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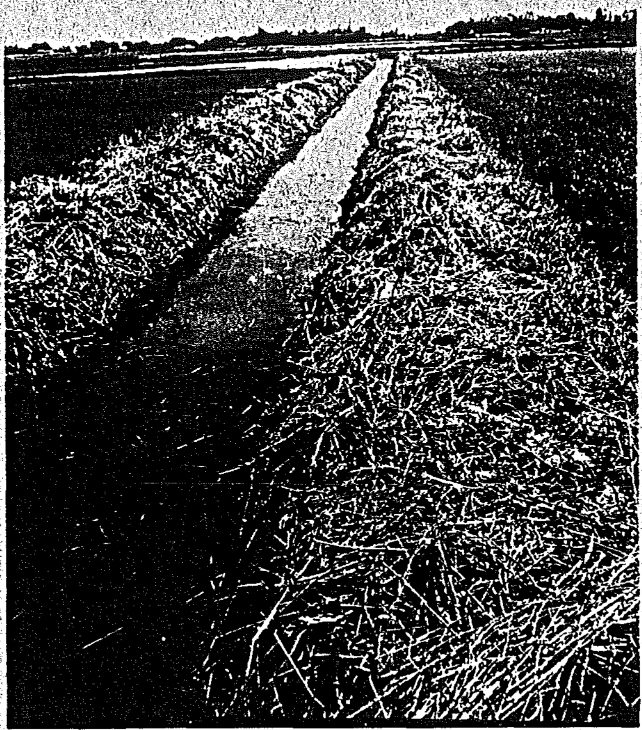

Assessment of the effect of the reclamation of acid sulphate soil for agricultural development in Vietnam

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ASSESSMENT OF THE EFFECT OF THE RECLAMATION OF ACID SULPHATE SOIL FOR AGRICULTURAL DEVELOPMENT IN VIETNAM

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SUMMARY

Vietnam is an agricultural country where rice is the main crop cultivated in the Red river delta in the North and in the Mekong delta in the South. Both deltas refer to lowland. However, the degree of development is clearly different between the two deltas. In the Red river delta, the dike system as well as the canal networks have been constructed. Flood is almost controlled. Canal networks have been excavated to supply water to the fields or to evacuate drainage water out of the areas of interest. Meanwhile, there are no dikes in the Mekong delta. This results in flooding every year with a duration of about two months and causing damages to the local people. Canal networks are poor, 5 m/ha on average. Field canals are rarely found in practice. The other constraint for agricultural development is the problem of acid sulphate soil (ASS). This type of soil accounts for a big portion of the total area of the Mekong delta, 1.6 million ha out of 3.9 million ha.

Under the pressure of the increasing population growth and the requirement on rice production attention is given to the development of the Mekong delta. Actual and future problems deals with a flood control and soil and water management on ASS. To contribute to the solution of these problems the Plain of Reeds is studied in this thesis. The study focuses on:
- development of criteria for dike design and technical specifications for drainage which can be applied in planning, design and construction;
- analysis and assessment of possibilities of removal of toxic elements from the potential acid sulphate soil.

To reach the objectives mentioned above an analysis of available data has been carried out and three simulation models have been used: the simulation model for acid sulphate soil (SMASS) to predict the duration of land reclamation and to determine strategies of soil and water management; the simulation model for one dimensional unsteady flow in channel systems (DUFLOW) for flood analysis, canal design and water management; and the geographical information system (GIS) for planning activities.

The analysis and simulation results show that submerged dikes designed for a return period (T = 3 years) and open drainage systems are appropriate under conditions of the Mekong delta. To enhance the land reclamation and water management a ground water table at 0.2 m-surface is considered as appropriate. Canal networks should be improved to increase the discharge capacity. Water control structures should be constructed to prevent a backwater flow and salt water intrusion under tidal conditions. In addition the GIS shows that the lay-out of existing canal networks is reasonable. It is possible to lay-out irrigation and drainage canals separately. The reclamation of acid sulphate soils for agricultural development is possible by proper water management measures.

Combination of data analysis with the simulation models can deliver more or less the the required information to enable policy makers and decision makers to take proper decisions. However, a study on dynamics of acid sulphate soil and consequences due to reclamation of acid sulphate soils are necessary and recommended to be carried out.

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Chapter 1

INTRODUCTION

1.1 General

Vietnam is situated in South - East Asia in latitude 8° 30′ till 22°30′ North and longtitude 102°15′ - 109°20′ East (figure 1). The deltaic area accounts for only 25% of the total area of the country. In Vietnam about 67.5% of the population is engaged in agriculture. Rice is considered as the main food crop. Paddy is by far the most important crop and plays an important role in agriculture as well as in the economy of the country. Paddy is cultivated mostly in the Red river delta in the North with an area of 1.0 million ha and in the Mekong river delta, the largest agricultural area of the country at an area of 2.0 million ha. On these areas two paddy crops are grown. Even in some areas three paddy crops a year are grown.

In paddy production, water, including irrigation and drainage water is assessed as the most important factor (e.g. water, fertilizer, labour and varieties). In the past a lot of large and small scale irrigation and drainage systems, including dams, barrages, weirs, and pumping stations have been constructed to obtain self-sufficiency in food supply throughout the country. The systems meet the requirements in water for agricultural production. The irrigation and drainage systems are mainly funded from the Government budget. In irrigation development of the country, Vietnam has been supported by The Netherlands (Project Huong My, area of 3,800 ha, operation in 1987), by Australia (Project Tam Phuong, area of 5,900 ha, operation in 1989), etc. As a result, agricultural production in general and rice production in particular is increasing rapidly. This has provided an adequate supply of rice to satisfy the local requirements. Besides that, 2 million tons of rice are exported every year now, and the country has become the world's third largest rice exporter.

