepared by Dr Pham Van Huan, is a 2D wind driven model. Other modelling attempts at MHC and the Institute of Oceanology, Hanoi, seem to be immature.

For future modelling attempts the Mission staff has suggested the following two-step approach for modelling of the lagoon system. As the *first step* one can propose to set-up 2D model (depth averaged). This model should incorporate the main rivers: Huong (and Bo), O Lau and Dai Giang. The lagoon itself should be covered with relatively fine grid to enable reproduction of inlets quite accurately. In such areas as Tam Giang - Cau Hai it is recommended to introduce non-uniform grid, eg. curvilinear grid, which enables refinement in areas of special interest (like inlets). With such a 2D model it is possible to incorporate salinity and temperature variation in horizontal plane, wind field over the area, and water level variation due to tides. As a result we get changes in water levels, depth averaged velocity patterns, spatial and temporal distribution of salinity, temperature, water density. -- In the *second step* one can propose an extension of 2D model to 3D (layered) model. In that case one gets a detailed information on velocity patterns and other phenomena like salinity intrusion. These types of models are very useful for detailed studies, but they are more demanding with respect to data collection.

***Basic problems*** of such two-step attempts are outlined and an example of possible approach to 2D modelling is given for the Tam Giang - Cau Hai lagoon (not a real 2D model for this lagoon, but only illustration of the strategy proposed). To observe the possible 'seasonal behavior' of the lagoon one can carry out very simplified runs as shown in the main body.

*Water quality modelling* is a next step in expansion of mathematical models for lagoons and coastal pollution alike. Light on this problem is shed only, and some basic problems are mentioned to clear the way, given that a reliable hydrodynamic model is worked out. Depending on dimensions of this model, the flow has to be delivered in a 1D, 2D or 3D format. To run the model the data shown in the main body has to be incorporated. In the process of calibration/validation, the concentration of the analyzed quantities has to be available. The calibration/validation procedure should cover seasonal changes.

## 10.2 Proposed Measures

### 10.2.1 General Framework and Terms of Reference

Strategies and recommendations for Vietnam's development keeping pace with climate change have been discussed for many years. Inter alia, some major ones were put forth at the Conference on Environment and Sustainable Development, held in Hanoi in December 1990. They include sectoral, industrial, human resource development, and institutional/legal strategies which should be promoted more actively and effectively in all regions of Vietnam. From 1996 to 2000, population control and watershed management should continue to be top priorities, along with the protection of reefs, wetlands, and inland waters. Watershed management programs should include reforestation, control of soil erosion, management of problem soils, and stabilization of shifting agriculture; they also should be linked to agricultural pollution control and estuary protection.

A summary of Vietnam's general strategies relating to our PS2, basing on various Vietnamese sources, is given below for reference and as a springboard for our site-specific conclusions and recommendations.

1. **Watershed** management, control and rehabilitation

Integrated watershed management should receive high priority, with the following features

* Integrated watershed management should emphasize multi-purpose utilization of water resources, soil erosion control through appropriate soil stabilization measures, forestry rehabilitaton by large scale reforestation, land use and human settlement planning, waste management, focused on recycling, and flood control measures.

* Development of new **water supplies** focusing on sources that are unlikely to become polluted in the future.

* Protection of existing forested **watersheds** and the rehabilitation of denuded watersheds. This will require a system of protected areas, enforcement of forestry regulations, fire and disease protection measures, and reforestation.

* Development of **water pollution** standards and controls on industrial effluent integrated pest management (IPM) in the agricultural sector, and proper systems of sewage treatment, solid waste management and recycling. The strategy should also develop and adopt water quality standards in relation to particular uses including drinking, recreation and industrial uses.

* Intensification of cultivation in areas that are in fact suited to sustainable, agricultural use. Special attention must be paid to improving and promoting techniques and systems, such as agro-forestry, aimed at sustainable hillside cultivation.

* Development of alternative, **non-agricultural** means of **employment** for the Vietnamese people.

2. **Coastal Zone Management**

Considering the environmental characteristics of a given area from the point of view of development potential, coastal zones can be delineated for specific development thrusts such as tourism, agriculture, aquaculture, ports & harbours, coastal industries, offshore oil and mineral mining, marine parks and protected areas etc. One of the most important issues in the area of coastal zone management is the need to prioritize the development directions so as to avoid conflicts and to prevent overlapping of development interests of the various resource sectors such as tourism development, land use planning etc., and to compromise on their exploitation levels to achieve sustainability. By integrating the development thrusts and conservation needs in the coastal zone, the Integrated Coastal Zone Management Plan aims at optimizing the exploitation of the various coastal resources to ensure their sustainability.

Sustainable land use planing and zoning could be an important tool for the planners. Development of such plans will particularly take into consideration the daily needs of the local population, job generation, and local traditional professional skills. The management plans should also place special emphasis on measures necessary to prevent the proliferation of such commercial activities in the zones that are detrimental to thesustenance of the natural resources (such as the collection, processing and sales of shell and corals for souvenirs etc.) and mass migration of labour from other regions attracted by the increased opportunities for employment generated by such development, that could increase the pressure on coastal resóurces: For this purpose, ICZM plans should also include measures necessary to monitor the pace of coastal development. The following aspects can be emphasized for our Pilot Study.

* Sustainable coastal zone management should emphasize *inter alia* the rational utilization of aquatic resources, coastal land use zoning, beach stabilization by vegetation, establishment of wind-breaker forests, control of pollution from both marine and land based sources, oil spill contingency planning and necessary coastal resource conservation measures, including wetland protection.

* Sustainable fisheries practices should promote environmentally sound fishing methods, giving up environmentally damaging methods such as dynamite fishing and poisons, prevention of over-fishing, mesh size regulation, minimum size limitation, protection of breeding grounds & spawning areas and ecosystems and fishing ban during breeding seasons.

* Promotion of coastal aquaculture, without destruction of vegetation (mangroves etc), as a means to increase protein intake and income. As a way of reducing fishing pressure, a wide variety of sea products such as shrimp can be cultivated along the coastline. However, coastal aquaculture initiatives should be designed with an understanding that destruction of mangroves and other vegetation to make fish and shrimp ponds results in a loss in marine fishery approximately equivalent to the apparent gain in pond fishery.

* Development of sustainable offshore fishery capabilities. This will require the development of new capabilities among fishermen; backed up by investments in larger boats and new gear. This may need to be supported by new or larger fisheries cooperatives.

* Protection, conservation and rehabilitation of mangroves, estuaries, lagoons and reefs which are critical spawning grounds for many commercial fish species. The mining of live coral for making Iime and building materials should be banned.

* The drafting of guidelines which would provide the framework for assessment of seashore developments.

* Emphasis should be placed on integrated disaster planning and mitigation; and the coordination of this responsibility should be assigned to the respective Environmental Authorities.

3. **Coastal, estuarine and lagoonal ecosystems**

*Mangrove forests, seagrass and other coastal vegetation*

Several well-known methods for mangrove forest management have been tried in many countries such as strip felling, logging rotation to allow for natural regeneration etc. Action is needed to rehabilitate the exploited forests and application of such techniques that would enhance regeneration of intensive mangrove habitats.

The mangrove area and the marginal land should be properly zoned; and the type and nature of development in this area be properly planned and regulated. For example, aquaculture and ponds should be allowed to be constructed only in the marginal areas, and never in the forest proper. It is also very important that whenever a plan for alternative utilization is drafted, a cost-benefit analysis should first be undertaken to determine the primary suitability of the area for the alternative use compared to the natural benefits accrued from it.

First and foremost, action is needed to remove/ease the pressure of exploitation on the mangrove areas by the following activities:

i) allow only limited selective logging by strict regulations;

ii) establish alternative fuelwood resources such as fuelwood plantations;

iii) establish special Melaleuca plantations for the production of aromatic oils (Because of the income generated, this could actually be considered as a development project under the small-scale industry sector);

iv) popularise alternative bee-keeping techniques (this could be better propagated as a small-scale cottage industry);

v) encourage alternative livelihood training along subsistence patterns;

vi) establish protected areas;

vii) promote awareness among people depending on mangroves for livelihood; and

viii) conduct research to observe the longterm effects of chemical warfare and the recover of affected areas.

In combination with further studies, the following **actions** are urgently required **for** coastal and lagoonal **ecosystems**:

- Vital **spawning areas** should be protected from fishing;

- Other **fishing controls**, such as limits on mesh size, banning of explosives and poisons, etc. should be established;

- Fishermen should be encouraged to fish further **out at sea**. This requires larger boats and, therefore, the formation of larger fishing cooperatives;

- **Reforestation** of mangroves and other species must be continued;

- The mining of live coral for making lime and building materials should be banned;

- **Pollution countermeasures** to control the discharge of organic and industrial wastes must be enforced;

- **Planning** permission must be necessary before seashore developments can be approved. Guidelines should be drawn up as to what types of development are to be excluded or limited.

**Seagrass beds** in PS2 area are overexploited, as described elsewhere in this report. Some countermeasures are indicated in this chapter. In addition, it should also be mentioned that several species of *marine turtles* occur and breed in coastal waters associated with the sea-grass beds. Both the adults and eggs are extensively exploited and their populations are presently reported to be on the decrease. Action is needed in the following areas tn conserve the commercially exploited populations of marine turtles:

i) establishment of limits on minimum size that could tie caught commercially;

ii) protection of breeding female turtles, nesting grounds and eggs through enforcement of banned seasons, quotas and license system for eggs removed from nests etc.;

iii) protection of traditional nesting beaches from other development;

iv) establishment of hatcheries;

v) ban on sale and export of turtle shells and other artifact souvenirs; and

vi) promotion of environmental awareness.

*Protection of Wetlands*

* Focus should be placed on supporting and implementing objectives of the Ramsar Convention on Wetlands, by establishing and managing wetland protection areas.

* A National Wetlands Conservation Programme for Vietnam should be observed once developed within a coastal zone management framework, along with a series of demonstration projects dealing with the sustainable utilization and rehabilitation of critical wetland ecosystems.

* Cooperative sub-regional projects and activities for the protection and development of such shared resources as the watersheds of the Red River and of the Mekong River should be strengthened.

*Coral Reefs*

Action is needed to tackle the following problems that affect the coral reefs:

i) increased runoff from rivers due to deforestation;

ii) increased sedimentation caused by freshwater outflow;

iii) marine pollution from land-based sources, especially from human settlements and agricultural practices;

iv) environmentally damaging fishing techniques such as dynamiting; and

v) excessive removal of reef organisms and harvesting of commercial species for food and manufacture of artificats.

With the anticipated growth of tourism in the near future, collection of reef organisms for the processing of souvenirs could soon become another important and environmentally damaging factor.

*Maintenance of genetic diversity*

The flora and fauna of Vietnam are very rich and diverse, and are characterized by a high degree of endemism. Some 7000 plant species have been identified, but it is estimated that another 5000 are encountered. Many of the floral species are confined to small geographic ranges and occur at low individual densities, features which render them particularly vulnerable to deforestation. Several of the most valuable timber species are becoming scarce and already are endangered with extinction. The biodiversity in the Study Area, outlined in Chapter 8, should be fostered for the sake of ecosystem protection and sustainable development.

4. **Pollution control** and **environment protection**

* Emphasize waste reduction, re-use, and recycling in pollution control. However, reduction, re-use, and recycling alone will not solve the pollution problem. Strategies will be required to address the flow of wastes from households, industries and farms.

* The promotion of "waste exchange" or re-use in both formal and informal sectors. Efforts to create industrial waste exchanges should be made between industries and an information centre could be created to support this activity.

* The proper treatment of household pollutants, primarily sewage and solid waste. This will require some form of treatment system in the case of sewage, and, in the case of solid waste, incineration dnd/or disposal in a suitably designed and located sanitary landfill.

* Encouragement of the use of organic fertilizer to reduce agricultural pollution mainly chemical fertilizers and pesticides. Integrated pest management, a system which makes maximum use of intercropping, crop rotation, natural pesticides, and other traditional pest control methods should be promoted. Regulations on the use, handling and disposal of pesticides should also be developed, including restrictions on the types of pesticides that can be used in Vietnam.

* The enforcement of pollution measures to control the discharge of organic and industrial wastes into fresh waters and into the sea. The use of potentially harmful agro-chemicals should be actively discouraged in favour of other pest control systems, particularly in areas where freshwater fisheries are important.

* A ban on the dumping of oil or radioactive wastes in Vietnamese waters. Measures should be taken to prevent oil leaks from marine oil exploration platforms. Furthermore, Vietnam should adhere to international conventions relating to the use of marine resources, for example the Law of the Sea, the International Convention on Dumping of Wastes at Sea and the International Whaling Convention.

5. **Coastal erosion** and **coastal protection** measures

Coastal erosion is a serious problem in some areas during times of strong freshwater outflow (especially from the Mekong and Red Rivers, but also the Perfume River system in PS2 area) and floods, as well as during monsoon stormy weather, tropical storms and typhoons, causing hardships to coastal populations and destruction of property and aquaculture ponds. The coastal erosion problem in PS2 area is accentuated at the northern tip of Thuan An., and may appear elsewhere in the wake of forthcoming coastal activities such as extension of the Thaun An port, rehabilitation and construction of flood control measures, development of tourism and infrastructure etc. To protect against such problems, an integrated coastal protection plan needs to be developed which should include the following actions:

i) **avoid** cross impacts from **conflicting development** activities through rationalization of resource utilization, so that benefits from one area do not conflict with or affect other activities in neighbouring areas or create a potentially disastrous situation;

ii) unless justified by proper analysis and design, wherever possible, avoid artificial, technically demanding and costly structural coastline protection measures, such as revetments, groins, bulkheads, dykes, levees etc. and instead

iii) **conserve coastline** in its natural condition and avoid loss of beach area regulating any construction that could increase stress on be geomorphology;

iv) plan coastal zone protection in broader geomorphological and ecological context as an integrated natural unit taking into consideration such human activities as coral extraction, sand quarrying, mangrove utilization etc.

v) **regulate sand mining** and beach rock quarrying;

vi) protect coral reefs as wave breakers;

vii) adopt natural beach nourishment methods such as aquatic vegetation prevent sediment starvation;

viii) develop dune ridges to trap and retain wind-swept sand and stabilize them with self-propagating and self-maintaining dune grass and shrubs;

ix) **encourage** natural establishment of **sand dunes** and their stabilization, protection and planting of beach vegetation; and

x) encourage mangrove establishment, wherever feasible, as buffer zone against coastal erosion and typhoon damage.

**Sedimentation and pollution** from land-based sources are brought about by environmental mismanagement on land and can mainly be controlled and prevented at the source through such activities as reforestation, improved agricultural practices, especially proper application of agrochemicals, and proper waste treatment. The damage caused by human activities in the field could be tackled through improved legislation and their enforcement by local authorities. This should include banning of environmentally undesirable fishing practices, limits on minimum sizes of species that could be harvested and commercially exploited, prohibition on collection, sale and export of endangered species, in any form, establishment of marine parks and protected areas, as well as promotion of environmental awareness, among those involved in subsistence livelihood. At the same time, research needs to be undertaken to arrive at a realistic estimate of their overall significance for both environmental and economic sustainability. Because of difficultues in quantifying the importance of some habitats, such as coral reefs, with respect to the feeding, breeding and nursery grounds of commercially important marine organisms and therefore for the sustenance of coastal fisheries, their significance in economic terms is often underestimated by planners.

6. **Hazardous wastes**

* Regulations on the use, handling, and disposal of toxic and hazardous substances should be developed and tightly enforced.

* The development and promotion of alternative methods, or the use of non-hazardous materials in industries that presently employ or generate hazardous substances should be emphasized.

* A special body should be formed to address problems relating to hazardous substances and to develop a program for their management and disposal. Regulations should be developed pertaining to the use, storage, handling, transport and disposal of hazardous substances.

7. **Environmental** education, **public awareness** and training

* Development of an integrated environmental and sustainable development curriculum. This curriculum should specifically focus attention on the basic concepts of sustainable development. Development of curricula, syllabus and textbooks should be given high priority for the introduction of environmental education at all levels and the establishment of specialized degree courses in various fields of environmental sciences.

* Promotion of environmental awareness is of paramount importance. Production of environmental awareness materials should be stressed in order to provide the tools for extension work and the raising of public awareness. The assistance of mass media, volunteer groups and NGOs should be sought for the widest dissemination of these materials.

* Development of national expertise in the field of environmental management through specialized training on the most urgent environmental issues in Vietnam.

* International assistance should be sought and urgently utilized for training of educationalists, authors, teachers and other resource persons

8. Environmental Impact Assessment **EIA**

* EIA should be undertaken during the planning phase and be incorporated into regional development planning.

* EIA centres should be established for the development of national expertise in Vietnam. Immediate priority areas to undergo EIA are seen as water reservoirs and dams; oil refineries; and plantations. Given that the development of a workable framework for EIA in Vietnam will likely take some time, the country should immediately institute a requirement that all proposed foreign assistance projects be subject to an environmental screening, and if warranted, to an EIA. The EIA would be conducted (or sponsored) by the donor organization, but would require the involvement of local trainees, in order to help develop Vietnam's capability in EIA.

### 10.2.2 Measures for the Study Area

#### 10.2.2.1 Scope of measures proposed

In considering the measures for the study area one should be guided by the four circumstances: (1) flood control, as the major stipulation imposed in the problem definition; (2) socio-economic developments anticipated in the lagoon system, taking place 'in parallel' with flood strategies; (3) other important problems, linked directly or indirectly to flood control; (4) climate change factors.

It is essential that any measures taken will affect the primary properties of the lagoon system, such as *salinity; circulation and exchange of water and other matter; flushing of the lagoon and renewal of its components; sedimentation patterns; lagoon morphodynamics and inlet stability.* Many other effects are derivatives of the above but by no means secondary, e.g. aquacultural and agricultural productivity.

(1) As already mentioned, the planning of flood control for the future should consist of a reasonable spectrum of different measures, the properties of which must be *compromised by* the use of *integrated management techniques*. The measures should include dyke construction and upgrading; construction of reservoirs; some diversion schemes; drainage measures; and respective infrastructure.

*Dikes* can be planned in a variety of alternatives. Illustration of dike upgrading practices is presented below. *Reservoirs* will lead to flood reduction and environmental protection, but will also affect the salinity regime and sedimentation patterns, together with downstream sediment deficit. *Diversion* of

**(4)** An analysis of **climate change impact** on the study area, in terms of its *boundary conditions*, shows that special actions must be taken in advance with regard to *reservoir operation rules; drought control; prevention of acid soil and salt intrusion; and entrapment of sediments* in reservoirs due to denudation processes (prevention of sediment deficit in the coastal strip). All other actions due to accelerated sea level rise are self-explanatory in the context of our extensive VVA programme.

**10.2.2.2 Illustration**

One of the alternatives aimed at improving the present situation around the laoon area consists in **dike upgrading** (Anonymous, Sea dike ... 1993). The project is intended to rehabilitate and upgrade 7760 meters of sea dikes in order to reduce the incidence of sea water reaching areas protected by this dike. The dike is located along the Tam Giang Lagoon in Thua Thien Hue Province. In the predesign situation, 25,500 inhabitants from the communes Quang Phuoc, Quang Loc (also called Quang An) and Quang Thanh are suffering from the saline and fresh water flooding on 2,000 ha of cultivable land after every major storm. The duration of the programme is two years, from 1994 to 1995.

Land levels in this area vary between - 0,1 and + 0,4 meters. Normal tide ranges from -0,2 to + 0,4 meters, with the highest tide ranging to 1,2 meters. People manually construct simple earthen embankments in an effort to exclude the highest tides. The routine maintenance of these dikes is carried out locally.

A more permanent solution than the current earthen dike is to armour the dike in order to protect it and to construct ancillary drainage structures against wave action and erosive overtopping. Therefore, the Hydraulic Service of the Thua Thien Hue Province formulated a proposal to redesign and strengthen the dike.

The 7,760 metres of the dikes belong to the following communes: Quang Phuoc; Quang Loc(also called Quang An) and Quang Thanh, situated near the Bo River. The dikes will be heightened and strengthened to improve the resistance to storms and typhoons. Better dikes promote favourable conditions for increasing agricultural production in the project area. The agricultural potential of this area is, because of the good soil, very high. Besides this, the typhoon related losses of the 25,500 inhabitants shall be reduced, and the yearly maintenance costs for the dikes shall also be reduced.

Due to the damage and destruction caused by typhoons and floods to the dikes, the local people have to devote much energy to filling up again the coastal hinter-dike. Three kilometres of the sea dike from the Tam Giang Lagoon are completely washed away, the remaining part is virtually non-existent, as of 1993.

When the seawater overflows into the rice fields, it results in crop failures and land salinity, which affects the yields of future crops every year two or three times. The water level in the rice fields is at that moment + 1.2 to + 2.0 m. Each period lasts one or two days. Every year, 15 - 20 hectares of rice land are lost due to the fact that the salinity penetrates deep inland and up to now 200 - 300 hectares are laid fallow. Except the 200 - 300 hectares which are laid fallow, about 1,700 hectares of rice are treated by salinity and fresh water flooding and have a reduced yield as a result of that. The reduced crop loss is about 2 tonnes paddy per hectare per year.

On the 7.76-km long dike section from Quan Cua sluice to Ha Do sluice, there are 6 sluices with 3 gates and 2 sluices with 2 gates; each gate 2 metres wide. They were used for both draining and discharging floodwater and controlling seawater penetration. Because of the nonexistence of large parts of the dikes, they are now out of order and without closing - opening gates. The long-term objective is to create favourable conditions for increased agricultural production in the project area by removing constraints created by inadequate sea dike systems. A better dike will improve the protection of land from flooding and intrusion of brackish water, thereby allowing farmers to intensify agriculture through double cropping and adoption of higher-yielding varieties of rice.

The immediate objectives of the project are:

- to rehabilitate and upgrade 7,76 kilometres of sea dikes so that they have better resistance to storms and typhoons and require less routine maintenance work; to protect the upgraded dikes against erosion by wind, waves and water currents;

- to reduce the saline and fresh water flooding on 2,000 ha of arable land and to provide more adequate protection to 25,500 inhabitants;

- to increase the area available for cultivation through double cropping and reclamation. As a result of this the yield shall increase with ab. 2 ton paddy per hectare per year (the area behind the dikes consists of a narrow area with good soil which can yield 4,5 - 5 ton/ha under normal conditions. But under current conditions, with the dyke being in bad condition, the yield is approximately 2,8 ton/ha)

- to reduce losses due to typhoons of human lives, crops and infrastructure for 25,500 inhabitants.

Aside from the above, the activities undertaken by the project will provide environmental protection for the area guarded by sea dikes. Damage to agricultural land caused by flooding and salt intrusion will be minimized. Trees to be planted (which is not a part of this project) will effectively contribute to the ecological stabilization of the area and will provide fuel wood at a later stage (through pruning of branches and thinnings), thereby contributing to the reduction of pressure on other sources of fuelwood.

Hence the proposed measures encompass:

- an earth fill dike covered with a gravel base along 7760 metres. The gravel is then covered with concrete 35 cm thick and quarrystone. Both the upstream and downstream toe of the embankment have a bamboo curtain driven 2 meter into the ground to prevent seepage;

- placement of rock revetments;

- repair of 8 discharge sluices (including 2 sluices with 2 gates and 6 sluices with 3 close-open gates);

- construction of a network of houses for control and inspection of the dikes;

- training for supervisory staff and maintenance workers.

Coastal sea dikes in the region are at present low and steep (slopes of 1:1 to 1:2). As a result, the annual risk of a dike system being breached is 40 to 100 percent. Upgrading of the dike system will be achieved by earth fillings heightening the dikes and moderating their slopes (to 1:3 to 1:4). Earth will be compacted to a standard appreciably higher than that achieved on present dike works. As a result of this, the annual risk of breaching shall be reduced to 10 -20 %.

During typhoons and floods, the dikes will be attacked by waves from the lagoon, overtopping into the ricefields and afterwards floods from the rivers will inundate the ricefields and cause overtopping into the lagoon. Heightening the crest level will cause floods to be more severe, lowering the dike will cause saline water to enter the ricefields. Increasing the capacity of the sluices will never be enough to cope with the enormous amount of floodwater. Therefore the concept of a medium low dike is chosen. It is allowed to be overtopped at certain times. Because of the strong construction, the dike will not wash away by this combination.

As a result of the high temperature, the clay hulks necessary for the dike filling become hard an cannot be compacted properly. Therefore, special attention will be paid to the compaction of the earth filling. Locally build compactors shall help to accomplish better compaction.

To protect the dike-body against erosion as a result of infiltration of sea water and rain under ordinary circumstances, as well as by overflow of water and wave impact during severe storms and typhoons, the slope at the sea-side of the dike will be strengthened with revetments.

Roughly, the dike work sequence should be as follows:

- remove grass layer from alignment of dike;
- set up model of dike cross section/geometry;
- apply clay earthfll in layers of 15 cm each;
- compaction with weight according to the quality plan;
- finish off the surface;
- proceed in such a way that there will be one month between earthfill and paving, etc.
- check dimensions before paving;
- place bamboo poles on each side of the dike, 5 poles/metre; length 2.50 m, diameter 6 - 8 cm;
- place concrete slabs 60 cm x 60 cm x 10 cm in double row along bamboo poles;
- place quarry-stone protection of toe;
- apply geotextile on lagoon-side;
- construct filter-layer;
- place concrete blocks on revetment from bamboo-poles upward;
- place concrete blocks on crest;
- make in situ transition-blocks from revetment to crest, including the 30 cm crest-sill;
- make connection between dike and sluices.

No major diffculties have been expected during execution, from a construction point of view. Special attention must be paid to transportation of materials to the dike-sections under construction in such a way that there will be no delays and no hinderence of intersecting transportation routes.

Parallel to the construction of the dike, the sluices should be reconstructed or repaired:
- construction of small dam around sluice in order to put sluice dry;
- thorough inspection of sluice with regard to the structural condition and especially the foundation. Special attention to be paid to the possibilities of seepage underneath the sluice:
- decision whether to reconstruct or to repair
- execution of the plan
- connection to the dike section adjacent to sluice.

In 1992 it was expected that the execution of the project would take three years. The planning of spring 1994 however showed a two-year programme. During the mission of summer 1994 it was found that the execution reached only 50% of the planned progress, and that the project would take three years instead of two. Due to a period of good weather during the autumn of 1994, execution could continue for a longer period as foreseen. So a part of the arrears was made up, but only some 30%. Nevertheless it was expected that the works will have been completed at the end of 1995, except for two or three sluices.

For the sake of completeness and experience sharing, it is noted that the construction was regularly inspected and the design slightly modified in the course of dike works.

In general the construction of the dike has been of good quality, but some remarks had to be made:

(a) Toe construction: some "bad spots" were related to the toe construction; and bamboo poles and toe slabs were not always placed in a straight line.

(b) Revetments of concrete blocks: at some locations the placing of the concrete blocks appeared to have been carried out very carelessly, with too wide gaps between the blocks.

(c) Filter layer of gravel underneath the concrete blocks: Inspection learned that at several places only some gravel had been thrown on the geotextile.

In spring 1995, 570,000 cu.m of geotextile was shipped to Vietnam, as a gift from the Netherlands to World Food Programme, Project 4617. The Ministry of Water Resources of Vietnam supplied about 45,000 sq.m to Hydraulic Services (HS) Hue for use in the revetment of the dike of the Tam Giang Lagoon. HS staff HS was trained on using geotextiles on seadikes. Later it was emphasized that if geotextile is used under the concrete blocks, a gravelfilter is still needed. A combination of geotextile and gravel is better than gravel only, but geotextile alone is not recommended. Under the quarry stone, geotextile can be used to replace the gravel filter. After more discussions it was agreed that:
- under guarry stone, geotextile will replace the gravel filter;
- under concrete blocks, geotextile will be used in combination with a layer of gravel at least 5 cm thick.

The inhabitants of the communes Quang Phuoc, Ouang Loc and Quang Thanh are involved in the implementation of the project. During the two year implementation period, each day there should be a labour force from 1200-1300 labourers, all from the aforesaid communities. Six workers - responsible for the maintenance of the dikes after construction - should be appointed. These persons are also members of these communities. Because the people work mainly on the dikes nearest to their homes, different people would take on the project. If each person works for 70 days over one year, 6,000 people will be employed for approximately four months each year during the two-year project period. This employment schedule can be considered another asset of the project.

More details on the design, construction, monitoring and other aspects of the Tam Giang dike project can be learned from Anonymous (Sea dike ... 1993), Meulen (1995), and Meulen & Kouwenhoven (1995a, b). The experience gathered from the upgrading of the nearly eight kilometres of the Tam Giang dikes can be useful in **furthering this alternative** of dike-aided flood mitigation at more locations across the entire study area.

#### 10.2.2.3 Research needs

Investigations and **research** must accompany new development programmes. For illustration, here is a brief list of projects under way, basing on citations from four various references acquired in the course of PS2 (for labels, see References).

Hue15
Basic investigation of the Tan Giang - Cau Hai lagoon aiming at planning and sustainable development in terms of economy, ecology in the years 1996-1997.
Objectives: 4.1 hydrodynamics; 4.2 ecology; 4.3 resources; 4.4 environemtal hazards; 4.5 social conditions; 4.6 planning; in particular
4.1: geodynamics; circulation in the lagoon, interaction of river, lagoon and sea; inlet stability;
4.2: lagoon ecology -- bottom, alluvia, geochemistry, hydrochemistry, environment; nutrients, water quality, bioproductivity

4.3: aquaculture, wetlands, water, landscape, fish.

Hue16
Research proposals for Hue City and its vicinity aiming at pollution control 1995-1996.
Proposals: pollution of water resources -- BOD, oxygen, pH, Coliform, NO3 all over the city area

Hue17
Research proposal for July 1995 - June 1997: Investigations in the Tam Giang - Cau Hai (to be done by Chu Hoi, Do Nam and Ngo Dinh Tuan)
Present status of research
5.1 Hydrodynamics
5.2 Ecology
5.3 Resources
5.4 Environmental hazards
5.5 Objectives
5.6 Proposed scope and measures
6 Method of implementation
7 Substantiation of research
8 Expected outcome: i.a. 5.6 inlet stability; channel stability; salinity intrusion; salinity distribution; pollution; optimization of modelling

Hue18
Investigations in the Tam Giang - Cau Hai
Haiphong Inst Ocean apparently implements field measurements, from 08 to 28 November 1995, consisting of: currents, tide, waves, water level; chemicals and pollutants; geochemistry and bottom nutrients; changes in inlets, channels, coastline, shore morphology; sedimentation; distribution of marshes; biology; distribution of seaweed. There will be 6 stations over 3 days of monitoring of hydrophysical, biological, topographical etc etc; 2 offshore stations over 3 days; bathymetry in 10 transects; 40 offshore sampling stations for hydrochemistry, geology and biology; 5 sampling stations in the river; inspection of marsh vegetation; 10 profiles for the structure of beach and dune; 2 sampling stations in the lagoon; status of aquaculture.

These short examples prove that a lot of research is needed for better understanding of the lagoon and the implementation of environmental and engineering measures.

# 11. Integrated Coastal Zone Management ICZM

## 11.1 Information and Analysis System for Hue

### 11.1.1 General background

Rational planning of flood control requires the use of adequate techniques aimed at coastal management. The same is true for integrated coastal zone management (ICZM) facing the climate change (CC). If climate changes over decades and centuries, the coastal zone will change accordingly. The most direct impacts will be felt in the coastal climate and morphology.

The coastal zone is a good example of an area where interacting, complicated problems should be addressed by means of systems analysis. In order to investigate to what extent a coastal area is ***vulnerable*** one must examine individual impacts of various factors and their interactions. In general, *vulnerability assessment* (VA) of a coastal area should be considered in the context of *sustainable development*, a notion which is referring to a nation's capability to cope with all kinds of stresses, problems and environmental damage in the coastal zone in a sustainable way. Ecology and economy should come to terms in order to formulate strategies for such a sustainable development. This is complicated by the fact that environmental degradation is a slow - but irreversible - process. Remedial actions should be taken well before the symptoms of degradation are manifested.

*Planning* of both flood control and coastal zone resources has technical, social, economical and environmental aspects. This requires the input of a wide range of *disciplines*, their actual mix depending on the nature of the study:

Aside from inputs from specialized disciplines it is necessary to have the capacity of *policy or systems analysts*, who can integrate the contributions of the specialists into a coherent analysis and can generate the strategies to be presented to the *decision makers*.

For a given coastal area (in which the sea, coast proper, land, fresh-water and other sub-areas are distinguished) one can list the following basic groups of ICZM planning tasks: (1) Data collection and processing; (2) Analysis of natural processes and systems; (3) Analysis of socio-economic activities; (4) Assessment of ecological effects; (5) Review and choice of strategy.

### 11.1.2 Coastal Information System (CIS)

#### 11.1.2.1 Layout

Appriopriate systems, such as Geographic Information System (GIS) must be used for data management and clear-cut database support. Once arranged, a GIS system can be employed for a good many destinations serving the purposes of both VA and future projects. The system should achieve a compromise based on project goals, the availability and cost of software and hardware, country potentials (manpower, experience etc) and other factors, supported by the best knowledge of the project team. A **Coastal Information System (CAS)** can be put forth as a system which enables the systematic storage, compilation, interpretation and presentation and visualization of data of a specific set of coastal issues.

The CIS selected for VVA is divided into four main modules:

1 **Coastal Data Management System** with GMS-DECIDE;
2 **Coastal Analysis System** with SPANS-EXPLORER;
3 **Databases** resulting from inventories, assessments and modelling.

Hence the CIS-software well adopted for the given requirements of CZM-CC relies heavily on the commercially available programs GMS-DECIDE and SPANS-EXPLORER.

The following forms of input data are discerned: maps, tables, graphs, texts and illustrations, reports and publications etc. Data handling, whatever form, consists basically of acquisition, preprocessing, storage, import/export (retrieval from other sources and transfer to external means of data storage), processing and analysis. All these activities require appropriate organizational, logistic etc arrangements within a certain system, possibly topic- or project-oriented.

The CIS packages themselves contain no data. Data of various kinds, including all needed maps in digitized form (either produced by e.g. SPANS-EXPLORER or by scanning available maps), figures, drawings, photographs, and other entries have to be prepared separately. The analysis and design of the overall CIS under SPANS-EXPLORER and GMS-DECIDE are based on user requirements, which in turn are defined in close cooperation with regional and local authorities and organizations.

#### 11.1.2.2 Coastal data management system (GMS-DECIDE)

GMS-DECIDE is a full-featured PC-WINDOWS application designed for decision-makers such as project managers, engineers and planners who need to access, store, manage and use various data and information resources, especially those that are geographically related. The package is open and handles several file types and data structures such as statistical datasets, images, reports, scanned maps, monitoring data, documents, GIS files etc, and brings them into the users' processing and decision-supporting software.

In general, GMS-DECIDE allows the user to:

- describe, document, and georeference databases, maps, images, reports, statistics, projects, lists of professional contacts into catalogues of data, in several software formats under MS WINDOWS (MS-OFFICE PLUS , ArcView, etc.);
- search for and select information sources, datasets, catalogues, using a number of different user-defined search criteria, and then retrieve the documents themselves;
- view, edit and manipulate the extracted data or files in the appropriate application for word processing, spreadsheet, image processing, GIS, CAD/CAM, etc.