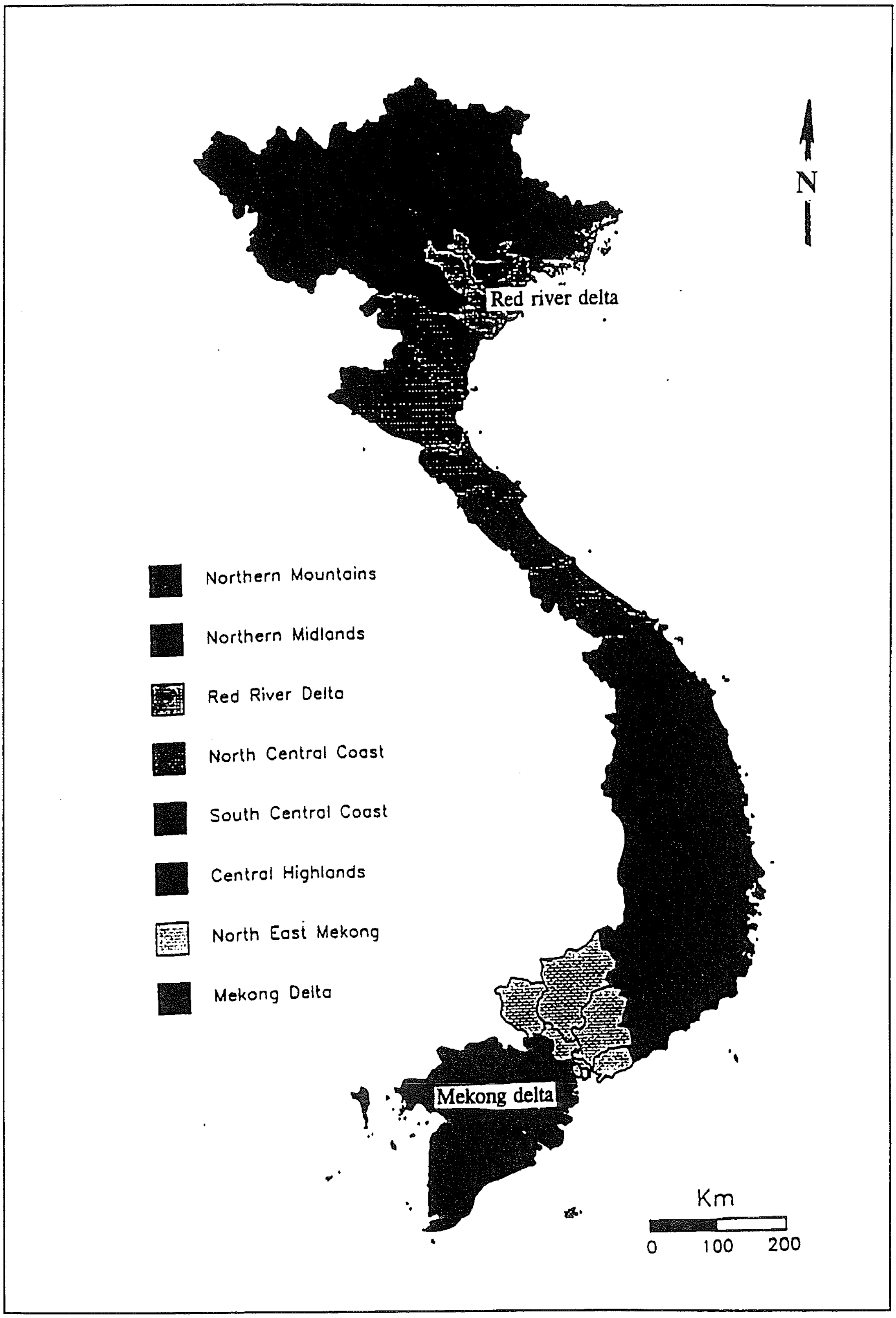

Figure 1 Map of Vietnam (The World Bank, 1995)

1.2 Objective of the study

Water control measures are crucial for sustainable agricultural development on acid sulphate soil in the Mekong river delta. Therefore, the objective of the study is the determination of an appropriate reclamation and drainage method in the development of acid sulphate soils for agricultural purposes. Main activities will be:

- development of criteria for dike design, optimum drainage method and technical specifications for selected drainage method including procedures that may be used in construction;
- analysis and assessment of the possibilities of removal of soluble chemical elements from acid sulphate soils by leaching and flushing.

To achieve the objective above, a study has been carried out on the pilot area in Tan hoa wards, Tan Thach district, province Long An in the Plain of Reeds.

1.3 Methodology

The present study will be based on:

- an extensive review of the literature;
- analysis of data of the project that deal with the subject in combination with model simulations such as the simulation model for acid sulphate soil (SMASS), the simulation model of one dimensional unsteady flow in channel systems (DUFLOW) and the geographical information system (GIS) by the IDRISI computer package.

Chapter 2

PRESENT SITUATION OF THE PLAIN OF REEDS

2.1 Background

The Plain of Reeds consists mainly of fallow land because the soil is an acid sulphate soil and so far, no water management measures have been introduced to promote the agricultural development.

To obtain the best methodology for using this soil for agricultural purposes research activities have been conducted at various scales by different institutions. One of these institutions is the Tanthanh research station for acid sulphate soils. It belongs to the Southern institute for water resources research which was set up in 1978. The station is located in the district Tanthanh, province Long An (figure 2).

In recent years research activities are organized in a process as shown below:

Elementary research **(R)** → Research and Development **(R-D)** → Production **(P)**

The station is implementing a study project, pilot project Tan Hoa which belongs to the research and development stage (R-D). On this stage, research activities are aimed at testing the elementary research results from the foregoing period (1980 - 1990) on larger scale area (281.6 ha) in the Plain of Reeds for further application in production. The project started in 1993. Duration of time of completion is 2 years.

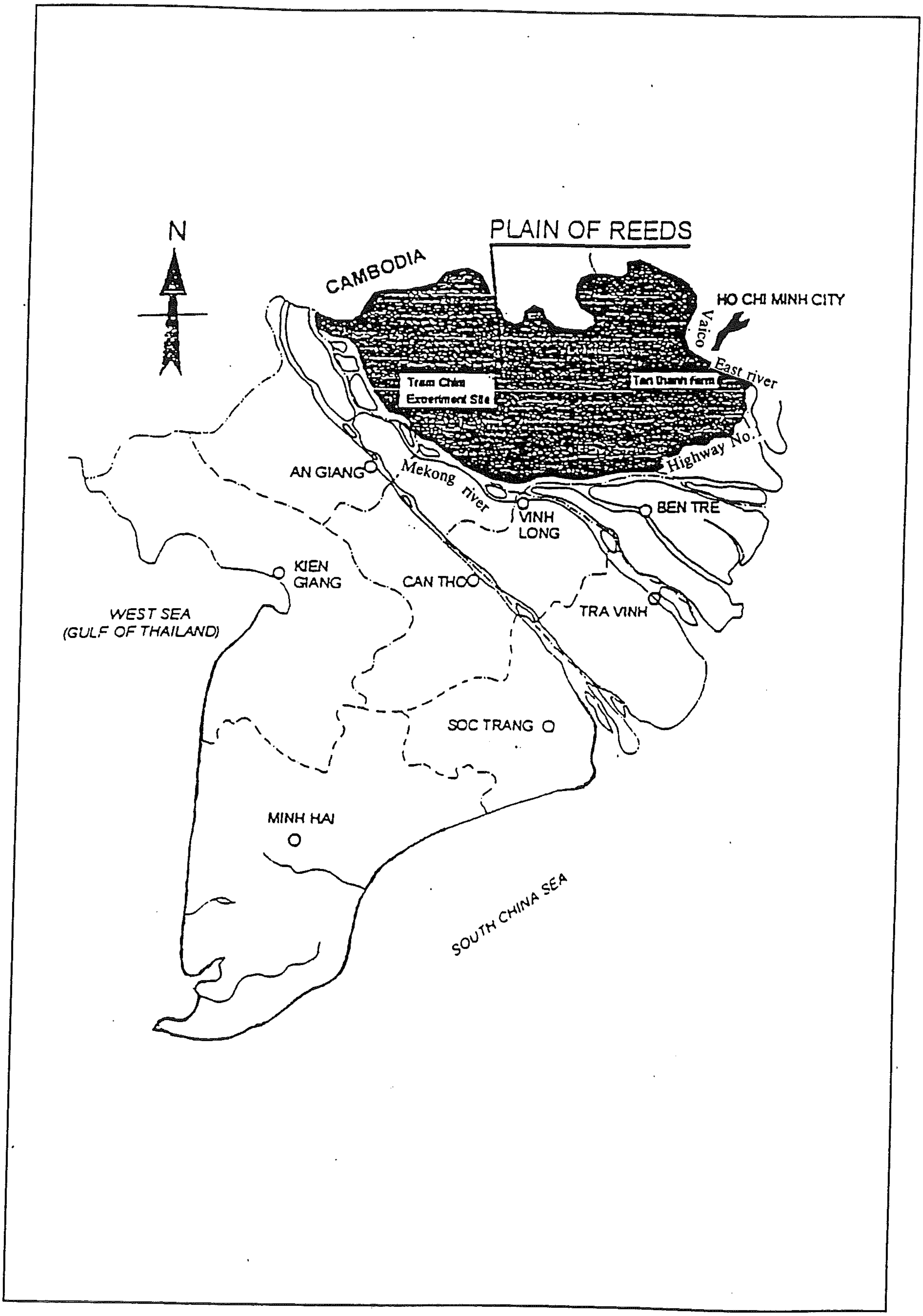

Figure 2 Location of the Plain of Reeds (Nguyen, 1994)

2.2 Location

The Plain of Reeds is located in the Lower Mekong basin, west of Ho Chi Minh city (previously Saigon) with a total area of 629,200 ha. It is distributed in the province of Long An (298,300 ha), Dong Thap (235,600 ha) and Tien Giang (95,300 ha). It is bounded by the Mekong river in the West which is the only source of irrigation water, the Vaico East river in the East which is the drain river almost for the whole area, the border with Cambodia in the North and the national highway No.1 in the South (figure 2).

2.3 Topography

In general the Plain of Reeds is very flat and low. By classification the Plain of Reeds refers to lowland. It consists of 5,000 ha with an elevation of less than 0.5 m+MSL, 520,000 ha with an elevation from 0.5 - 1.5 m+MSL. Ground surface is depressed in the West-East or West-Southeast direction due to sedimentation process of the Mekong river. The further the water flows the less sediments deposit. This parttern is convenient to construct irrigation and drainage canals separately. Irrigation water is easy to divert from the Mekong river and drainage water is easy to discharge into the Vaico West river. During the flood time of September and October the whole area is flooded with an average water depth of 1.0 to 1.2 m. Maximum water depths can reach 2.1 m or more which depends on the discharge in the Mekong river and the tide in the South China sea.

2.4 Soil

The soil in the Plain of Reeds is a problem soil referring to potential and developed acid sulphate soil. Its formation process is relatively complicated. It originates from gradual sediment deposition of the Mekong river. The upper basin is a tropical laterite area with compounds of iron and aluminium. Originally, the Plain of Reeds was an inland bay (Khanh, 1986). When river water reached the area sedimentation takes place in brackish water. Under tidal conditions the marsh dried up and flooded, which make it suitable for tropical coastal flora to develop. The flora has a very specific vegetation pattern (Brinkman, 1979). Maybe, for this reason the acid sulphate soil in the Plain of Reeds is not similar to such soil in other in other areas in the world. Under the presence of microorganisms and bacteria in the soil pyrite (FeS_2) is formed.

Under the influence of environmental factors (hydrology, climate, etc.) acidification processes take place. Upon drainage and ripening of the sediment, air enters the soil and sulphite will become oxidized through one of the following reactions (Dent, 1986 and Evangelou, 1995):

$$FeS_2 + 7/2\ H_2O + 15/2\ O_2 \rightarrow Fe(OH)_3 + 4\ H_2 + 2\ SO_4 \qquad (2.1)$$

$$FeS_2 + 15/4\ H_2O + 5/2\ O_2 + 1/3\ K^+ \rightarrow 1/3\ \underset{\text{(jarosite)}}{KFe_3(OH)_6(SO_4)_2} + 4/3\ SO_4 + 3\ H^+ \qquad (2.2)$$

Acid sulphate soil in the Plain of Reeds is classified into potential and developed acid sulphate soil. The characteristics are presented in Table 1 and are shown in annex A.1. Such soil characteristics make the soil unsuitable for agricultural use, especially for rice, because most indicators of the chemical properties of the soil are greater than the boundary values that have been proposed by the Can Tho University (Duoc, 1994) for acid tolerance rice varieties grown widely in the Plain of Reeds.

The boundary values for rice cultivation are as below:

Al^{3+} : < 300 ppm

Fe^{2+} : < 300 ppm

Fe^{3+} : < 400 ppm

SO_4^{2-} < 1000 ppm

pH $\geq$ 4

To use this soil for agricultural development it is necessary to conduct landreclamation measures. The best way is that irrigation and drainage measures (leaching and flushing) must be introduced. The question to be solved is how and what kind of soil and water management methods can be applied effectively on this soil. As it is known that the soil in the area is a sediment deposition of the Mekong river, the clay component is high, 53%. Other components are described as below (Southern Institute for Water Resources Research, 1995):

Clay:	53%	Wilting point :	pF = 4.18
Silt:	30%	Field capacity:	pF = 2.0
Sand:	17%	Porosity:	n = 0.37 - 0.62

Saturated water content: θ = 0.57-0.73

The soil in the area is newly formed soil, so the coefficient of filtration is relatively high. At the first year of exploitation the soil has a coefficient of filtration of 0.34 m/day (Husson and Mai, 1995) and then decreases considerably in next years and different from place to place. In general the coefficient of filtration is about 0.1 m/day (Thuan, 1992). In addition, the vertical coefficient of filtration is greater than the horizontal coefficient due to the remainders of plants. It is also found that the horizontal coefficient of filtration in jarosite is greater than in pyrite.

2.5 Climate

The Plain of Reeds is located in the tropical monsoon region with two clear seasons: dry season (December to April) and wet season (May to November). Annual average temperature is 26 °C to 27 °C. Maximum temperature reaches 36 °C, usually in April and May. However, such high temperature occurs only a in short time during the day. Consequently there are no effects on the growth of rice. The open water evaporation is relatively high, up to 7 - 10 mm/day in the dry season which causes an increase of crop water requirement. This results in severe shortage in water and upwards movement of toxic elements from the saturated zone to the unsaturated zone (figure 3). These elements are accumulated in the top-layer and harmful for crops.
Humidity shows a slight difference in each month in comparison with monthly average humidity. It varies from 75% to 84%.

Annual rainfall is 1,400 - 1,500 mm. However, it is distributed quite unevenly which leads to shortage or excess in water in the seasons (figure 4), 84% of the annual rainfall falls in the wet months, mainly in September and October. November and April are considered as transition months and account for approximately 12% of the annual rainfall. Meanwhile, the amount of rainfall from December till March is only 4%. Monthly rainfall, temperature, and humidity of the Plain of Reeds are presented in table 2.