#### 11.1.2.3 Coastal analysis system

Spatial analysis (or GIS) is a computer-based technology for producing, organizing and analyzing spatial or geographically-referenced information. It combines elements of database management, mapping, image processing and statistical analysis. The distinction between GIS and traditional information systems is the use of locations for referencing information, as an important variable in quantitative analysis. By exploiting the spatial dimension, GIS introduces a new perspective which can greatly enhance decision making and problem solving. As a result, GIS applications are of increasing importance in a wide range of disciplines using spatial data.

GIS can be extremely helpful for CZM applications. There are more than 100 GIS types all over the world. The most common ones are ArcInfo, Intergraph, IDRISI, SPANS and a handful of others. Both SPANS and other types of GIS lines of software products are designed for organizations and professionals who need to integrate and analyse geographic information as a part of their decision-making process and who want to use spatial analysis as a tool to do their work more effectively.

All GIS types consist of thematic maps, which are maps of single attributes (in subareas) such as elevation, population density, type of forest, type of shore protection etc. However, not all GIS types encompass all elements mentioned above (data management, image processing etc). The most powerful, elaborate and advanced **analysis functions** can be found with SPANS. The analytical capabilities of SPANS can be grouped in four classes: `transform --analyze -- identify -- model'.

The SPANS system consists of a few products, available in the Windows 3.1, OS/2 and UNIX environments. The products are *inter alia* SPANS MAP and SPANS GIS. The former is a comprehensive desktop mapping package for the visualization and querying of geographically referenced data. The query function offers one up to five simultaneous views in different formats: digital map, chart, spreadsheet, image and text. The data in the map, chart and spreadsheet is dynamically linked, so that an alteration in one view is automatically reflected in the others. Areas and lines have to be imported from other sources (either GIS or non-GIS such as CAD) while point data can be added to the SPANS MAP internal database. SPANS GIS is a modular system consisting of stand-alone modules for building databases, constructing analytical models (and the visualisation and querying of data, without desktop editing, as in SPANS MAP). The following analytical modules can be fully integrated: 3-D view, contouring, surface generator, point aggregation, neighbourhood analysis, network analysis, topological analysis, visibility analysis, interaction modelling, multicriteria modelling, map modelling, table modelling, point modelling, and application developing.

SPANS EXPLORER bridges the gap between desktop mapping/editing and GIS. In particular, SPANS EXPLORER encompasses all elements of SPANS MAP plus some elements of analysis from SPANS GIS. The EXPLORER's features include:

- full raster and vector integration,
- on-screen digitizing,
- table attribute modeling,
- multi-criteria analysis,
- vector and matrix overlay functions,
- interactive map composition.

## 11.2 Economic&Environmental Analyses of Flood Control and Climate Change Impacts

### 11.2.1 Examination of ICZM concepts

In the coastal zone, as much as in flood control, and even more so in our pilot study's combination of flood control and CZM, one encounters a number of user-induced conflicts, such as those shown schematically in **Figure 11.1.**

Any lagoon or coastal system can be depicted as in **Figure 11.2.** The agents of change in our PS2 are flood control strategies, natural socio-economic etc. developments and climate change factors, as described basically in Chapters 4, 5 and 6 and summarized in Chapter 10. Those agents of change bring about a variety of impacts, as analyzed throughout this report.

Management of a coastal zone, or the lagoon system in our case, must take into account a number of interactions, demands, goals, strategies etc, as schematized in **Figures 11.3** and **11.4**.

Planning of coastal and lagoonal management must include the elements arranged in **Figure 11.5**. CZM planning should comprise the determination of the zones of importance of various domains of human economic activities (shipbuilding, navigation, recreation, mining industry, fishing, tourism and infrastructure etc.), with the entire hinterland. Social, cultural and ecological aspects are of great importance as well.

Once it is realised what are the objects and context of management, one must

(1) identify the central issues around which the management will be centered;
(2) work out alternative strategies of management;
(3) evaluate as quantitatively as possible the benefits and shortcomings of the various strategies;
(4) take decision(s) on selection of the optimum management.

The element of **integration** at institutional, legislative, organizational etc levels, as well as in space and time of the management efforts, is taken for granted. This means that the decision on optimum management will be based on demands of a broad spectrum of many entities.

The central issue around which CZM is built up (1) can be shore erosion, flood hazards, pollution control and many other 'leading themes' of coastal and lagoonal managers' concern.

Historically, the concept of CZM evolved from relatively simple conservation of shoreline, beyond some unsurpassable limits of retreat, to much more complex sets of requirements on keeping in equilibrium a coastal ecosystem, with its biodiversity of species at various levels of the life chain (the Dutch concept of `amoeba').

Evaluation (3) of various measures and outputs can be relatively simple if in monetary terms, which is seldom possible for environmental and ecologic values. Some efforts to overcome this difficulty are outlined in **11.2.2**.

Among a variety of techniques derived for decision taking (4) some are simpler and common while some other are only paving their way. A short overview is given in **11.2.3**, while commercially available computer packages for implementation CZM concepts are presented in **11.2.4**. More illustration is provided in **11.2.5**.

### 11.2.2 Evaluation of environmental assets

**Figure 11.6** makes a distinction between economic and environmental values. Although it is more difficult to assess quantitatively the environmental values, the number of methods aiming at such evaluation is growing, as shown in **Figure 11.7**. Some of them are selected for illustration in **Figure 11.8**.

Special attention in this respect should be paid to rapidly developing appraisal techniques basing on questionnaires addressed to the users of coastal assets, including the environmetal and ecological ones. The example illustrated in **Figure 11.9** and **11.10** have been exctracted from a study on evaluation of a Polish beach. Through a set of questions asked to those who make use of the beach, weights attached to question groups and a simple computational procedure it is concluded quantitatively how much the beach users are willing to pay for the use. -- A similar approach can be attempted for the TG-CH Lagoon, although some modifications should be worked out beforehand. For instance, the willingness to pay should be replaced by the willingness to care, because simply very few lagoon dwellers can afford any payment. Vietnamese institutions involved in the lagoon use should be asked slightly different questions etc. their limited financial resources

It is interesting to note that WTP-type concepts are already being introduced in Vietnam. Anonymous (1995, Hue3) presents the concept and technique of Participatory Rural Appraisal PRA. It is an improvement of earlier Rapid Rural Appraisal originated in the eighties. PRA is a process whereby outsiders are able to collect data and information about all aspects of rural life in a short period of time, by using simplified questionnaire surveys. At the same time, PRA enables local people to exchange their knowledge of life, to learn together with others. Hence PRA leads to situation analysis; identification of constraints, opportunities and solutions; planning and actions.

**Appendix 11** provides more details of PRA, its advantages and disadvantages, and some examplary questions and solutions. Methods and tools are elucidated for PRA in coastal commumities, where PRA is advanced as a step to help people do something about their coastal problems. Semi-structured interviewing SSI is defined as guided interviews where only some questions are predetermined while new questions come up during the interview.

By and large, PRA can be regarded as a simple technique for qualitative analysis of coastal problems, by which the latter are identified, described and tentatively solved. PRA can be suggested as an introduction to more sophisticated quantitative tools such as willingness-to-pay assessments.

### 11.2.3 Comparison of decision-aiding techniques

There are many techniques making possible a relatively impartial quntitative evaluation of various strategies (for flood control and lagoon & coastal management in our case), together with their comparison. The oldest and simplest cost-benefit analysis has been gradually succeeded by more sophisitcated tools, of which some are enumerated in **Figure 11.11**. They can be both monetary and non-monetary, to account for more qualitative assets, such as ecologic ones. Their advantages and disadvantages are summarized in **Figure 11.12**.

Modern decision support techniques stem from systems analysis, wherein a substantial share is taken by multicriterial analysis. Since the latter is also mentioned elsewhere in this report, some background is given in **Figure 11.13**.

### 11.2.4 Software for implementation of ICZM concepts

The basic trouble in quantitative planning ICZMP arises from a great number of interacting factors and the quantification of non-measurable or hardly measurable social, cultural and environmental values and effects (e.q. price of 1sq.m. of a national park, price estimation of polluted and clean beaches etc.). A *cost-benefit analysis (CBA)* is the simplest way for quantitative estimation if a good evaluation of all components is provided. Quite often, this evaluation is difficult to obtain.

Together with the simplistic CBA, risk analysis, decision theory, multiple-attribute approach (MAA), and some other theoretical approaches may be tried for ICZM, whereupon criteria for evaluating components of CZM and ICZM strategies have also been assessed.

*Risk analysis* includes some concepts and techniques which might be useful in CZM-CC planning. E.g. fault trees can provide an overview of mechanisms and processes which lead to (or from) vulnerability to ASLR. *Decision theory* is helpful in selecting the most quntitative CZM strategies. Decision support systems *(DSS)* can be used in their elaborated forms wherever they appear as components of our intended CZM plans. *MAA* has been incorporated in the software package ASE tested under SE13, and its general merits will be further pursued. *Habitat approach* must be included as an assessment tool for ecological values. Valuation of ecological effects is an important although volatile part of the quantitative comparison of CZM strategies.

GMS-COAST is an application software developed on the basis of the GMS-DECIDE package by DaVinci (Belgium), a powerful information management and analysis system. GMS stands for GeoManagement System, whereby geomanagement is understood as the art of managing widespread resources and activities through coordinated decisions using scattered information sources. GMS-COAST is a limited demonstrative version (with some restrictions on its features and number of records) of GMS-Decide discussed later in this report, and selected as an important component of the system CIS tailored for the purposes of this project.

WCOAST is a geographically referenced information handling and decision support system for ICZM and research, derived by Compuplan, the Netherlands. It enables one to study the effects of climate change (sea level rise), linked to spatial and attribute data (e.g. maps and population density or land use, respectively). SLR flooding can be simulated and the costs of damage can be calculated. The following modules are included in WCOAST: introduction; spatial data handling; attribute data handling; thematic analysis; SLR simulation; damage costing; simulation and analysis of response options; evaluation (policy and decision making based on CBA). At present WCOAST is only a training package but soon should be made available in a version for guided applications and comparative research.

ASE is Adaptation Strategy Evaluator software developed by the US EPA for coastal managers and planners to evaluate ALSR adaptation strategies. It is using the multi-attribute approach (MAA) to evaluate different adaptation strategies. Adaptation strategies in terms of ASE are not only the 'regular' IPCC options (retreat, adjust/accomodate, protect) but also legal actions (regulatory, ownership change etc), incentive mechanisms, planning commitments etc. The evaluation attributes used in ASE are expenses, net benefits, environmental impact factors, robustness/flexibity of strategy implementation, chance of success, implementation feasibility and fairness of a strategy (its impact on neighbours and future generations). Unfortunately, a number of faults have been detected in the presently available version of ASE (ver.2.0), so subsequent use of ASE for the purposes of this project depends on the response from US EPA to the queries placed with them in the wake of our testing.

### 11.2.5 Illustration of the flood control context

A rapid appraisal of the economic benefits of flood-mitigation strategies for North and Central Vietnam has been devised by Lustig (1992). As with many such projects, in both developing and developed countries, the data was insufficient for a rigorous analysis. Some data could be obtained during the appraisal mission, but other information, such as the risk of failure of a section of dyke, could not be generated without months or even years of investigatiun. There was however, within the Ministry of Water Resources, a wealth of engineering experience. In order to derive values for the risks of failure, some of these engineers were taken through a series of events and asked to give their estimates of the numher of failures throughout the floodplain for different floods, their rankings of the areas of risk, and their assessments of the areas which would be flooded. As a precaution against over-estimation, some ofthe figures were adjusted to give a degree of conservatism, and later suhjected to sensitivity tests. The results gave benefit-cost ratios which were very high by the standards usually accepted in developed countries, indicating that more detailed studies of their feasibility could demonstrate that there existed worthwhile strategies for flood mitigation, emergency preparedness and disaster management in Vietnam.

The *land protected* by the dykes is a major part of the total *agricultura*l area and population of the coastal and lagoon systems. When there is failure of dykes the losses are very high. The population lives on the riverland, the land around the banks of the rivers, which is not protected by dykes. This land is usually flooded during each wet season. Nevertheless, provided the farmers know that a flood is coming down the river, they can often quickly harvest much of thcir crops and move them out of the path of the flood.

Flood-prone housing -- there are many houses which subject to flooding every year. This causes severe social problems, but some families have nevertheless lived there for several generations. Every ycar when the floods come, there will be a shortage of food and fresh water, a susceplibility to eye infections, fever, skin infections and stomach problems. Sometimes the flooding can last for a few months.

In order to evaluate the benefits of lhe different strategies for reducing losses from flooding in river deltas and along the coast, it is necessary to estimate the current losses being experienced, then to assess what the reduction in losses would be with each strategy. As a first step, brief surveys of residents and industry were undertaken, in order to gain an appreciation of the scaale ot losses which could be incurred.

Some of the results obtained were a little surprising. Whereas it had been assumed that the major losses would be agricultural, the losses to housing worked out to be about as much. Further, it was thought that the losses of rice crops would be the dominant agricultural damage, but it was found that losses to other agricultural produce such as liveslock and fruit trees would be just as large. Assumptions were also needed on the losses suffered by commercial establishmenls such as shops. To help with this, some streets were surveyed by Lustig (1992). To estimate the losses by industry, the statistical information on thc value of industrial production was obtained; in addition, two reasonably large industrial establishments were surveyed.

The floodplain management strategies considered by Lustig (1992) encompassed the following:

(1) current system of dyke monitoring and repair;
(2) new system of dyke monitoring and repair;
(3) redevelopment of riverland housing (including high-level storage platforms);
(4) upgrading sea-dykes in Central Provinces;
(5) new warning system (radar & satellite backed; benefits to hinterland, riverland, coast etc)
(6) new warning and storage system

Frequency of flooding and some details of flooding scenarios and routing had to be worked out as a background to the cost-benefit analysis. None of the comparisons by Lustig (1992) take account of the profound social benefits which could accrue, but some analogies to more developed countries were drawn.

The cost-benefit ratios determined by Lustig (1992) are the highest for the current and new systems of dyke monitoring and repair (in the range of 50--60) but also greater than unity (~2) for upgrading sea dykes of the Central Provinces.

The estimates have been necessarily very approximate. However, when making rapid assessments, it is not essential that there be a final, accurate economic evaluation: it is suffcient if one is able to make judgements whether certain strategies appear feasible, and which of them appear to have the highest priority and/or produce the grcatest economic benefits. The method presented by Lustig (1992) has been able to make use of the substantial local e.xperience of flood-fighting in North and Central Vetnam, and appears to identify hazardous typhoons, floods and storm surges, along with improved estimates of their frequences; extensive surveys of households, commercial establishments, factories and infrastructure to estimate possible damages resulting from floods of different magnitudes; social surveys of households to check on the social benefits and costs; that there are a range of flood-mitigation strategies which could be economically attractive as well as socially worthwhile.

# 12. Conclusions, Discussion and Possible Follow-up

## 12.1 Conclusions & Highlights

A good deal of conclusions can be found in the SUMMARY, preceding the main body of this report. Chapter 10 is also conclusive in the sense of problem analysis and synthesis. Hence, to save paper and for the sake of brevity, it seems inappropriate to repeat the findings or comment on them. Instead, some highlights are offered to emphasize the major issues.

**1. Thua Thien HUE Lagoon System is a quite unique Semi-Enclosed System:**

**--- land-locked (surrounded by mountains)**

**--- a coastal unit between headlands**

**--- lagoon-oriented/controlled ...**

**2. FLOODING is a central issue in the Pilot Study Area in view of:**

**--- huge losses (death and health penalty, land and property ...)**
**--- Huong Song's flow (non-uniform to date) and flood control demands**
**--- flushing of the lagoon system (positive!)**
**--- impact on the lagoon salinity**
**--- sediment transport (natural beach nourishment ...)**
**--- general impact on the lagoon ecosystem and all users etc.**

**3. Physical, biological etc and socio-economic factors are all**
**lagoon- and flood-oriented and controlled**
**Climate change factors(SLR!) strongly control lagoon systems**

**4. Salinity is one of the HUE lagoon system's most important factors;**
**i.a. ecosystem, human activities (agri- & aquaculture etc) are all affected**

**5. Inlet stability and lagoon morphology are very sensitive components of the lagoon system, are vulnerable to climate change factors, and depend on flood control strategies**

**6. Present and new activities (Ta Trach, Chan May ....) all interact with the lagoon system and flood patterns and control**
**hence → Integrated Coastal Zone Management must be harnessed**

## 12.2 Follow-up Opportunities

It is realized that Pilot Study may be regarded only s a very general outline of the Tam Giang - Cau Hai Lagoon ecosystem and its interaction with lagoon-oriented users, largely controlled by the flood aspect. This is so `by definition', because of the very wide spectrum of problems encountered and the limited time and means devoted to the Pilot Study. It is equally well perceived that both studies and technological, socio-economic, environmental etc. activities pursued so far should be continued.

Potential foolow-up activities may encompass many various efforts such as, in very general terms:

(a) Detailed analysis of the lagoon ecosystem and its interactions, including many links skipped in our report;

(b) 2-D and 3-D modelling. lagoon circulation, salinity and water quality for various development scenarios;

(c) Modelling lagoon morphology, including sediment transport (in both rivers, lagoons and the coastal zone) and tidal inlet stability;

(d) Upgrading environment protection studies and activities;

Some particular features of the ecosystem to investigate may include:

--- suspended and bedload measurements and estimates,

--- distribution of water and sediment in lower branches of Huong Song and Hue lagoon system (scarce data so far),

--- modelling the lagoon hydraulics for dredging etc. operations,

--- transport and dispersion of nutrients, micropollutants, primary production and life cycle in the river-lagoon system.

Enforcement of environment protection measures should be aimed at for the benefit of both present and future users. This should be accompanied by build-up of **public awareness**.

Enhancement of public awareness of pollution and the need for coordinated use of the lagoon system should be one of the first steps towards Integrated Coastal Zone Management (ICZM).

Perhaps most attention in follow-up should be devoted to working out an extensive **ICZM plan**. The techniques illustrated in Chapter 12 should be employed for the evaluation of both monetary and non-monetary assets, the support of decisions *vis-a-vis* the lagoon ecosystem and flood control, as envisioned in this report, and a professsional selection of strategies aiming at reaching the long-term goals outlined herein.

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Chu Hoi, Tran Duc Thanh & Nguyen Huu Cu 1994. Closure/Summary of Workshop on TG-CH (in Vietnamese), **Hue6.**

Tran Duc Thanh 1994. basic problems of natural environment and ecosystem of Tam Giang -Cau Hai (in Vietnamese), **Hue6.**

Doan Suy Nghi & Ton That Phap 1993. Scientific Information Journal (Thong Tin Khoa Hoc), Hue University; SIJ 2: 88-94. **Hue7**

Doan Suy Nghi 1991. Some physical and chemical characteristics of the brackish water in coastal lagoons of Thua Thien Hue (in Vietnamese). SIJ 7: 124-131. **Hue8**

Ton That Phap & Doan Suy Nghi 1991. Some data on the salinity of Thua Thien Hue lagoons (in Vietnamese) SIJ 7: 124-131. **Hue8**

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Voa Van Tan & Le Thi Ly 1995. Study on detrmination of traces of heavy metals in Huong River (in Vietnamese). SIJ 3: 17-19. **Hue9**

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Nguyen Tuong 1995. Potentials and development strategy for tourism in Thua Thien Hue (in Vietnamese). SIJ 3: 54-58 **Hue9**

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Vo Van Phu 1993. Fish components of Tam Giang lagoon (in Vietnamese). SIJ 8: 150-153. **Hue10**

Vo Van Phu 1994. Luthianus Crythroptorus in Tam Giang - Cau Hai lagoon (in Vietnamese). SIJ 9: 190 - 195. **Hue11**.

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Anonymous 1995. (in Vietnamese). People's Committee Thua Thien Hue **Hue16**
Anonymous 1995. (in Vietnamese). People's Committee Thua Thien Hue **Hue17**
Anonymous 1995. (in Vietnamese). Research plan for Tam Giang Lagoon - Reasonable use. People's Committee Thua Thien Hue **Hue18**
Vo Van Phu 1995. Thua Thien Hue Lagoon biology Ph.D. thesis (in Vietnamese).. Hue University. 24pp. **Hue19**
Anonymous (Pham Ba Dien) 1995. Thua Thien Hue Potentials and Prospects. People's Committee Thua Thien Hue. 56pp. **Hue20**