Table 1 The characteristics of potential and developed acid sulphate soils in the plain of Reeds (Dong, 1989)

Items	Potential acid sulphate soil	Developed acid sulphate soil
Physical structure	3 layers: - Shallow top-layer: 0.05 to 0.15 m - Jarosite: 0.15 to 0.65 m - Pyrite	2 layers: - Top-layer: 0.0 to 0.50 m - Jarosite: 0.50 to 1.00 m
Value pH	3 to 4 it may drop to 2	< 4
Nitrogen (%)	0.04 to 0.1	0.3 to 0.4
Phosphate (%)	0.01 to 0.05	0.02 to 0.05
Movable iron and aluminium	very high, till 2,000 ppm	relatively high
Sulphur in soil (%)	2 to 3	
Specific characters		- Originated from potential acid sulphate soil - Top layer is rich in organic matter, 6% to 12%

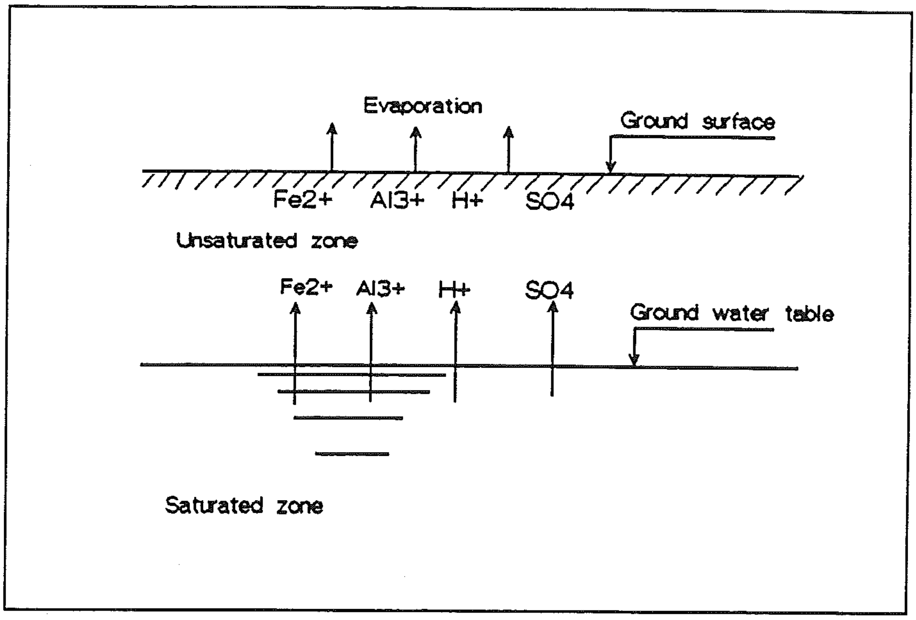

Figure 3 Accumulation of toxic elements in the soil system

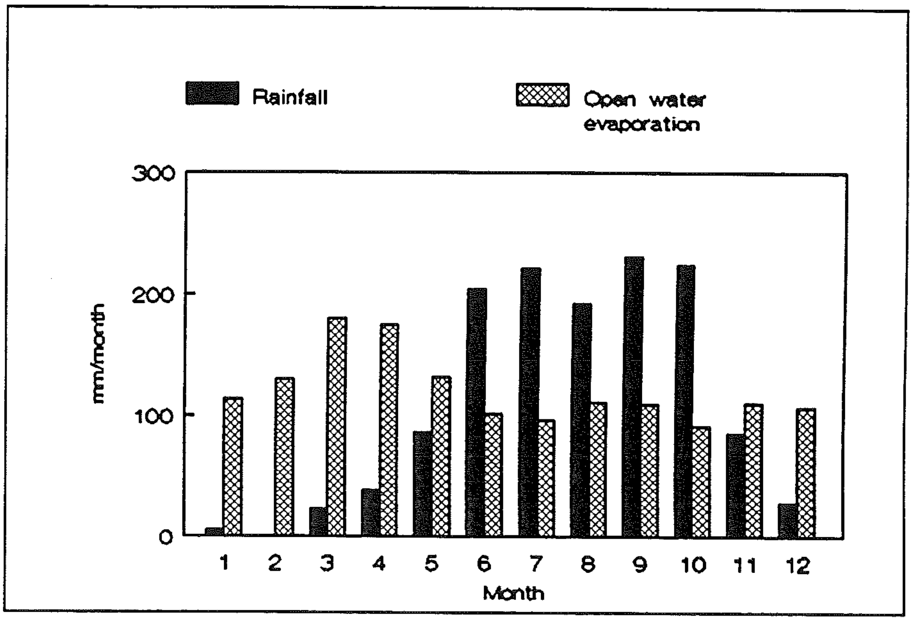

Figure 4 Monthly rainfall and open water evaporation (Hydro-meteorological service department,1995)

2.6 Hydrology

From the name of the delta it is obvious that the hydrology involved in the area is prevailing determined by the Mekong river. The Mekong river is one of the world's greatest rivers and tenth largest in terms of annual flow. It begins its 4,200 km journey to the sea in the mountains of Tibet (China). In an yearly average more than 475,000 million m^3 of water is discharged by the Mekong river to the sea. However, the discharge in the Mekong river considerably changes during the seasons. Maximum discharge in the wet season is 57,000 m^3/s and minimum discharge in the dry season is only 1,700 m^3/s. The average discharge is 13,970 m^3/s.

Table 2 Average monthly rainfall, temperature, evaporation and humidity of the Plain of Reeds (Hydro-meteorological service department, 1995)

Months	Rainfall in mm	Temperature in °C	Evaporation in mm	Humidity in %
January	5.4	25.1	2.6	81.8
February	0.3	25.7	3.2	79.8
March	22.5	27.1	4.1	76.8
April	37.7	28.7	4.1	78.8
May	86.0	28.5	3.0	81.8
June	204.4	27.4	2.4	86.0
July	221.4	26.8	2.2	86.5
August	192.2	26.9	2.5	86.2
September	231.2	27.2	2.6	85.4
October	223.8	27.0	2.1	84.4
November	85.7	26.6	2.6	80.4
December	27.7	25.7	2.4	80.8

Attention in this case has to be paid to the fact that the natural great reservoir Tonle sap in Cambodia actively takes part in the water level regulation, resulting in a reduction of water levels in flood time. In the flood period the water level in the river rises gently at a rate of a few centimetres a day and water overflows the banks at both sides. The Plain of Reeds

Reeds serves as a single reservoir in the wet season and as a storage area for the Vaico West river. The flood water level in the Plain of Reeds goes down gradually at a rate of 1 - 2 cm a day (Dong, 1989).

In the last years (1966-1992) a lot of projects like dams for electricity generation, irrigation, etc. were constructed in the countries in the upper catchment of the Mekong river. These works influence the normal river flow and river morphology. These projects change the river sedimentation and erosion processes. River dynamics and channel changes impose a degree of uncertainty in the planning for the future developments, for instance, salt intrusion problems. According to the assessment of the Master plan of the Mekong river delta there will be shortage of water at the economically full development stage. Problem to be solved is a proper use of water resources.

The other hydrological factor to be involved in the area is the tide. The tide has a significant effect on irrigation and drainage. It determines the water level for irrigation at intakes and the water level in drains and outlets. The variation of the water level in the rivers is affected by the sea tide from the South China sea. It is a semi-diurnal tide. This effect can reach hundreds of kilometres. The effect of the tide is easy to observe in the dry season at the hydrological station Tan chau at a distance of about 200 km from the sea.

2.7 Water management

Agriculture is the main sector of Vietnam's economy. It depends considerably on water management activities. Good water management offers a high yield. For acid sulphate soils, a good water management is the most important element to improve the agricultural production. For example, rice production in the Plain of Reeds is increasing due to the introduction of water management as presented in Table 3. At present water management activities in the area concentrate on:

- Flood control;
- Irrigation;
- Drainage.

Table 3. Rice production in the Plain of Reeds (Le, 1995)

Year	Winter-Spring crop		Summer-Autumn crop		Autumn-Winter crop	
	Area (ha)	Yield (ton/ha)	Area (ha)	Yield (ton/ha)	Area (ha)	Yield (ton/ha)
1988	161,000	4.7	147,570	3.4	87,330	2.0
1989	196,000	4.7	188,000	3.4	79,000	2.0
1990	230,000	4.8	193,800	3.6	57,600	2.1
1991	232,000	4.6	233,683	3.1	24,406	1.5
1992	234,675	5.2	231,870	3.5	42,813	3.3
1993	272,243	4.5	240,012	3.7	61,038	3.2
1994	276,766	5.0	249,306	3.7	76,072	3.5

Source: Report on program of investigation of the Plain of Reeds, 1995

Because of importance of water manegement, the Ministry of Water Resources has been formed and is completely responsible for the country's water management. It is said that water management activities closely relate to each other from the Ministry to the lowest order, as water users or cooperatives, to promote effective water management as shown in figure 5.

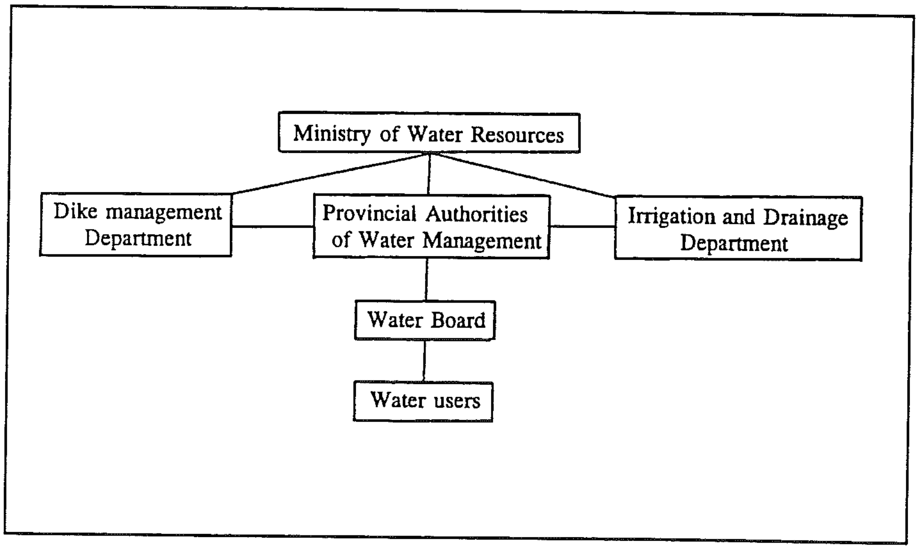

Figure 5 Set-up of water management in Vietnam

In general each district has its own water board that runs the canals and drains of the secondary order upwards. Farmers or cooperatives run the tertiary canals and drain systems. Farmers must pay water fee to the water board.

*** Flood control**

The dike management department is in charge of flood control activities. Nowadays dike systems on both sides of the Mekong river are absent. Floods occur every year and bring damage directly to the local people and indirectly to the Government. In order to prevent the early August flood the local people make dikes around their fields. The dike construction is executed manually or by machinery at the same time with the excavation of drains and canals. Under conditions of acid sulphate soil a small ditch between the dike body and the field has to be constructed in order to avoid that the acidity will enter the field from the dike material. Thanks to the field dike a third crop (Autumn-Winter crop) has been introduced at some places in the Plain of Reeds. Normally, dikes along the big rivers are made by the local people under the supervision of the technical staff. Dike material is taken from a place nearby at determined distance.

***Irrigation**

Irrigation activities in the area just started at the end of the 70's and at the beginning of the 80's with the construction of feeding canals in order to divert irrigation water from the Mekong river. Up to now irrigation is needed. The irrigation water quality is quite good because the diverted water is not affected by salinity intrusion. Intrusion of salty water of 400 ppm less than the allowable content (1,000 ppm) does not reach the water intakes in the Mekong river. But irrigation water quality within the Plain of Reeds becomes not so good due to mixing with drainage water. In the irrigation process farmers take perfect opportunities during the spring tide to irrigate their land by gravity. At other places they use low head pumps to supply water to the field when the tide is going up. These pumps are of economic effectiveness, low energy consumption, high discharge, for example $Q = 1400$ m^3/h, $N = 12$ HP and $H = 0.4$ m (Dong, 1989)

*** Drainage**

Drainage activities started at the same time as irrigation. Drainage is aimed at the evacuation of excess water in order to grow rice in the wet season. All the drainage water from the Plain of Reeds is discharged into the Vaico West river by gravity or by pumps of low head as used in irrigation. The tide plays an important role in drainage. Using the opportunities of the relief all the main drains are excavated in the direction of the Vaico West river. In the dry season the water level in the drainage system is 0.5 - 1.0 m-surface to create the gradient for removal of toxic elements by leaching. The quantity of irrigation water is sufficient in the dry season. Irrigation and drainage canals are very poor, only 5 m per ha (Le, 1995). There are no control and regulation structures in canals except the sluices Bac dong and Rach chanh in the Vaico West river to prevent salt water intrusion. At present in the whole area the main canal network is excavated as illustrated in annex A.2. These canals are connected to each other without structures, so it is difficult to manage and operate the canal.

In the water management development, in the Plain of Reeds the Government played and plays a very important role. The construction of headworks, main irrigation and drainage canals is funded by the Government from the national budget, while hydraulic constructions always require significant investments. In recent years a lot of the constructions were completed. Especially, large investments have been made to build the canal Hongngu (bottom width B = 40 m) in 1984, the central canal for the whole area of the Plain of Reeds.

2.8 Agricultural production

2.8.1 Cropping pattern

As floods regularly occur in the Plain of Reeds, the people have tuned their lives and agricultural practices to them. In the past, there were no irrigation and drainage networks, only one crop of floating rice with low yield was grown during the wet season on an area of 300,000 ha. At present when irrigation and drainage systems are put into operation, new varieties of rice are introduced by the Omon rice research centre, agricultural production made good advances. Spectacular results have been booked with the introduction of 100-day rice varieties (so-called short term rice varieties) enabling to raise two crops a year avoiding critical periods of deep flooding as well as low flow. However, the area so far is basically single cropped. Except rice, dry land crops like sugar cane, pineapple, batata, etc. can be grown on raised beds, but in a very small area where rice can not be grown.

2.8.2 Cropping calendar

The hydrology and the rainfall are the main factors that influence the cropping calendar in the area. As mentioned above two crops of rice a year are grown: winter-spring crop and summer-autumn crop. In order to utilize effectively the hydrological and rainfall conditions the two crops are planned as follows:

- *Winter-spring crop:* land preparation starts in December as soon as possible when the flood water depth on the field is around 0.3 m. At this moment the soil is flushed by surface flow. Then seed is broadcasted and the harvest begins in March - April;

- *Summer-autumn crop:* land preparation is carried out 7 to 10 days after the harvest of the winter - spring crop. Then seed is broadcasted and the harvest takes place in August.