## Appendices (enclosed)

**(Appendices have been bound separately and have not been submitted with the draft report)**


Figure 1.I General map of Vietnam

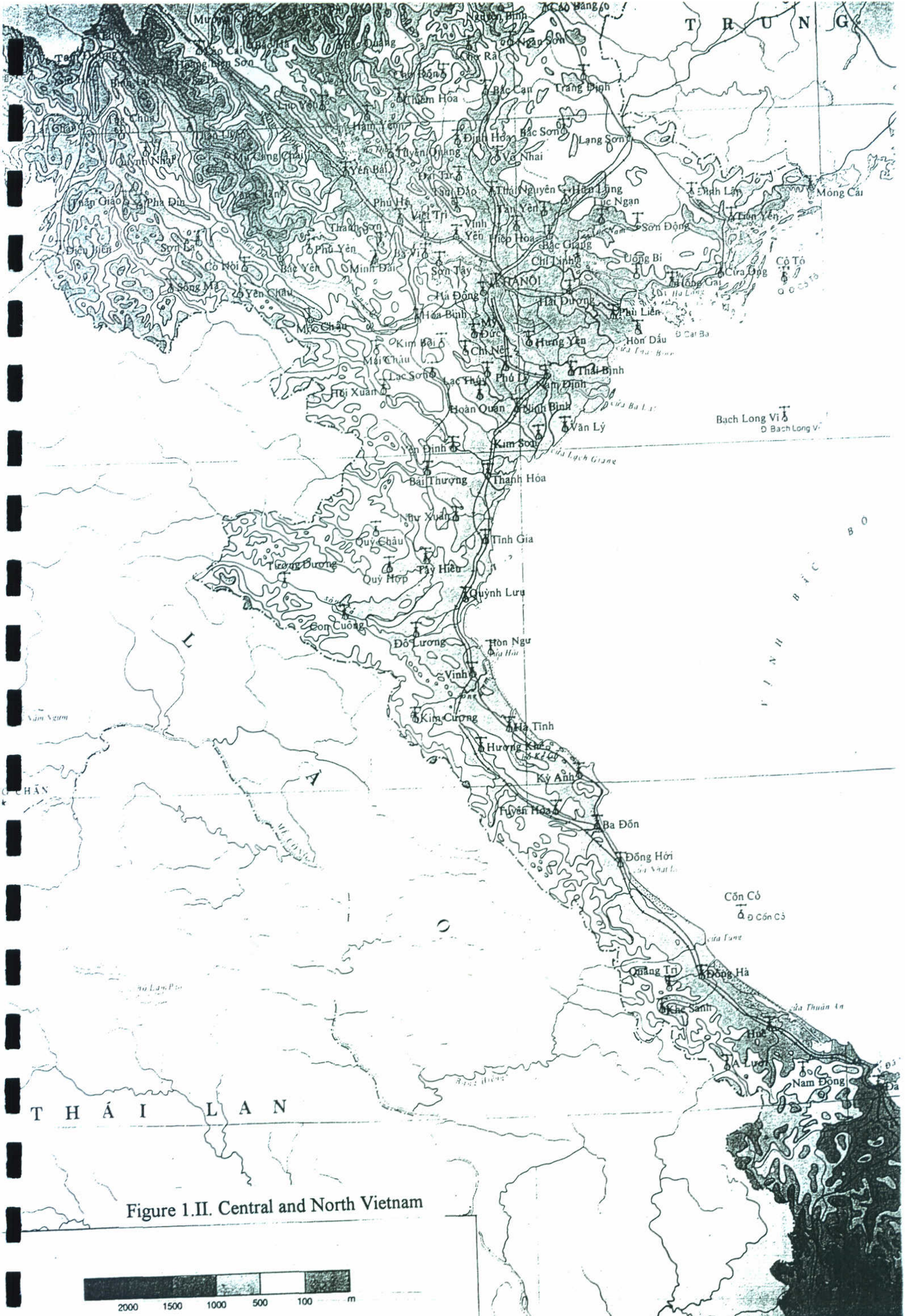


Figure 1.II. Central and North Vietnam

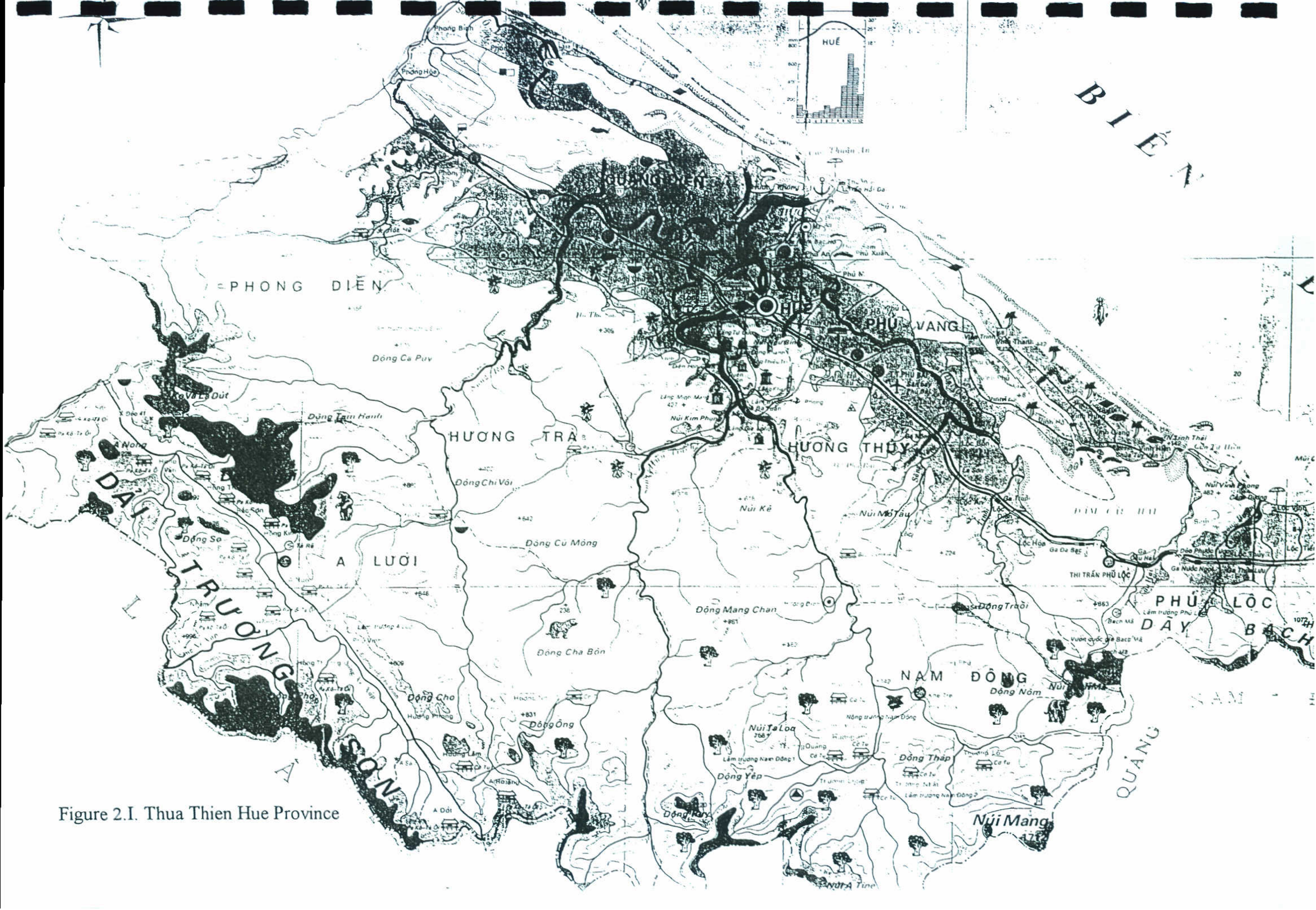



Figure 2.I. Thua Thien Hue Province

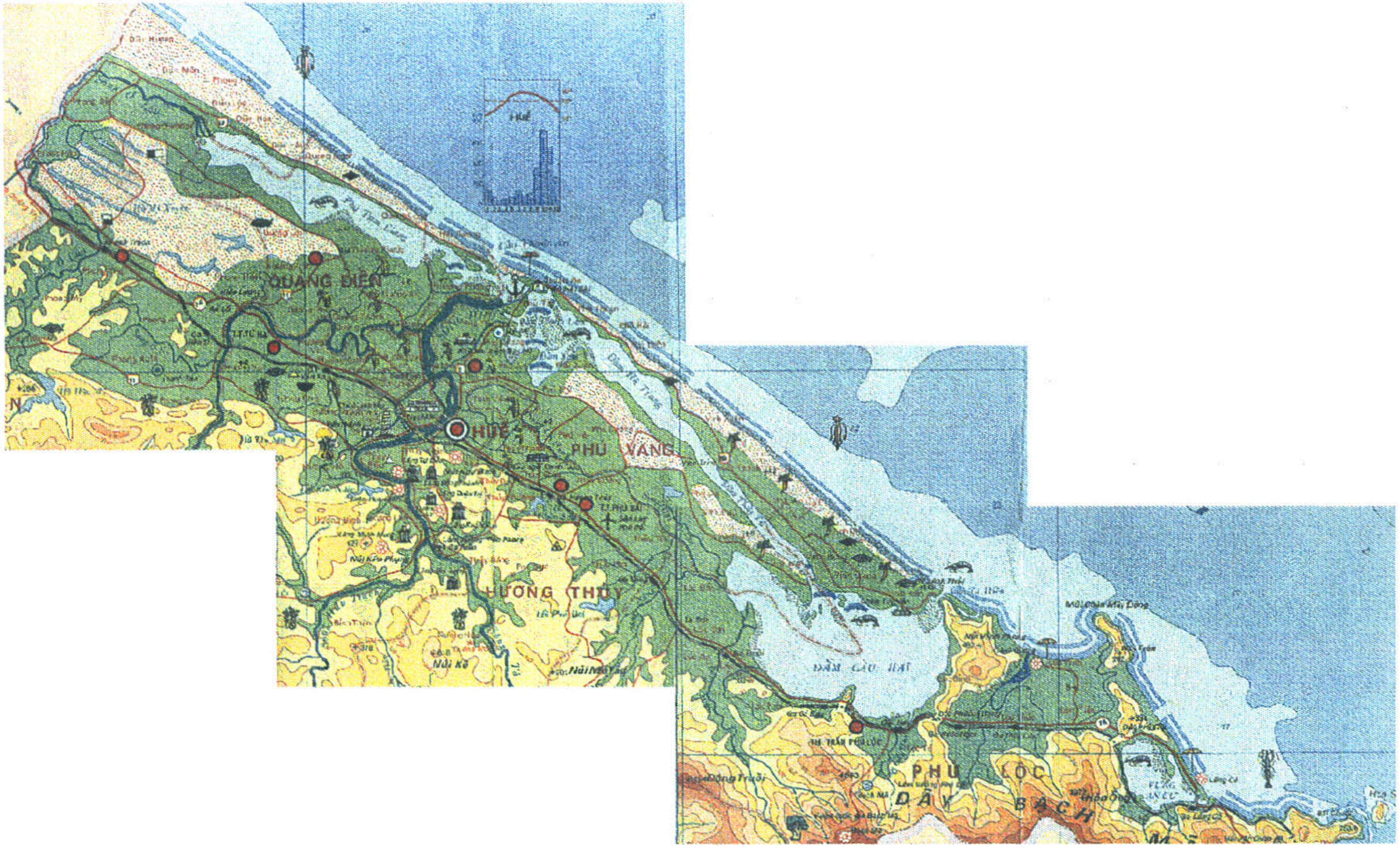



Figure 2.II. Hue and its lagoon system

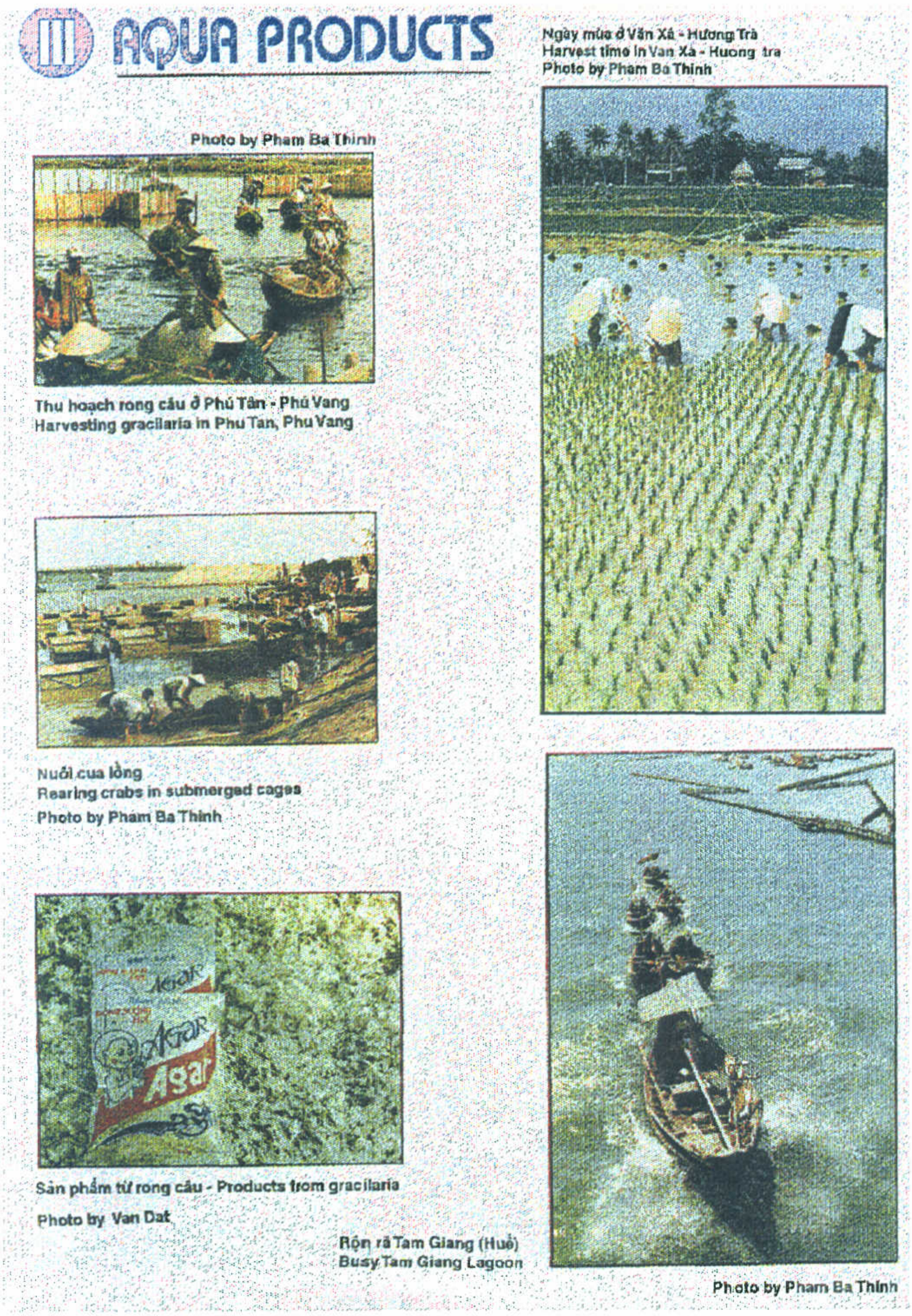



Figure 2.III A caleidoscope of Thua Thien Hue land users

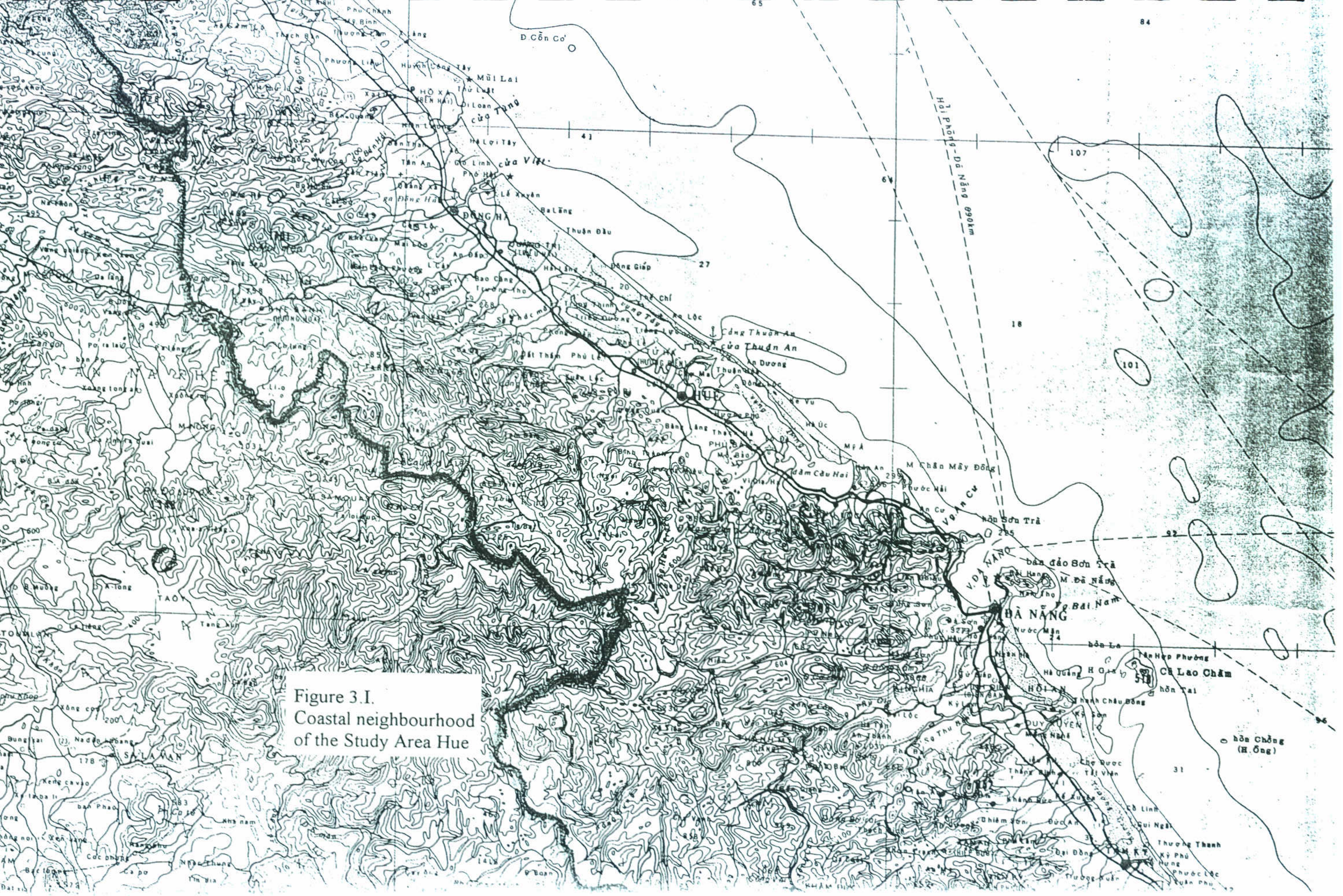



Figure 3.I.
Coastal neighbourhood
of the Study Area Hue

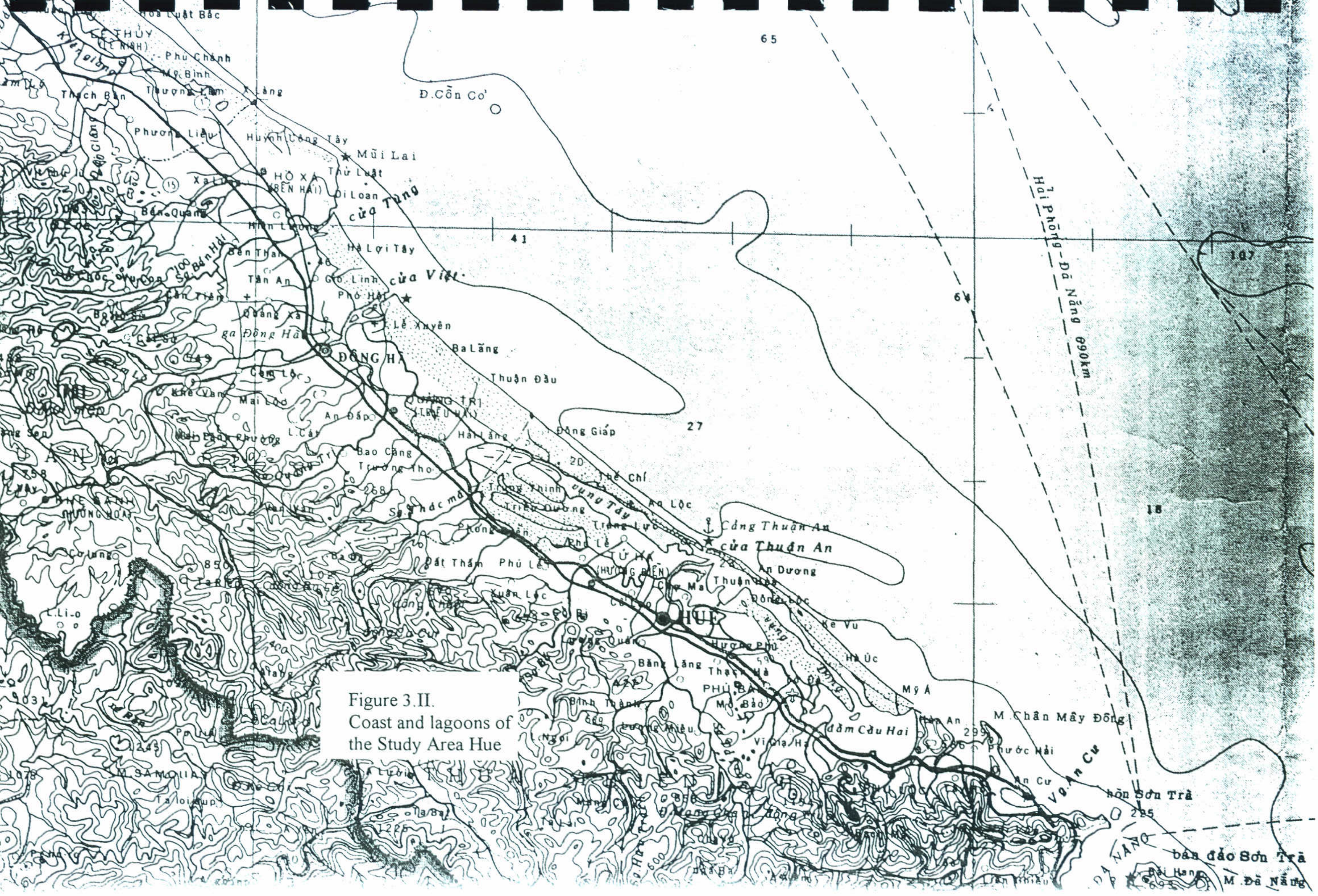


Figure 3.II.
Coast and lagoons of
the Study Area Hue

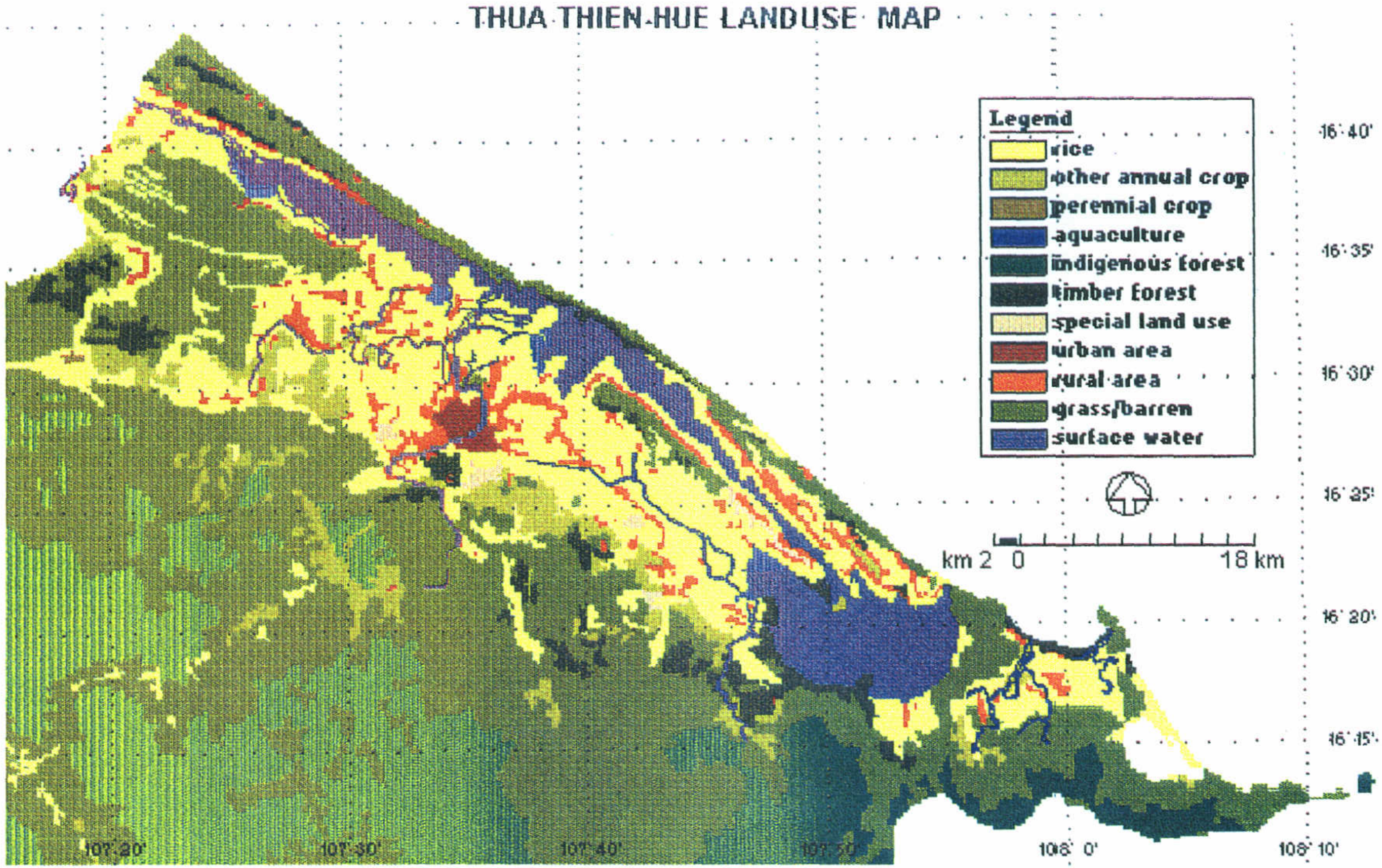



Figure 4.I. TTH landuse map

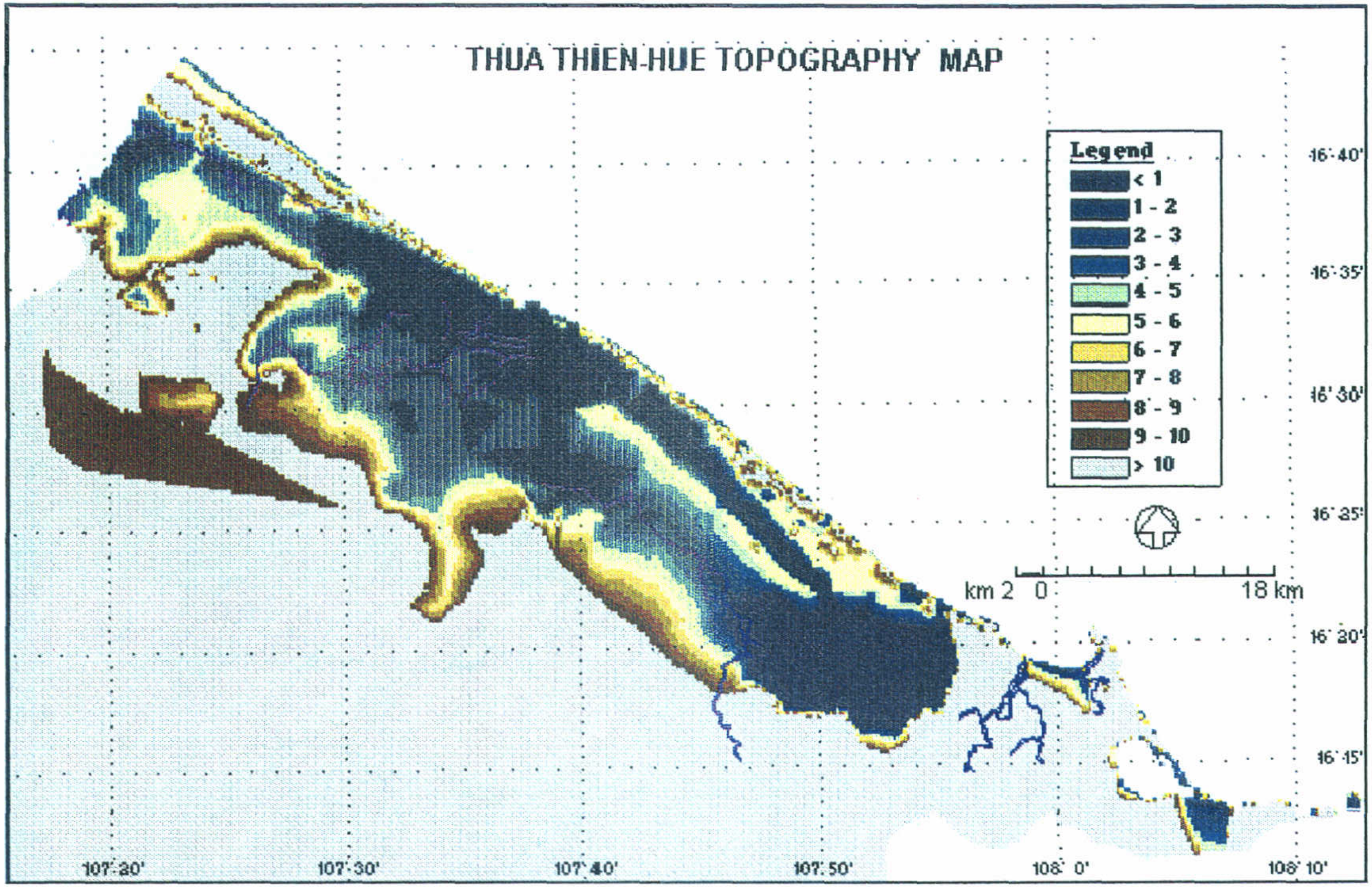



Figure 4.II. TTH topography map


**Shrimp pond at the experimental station withinTam Giang**

**Flow control facilities in shrimp ponds**


Figure 4.III.

**Fishing net systems in Tam Giang**


**Fishing nets in Tam Giang are abundant**


**A family catching fish in Cau Hai**

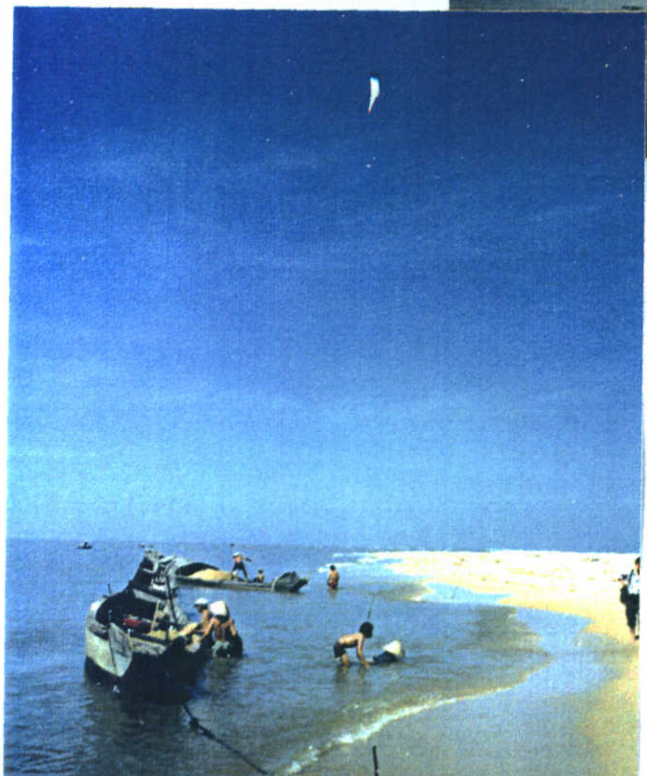

Figure 4.IV.

**Larger boats are commonplace in Tam Giang/Thuan An area**

**MINING activities**

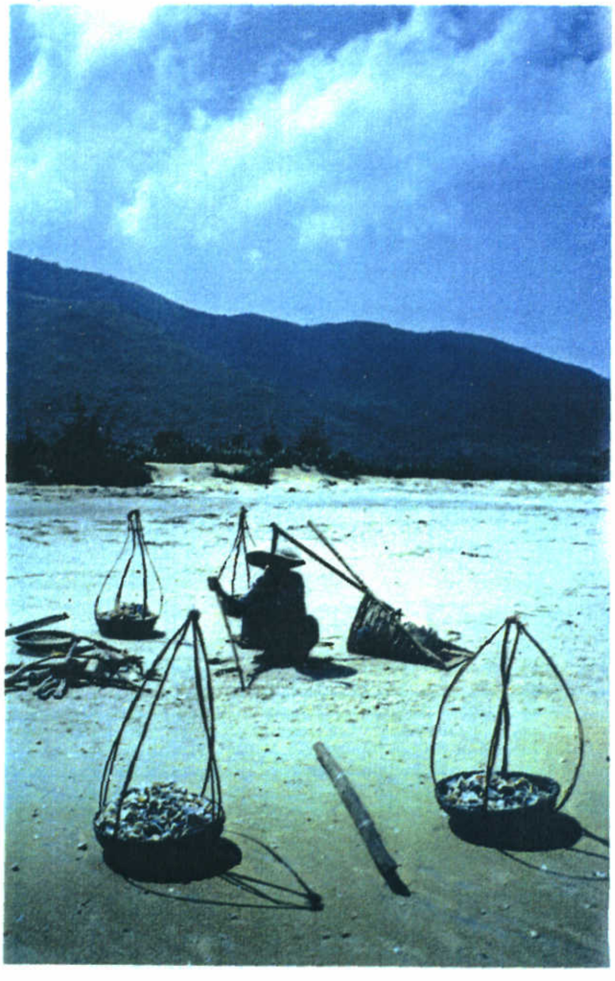
Seaweed (top)

Sand and gravel at Thuan An (right)

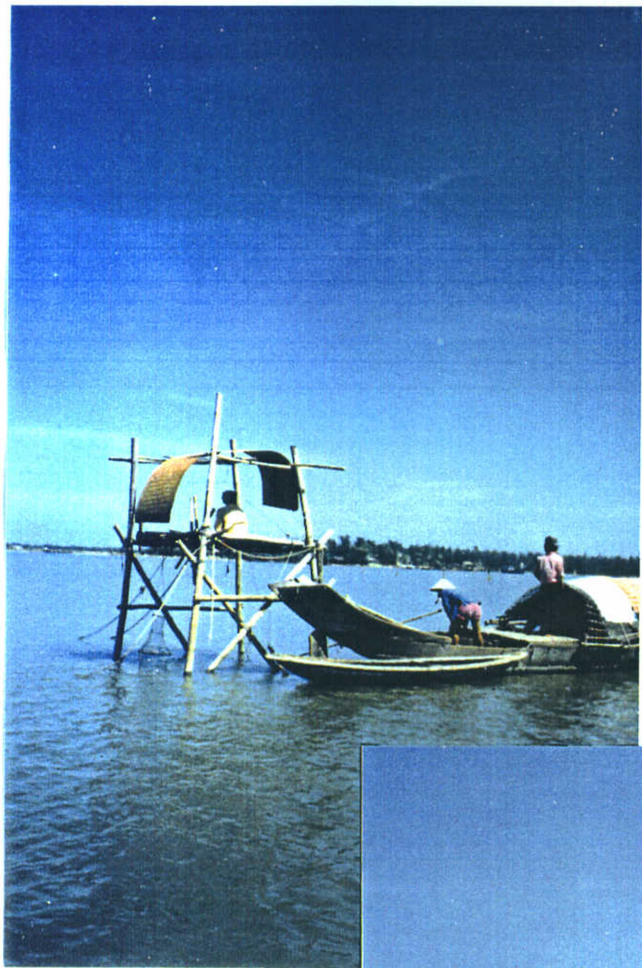


Sand and gravel at Thuan An

Figure 4.V.



Lime on beach close to Tu Hien



**LIVING CONDITIONS:**
**from living on boats (left)**

**to**

**better housing secured by the government (below)**


**and perhaps more**

**comfortable in future**

**(owned now by V expatriates in Tam Giang close to Thuan An; at bottom)**


Figure 4.VI.

**Busy street on the Cau Hai/Tu Hien sand spit**

**Living quarters on the Cau Hai/Tu Hien spit**

Figure 4. VII.

**Fishing net in Cau Hai close to the entrance leading to Tu Hien**

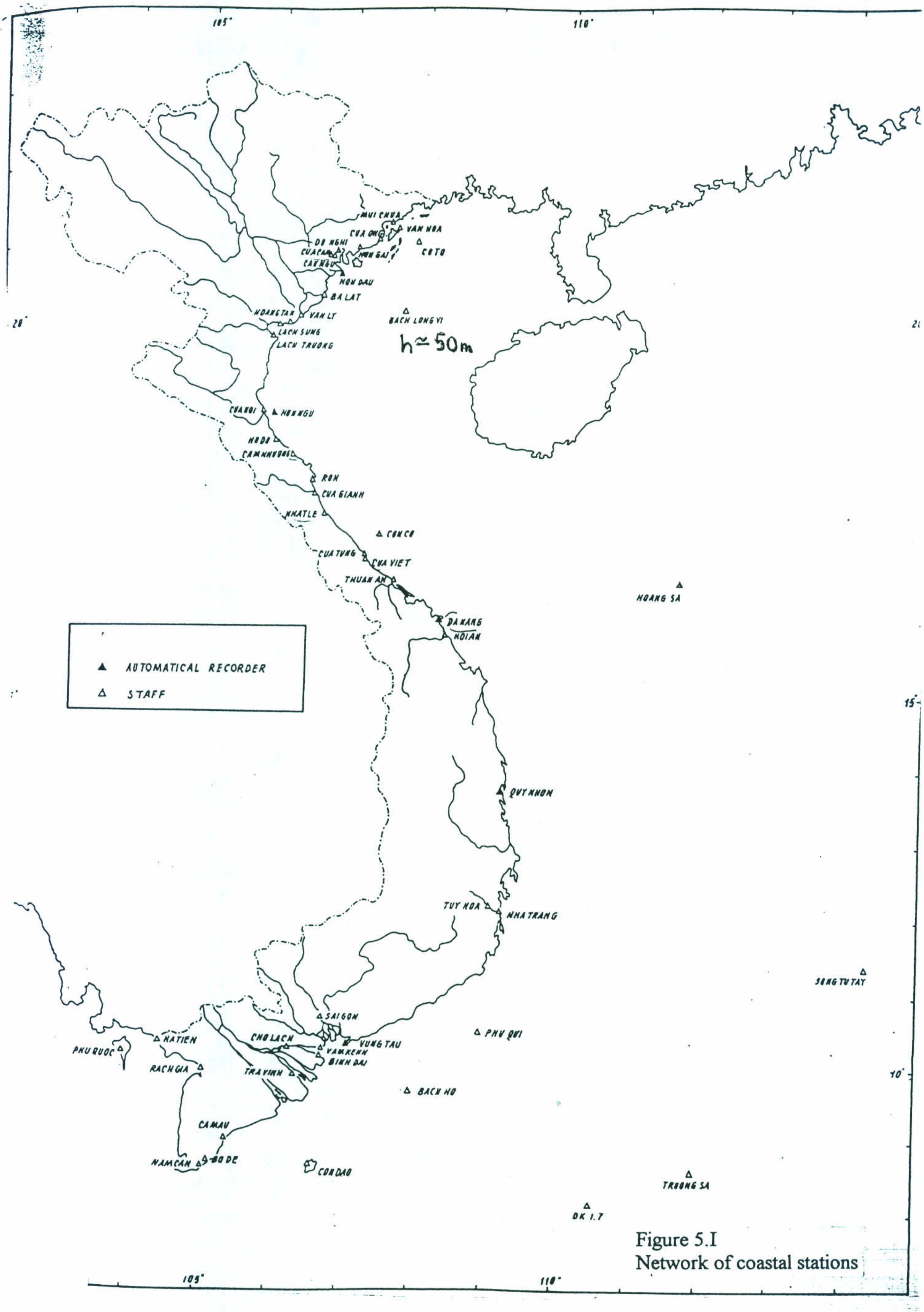



Figure 5.I
Network of coastal stations

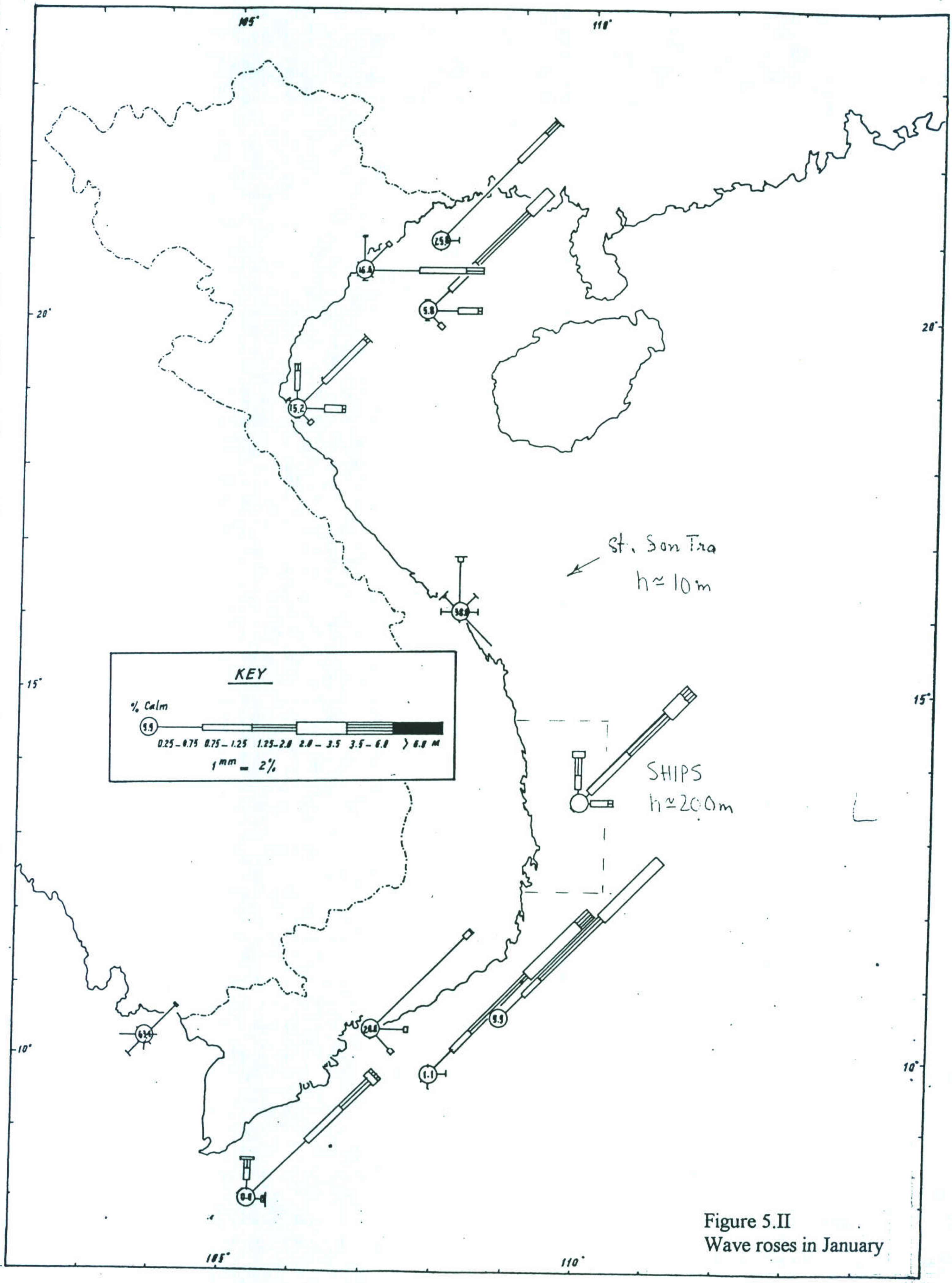
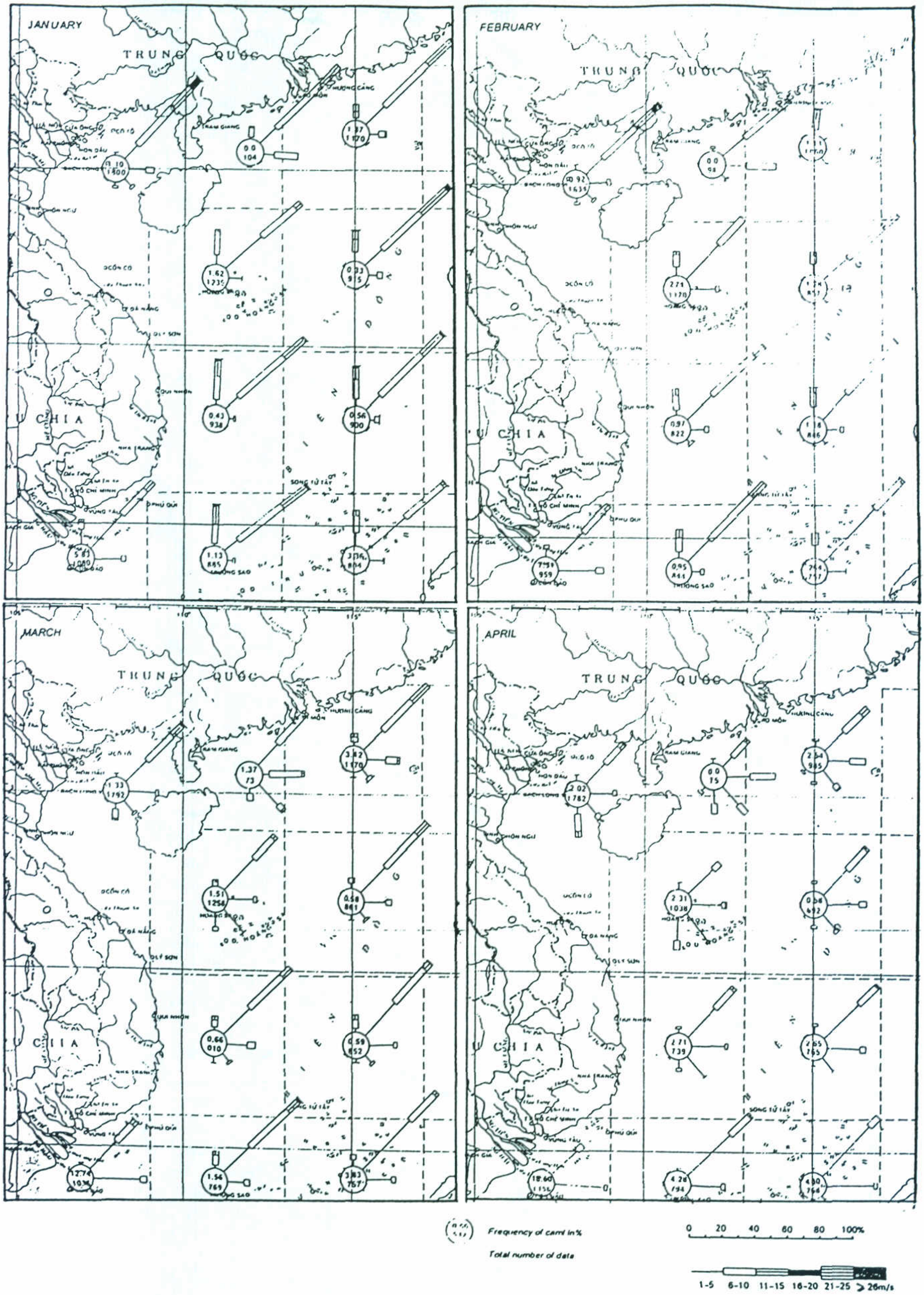
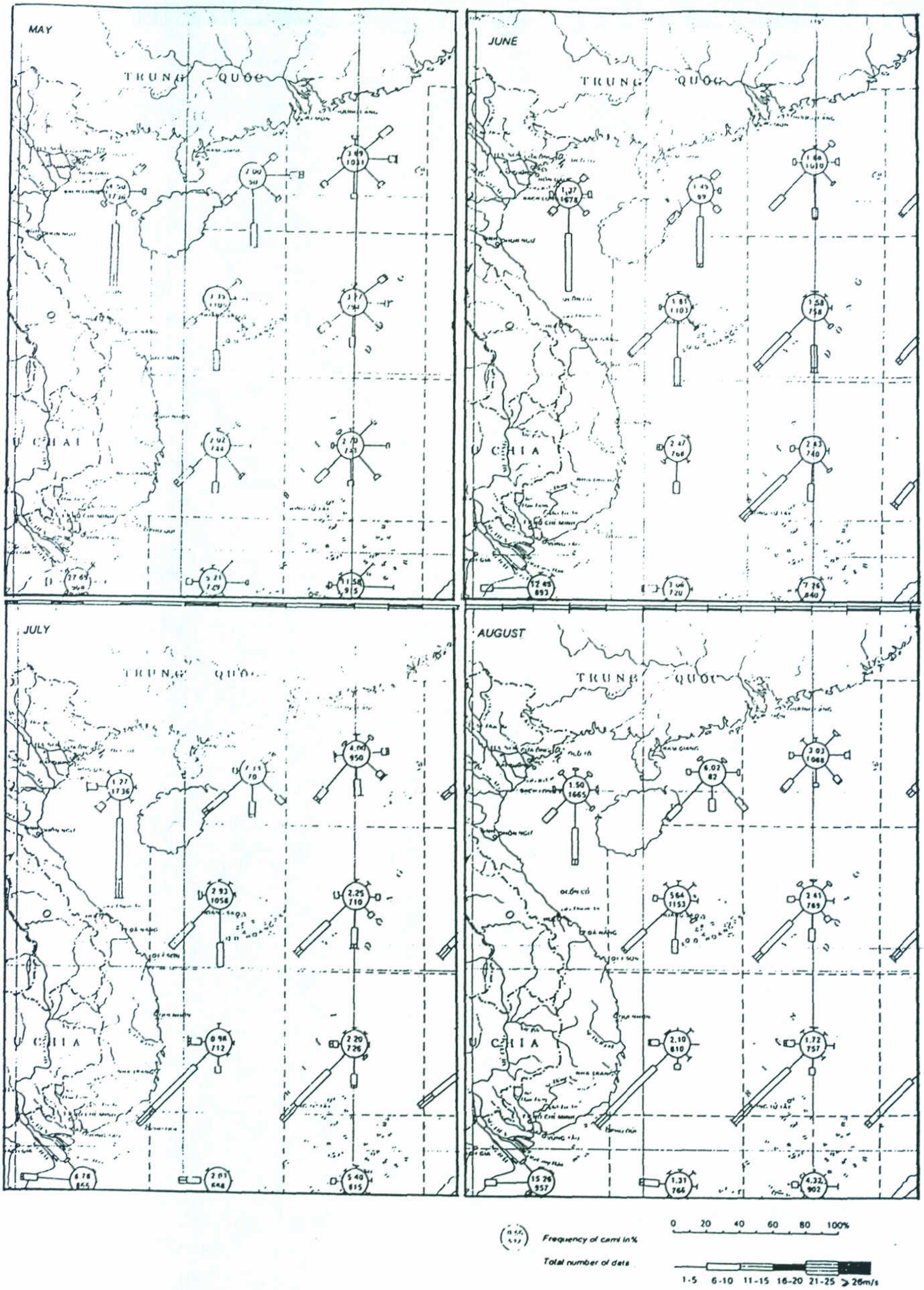