In the Plain of Reeds land preparation is now executed by machinery and no transplanting is applied. The cropping calendar is presented in figure 6.

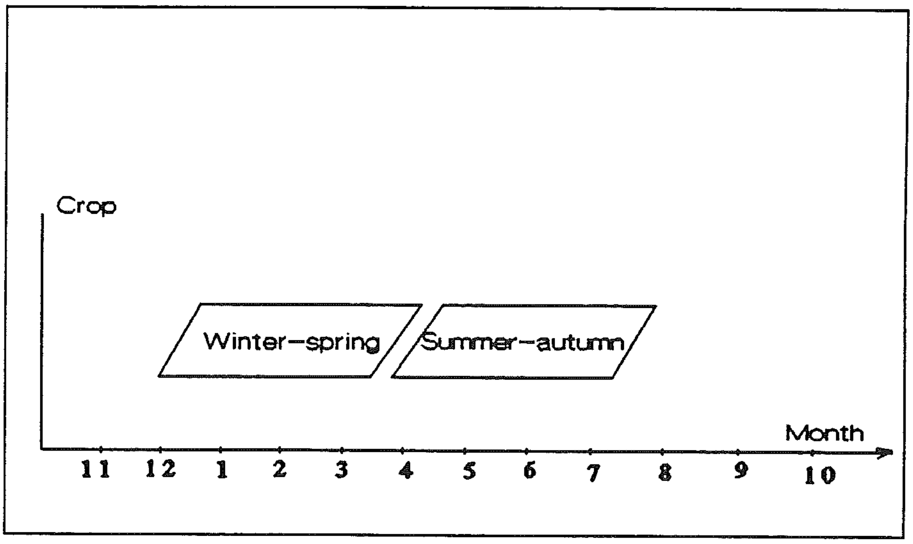

Figure 6 Cropping calendar of rice in the Plain of Reeds

2.8.3 Crop production

The rice yield is considerably affected by water management as well as by fertilizer, plant protection, etc. In the past, the yield of floating rice was very low, 0.5 - 0.7 ton/ha. Great efforts have been made in recent years for economic development such as irrigation and drainage development, application of fertilizers, herbicides, pesticides, land preparation mechanization, etc. These have resulted in a high growth rate in rice production. The rice yield is 2.5 - 4.5 ton/ha on average per crop. The higher rice yield can reach 5 - 6 ton/ha per crop (Newspaper Nhan dan, 24 october 1993) at Ward Ninh nhon, district Tanthanh, province Long An. It is evident that the potential for agriculture in the Plain of Reeds is high. The Plain of Reeds is assessed to be the biggest food storage of the country and to be able to provide millions of people with food if soil and water management measures are significantly improved. Otherwise, low yield or yield loss is unavoidable in some areas. Usually, the yield of winter-spring crop is higher than of summer-autumn crop. Rice yield throughout the area is presented in table 4.

Table 4 Rice yield per province in the Plain of Reeds in 1994 (Le, 1995)

Provinces	Winter-spring crop		Summer-autumn crop	
	Area in ha	Yield in ton/ha	Area in ha	Yield in ton/ha
Dong Thap	126,055	5.7	113,986	4.0
Long An	94,369	3.7	73,886	2.5
Tien Giang	56,342	5.8	61,433	4.8

Source: Report on program of investigation of the Plain of Reeds, 1995

The difference in rice yield can be explained by :

- Land reclamation;
- Irrigation, drainage and flood control;
- Type of soil;
- Investment of farmers in terms of fertilizer, plant protection, etc.

2.8.4 Land use

Land use is an actual problem in the area due to resettlement from densely populated areas. Land is mainly used for rice cultivation. Areas of fallow land in the past change into cultivated areas. For example, the area of fallow land of 241,800 ha in 1976 reduced to 93,100 ha in 1994. The fallow land is at low places due to accumulation of acidity due to poor drainage systems. The other areas are reserved for mangrove forest. This area can be used for rice cultivation in the future. Some area is used for shrimp cultivation. According to the land law, land belongs to the state and farmers only have the right of using land. Therefore, it is interesting that farmers replace their land previously used for rice cultivation by shrimp cultivation or replace their land previously used for forest by rice cultivation because of economic profits. A small part of land is used for homesteads, roads, canals, etc. The present land use of the area is presented in table 5 and its distribution is presented in annex A.3.

2.9 Socio- economy

Within the framework of the renovation process of the country, the agricultural policy strongly changed into a market economy. Farmers have to pay water fee, agricultural tax on land use by Government regulations. Their living standard is improved. Recently rights to long term or short term land use for farmers run into power which encourages farmers to improve their land intensively. Agricultural production has jumped into a new stage of its development. Usually, after some time of implementation of a new policy, a socio-economic investigation will be conducted. According to available data the following aspects are outlined:

* **Infrastructure**: the irrigation and drainage networks are being constructed. Priority number one is given to this matter. Road networks are poor except main roads that connect administrative centres. Transport means that between villages there are boats. Schools and medical service stations have been constructed. National electric transmission lines are extended to the area. Actual problem which has still to be solved is the drinking water supply.

Table 5 Land use of the Plain of Reeds (Report on program of investigation of the Plain of Reeds, 1995)

Type	Area in ha	Area in %
Cultivated land	334,300	53.1
Shrimp cultivation	1,400	0.2
Grass cultivation	8,700	1.4
Forest	124,400	19.8
Fallow land	93,100	14.8
Canal,homesteads, and roads	67,300	10.7
Total	629,200	100

* **Population**

Based on the data of the 1994 population sensus in the Plain of Reeds there are 1,847,000 people. The growth rate in population is very high: 2.28%, higher than the average growth rate in the population of the country: 2.18%. In addition, attention is paid to the fact that a lot of people have moved to settle here based on the population redistribution strategy throughout the country. For example, more than 150,000 people moved to settle in the province Long An during the period (1983-1993) (Newspaper Nhan dan, 10/1993). It is expected that human migration in the area will continue. Out of the total population, the percentage of male and female is 48.9% and 51,1% respectively. Labour is available at a high rate, and can reach two labourers out of three people in new comer families. Land is the most valuable asset, its importance is of such magnitude that we take it as a basis for distinguishing. Average area per one farmer is 2 to 3 ha, number of farmers which posses an area of 10 to 20 ha is 20% of the total population (Duoc, 1995)

*** Income**

Agriculture is the main source of income, 60% of the total income comes from agriculture (table 6).

Table 6 Source of farmer's income, 1993 (Newspapers Nhan dan, 10/1993)

Source	Income in %
Agriculture	60
Breed	16
Other	24

However, such a structure of income is not appropriate, it must be changed. Breed and service activities would have to be in proportion with agriculture.

*** Credit**

Agricultural development banks have been set up recently. It seems that the agricultural development banks are the main source of credit facilities for farmers. This institutional system meets the requirements of the farmers. They can borrow money from the bank at a low rate of interest for 6 months or one year. In the policy to support poor farmers, these farmers have permission to borrow money from the bank without any rate of interest. To use this credit is being considered. They can stop farmers from borrowing money if they spend this money out of the addressed aim.

2.10 Environmental impacts

Environment is being an actual problem of global scale. It influences the daily life of every one in different ways, directly or indirectly. The environment means the sum of all the physical and biological components and processes making up the surrounding of man. It includes:

- Biophysical components and resources such as agriculture land and crops, fisheries, wetland and wildlife and the physical and biological factors and processes which support these resources;
- Social components make up of the human communities and population which occupy the vast flood plain and utilize the various resources.

Any water resources development program will consequently influence not only the agricultural production but also the social life of the people in the region. The various socio-economic classes feel the impacts in different ways and there will be negative as well as positive changes and sometimes new problems arise.

After water management activities are introduced in the Plain of Reeds, environmental changes are unavoidable. Environmental impacts analysis has been carried out based on the methodology of the International Committee on Irrigation and Drainage (ICID) checklist. The main points are outlined.

2.10.1 Positive impact

A comprehensive evaluation gives a clear picture of the benefits derived. The primary impact on agriculture is the land use, considerable increase in cultivated area, fallow land changes into cultivated area of two crops a year, even three crops, rice yield is going up.

Another impact on agriculture is the crop security. Now, if the dike system is constructed it will prevent the early (August) floods. Early floods usually damage to crops at the harvesting stage. These positive effects above satisfy the farmer's life and the income of the people will be increased.

In terms of social aspects this is a region of human migration. Only during 4 years (1987-1990) 21,270 families have been settled in the Plain of Reeds from provinces in the North and neighbouring provinces of which 14,117 families settled in Long An province, 3,800 families in Dong Thap province and 2,118 families in Tien Giang province. This trend is expected to continue in the coming years.

Increase in agricultural production is assessed to be the great achievement of the Plain of Reeds, from 0.57 million ton of rice in 1976 to 2,6 million ton of rice in 1995.

Employment opportunities will be increased. Women labour also actively takes part in agriculture and breed. The rate of labour absorption will be higher than before when three crops will be grown in the area.

2.10.2 Negative impacts

The main possible negative impact of reclamation of acid sulphate soil causes consequences within or downstream the area. Due to reclamation of acid sulphate soil the water quality in the Vai co West river is affected strongly as presented in table 7.

Table 7 Water quality in the Vaico West river in 1994 (Southern Institute for Water Resources Research, 1995)

Place	pH	Ec (μS/cm)	Fe (mg/l)	Al (mg/l)	Cl (mg/l)
Tuyen nhon	4.6	260	0.78	1.0	34.2
Tan an	4.2	330	1.1	1.64	30.7

Toxic elements drawn out from the soil influence the habitat of the fisheries. The evidence is that the death of fish and shrimp is observed at some spots (during the fieldtrip to the Plain of Reeds, 1996). It is urgent to take preventive measures such as more diversion of water from the Mekong river into the Vaico West river or flushing of drainage water (more detail will be discuss in section 4.3).

The dike construction to protect the Plain of Reeds against early (August) floods causes consequences on the left bank area as increase in water level (water depth of flood), morphology of the river changes because in the past the Plain of Reeds served as the natural single reservoir, and now the velocity in the river increases. Sedimentation of alluvial material will decrease and soil fertility will decrease. Consequently, crop yield will be decreased as well. Increased rice crop production in recent times which usually requires higher inputs of chemical pesticides, herbicides and fertilizer to maintain the higher production level. Increased use of these chemicals of course has to have some effects on the habitat of fisheries, water pollution, etc.

Chapter 3

FLOOD CONTROL

3.1 Present situation

In Vietnam so far flood is considered to be more dangerous than fire due to damages caused by the flood itself. They are:

- Firstly, damage such as loss of crop and damages to infrastructure and houses which can be readily estimated;
- Secondly, damages such as loss of income, interruption of communication, arising diseases and caring of evacuation which are not easy to be estimated;
- Thirdly, indirect damages such as loss of human lives, public moral and above all the limitation to land potentialities.

Recently, extensive dike systems of several thousands of kilometres in length have been constructed along the Red river delta to protect the areas against floods effectively in combination with flood detention reservoirs for example, the Hoa binh reservoir in the Black river and the Thac ba reservoir in the Thao river.

On the contrary, there are no dikes in the Mekong delta and floods occur every year. Within this thesis the emphasis will be focused on floods in the Plain of Reeds. Flood brings a large damage to the Plain of Reeds every year, for example, 2.3 billion Vietnam dong (VND), dong is Vietnamese currency, about 2.2 million US$ and 405 victims in 1994 (Nguyen, 1995). Apparently, the factors volume and time play an important role for flood characteristics.

In terms of volume: the whole area of the Plain of Reeds (629,200 ha) is flooded. However, the depth of flooding in the area is different, maximum to 2.1 m. Water depth of flooding in the Plain of Reeds is on average 1.0 to 1.2 m (Dong, 1989).

In terms of time: the flood duration is as much as 2 to 3 months. Floods usually start in August/September and stop in November/December. The maximum flood level is attained in September/October. Especially, flood duration in combination with heavy rains in September and October result in the increase in water depths of flooding. However, it can be said that the flood water level in the river rises gently at a rate of few centimetres per day. In principle, the flooding can be avoided in several ways as shown in figure 7.

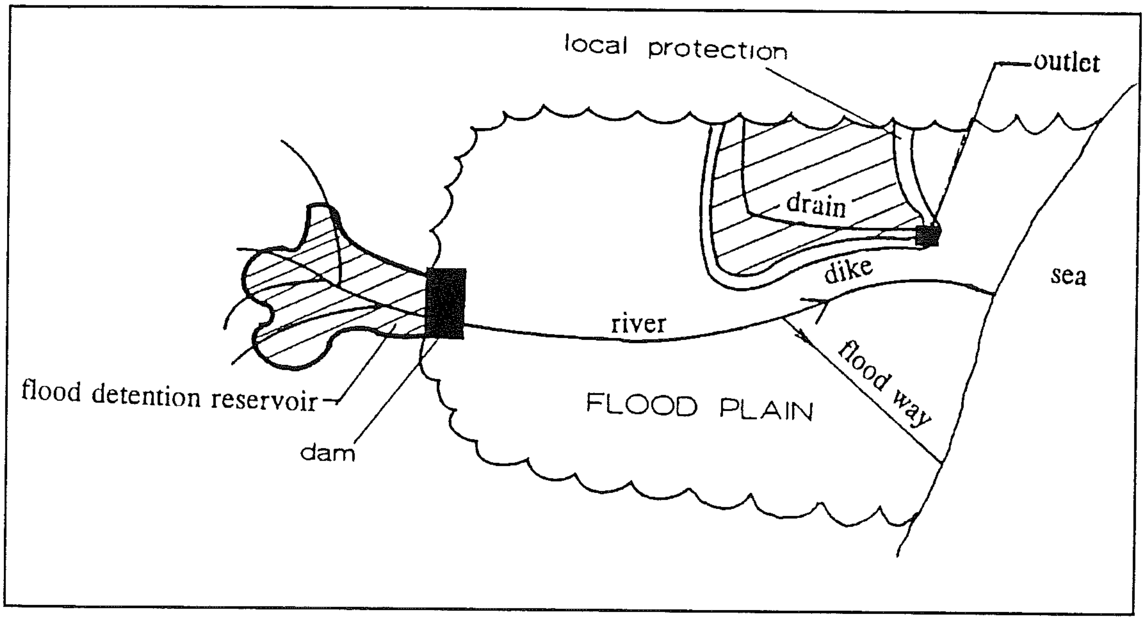

Figure 7 Flood control and flood protection in the river valley for the Plain of Reeds (after Schultz, 1996)

The following measures are considered:

- Construction of flood detention reservoirs in the upstream part of the catchment;
- Construction of dikes along the rivers;
- Excavation of flood ways;
- Combination of the above measures.