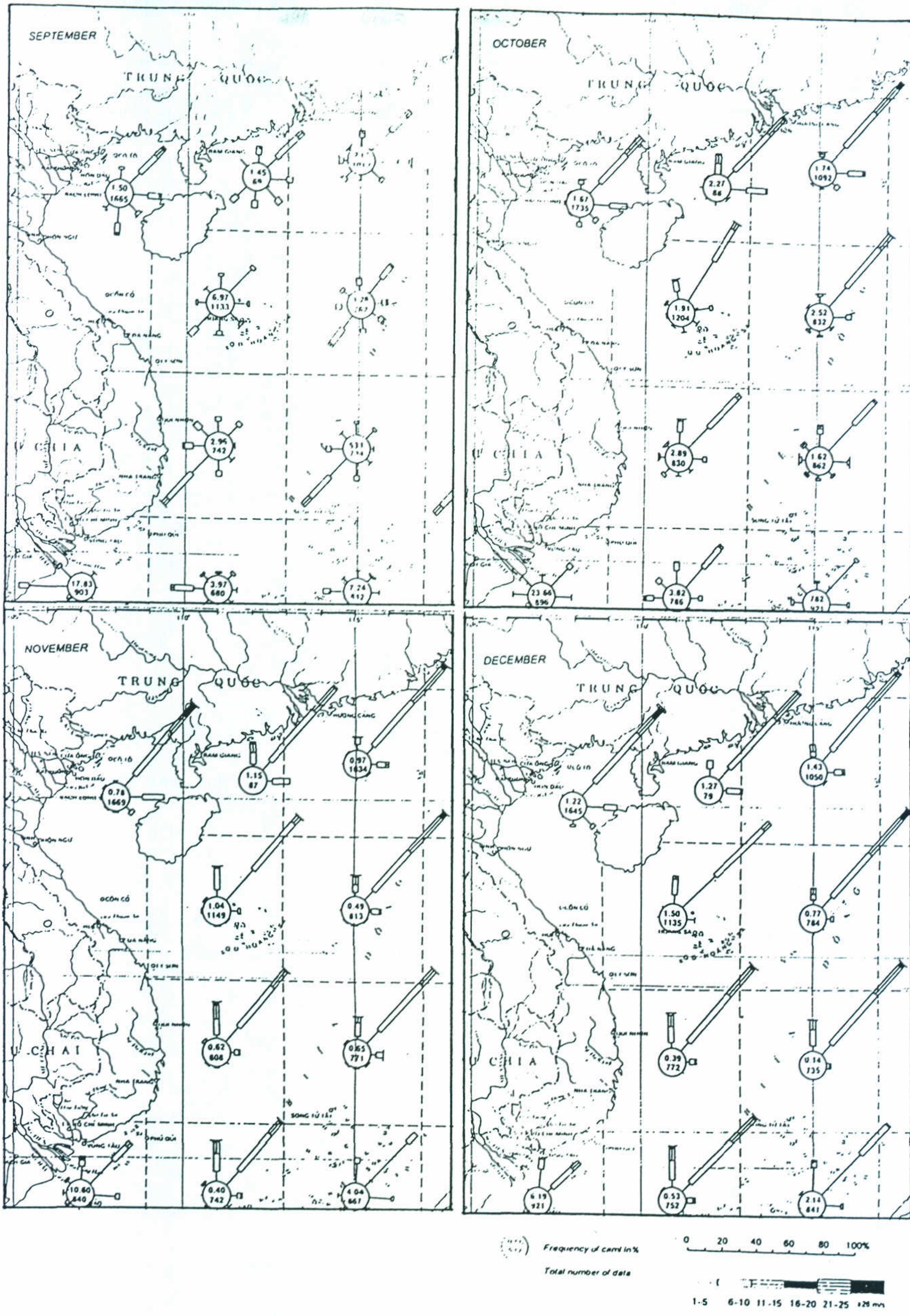

Figure 5.II
Wave roses in January



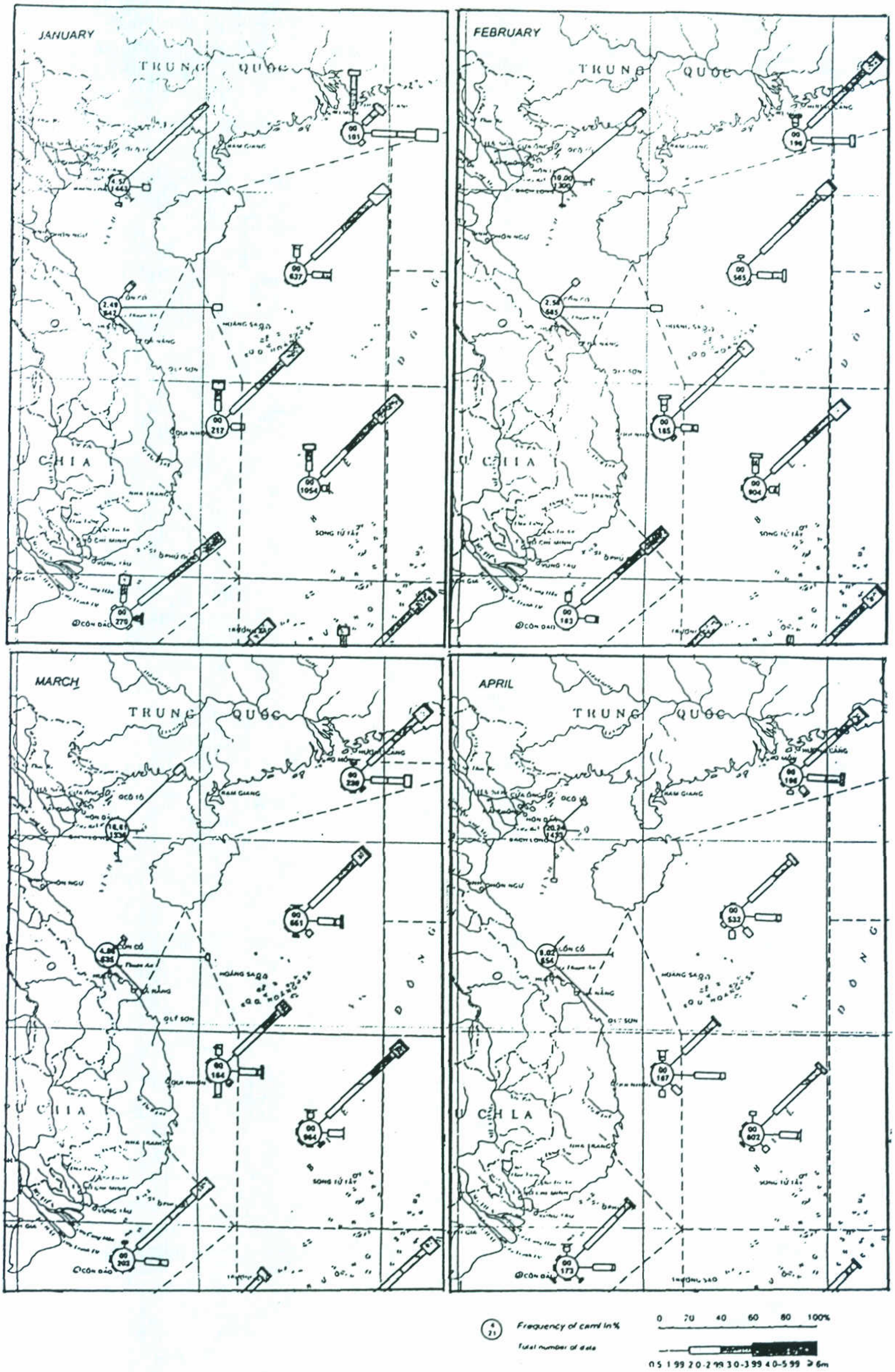

5.1.1 Monthly wind roses over the South China Sea - Vietnamese Meteorological Atlas (1994)
(a) months: January - April



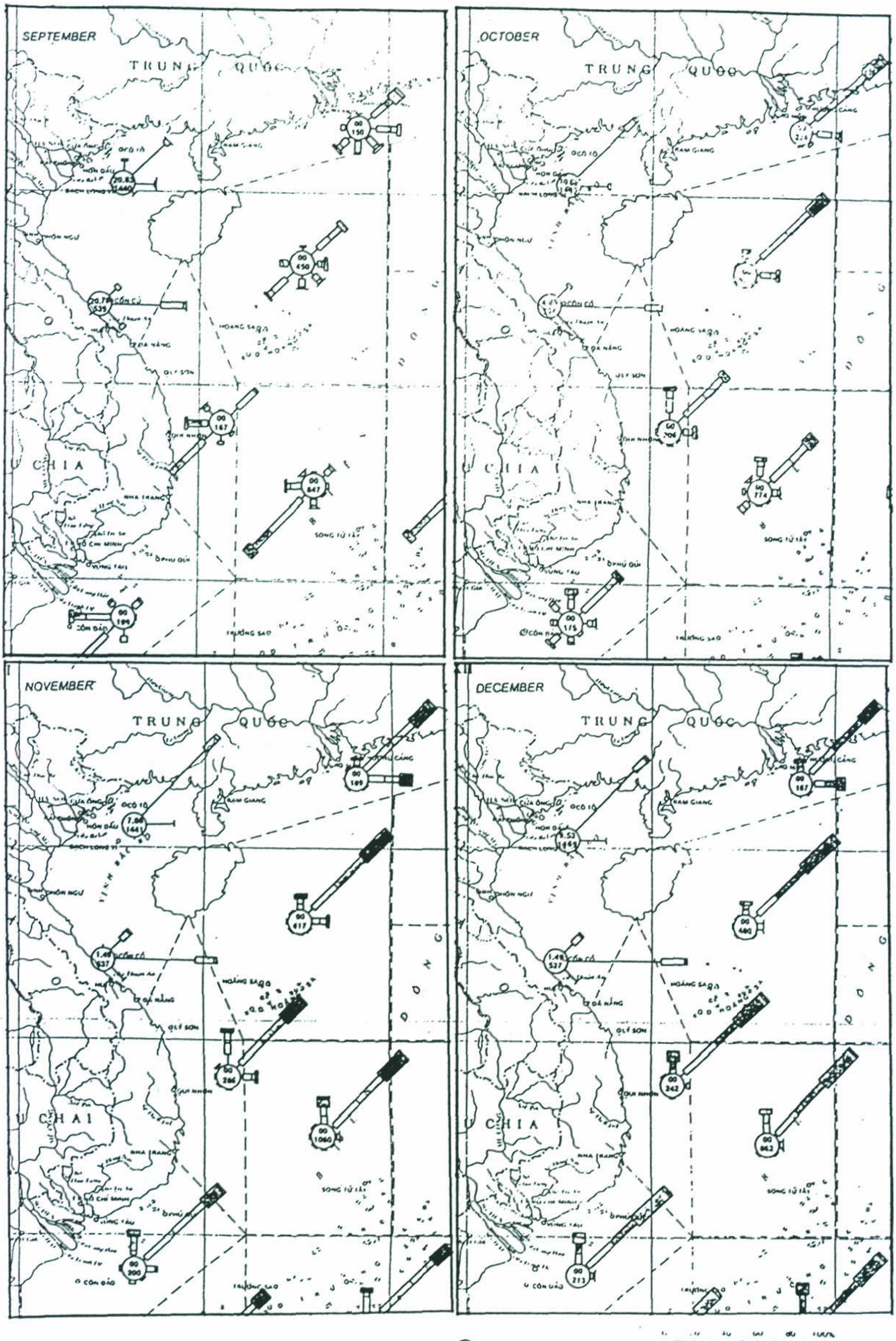

5.1.1 Monthly wind roses over the South China Sea - Vietnamese Meteorological Atlas (1994)
(b) months: May - August



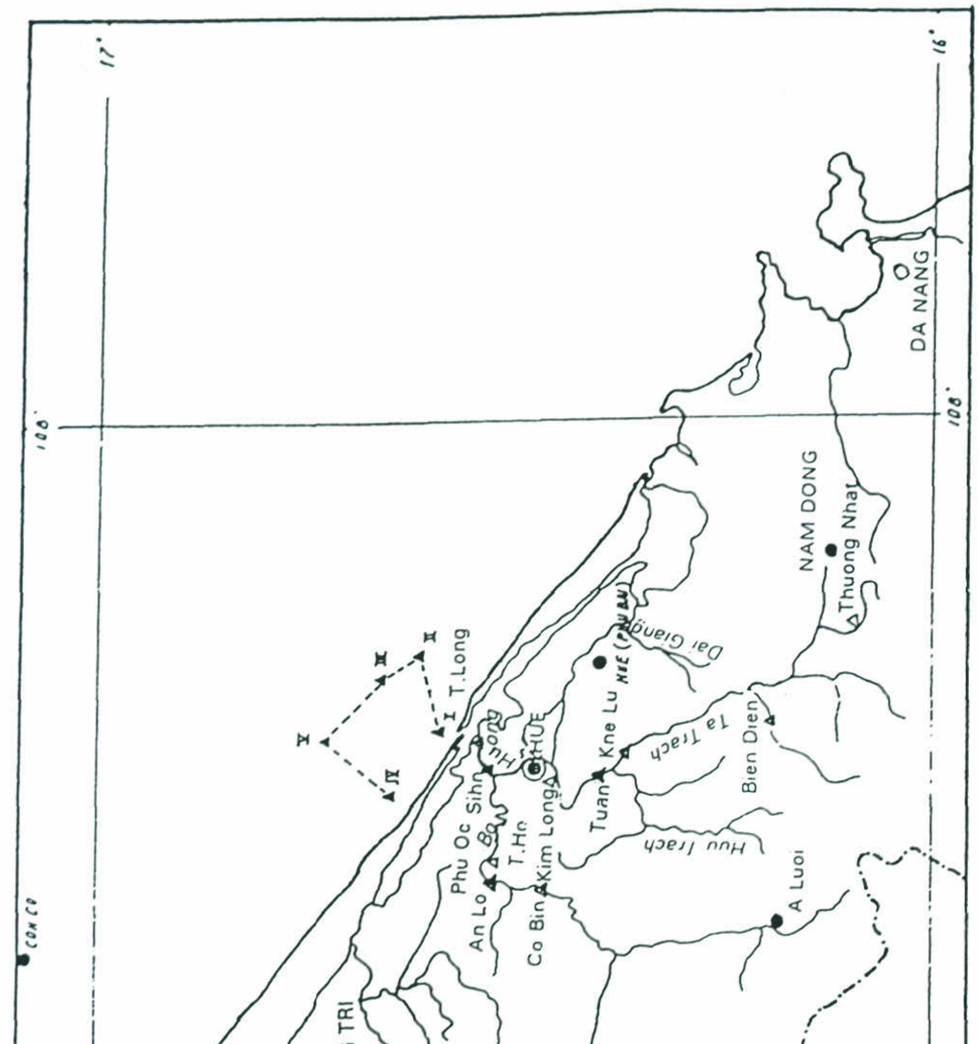

5.1.1 Monthly wind roses over the South China Sea - Vietnamese Meteorological Atlas (1994)
(c) months: September - December



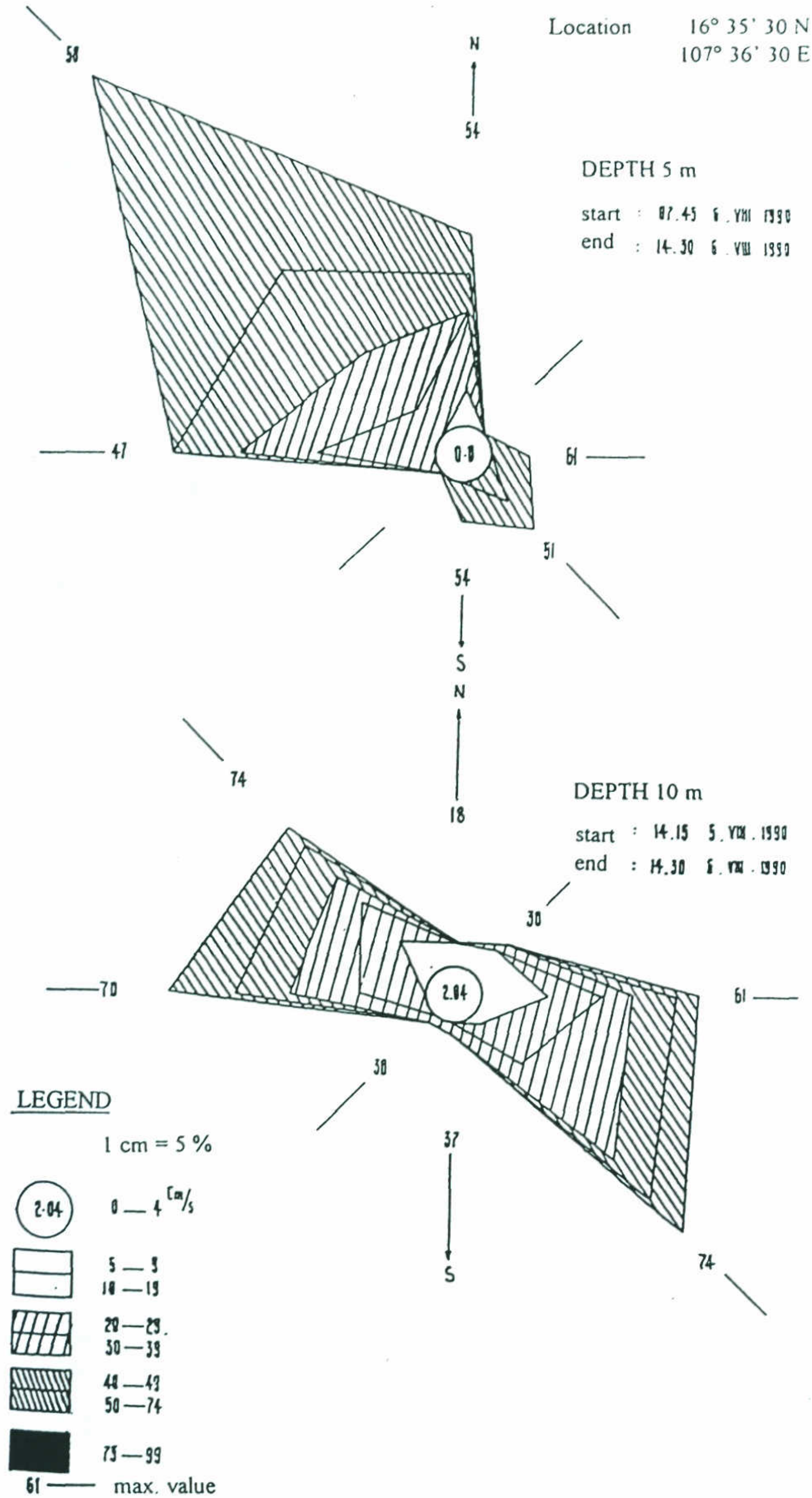

5.1.2 Monthly wave roses over the South China Sea - Vietnamese Meteorological Atlas (1994)
(a) months: January - April



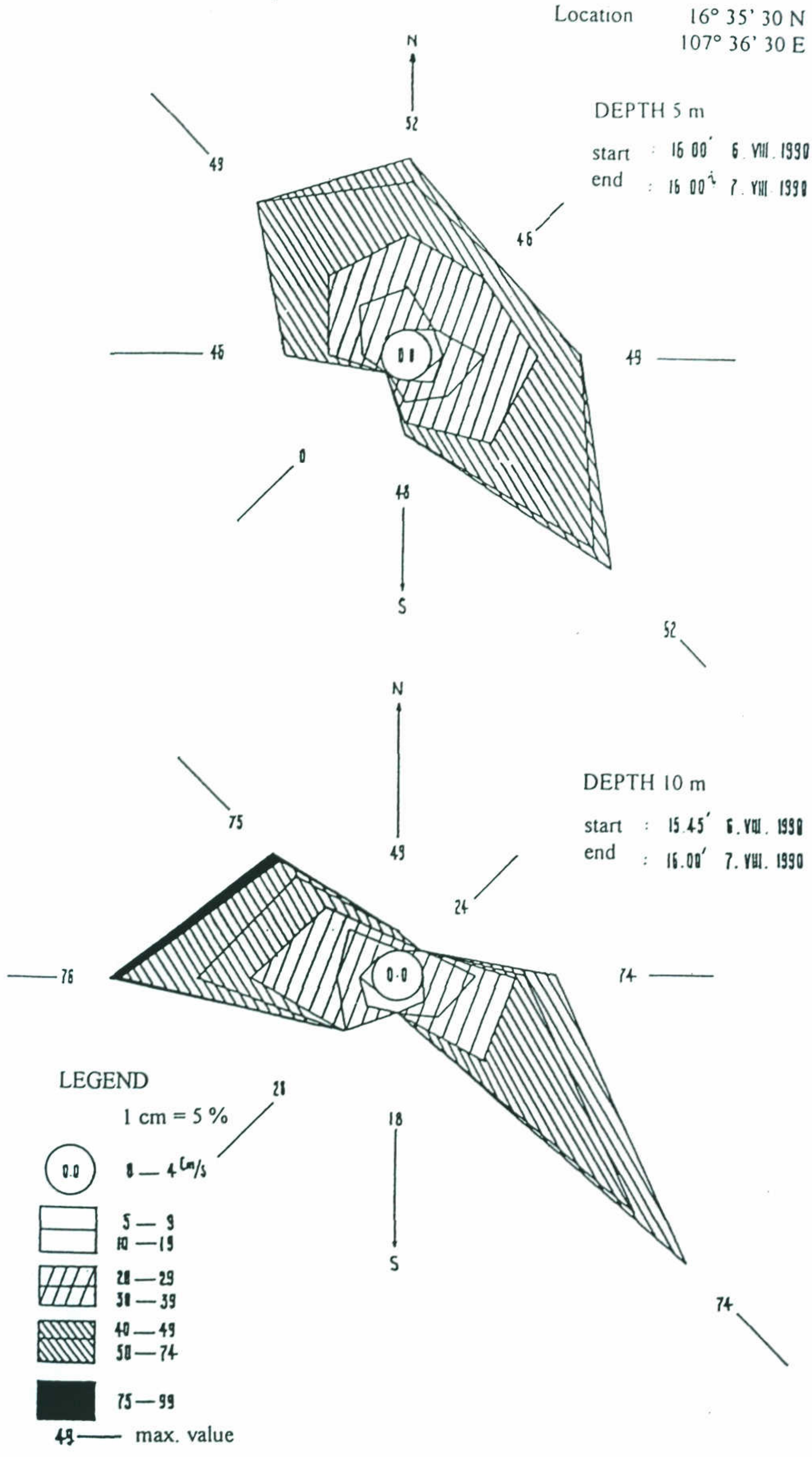

5.1.2 Monthly wave roses over the South China Sea - Vietnamese Meteorological Atlas (1994)
(c) months: September - December



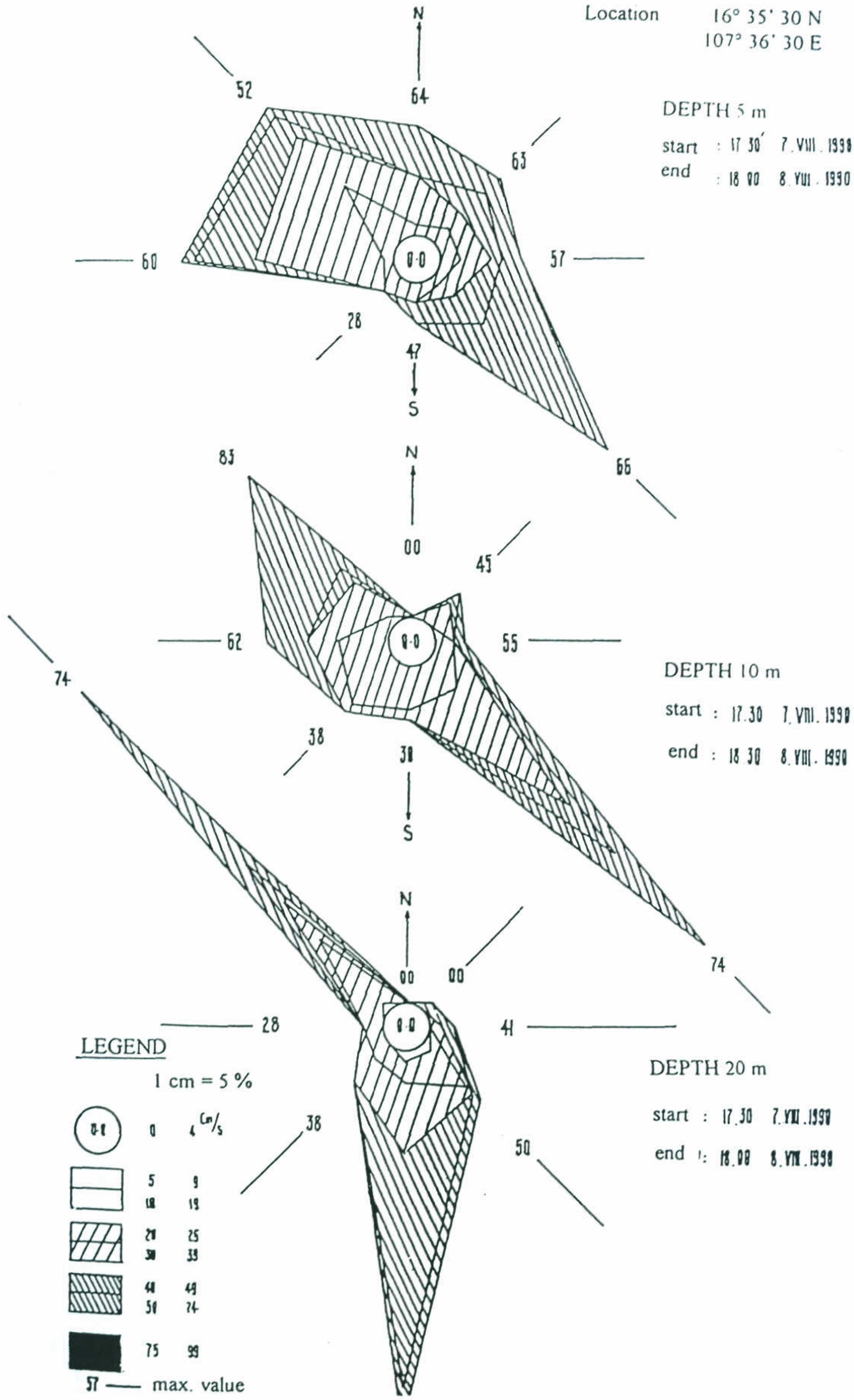

5.1.3 Map with the river system merging Tam Giang - Cau Hai lagoon and location of stations



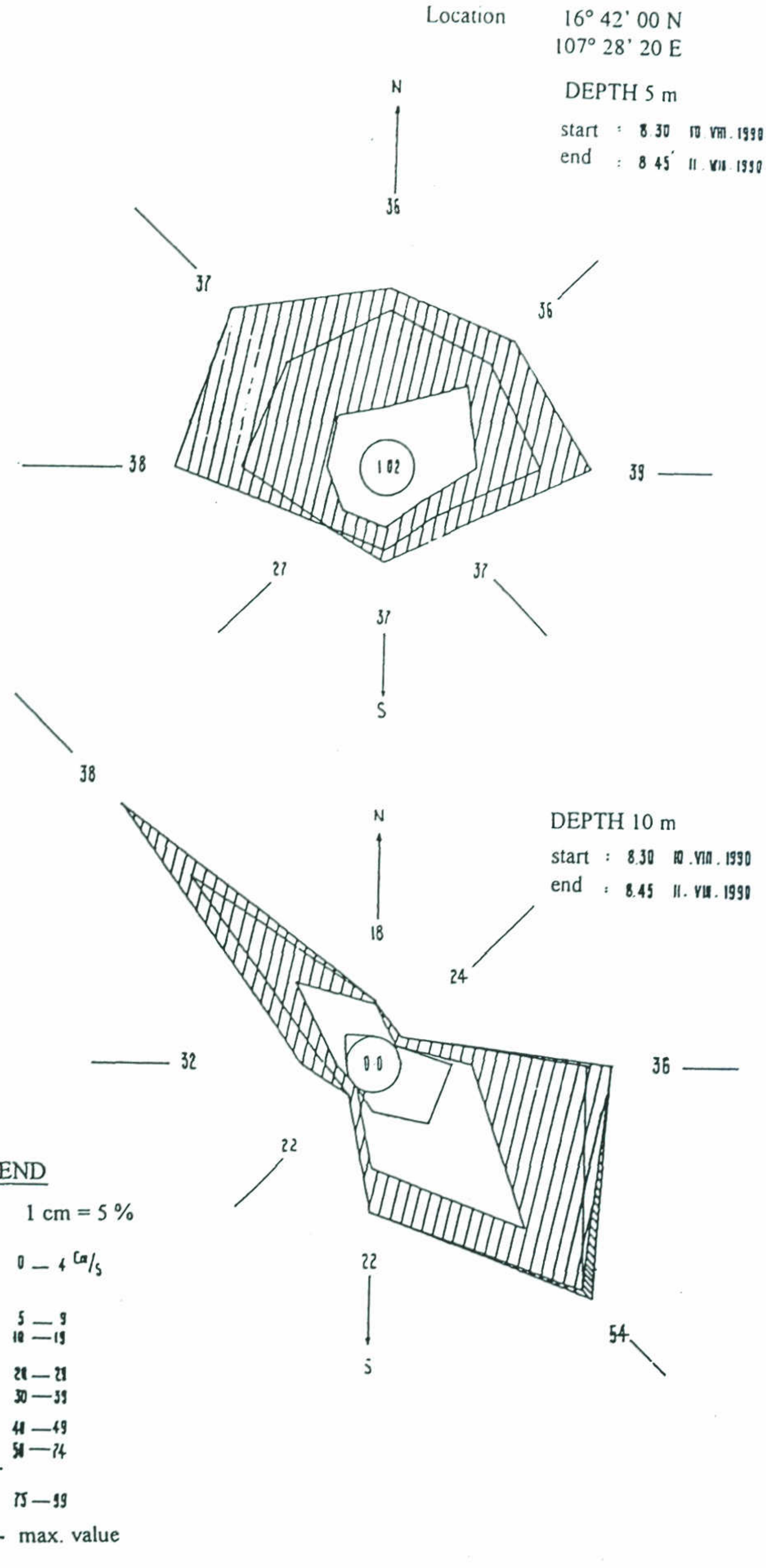

5.1.4 Current rose at station I (Thuan An)



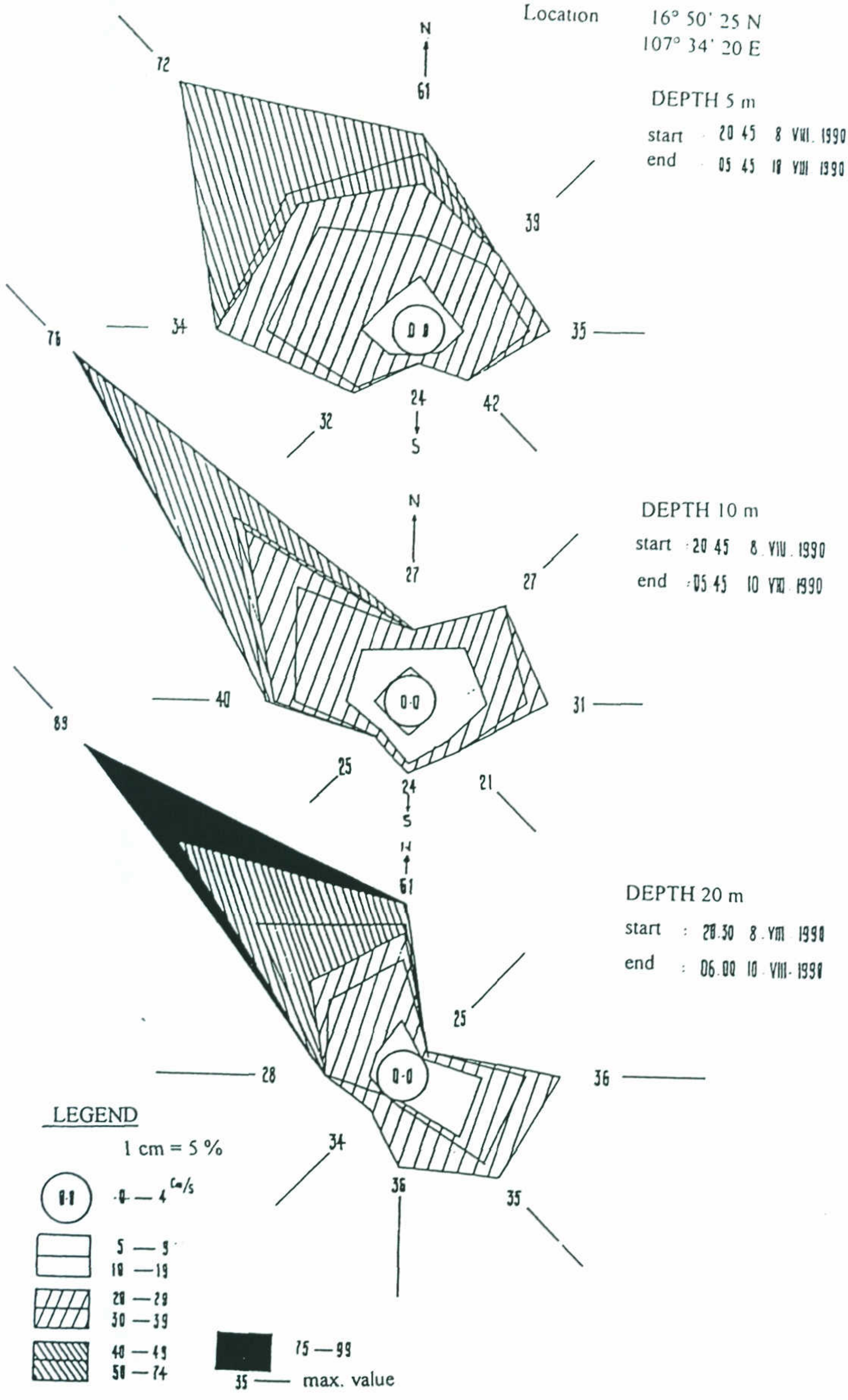

5.1.5 Current rose at station II



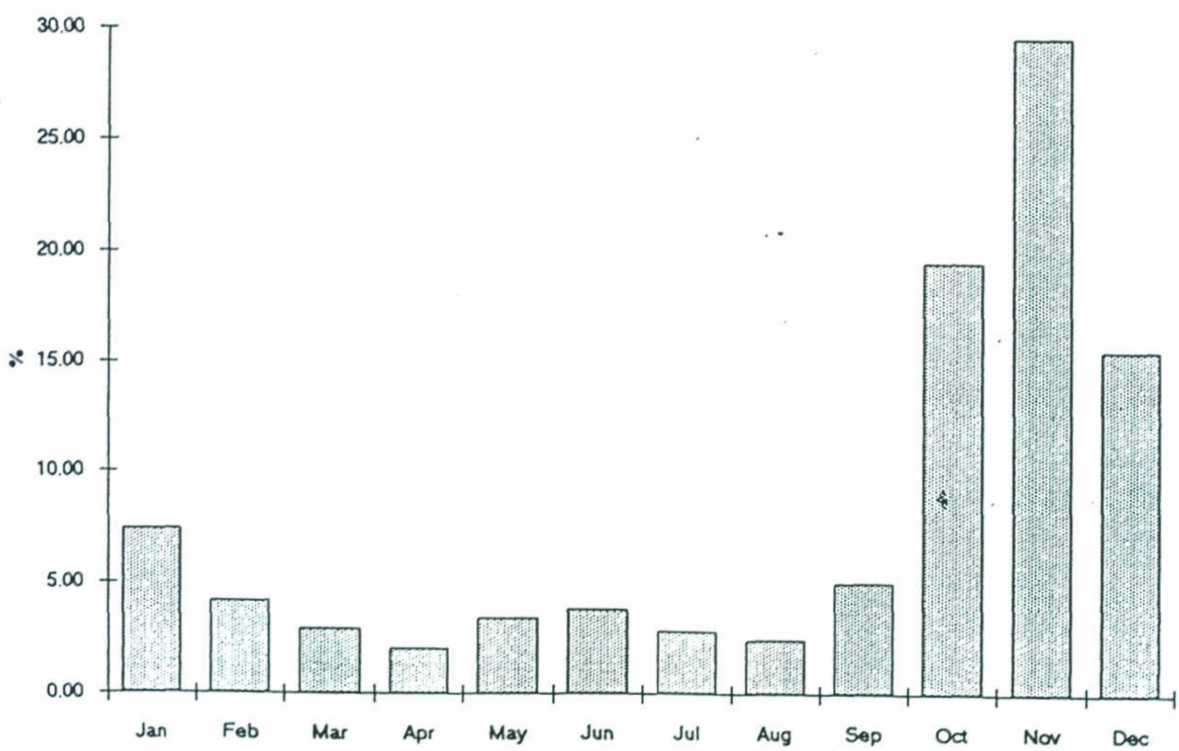

5.1.6 Current rose at station III



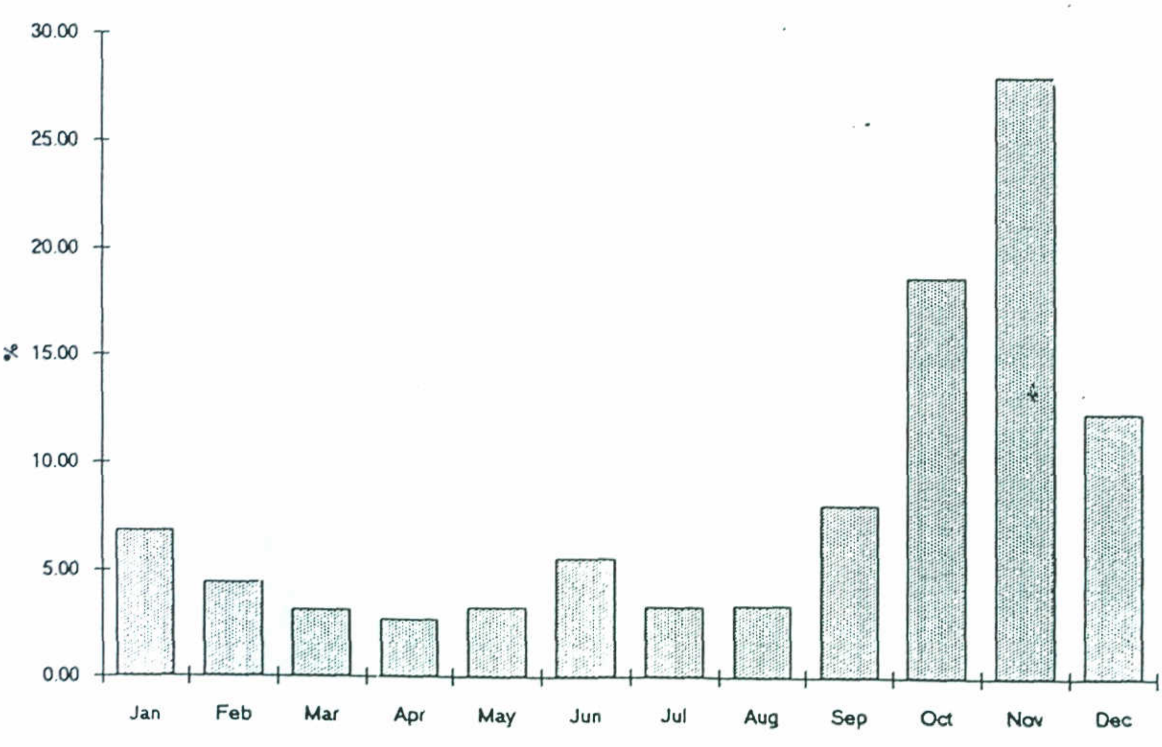

5.1.7 Current rose at station IV



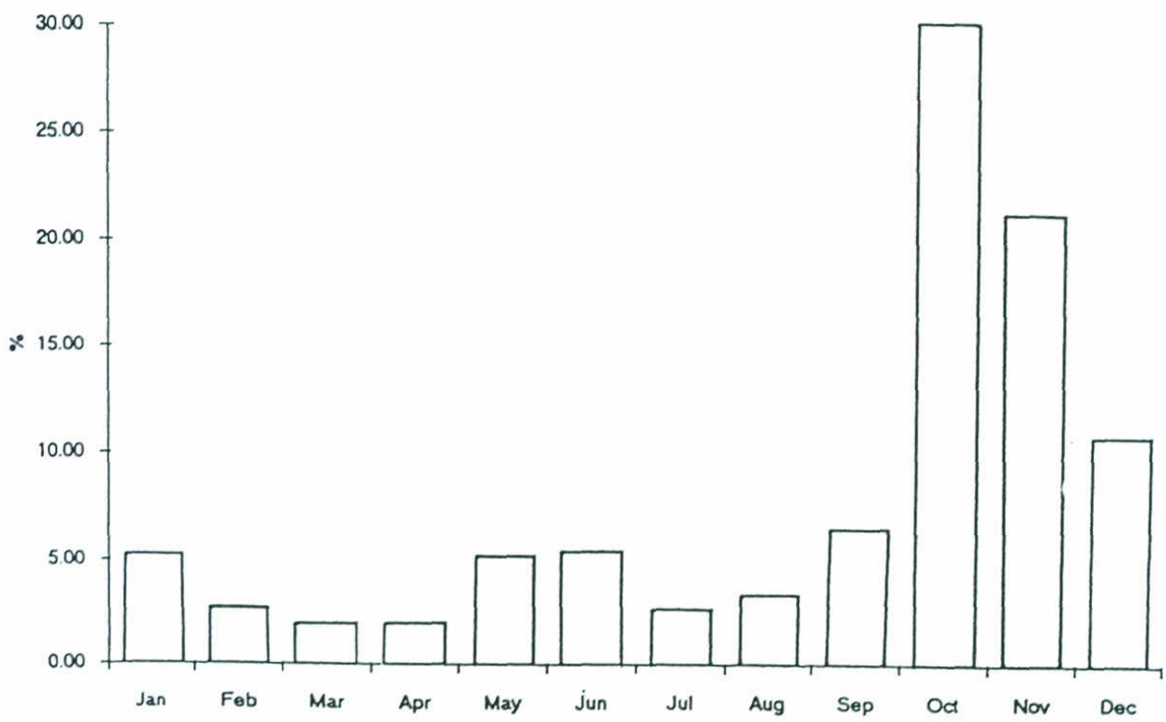

5.1.8 Current rose at station V



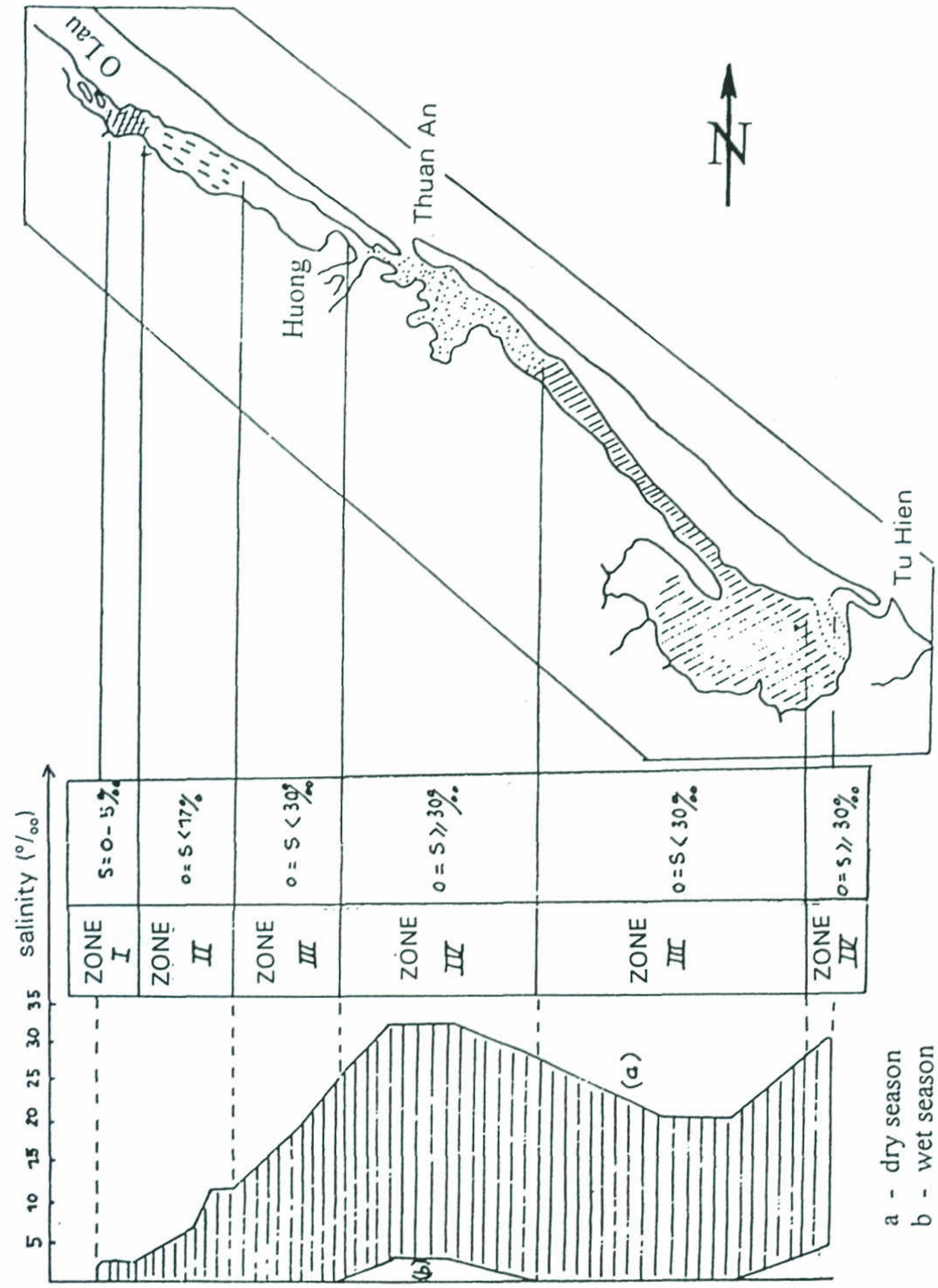

5.2.1 Flow distribution within the year at NongSon station



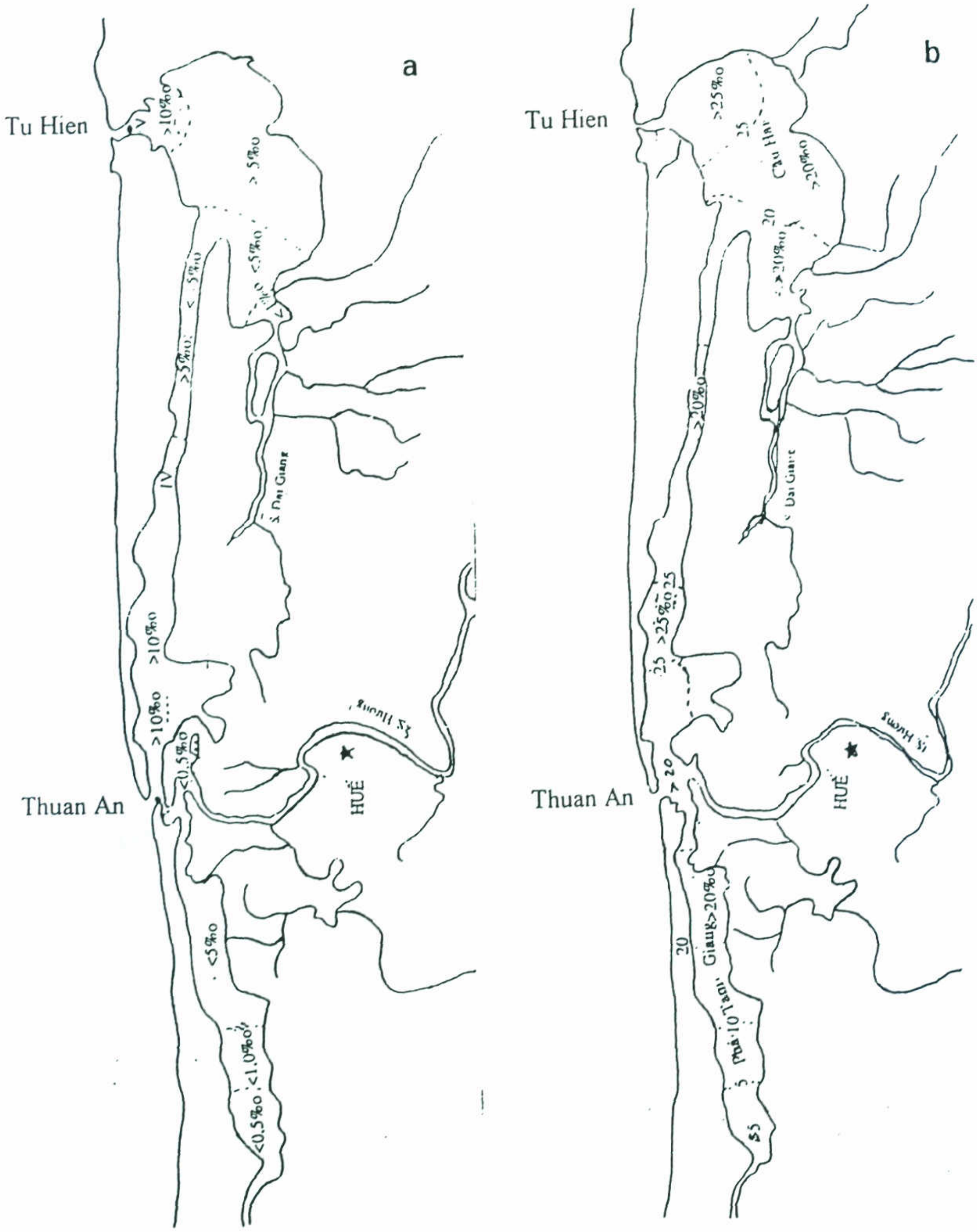

5.2.2 Flow distribution within the year at ThanhMy station



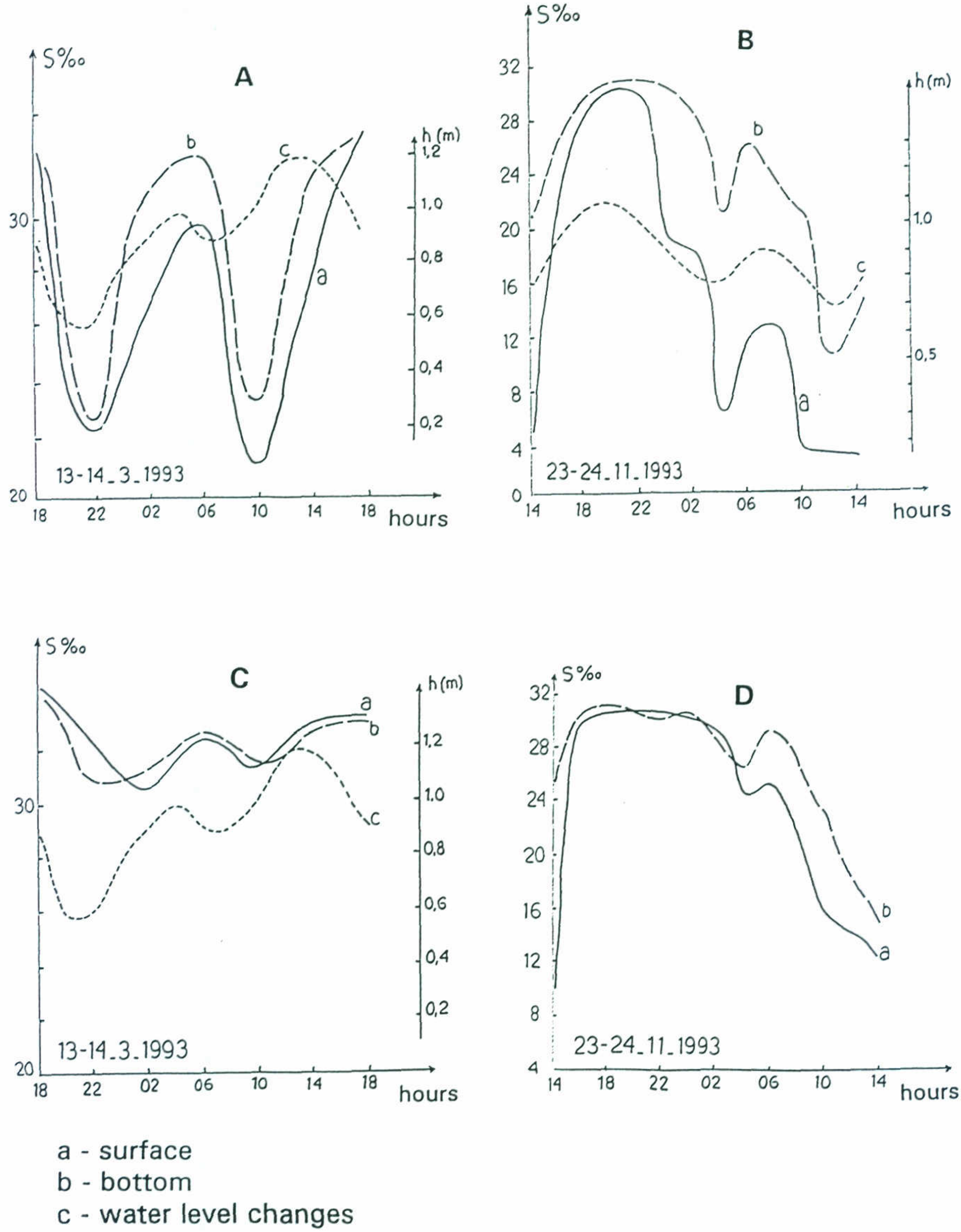

5.2.3 Flow distribution within the year at Thuong Nhat station



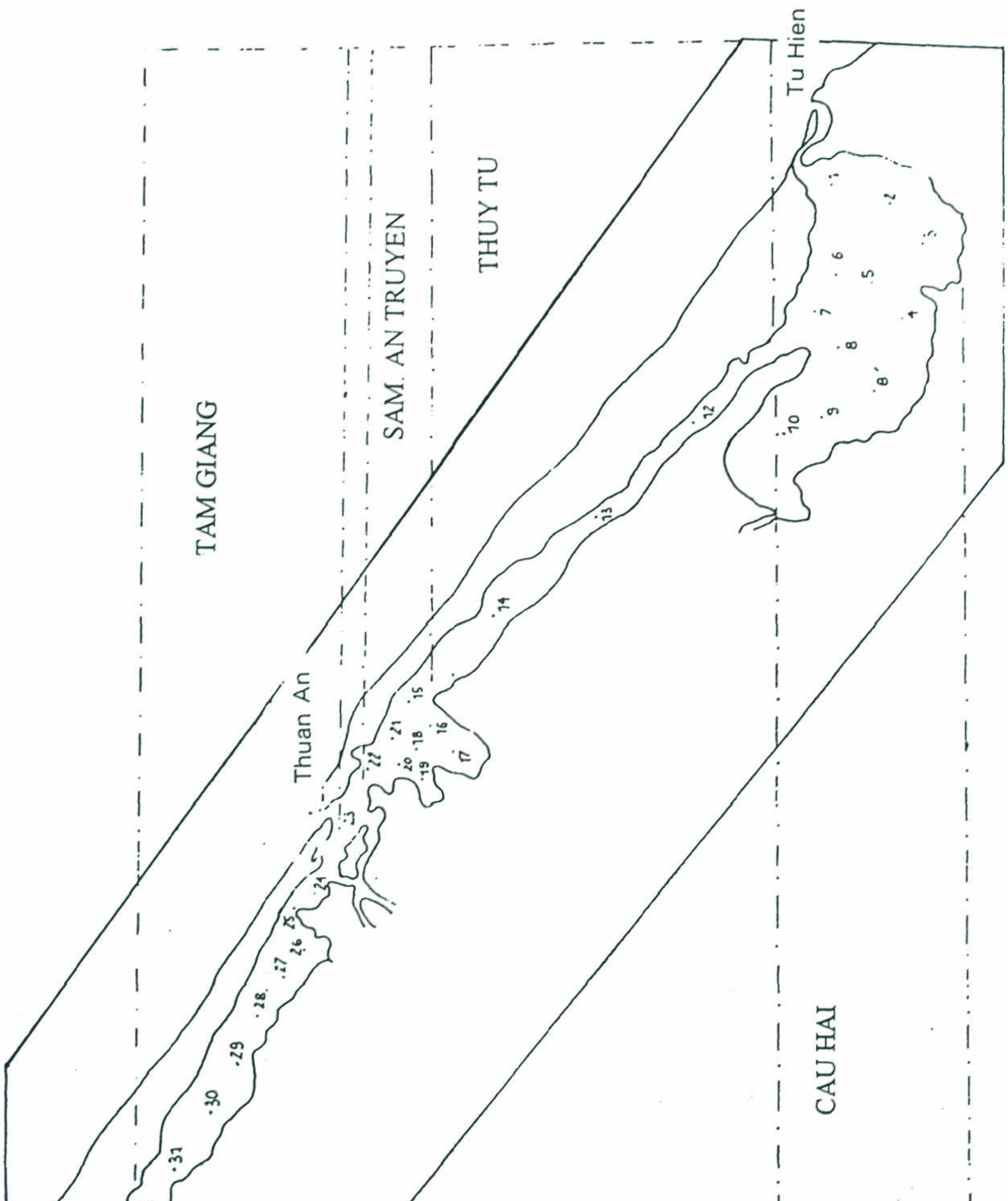

5.3.2.1 Salinity variation in Tam Giang - Cau Hai lagoon




5.3.2.2 Salinity distribution in Tam Giang - Cau Hai lagoon: (a) November 1993, (b) March 1993




5.3.2.3 Salinity distribution in Thuan An inlet: (A) dry season, (B) wet season, and Tu Hien inlet (C) dry season, (D) wet season.

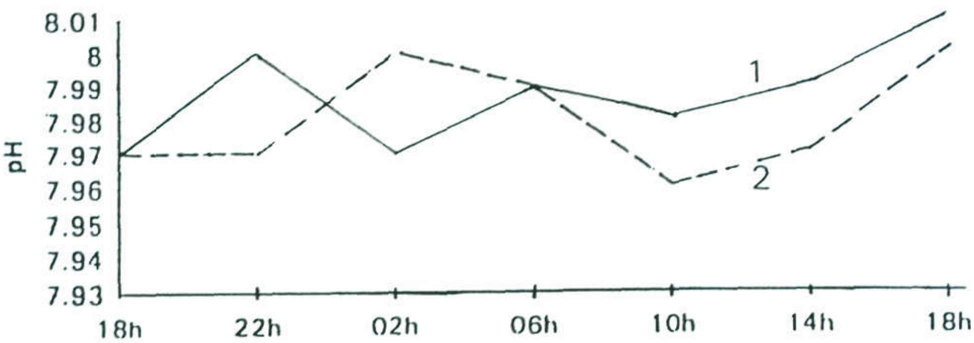



5.3.2.4 Location of stations shown in Tabs 5.3.2.1- 5.3.2.6


5.3.3.1 Spatial distribution of pH: (a) dry season of 1993, (b) wet season of 1993

(13 - 14/3/1993)

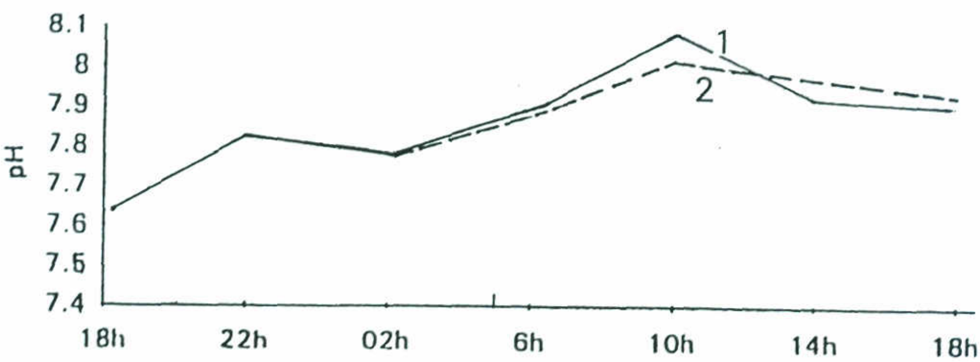
a




1 - surface 2 - bottom

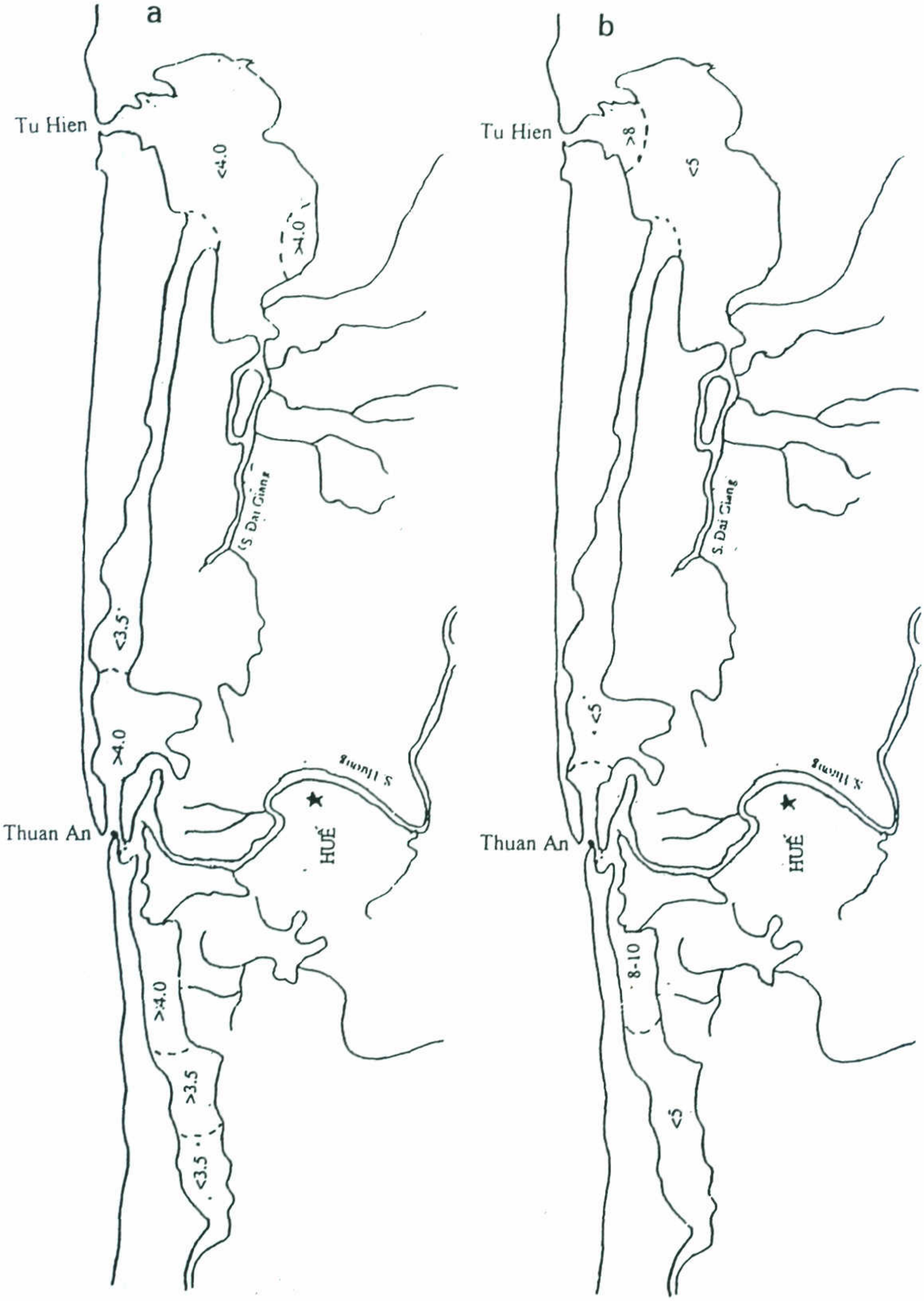
(13 - 14/3/1993)

b

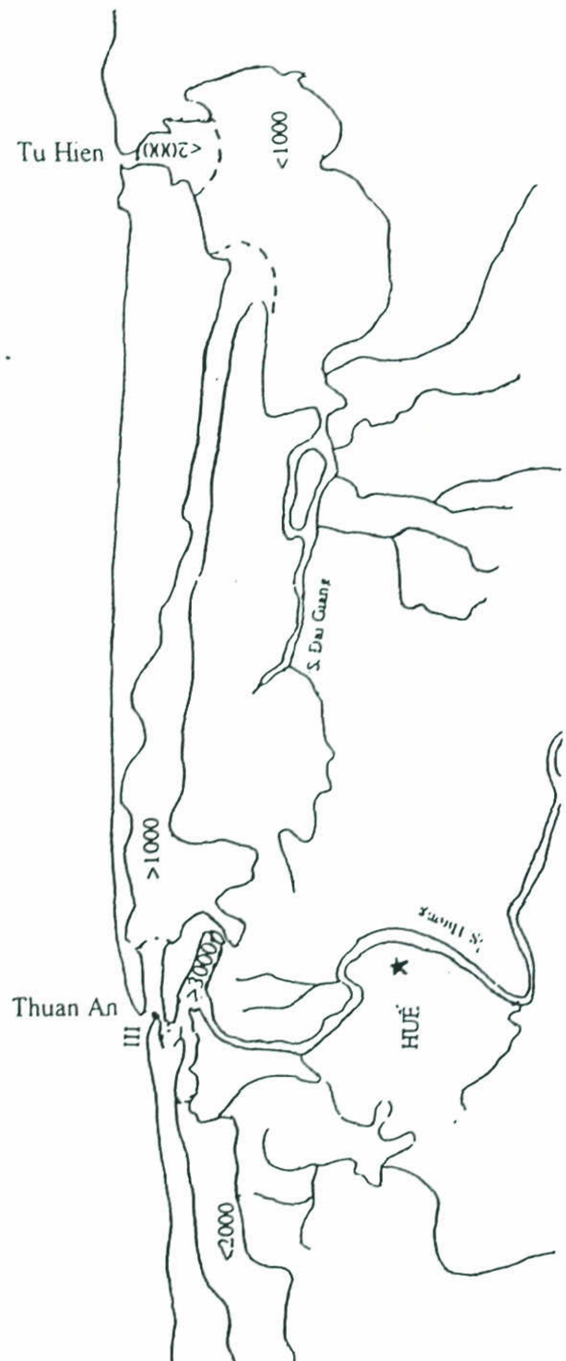



1 - surface 2 - bottom

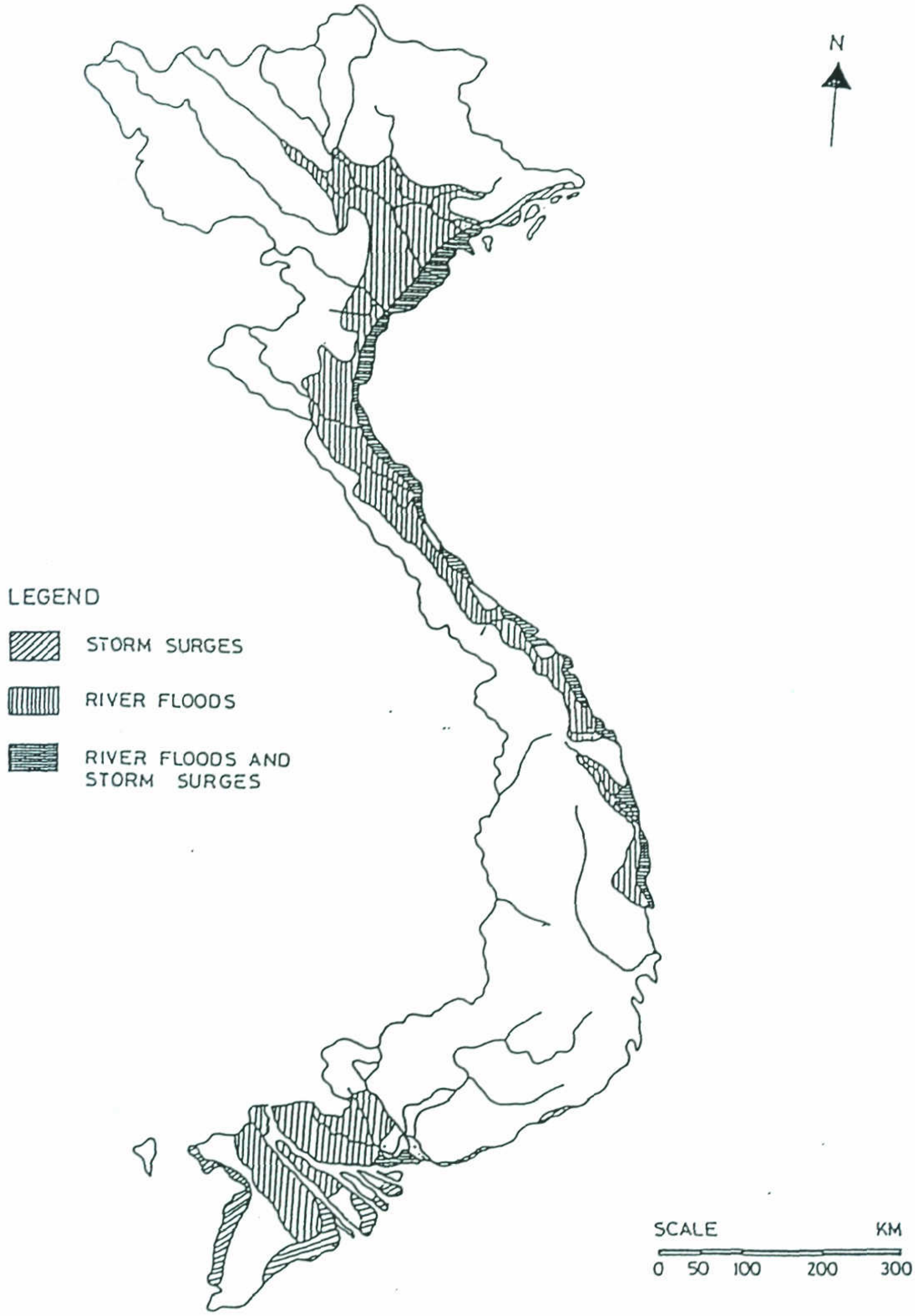
5.3.3.2 Variation of surface and bottom concentration of pH within a day 13-14/3/1993: (a) Thuan An inlet, (b) Tu Hien inlet



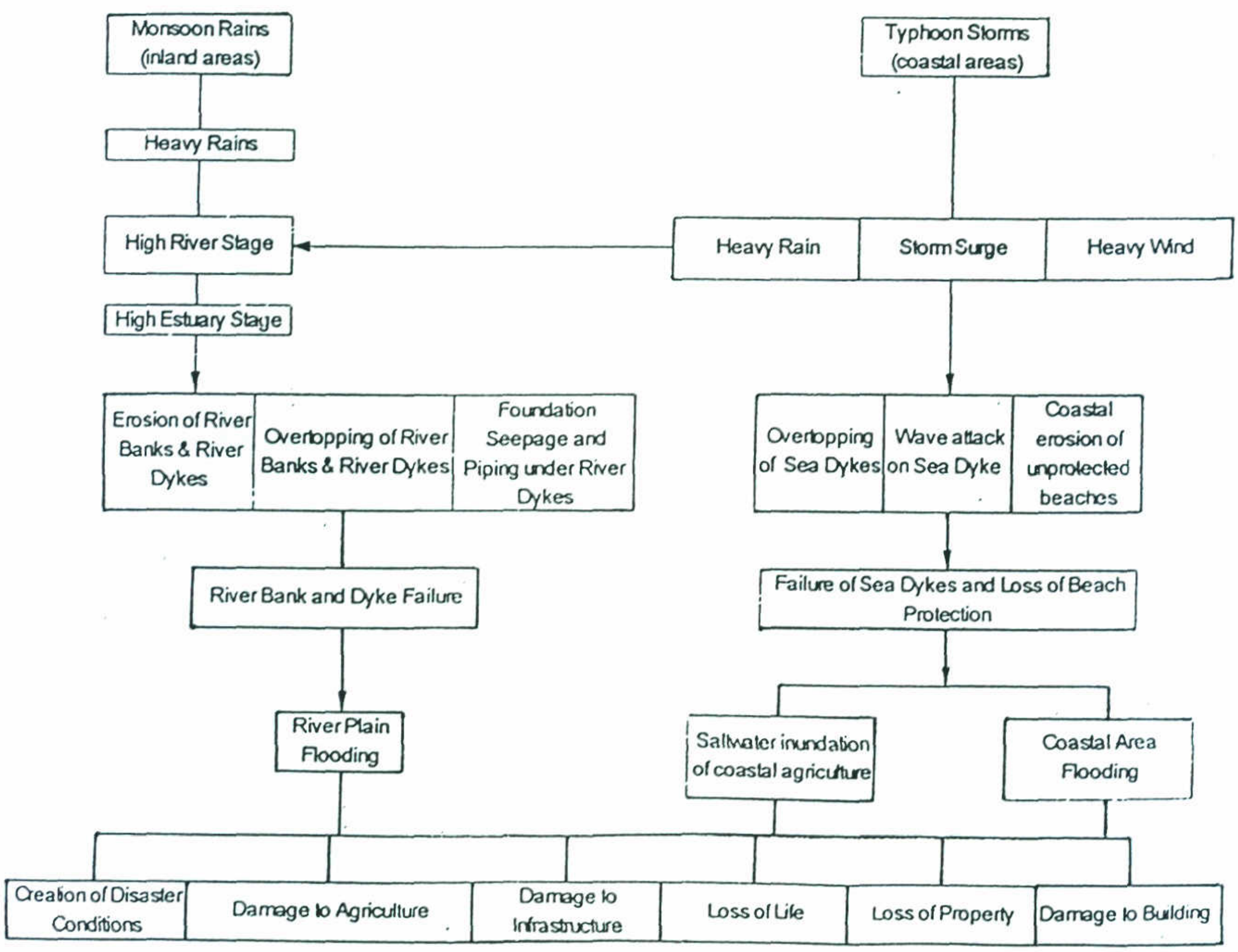

5.3.3.3 Spatial distribution of $PO_4$: (a) dry season of 1993, (b) wet season 1993




5.3.3.4 Spatial distribution of $SiO_2$ in dry season of 1993




6.1.1 Areas subject to flooding in Vietnam




### 6.1.2 Sources of flooding in Vietnam

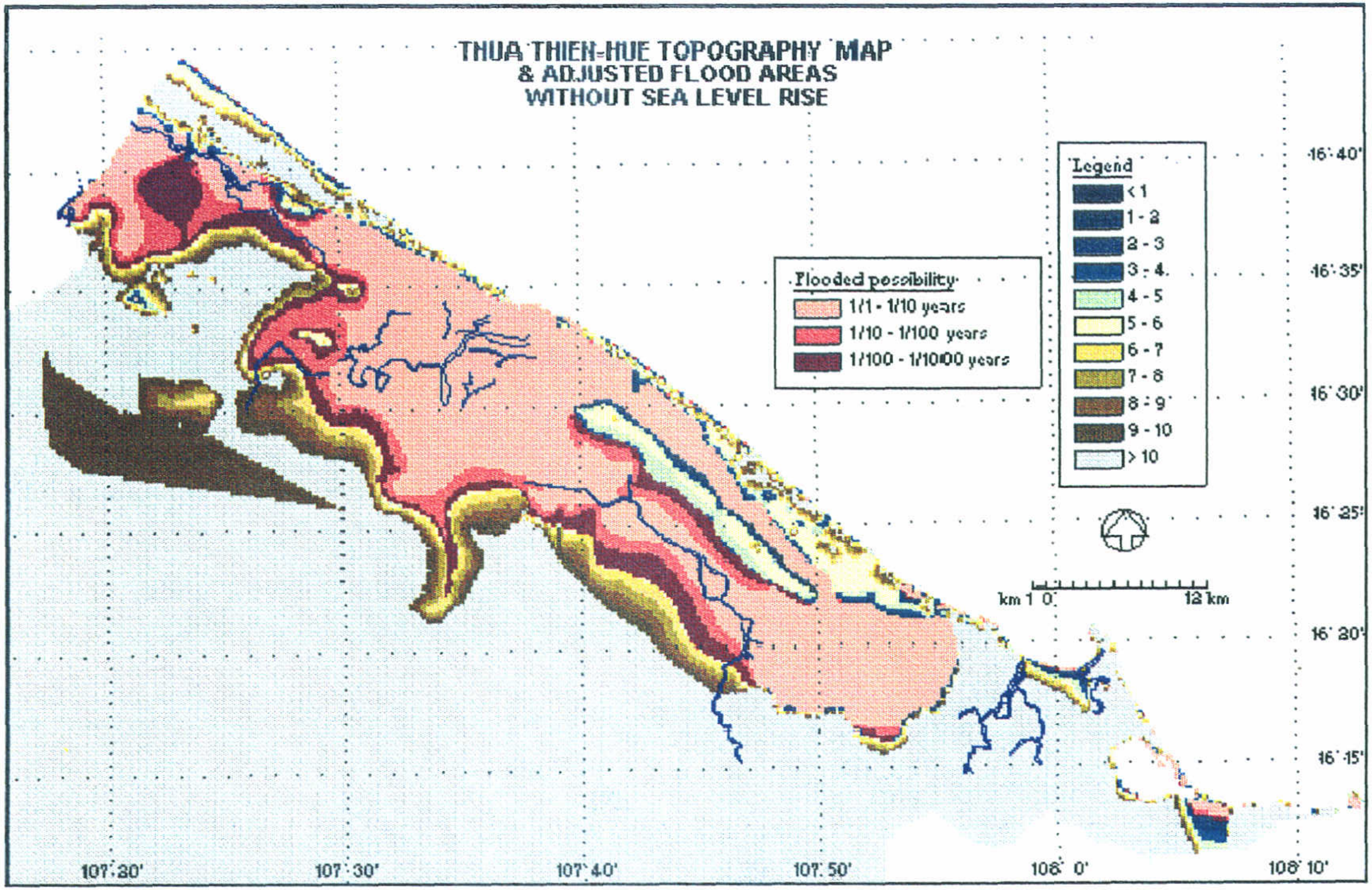



Figure 6.1.3 Thua Thien Hue Flooding

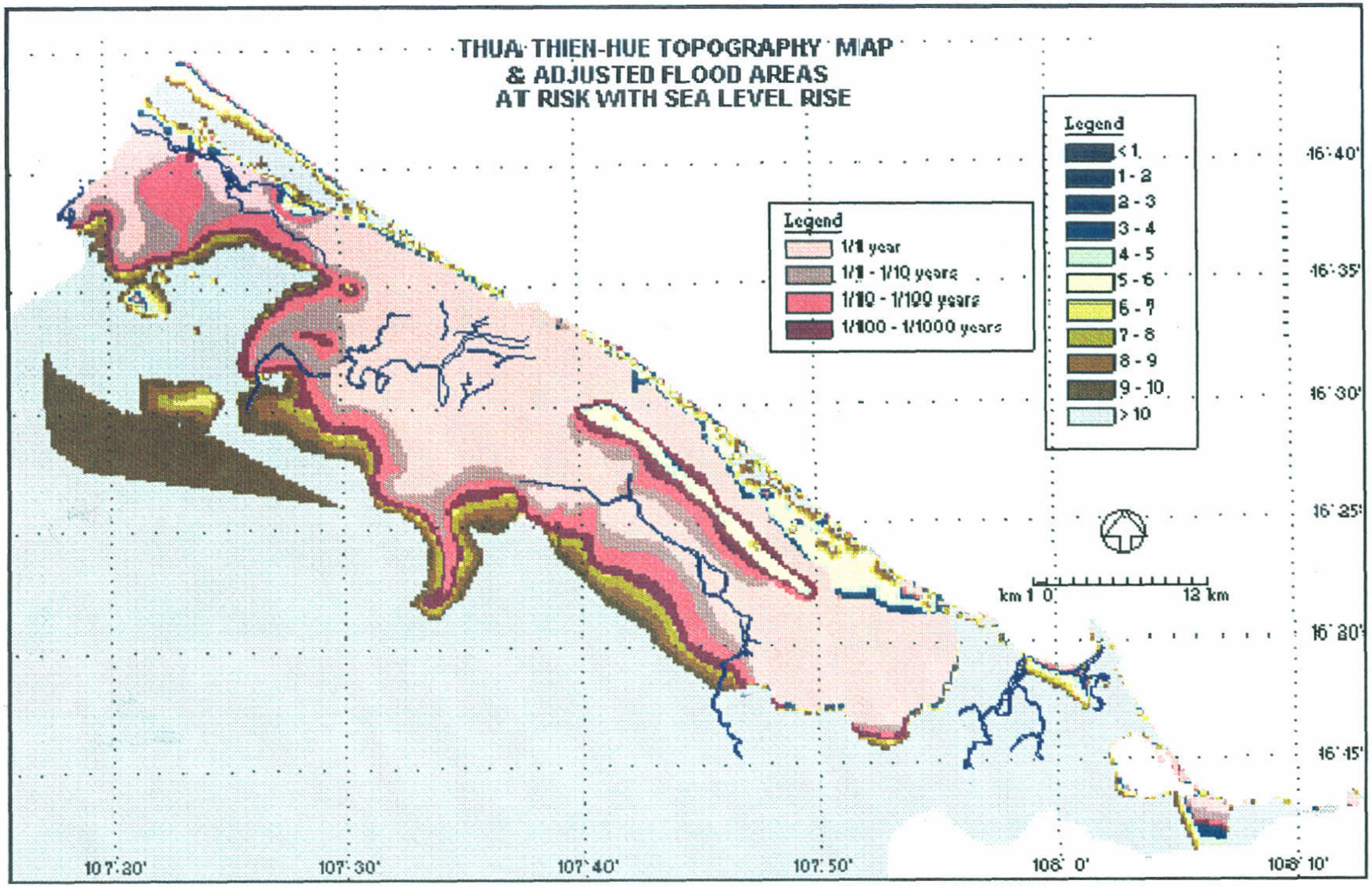



Figure 6.1.4 Thua Thien Hue Flooding

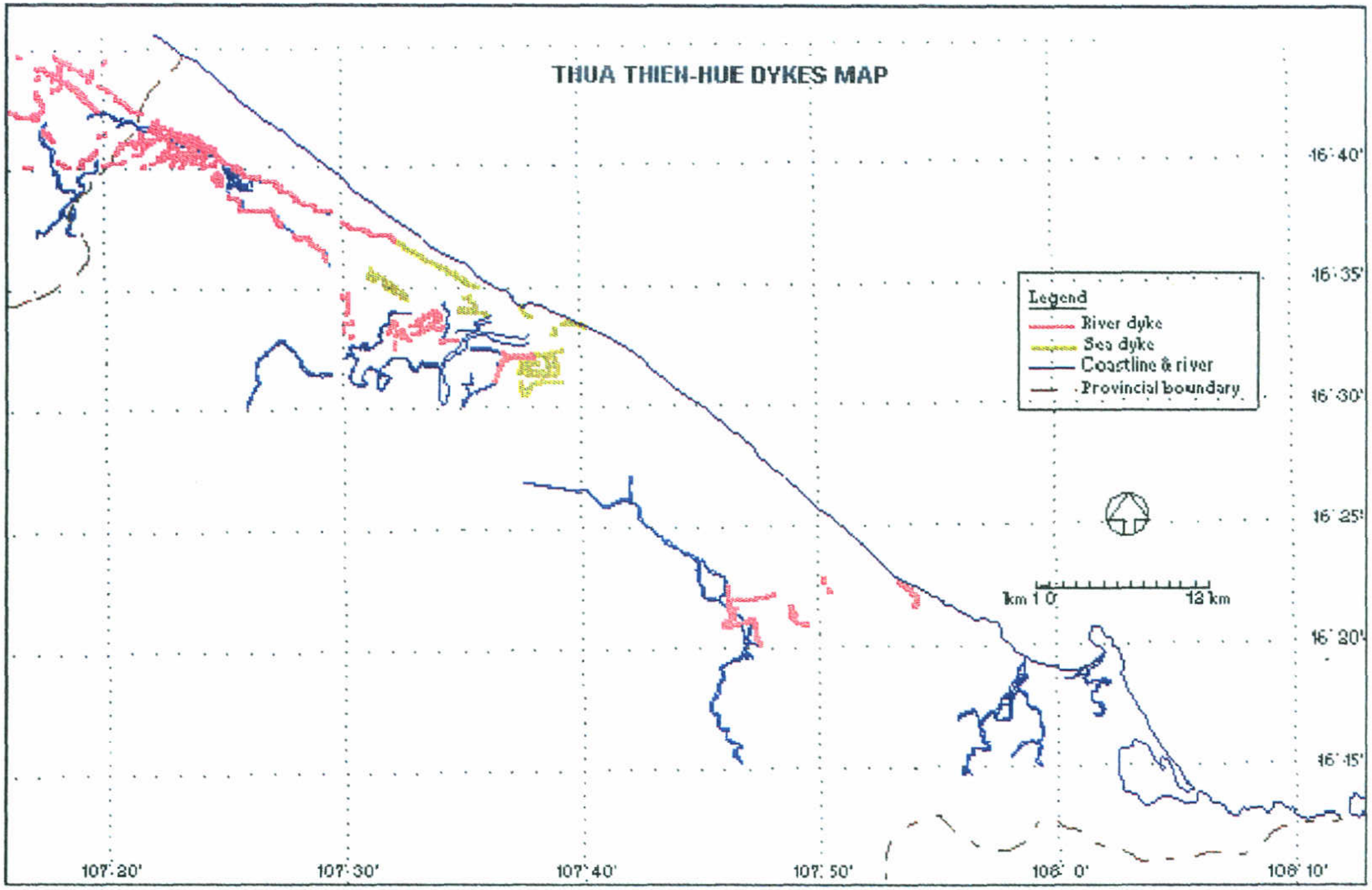
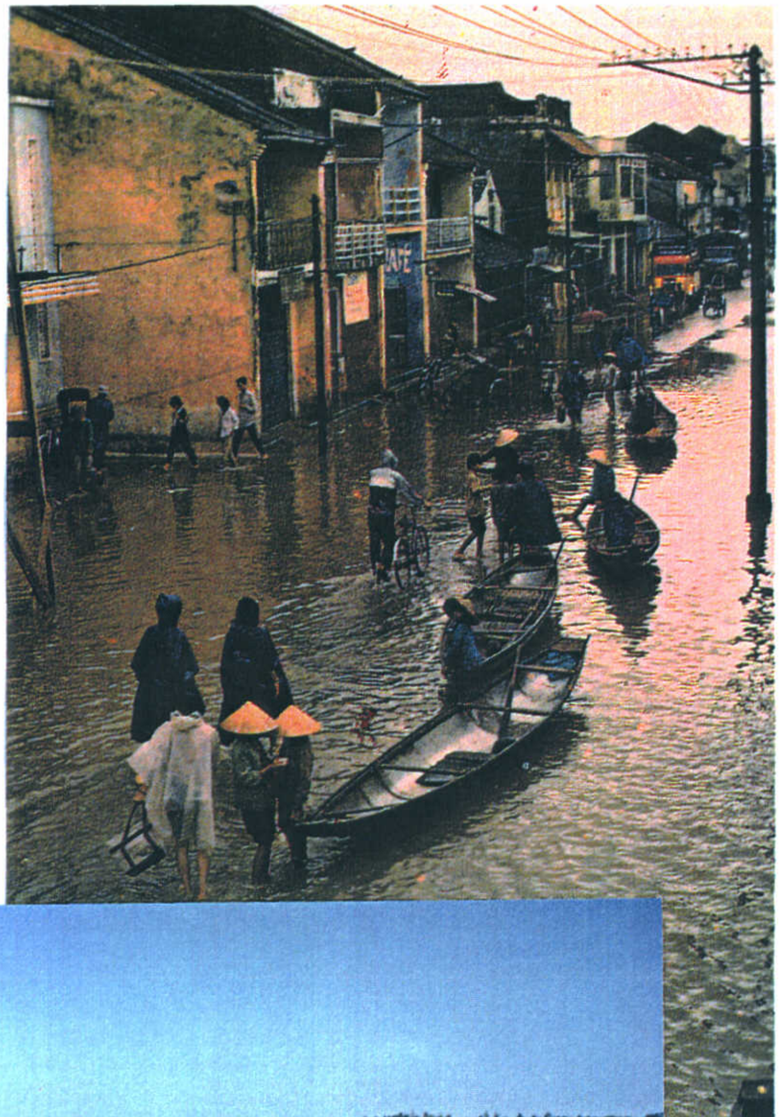



Figure 6.1.5 TTH Dykes (GIS/GMS)

## HUE FLOOD




**Flood control barrier preventing flood waters from entering Tam Giang**

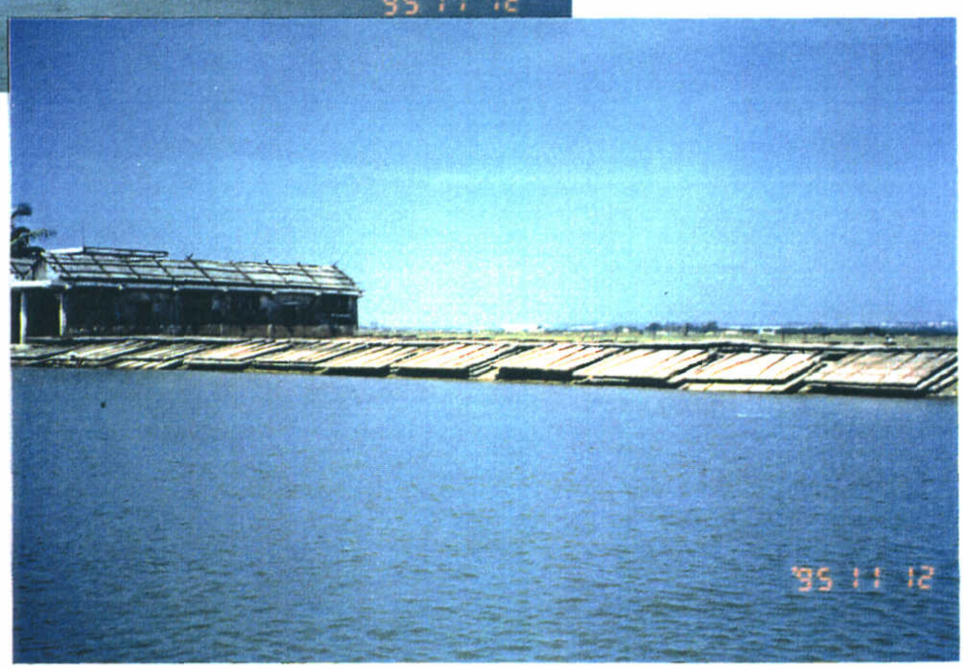



Figure 6.1.6

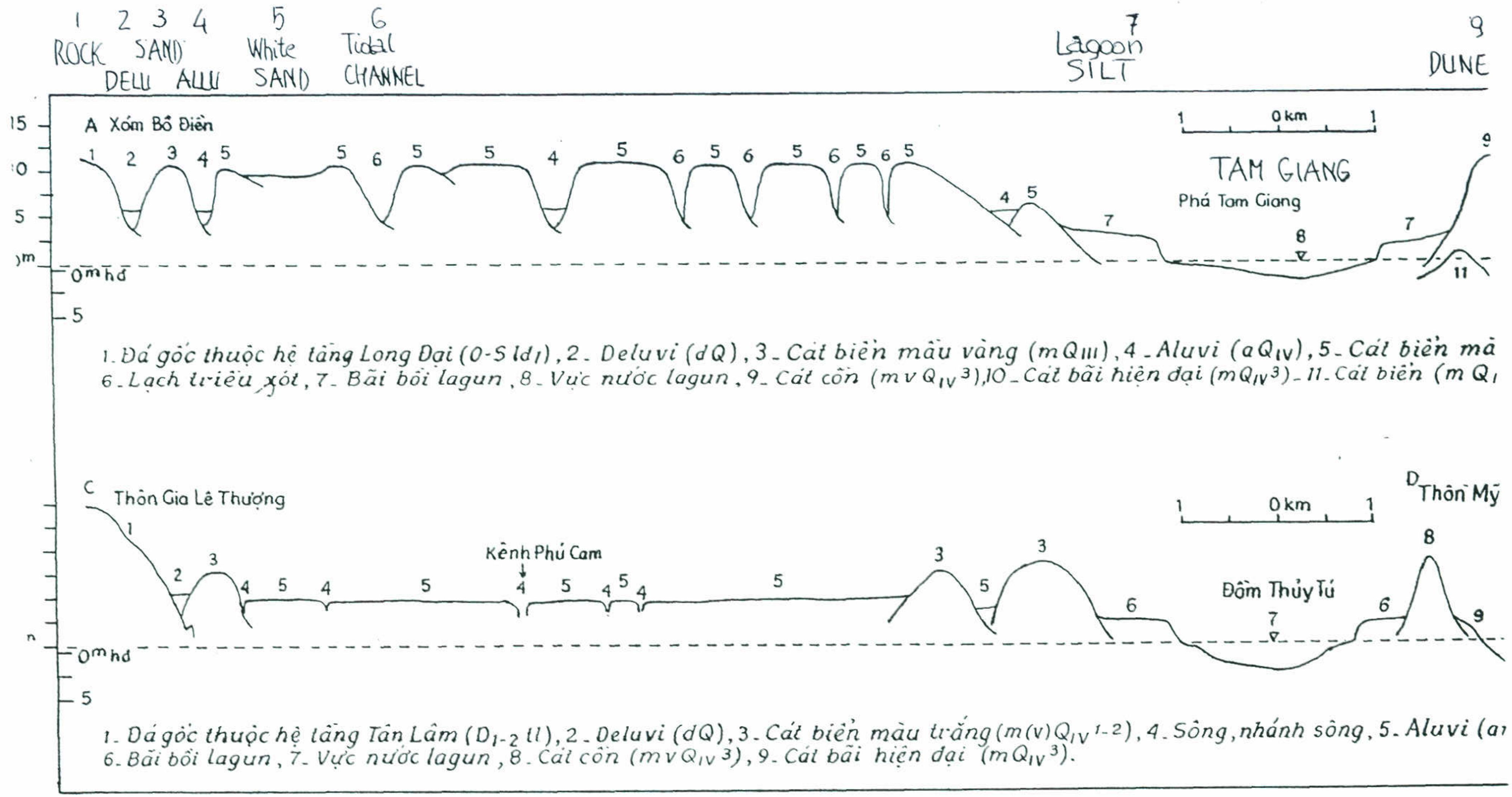



Figure 7.1 TG–CH Stratigraphy

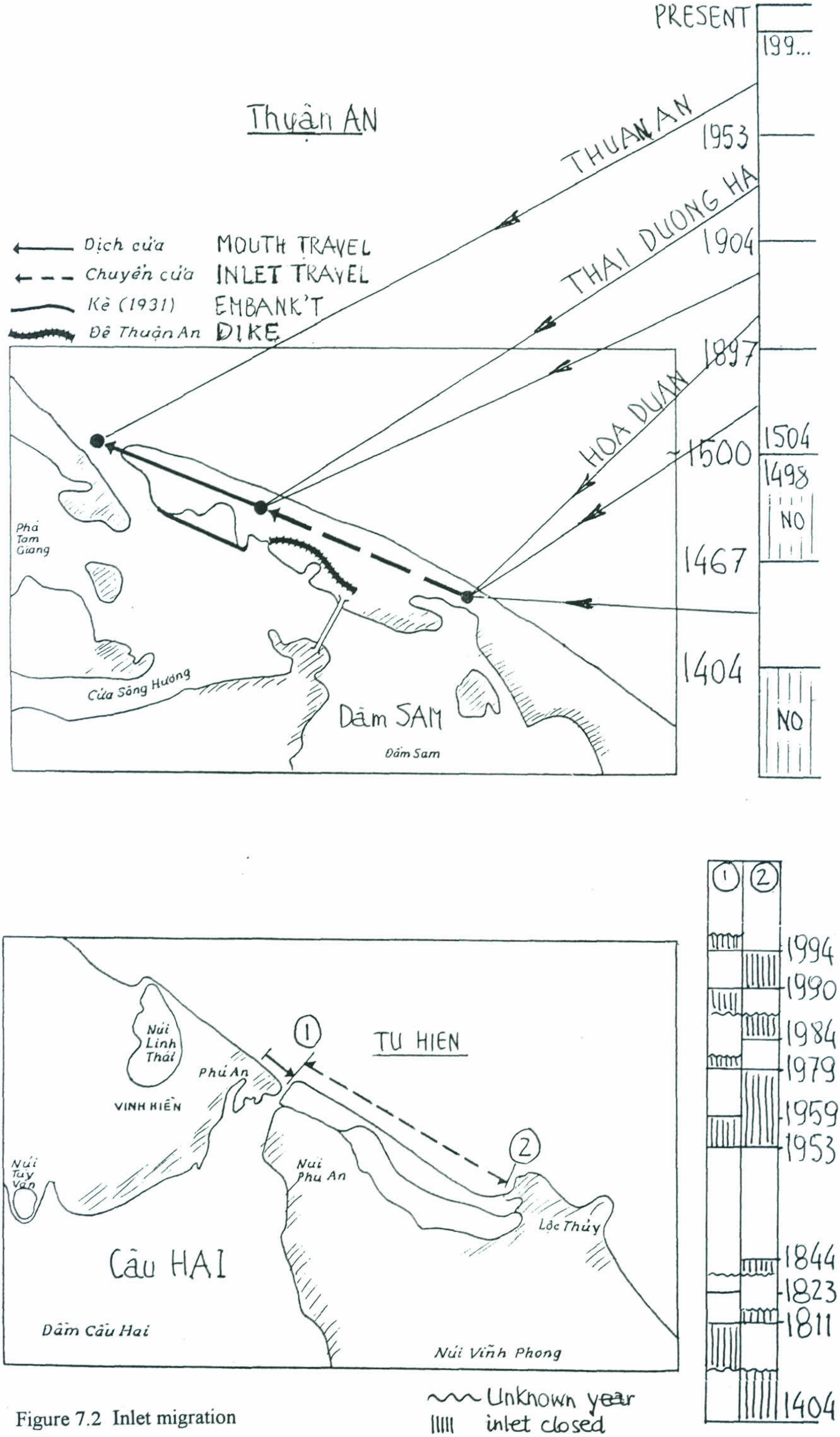



Figure 7.2 Inlet migration

# INLET STABILITY

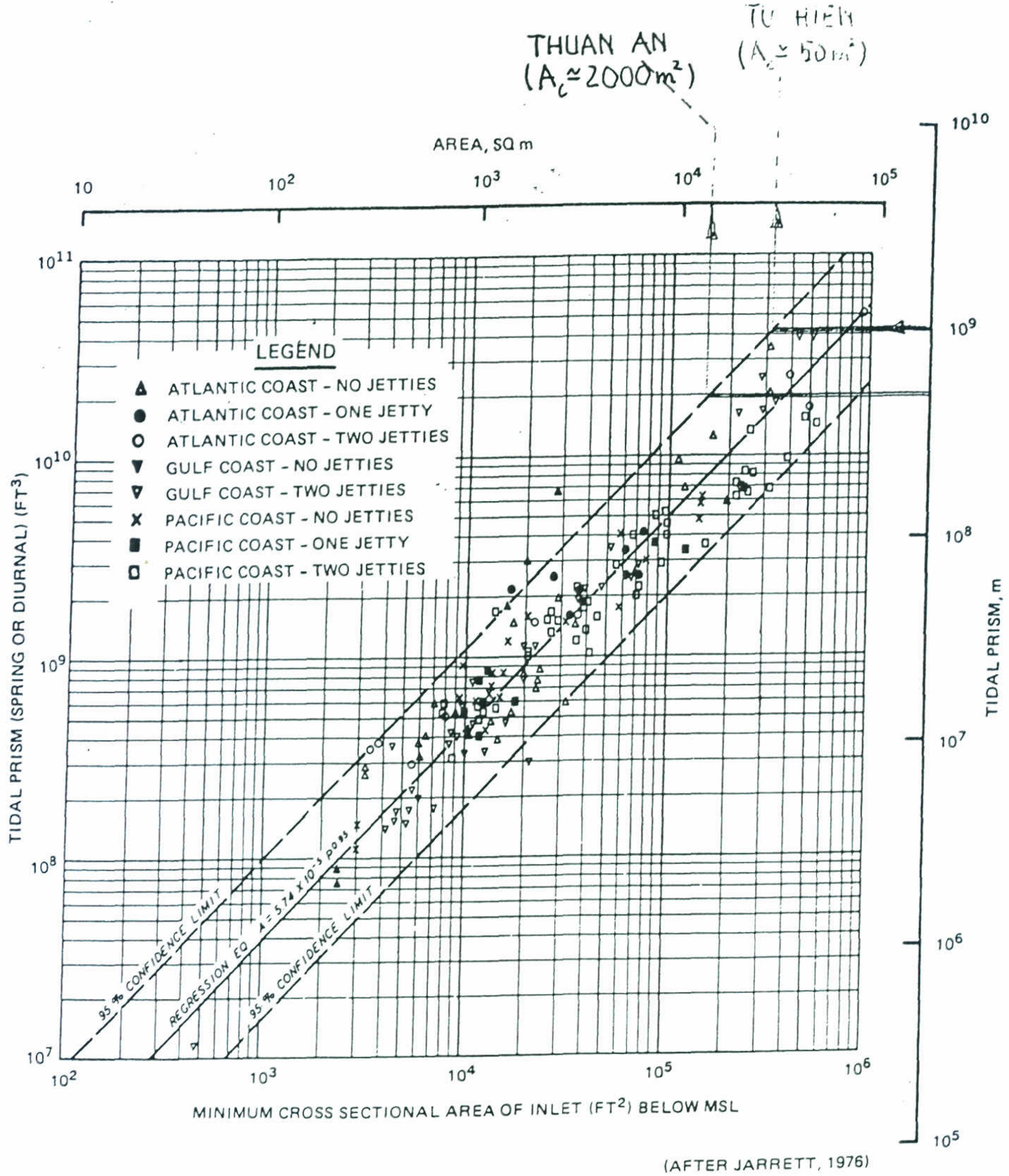



Figure 7.3 Inlet stability by CERC (Fig. 4-70; SPM)

Tu Hien inlet looked at from N to S

Tu Hien inlet as seen from a nearby dune

Sand spit close to Tu Hien, with people mining for lime

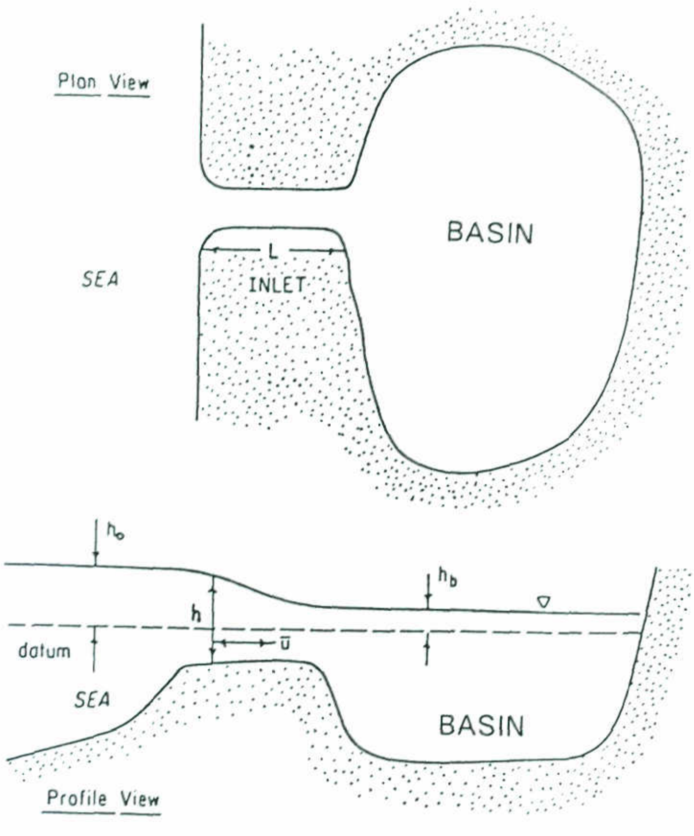
Figure 7.4

Dune vegetation on the spit close to Tu Hien

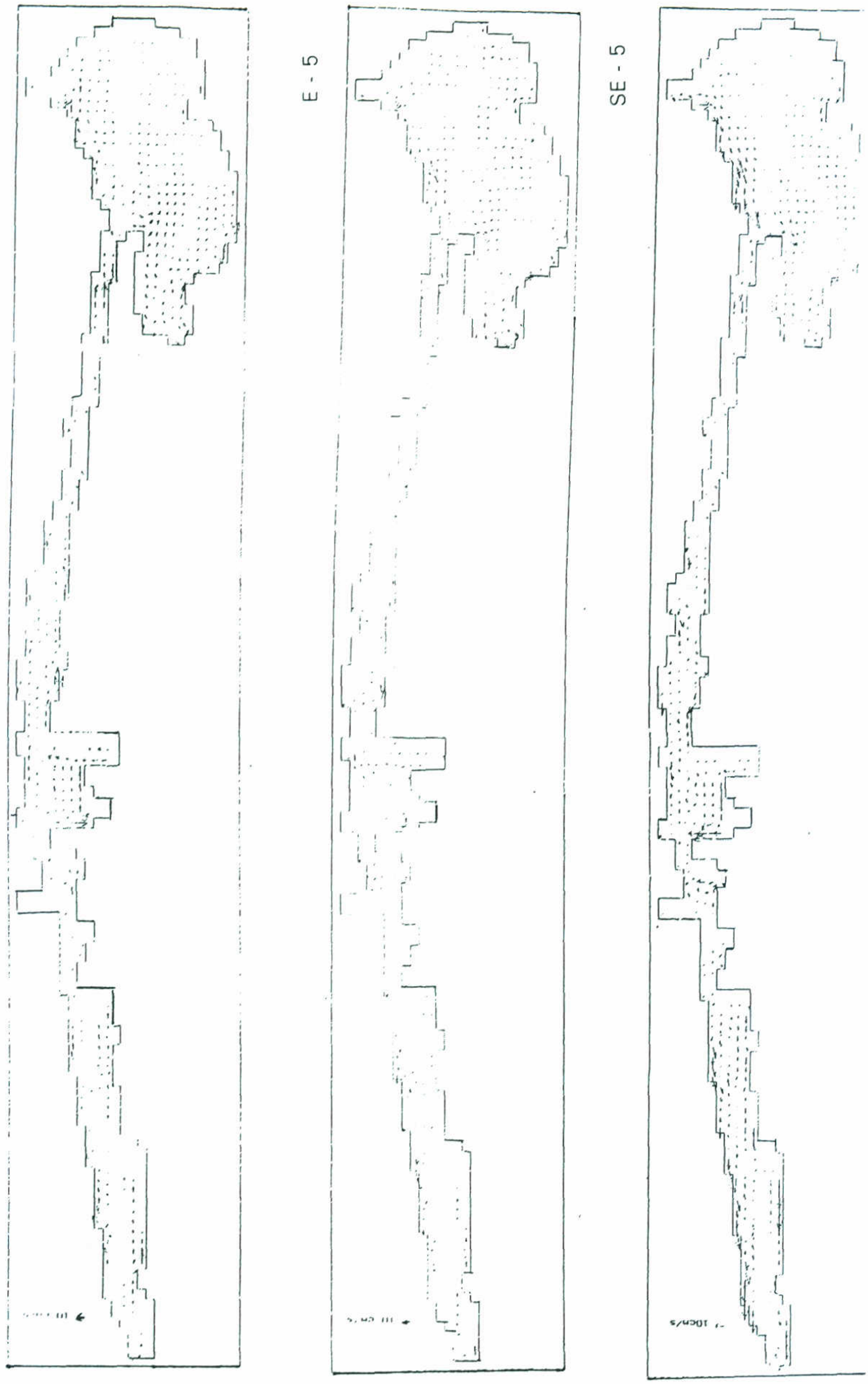
Spit plant habitat on the lagoon side of Tu Hien approach

Figure 7.5

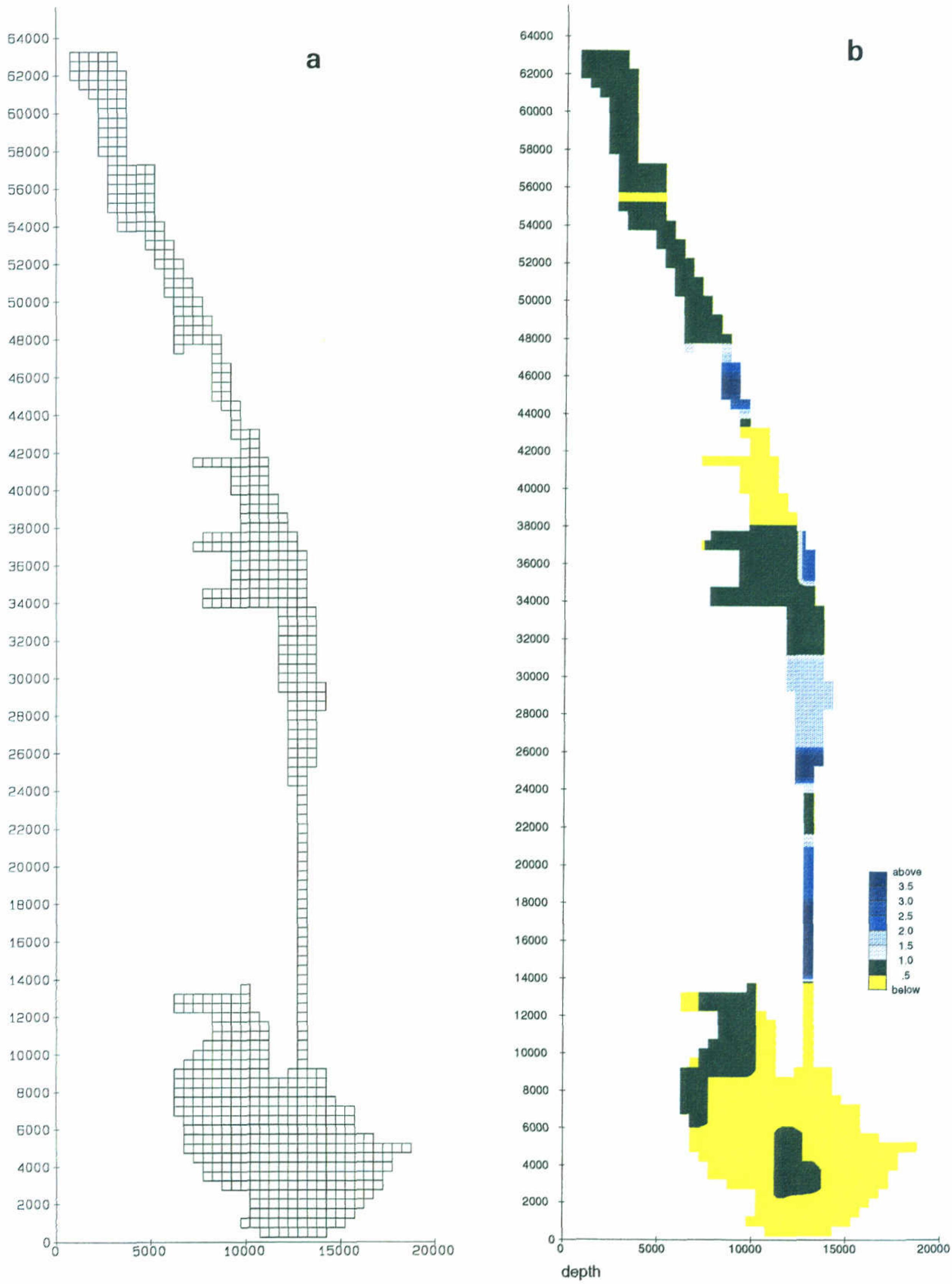
Plant roots stabilizing Tu Hien approach banks



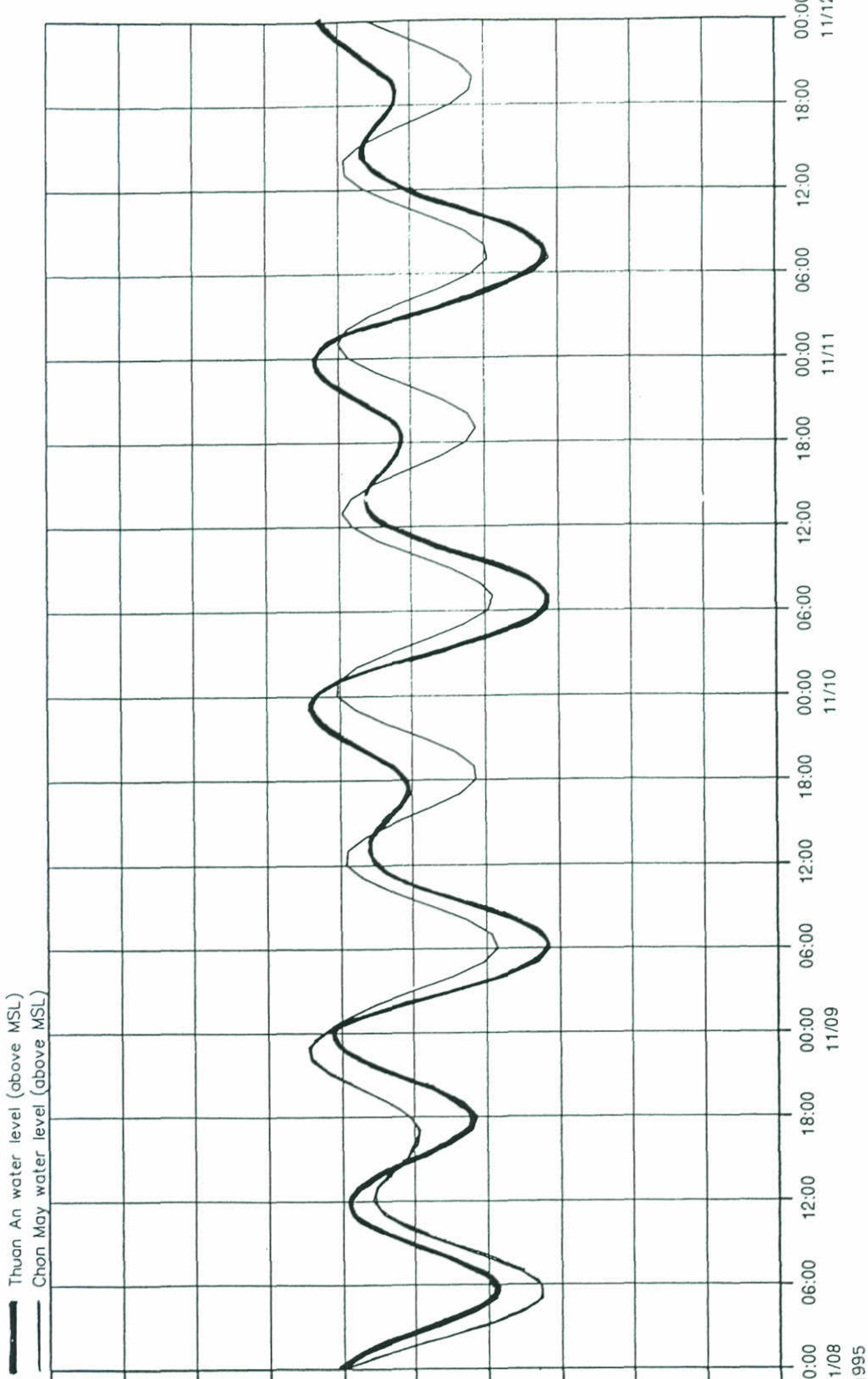

9.3.1 Scheme of inlet - lagoon system



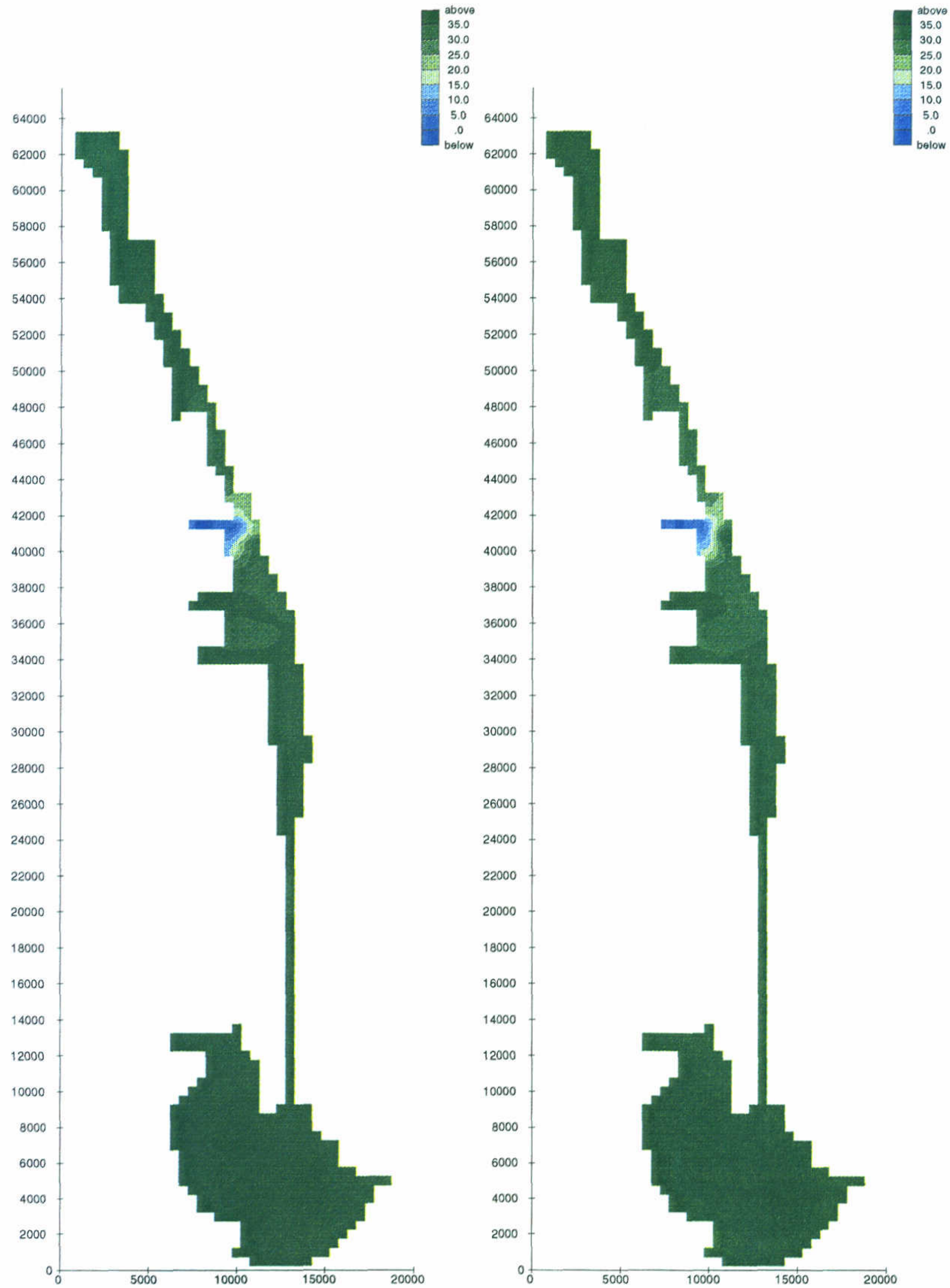

9.3.2 Flow fields obtained by numerical model of Pham Van Huan, (a) NE-5m/s, (b) E-5m/s, (c) SE-5m/s



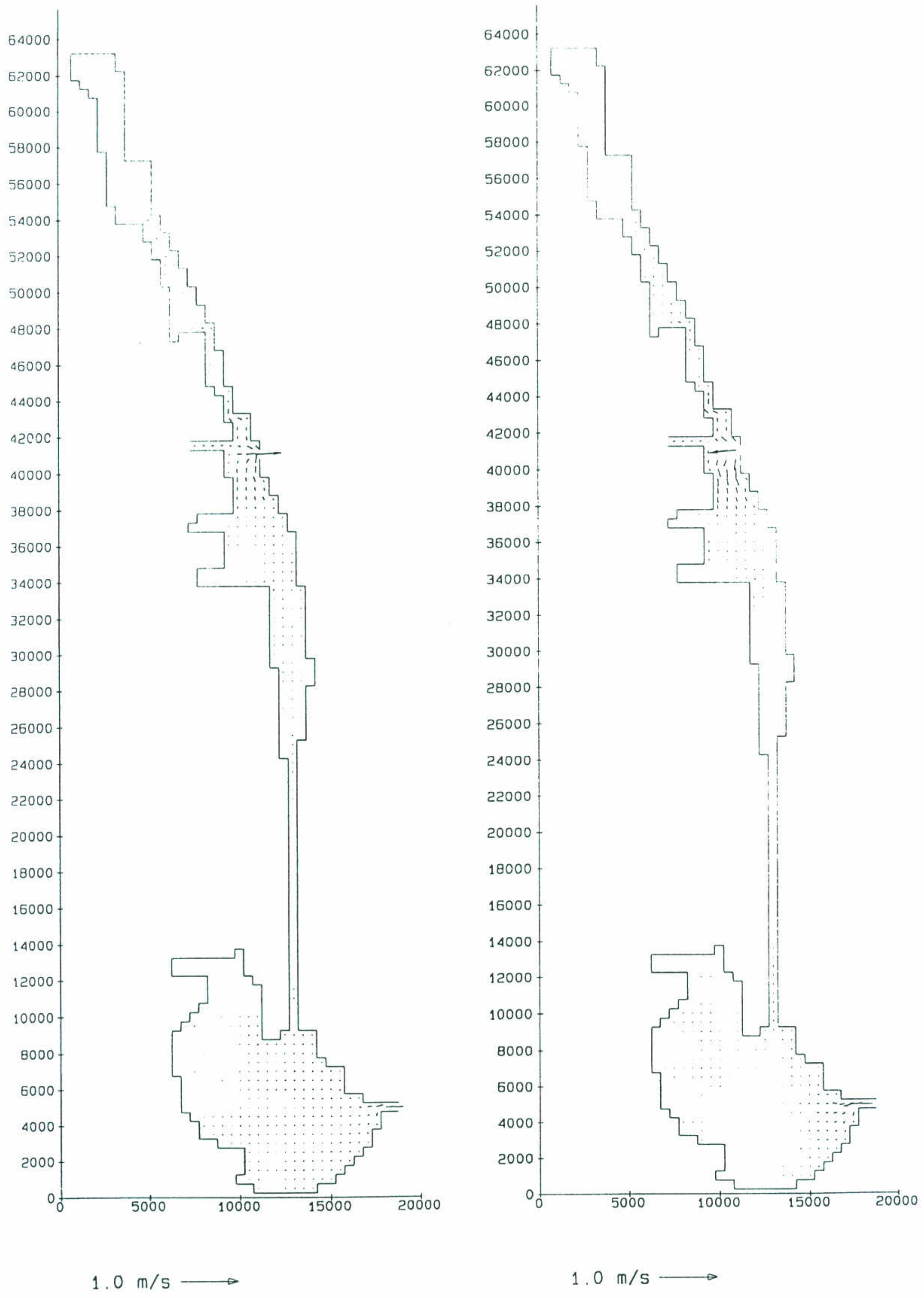

9.3.3 Example of model set-up for Tam Giang - Cau Hai Lagoon, (a) grid, (b) bathymetry




9.3.4 Sea water levels in the vicinity of two inlets, Thuan An and Tu Hien

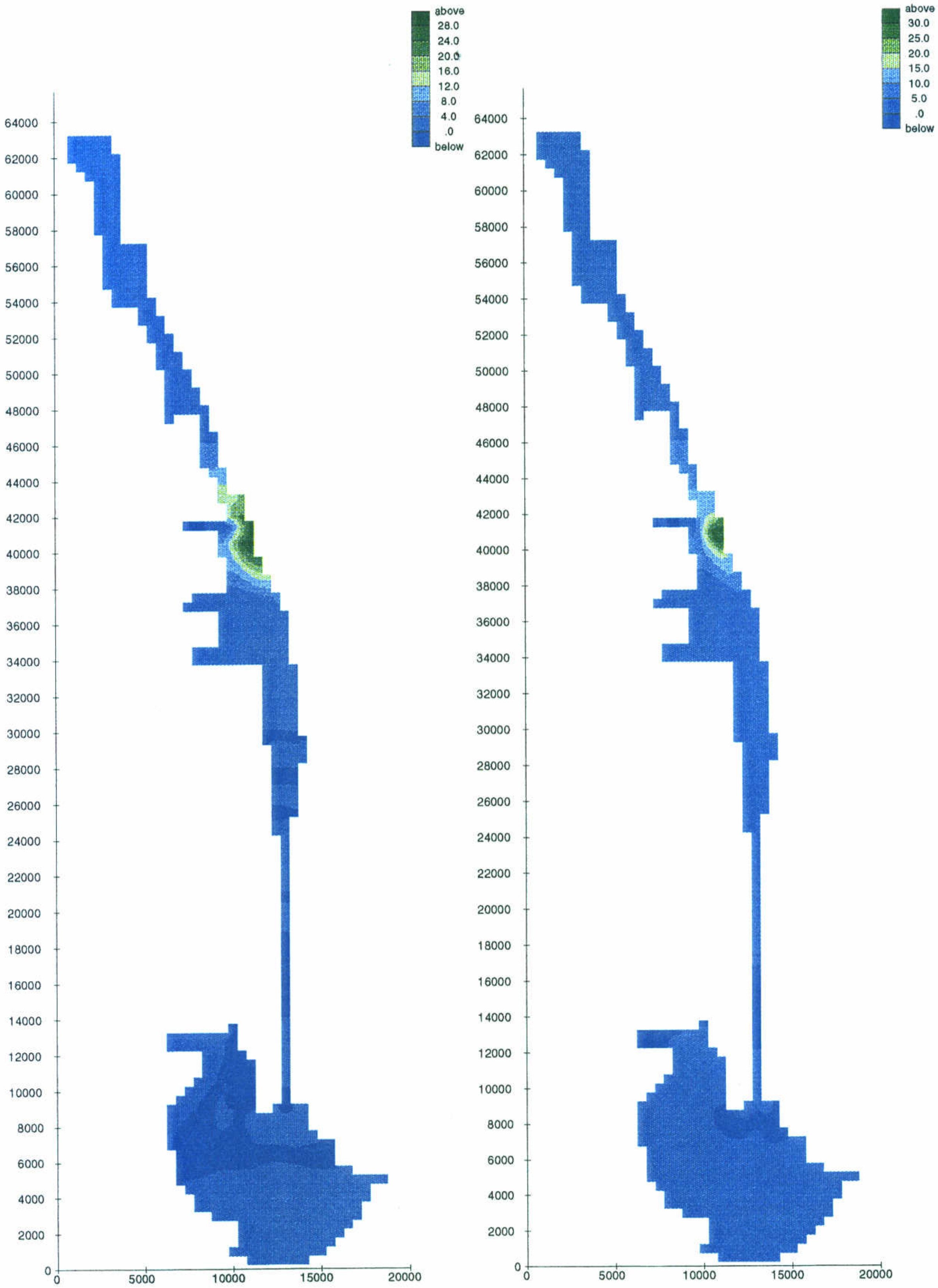



9.3.5 Spatial salinity distribution in 'dry' season



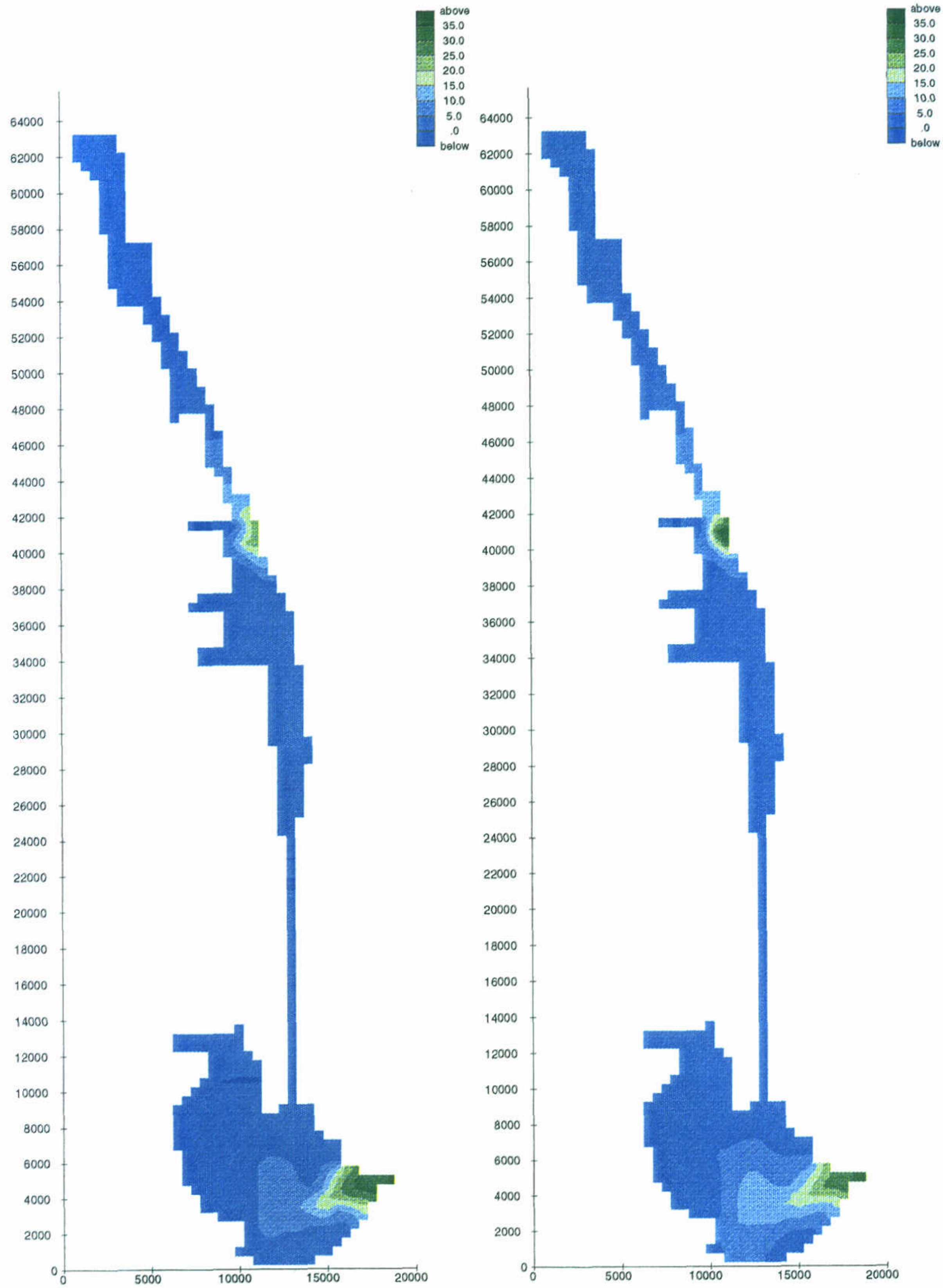

9.3.6 Velocity flow fields in opposite phases of tidal motion in inlets, corresponding to salinity shown in Fig.9.3.4


9.3.6 Velocity flow fields in opposite phases of tidal motion in inlets, corresponding to salinity shown in Fig.9.3.4



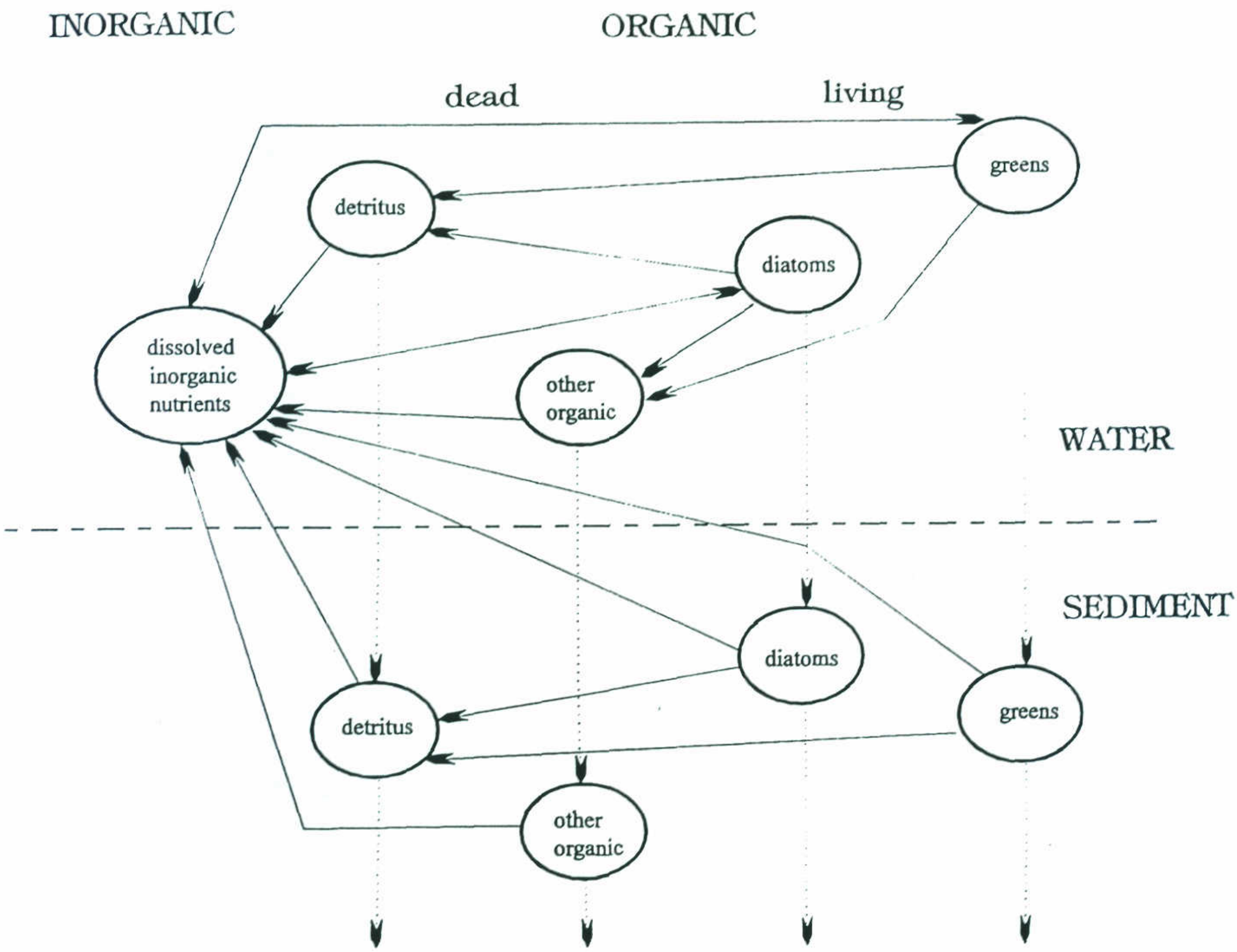

9.3.7 Spatial salinity distribution in 'wet' season in case of one active inlet (Thuan An)


9.3.8 Velocity flow fields in opposite phases of tidal motion in Thuan An inlet



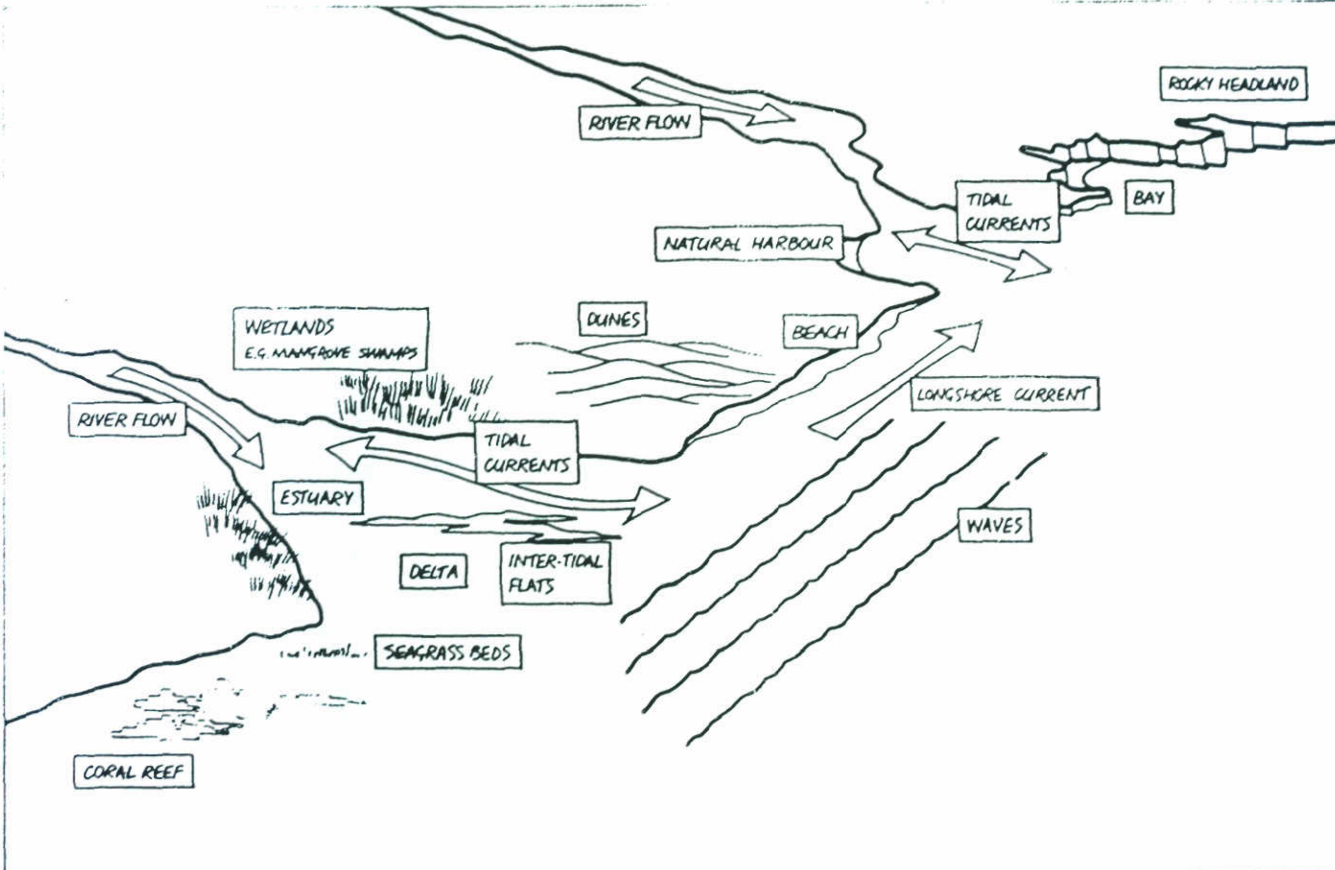

9.3.9 Spatial salinity distribution in 'wet' season in case of two active inlets: (Thuan An and Tu Hien)


9.3.10 Velocity flow fields in opposite phases of tidal motion in Thuan An and Tu Hien inlets




9.3.11 General scheme of nutrients circulation and the interacting processes

## DYNAMICS OF COASTAL ECOSYSTEMS




## SOME POTENTIALLY CONFLICTING USES OF COASTAL RESOURCES

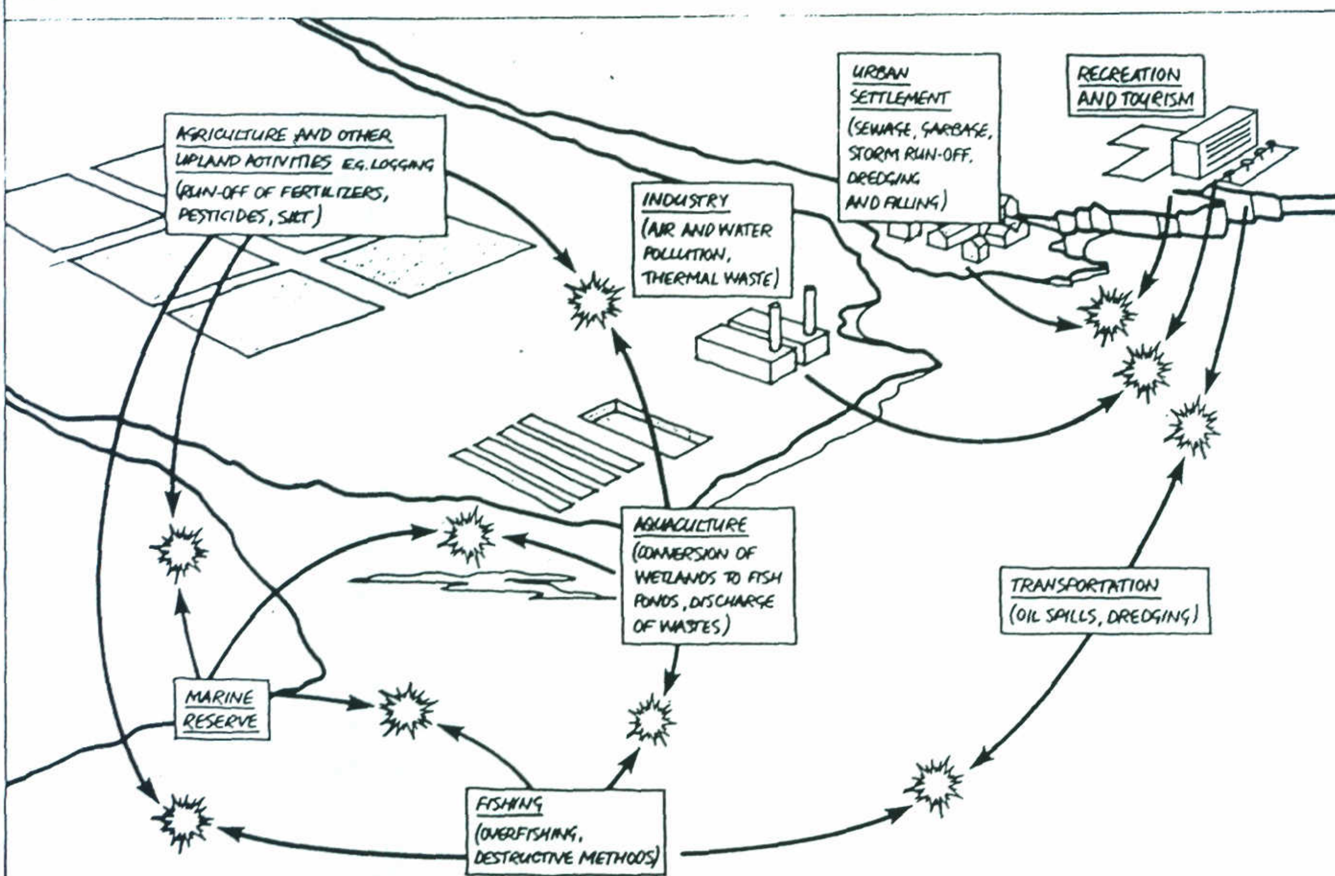



*Figure 11.1*

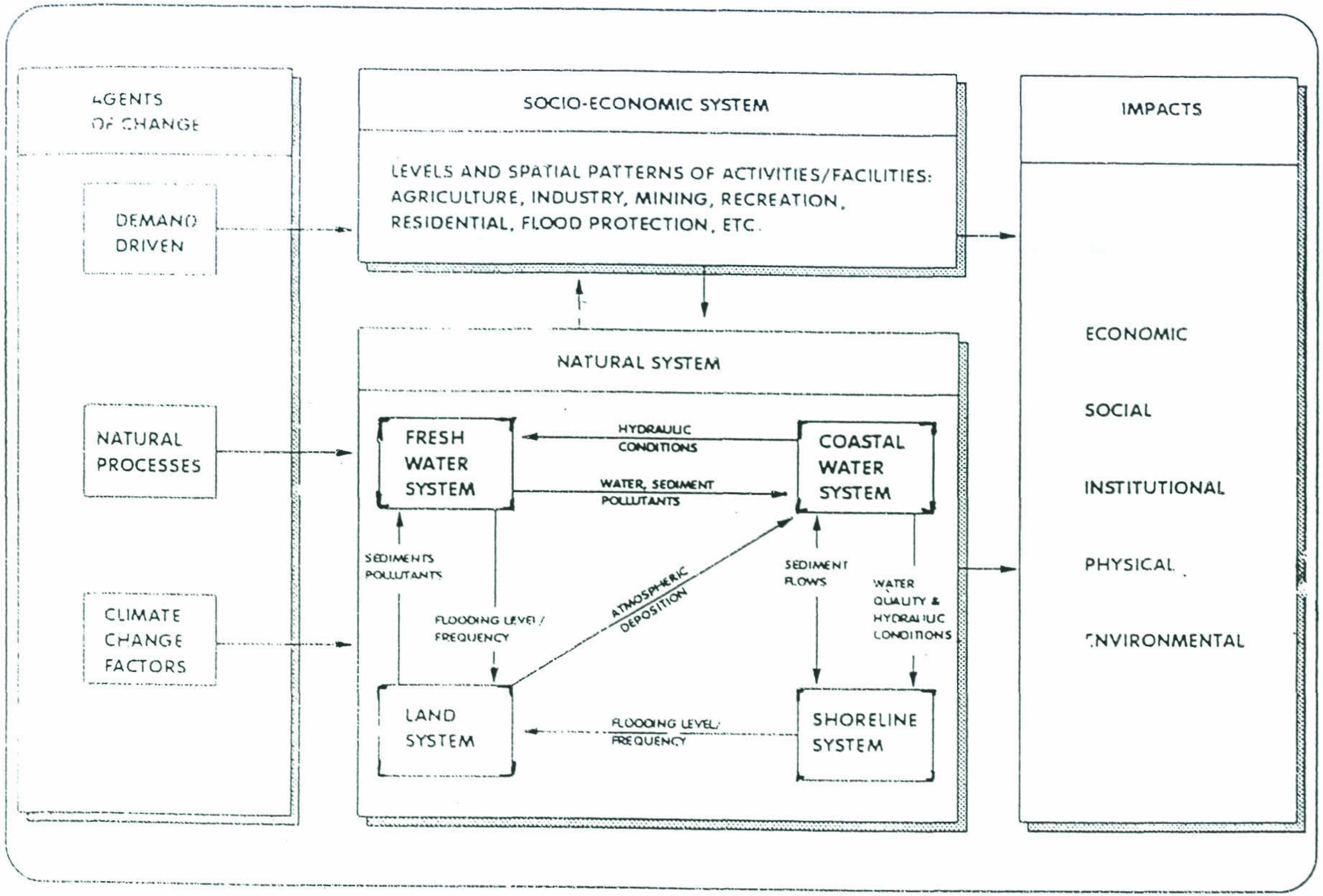



*Figure 11.2* Overview of Coastal System.

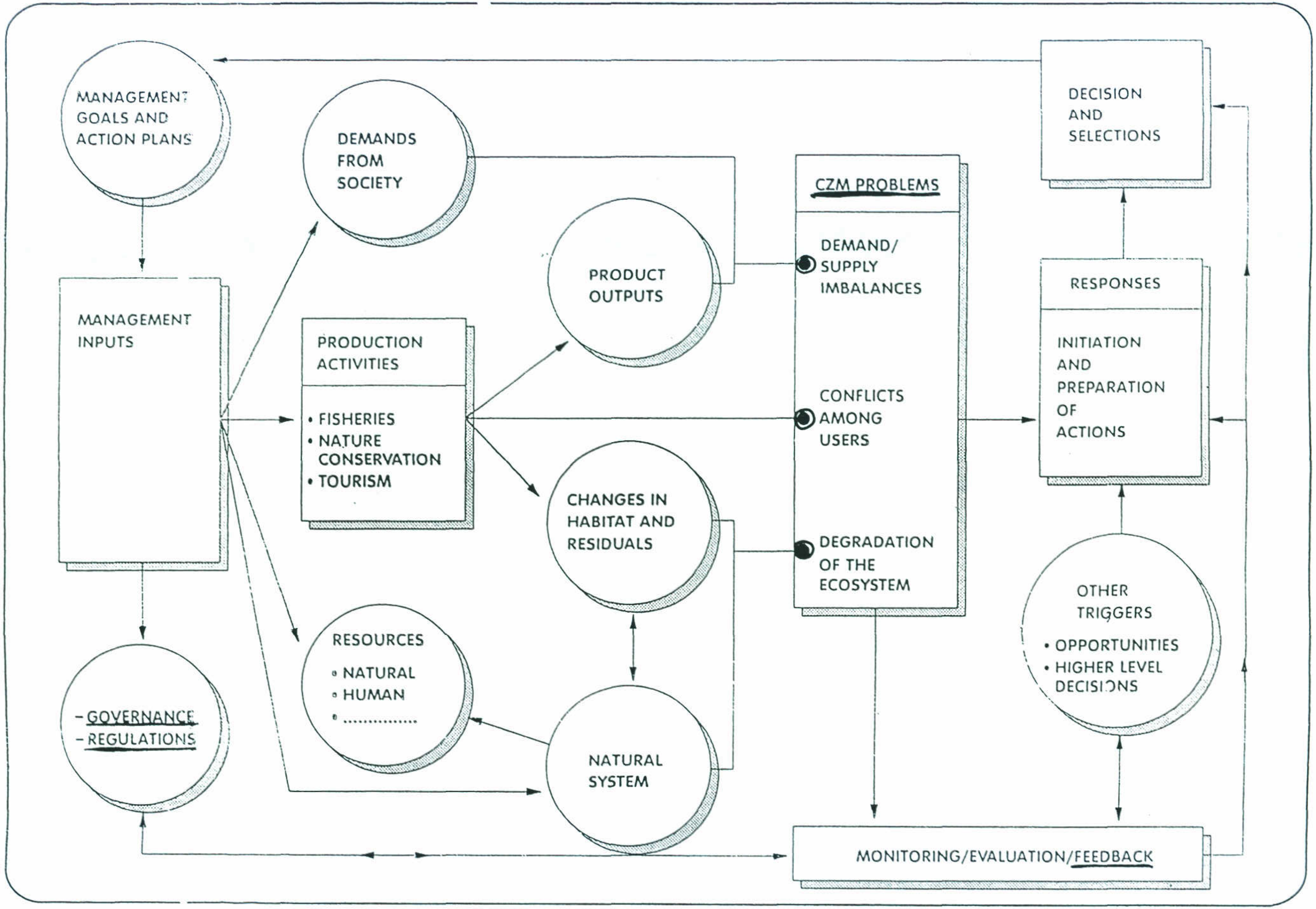



*Figure 11.3* The Context of Management.

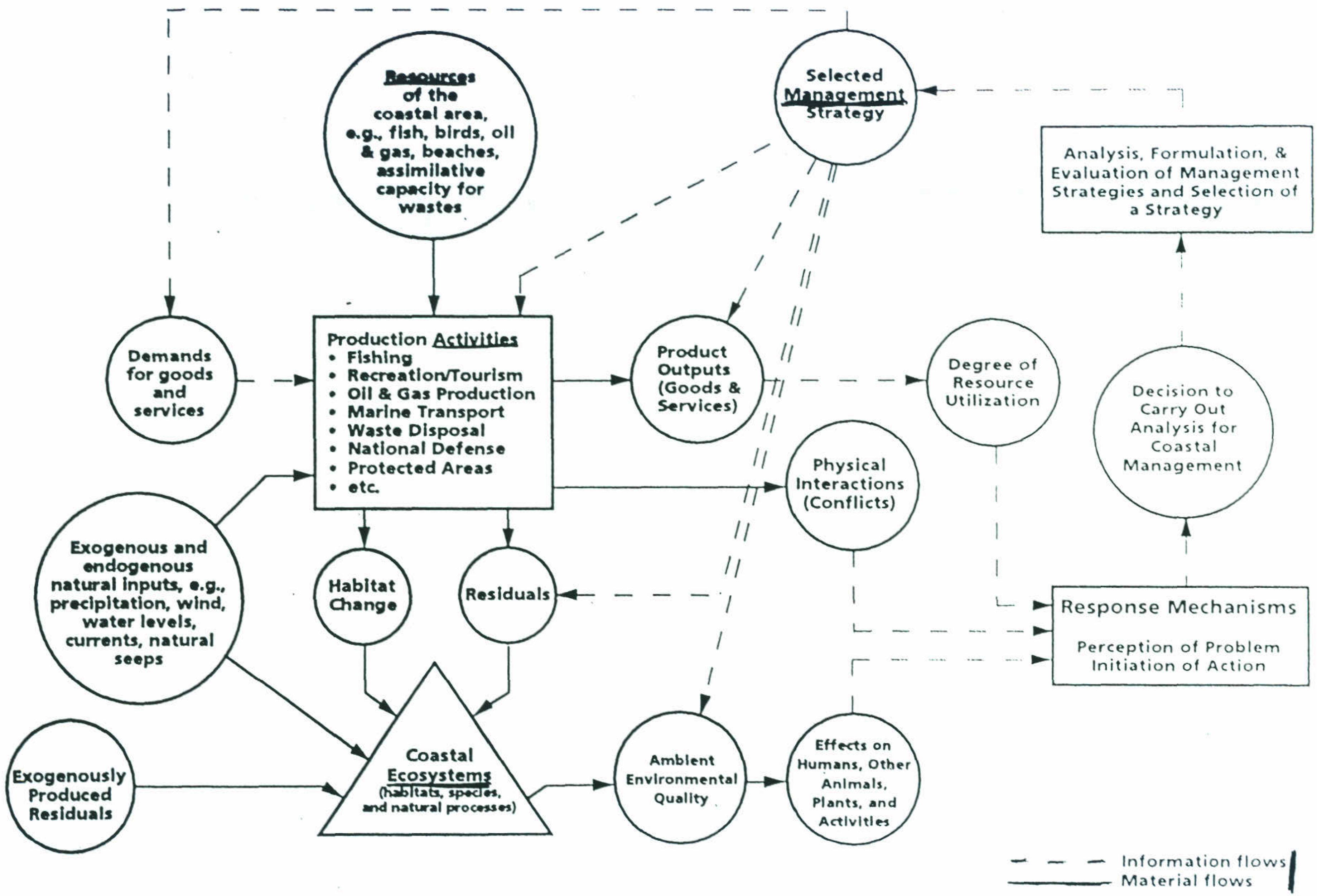



*Figure 11.4* The Integrated Coastal Management System

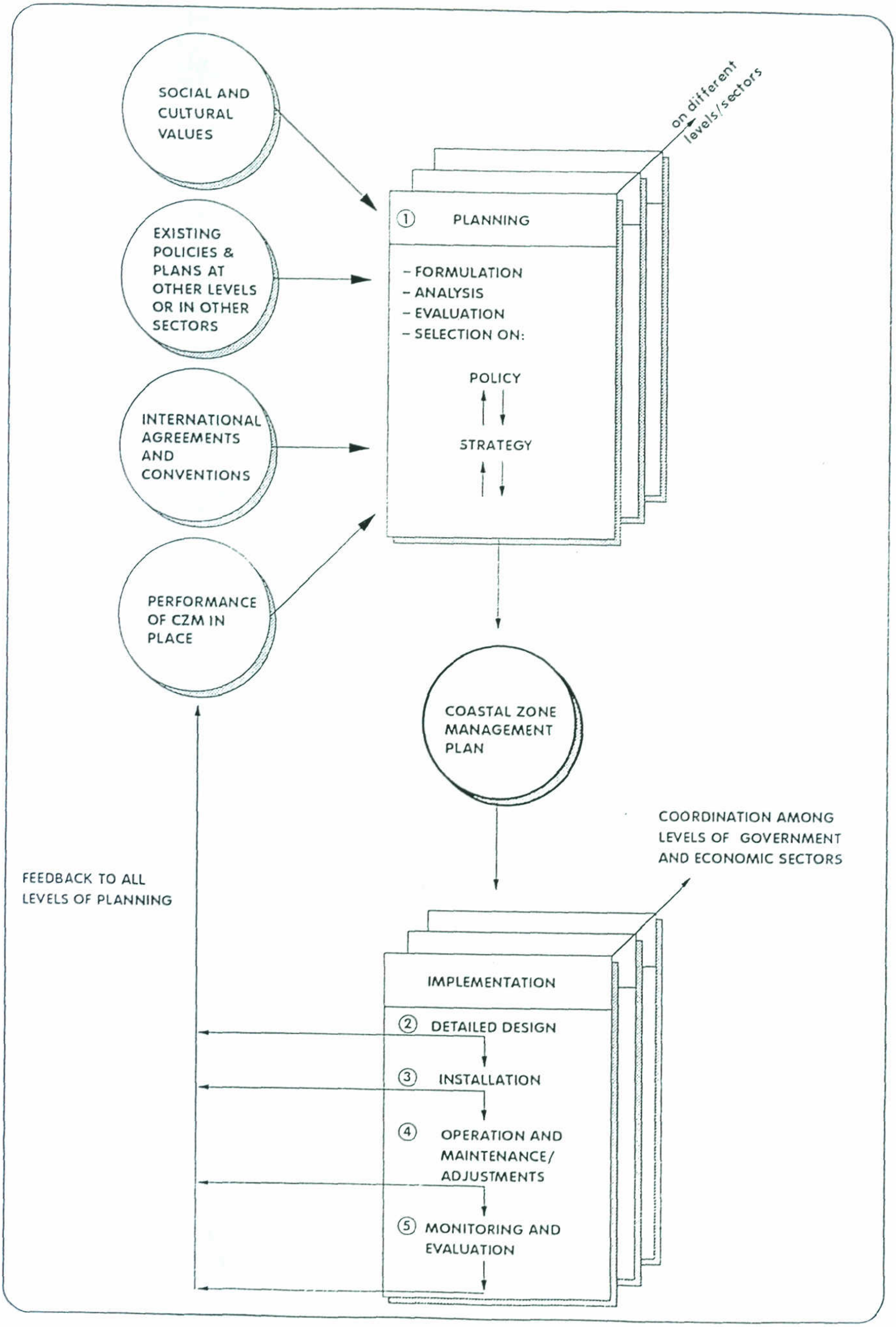



*Figure 11.5* The Elements of Management

## Total Environmental Value and Total Economic Value

USE VALUE (DUV + IUV + OV + QOV ?) — NON-USE VALUE (? BV + EV)

TEV = DUV + IUV + OV + QOV + BV + EV

ANTHROPOCENTRIC INSTRUMENTAL VALUE (DUV + IUV + OV + QOV + BV)

ANTHROPOCENTRIC INSTRISINC VALUE (EV)

TV = PV + TEV : IV

PV + TEV: ANTHROPOCENTRIC INSTRUMENTAL VALUE NON ANTHROPOCENTRIC INSTRUMENTAL VALUE

IV: NONANTHROPOCENTRIC INSTRINSIC VALUE

Notes:

TV = Total Environmental Value
TEV = Total Economic Value
DUV = Direct Use Value
IUV = Indirect Use Value
OV = Option Value (including bequest value)
QOV = Quasi Option Value
EV = Existence Value
PV = Primary Value
IV = Intrinsic Value
BV = Bequest Value

*Figure 11.6*

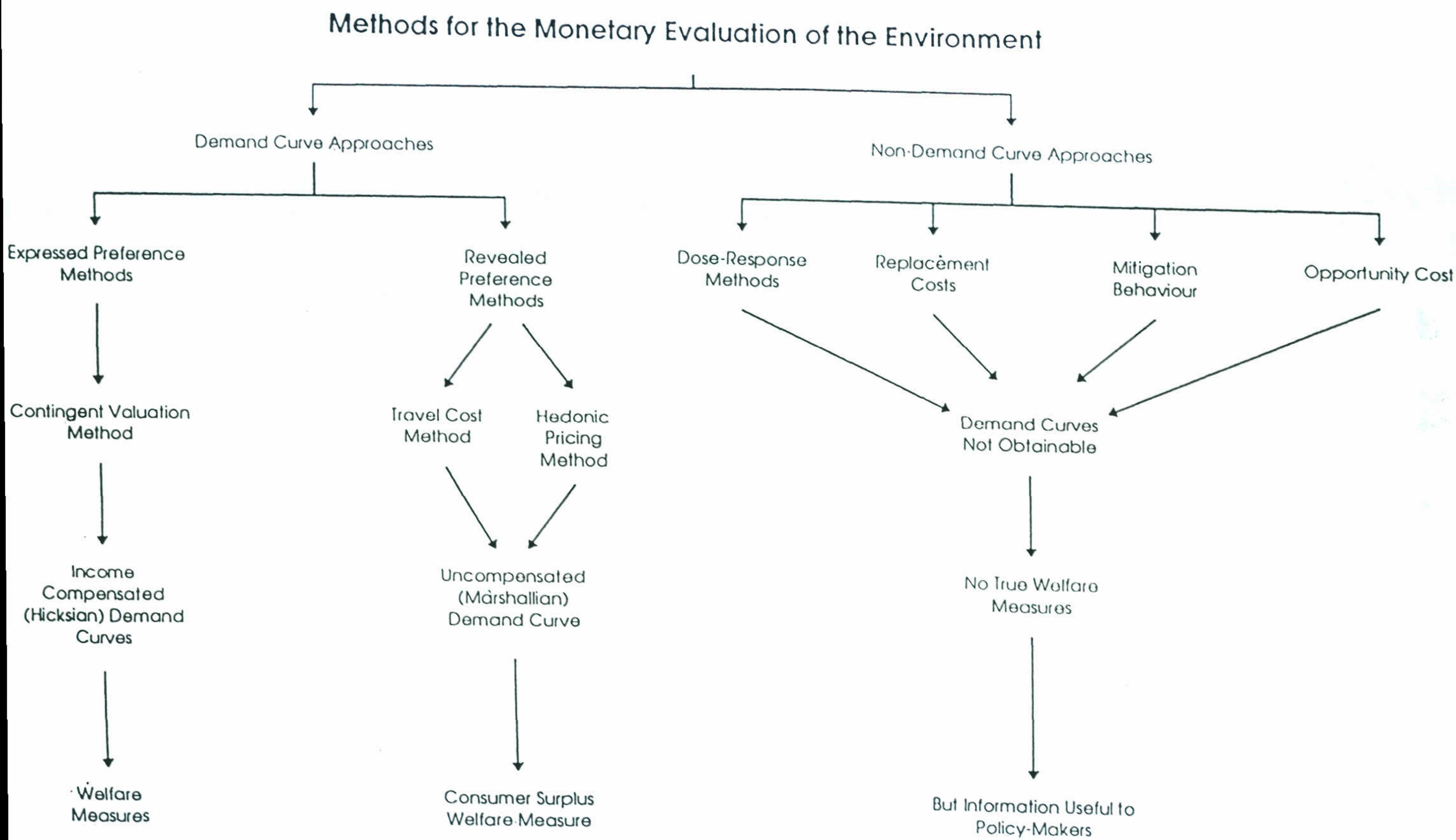
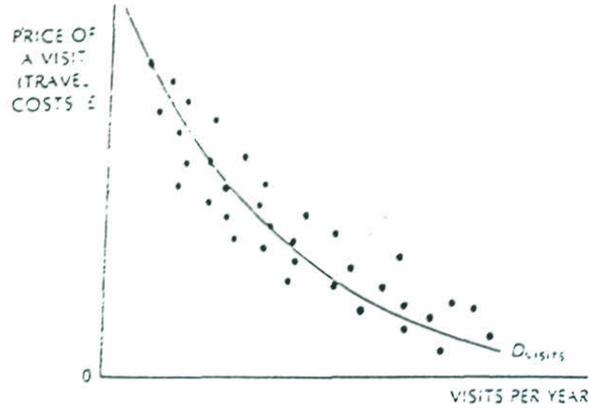

Methods for the Monetary Evaluation of the Environment
Demand Curve Approaches
Non-Demand Curve Approaches
Expressed Preference Methods
Revealed Preference Methods
Dose-Response Methods
Replacement Costs
Mitigation Behaviour
Opportunity Cost
Contingent Valuation Method
Travel Cost Method
Hedonic Pricing Method
Demand Curves Not Obtainable
Income Compensated (Hicksian) Demand Curves
Uncompensated (Marshallian) Demand Curve
No True Welfare Measures
Welfare Measures
Consumer Surplus Welfare Measure
But Information Useful to Policy-Makers

*Figure 11.7*

# EVALUATING ENVIRONMENTAL VALUES:

Travel Cost Method




Hedonic Price Method

Contingent Valuation Method CVM:
asking to place values on env'tl assets ⇒
Willingness To Pay /Accept/Care' WTP/WTA/WTC:

$WTP_i = f\ (Q_i - Q_0,\ P_{own,i},\ P_{sub,i}.\ Se_i)$

where:

$WTP_i$ = willingness to pay (care) of household $i$ for a change from an initial environmental quality $Q_0$ to the improved quality $Q_i$,
$P_{own}$ = price of using the environmental resource,
$P_{sub}$ = price of substitute for use of the environmental resource,
$Se_i$ = socio-economic characteristics of household $i$.

Benefits Transfer

Alternative Frameworks for Evaluation e.g.

Cost-Effectiveness Analysis CEA instead of Cost-Benefit Analysis
wherein environmental standards are set to constraint CBA

Multi-Criteria Decision Analysis MCDA with i.a.:

Environmetal Evaluation System (EES)
Goals Achievement Matrix (GAM)
etc .....

Environmetal Impact Assessment EIA such as
Expert Opinion Gathering
etc etc...

*Figure 11.8*

Some Details of

## Willingness To Pay/Care WTP/WTC Valuation Questionnaire

(Poland's Baltic Beach)

| Variable | Definition |
|---|---|
| BID | Offer sum in WTP question |
| INC | Dummy variable - Household income per capita per month (1 if inc > 2250000 0 otherwise) |
| AGE | Dummy variable - Age (1 if age < 35 years 0 Otherwise) |
| EMP | Dummy Variable - Employment (1 if employed 0 otherwise) |
| ENV | Dummy variable - Member of environmental organisation (1 if member 0 otherwise) |
| INFO | Dummy variable - Information on Baltic previously seen (1 if previously seen 0 otherwise) |
| HOLS | Dummy variable - Respondent on holiday when interviewed (1 if on holiday 0 otherwise) |
| DAYS | Dummy variable - Respondent on day trip when interviewed (1 if on day trip 0 otherwise) |
| RES | Dummy variable - Respondent is local resident or works in area (1 if resident or works in area 0 otherwise) |
| FIRST | Dummy variable - Respondents first visit to area (1 if first visit 0 otherwise) |
| WATER | Dummy variable - Respondent participates in water based activity (1 if water based participation 0 otherwise) |
| SUN | Dummy variable - Respondent is sun bathing (1 if sun bathing 0 otherwise) |
| OTHEREC | Dummy variable - Respondent participates in other recreational activity (1 if other recreational activity 0 otherwise) |

*Figure 11.9*

Some Details of

## Willingness To Pay/Care WTP/WTC Valuation Questionnaire

(Poland's Baltic Beach)

6. **Why don't you want to visit this place again?**

7. **How many of the people in your party are here today (including yourself)?**

8. **How many people are there in your individual family household (including yourself and those who are not here today)?**

9. **Where do you live? Do not give your address, just the town/village and County?**

10. **How far away is that?**

11. **Did you travel directly here?** Y/N

    (if Y - go to 14)

12. **Where did you set out from today?**

13. **How far away is that?**

14. **How did you travel here?** (car, local bus, coach, railway, motorbike, bike, walk, other)

15. **Was the route taken to get here the most direct, or was a longer but more interesting or scenic route taken?**

    1. most direct 2. other 3. Don't know

16. **How long, approximately, did your journey take?**

17. **Approximately how much did your journey cost?**

18. **Are you employed?**

    1. Employed 2. Unemployed 3. Student 4. Retired
    5. Other (if 2, 3, 4, or 5 - go to 22)

19. **Are your work hours variable?** Y/N

*Figure 11.10*

# Comparison of Decision-Aiding Techniques

| Conceptual basis/method | Description |
|---|---|
| 1. Standard benefit-cost analysis | Evaluates policies based on a quantification of net benefits (benefits-costs) associated with them |
| 2. Extended benefit-cost analysis | Evaluates policies based on a quantification of net benefits (benefits-cash) associated with them |
| 3. Risk-benefit analysis | Evaluates benefits associated with a policy in comparison with its risks |
| 4. Decision analysis | Step-by-step analysis of choices under uncertainty |
| 5. Environmental impact assessment | Measurement and quantification of diverse environmental impacts |
| 6. Multi-criteria decision methods: lexicographic methods (non-monetary) | Ranking procedure, provides "best" alternative option on basis of limited number of different criteria |
| Graphical methods (non-monetary) | Illustrates the order of alternatives on the basis of all criteria |
| Consensus-maximising methods (non-monetary) | Provides "social weights" for a range of criteria, rather than the optimal option |
| Aggregation methods (non-monetary, except for Planning and Balance Sheet) | Provides order of alternatives on the basis of all criteria |
| Concordance analysis (non-monetary) | Provides a sub-set of non-dominant alternatives based on all criteria |

Source: OECD (1992)

*Figure 11.11*

# Decision-Aiding Techniques DAT

## Advantages and Disadvantages of DAT

| Advantages | Disadvantages |
|---|---|
| Considers the value (in terms of what individuals will pay) and costs of actions; translates outcomes into commensurate terms; consistent with judging by efficiency implications | No direct consideration of distribution of benefits and costs; significant informational requirements; tends to omit outputs whose effects cannot be quantified; tends to lead to maintenance of status quo; contingent on existing distribution of income and wealth |
| Willingness to pay basis still retained but conditioned by critical natural assets conservation rule; shadow project or offset concept costed into the appraisal process; consistent with judging by efficiency and equity implications | Significant informational requirements; lack of scientific information on natural assets value and substitution possibilities |
| Framework is left vague for flexibility; intended to permit consideration of all risks, benefits and costs; not an automatic decision rule | Factors considered to be commensurate are not always so; lay and expert perceptions of risk may not be consistent |
| Allows various objectives to be used. Makes choices explicit. Explicit recognition of uncertainty | Objectives not always clear; no clear mechanism for assigning weights |
| Quantified (non-monetary) data on diverse set of impacts | Diverse data not placed on a common scale; no evaluation possible |
| Flexible method, easily adjustable for new options or changes in criteria weights; limited data requirements | Needs a clear exogenous ordering of criteria priorities; equity not considered |
| Flexible method, results are consistent if trade-off functions (weights) are accepted | Data requirements high. Comprehensive data on ratio/interval scale required fro all criteria; weights required for trade-offs; final output masks hidden weights, trade-offs and distributional impact |
| Explicitly incorporates equity considerations | Requires data on individual preferences and weights gained via detailed involvement of individuals and groups |
| Flexible methods can consider any number of alternatives; some methods explicitly include equity criterion | Data requirements often high; complexity translates into "hidden" weights and distributional impacts; subjective judgements given same weight as those based on scientific data |
| Adaptable and methodologically consistent | Complication technique, magnitude of impacts, normalising function and criteria weights require and then "hidden" in the analysis |

*Figure 11.12*

## Background for Multi-Criterial Decision Analysis MCDA

Quality Q :: $\Rightarrow$ criteria (attributes) $Q_1, \; Q_2, \; \dots \; Q_k$

Decision variables $a_1, \; a_2, \; \dots a_r$

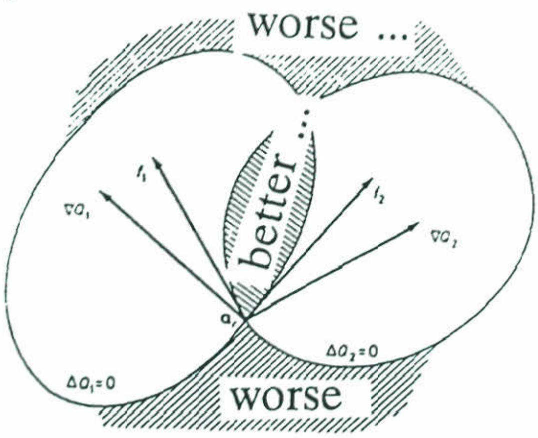
:: Comparison of vector couples [Q=Q(a), a] by i.a.

vector ordering, using Pareto optimization ...

expressed through general usefulness function

$U(Q_1, \; Q_2, \; \dots Q_k)$

Structure of preferences




Optimization sought i.a. by the

### Method of opposite gradients

$$\Delta \mathbf{a}^k = s_k\left(\frac{\nabla Q_1(\mathbf{a}^k)}{\|\nabla Q_1(\mathbf{a}^k)\|} + E\,\frac{\nabla Q_2(\mathbf{a}^k)}{\|\nabla Q_2(\mathbf{a}^k)\|}\right).$$