The first measure can not be realised because the Mekong delta in Vietnam is located at the low part of the low Mekong basin. The last two measures seem to be proper to the practical conditions. In recent years the reservoir Pa Mong near Vientian (Laos) and the reservoir Stung Streng in the north of Cambodia have reduced the peak flow in the Mekong river. Some canals as flood way have also been excavated to convey the flood water into the sea. However, the flood problem is still not solved. Until recently, local people and the Government have recognised that protection against flood was considered as an absolute necessity by dike construction in the Mekong delta in general and in the Plain of Reeds in particular as a main measure. Flood control is being considered by the Government as proved at conference on flood control in the Mekong delta in January 1996. The main reasons are:

- This is and will be a more densely populated area in the near future;
- This is an economically important zone of the country.

The discussion now will be focused on the fact that if dikes will be built the water level in the river will be raised due to flow contraction. Finally, the submerged area will be extended upstream.

To solve this problem it will be required to refer to regional entities and to take these into account carefully. To make a reliable prediction of the effect of the dike construction physical and mathematical modelling was conducted. In fact, complete prevention of the flooding of the Mekong delta in Vietnam is rather difficult. Obviously, the magnitude of the water level rise at any location depends on the magnitude of flood and extent of dyking. For example, according to a mathematical model the 100-year flood would increase by not less than 2.7 m in Phnom Penh (Cambodia) in case of complete dyking (after SOGREAH, 1969). Therefore, partial (submerged) embanking is the best way to protect the lands against flood. It is noted that embanking can only be attained to a certain degree that is technically and economically feasible. A commonly used economic criterion is the minimum of total annual damage and total annual cost.

As mentioned above in the cropping calendar, the introduction of rice varieties with a growing duration of 100 days, harvesting in August to avoid the deepest floodings in September and October have completely changed the concept of flood control. It is no longer required to build high dikes as done in the North of Vietnam. Now, partial flood protection is sufficient with submerged dikes to keep out the water of the early August floods. The flooding in September till November/December will continue to take place freely. This has many environmental advantages, like no rise of the flood level due to embanking (discussion in section 4.3), migration of fish is not blocked, flushing of canals remains possible. However, attention should be paid to the pollution problem. Before floods occur, it is common that the pH in the drainage canals and the farm ditches becomes less than 3, with aluminium concentration exceeding 7.2 mg/l (Kham, 1988). The water in the drains will be dissolved with the flood water. This polluted water affects the area of non-acid soils, the pollution is even not confined to the reclaimed areas. Thus, drainage management is such that most drainage water will be discharged by the early August floods.

When dikes along the Mekong river will be constructed the problems to be solved will concentrate on drainage. Drainage of flood water in the Plain of Reeds is closely related to the hydrology of the Vaico West river and the drainage system inside. With the DUFLOW model we can determine the required dimensions of canals (discussion in section 4.3)

For the design of embankments, a good understanding of the riparian environment is essential. This encompasses morphology, hydraulic boundary conditions, geological and geotechnical boundary conditions, and sedimentation. However, within the scope of the study only hydraulic boundary conditions are to be considered. It is assumed that the effect of wind, force of Coriolis etc. may be ignored. Annually maximum water levels are of primary concern. In the dike design as well as construction the following also should be taken into account:

- Maximum use of locally available material;
- Labour intensive construction.

In order to reduce the construction cost it is generally required that the dike design should rely on locally available material as much as possible. Dikes are built almost completely manually because labour is easily locally available and is provided with charge of adults in the amount of some days per year.

3.2 Data screening

In flood control the dike design is generally based on a hydrological frequency analysis (HYFA) of annual maximum water levels in the river. Before carrying out the HYFA the data screening must be completed to test for the absence of trend and for stability of the variance and the mean. In case there is any trend, or if the variance or the mean are not stable, the sample data are not suitable for a HYFA. In addition, data screening is necessary because the water levels are related to time series. It could be that during the time of recording there are mistakes, or changes of flow, etc.

The data for the HYFA are available from the hydrological stations Tan chau and Mi thuan. Station Tan chau is located near to the border with Cambodia and station Mi thuan is located at the intersection between highway No.1 and the Mekong river (figure 2). These data are presented in annex B.1. To verify the absence of trend, Spear's rank-correction method is recommended (Dahmen and Hall, 1990). It is simple and distribution free i.e it is suitable for any kind of distribution. The method is based on the Spearman's rank correction coefficient (R_{sp}), which is defined by formula (3.1):

$$R_{sp}=1-\frac{6\sum (D_i)^2}{n(n^2-1)} \qquad (3.1)$$

in which:

R_{sp} = Spearman's rank correction coefficient

n = total number of data

D_i = difference between ranking

i = chronological order number

The difference D_i between ranking is determined as below:

$$D_i = Kx_i - Ky_i \qquad (3.2)$$

in which:

Kx_i = the rank of the variable x, which is the chronological order number of the observations.

Ky_i = transformed to its rank equivalent by assigning the chronological order number into the original series corresponding to order number in the ranked number series y.

The Student's t- distribution is given by formula (3.3):

$$t_t = R_{sp}\left(\frac{n-2}{1-R_{sp}^2}\right)^{0.5} \tag{3.3}$$

Where: (n - 2) is the degree of freedom.

Annex B.2 contains a table of the percentile point of the t-distribution for a significant level of 5% (two tailed). At a significant level of 5% (two tailed) the two sided critical, u, of t_t is bounded by:

$\{-\infty, t\{v, 2.5\%\}\}$ u $\{t\{v, 97.5\%\}, +\infty\}$

The time series has no trend if t_t is not in critical region or if:

$t\{v, 2.5\%\} < t_t < t\{v, 97.5\%\}$

The results of the trend analysis on the water levels is presented in Table 8 and Table 9. Using the data of Table 8 and Table 9 and equations (3.1) and (3.3) yield:

For Tan chau station

$R_{sp} = -0.15$

$t_t = -0.708$

For Mi thuan station

$R_{sp} = 0.24$

$t_t = 0.972$

From annex B.2 the critical values of t_t at the 5% level of significance for (n - 2) degrees of freedom are:

$t\{n-2, 2.5\%\} = -2.11$ and $t\{n-2, 97.5\%\} = +2.11$

Since $t_t = -0.708$ for Tan chau station and $t_t = 0.972$ for Mi thuan station, their values are between -2.11 and +2.11. The time series have no trend.

Table 8 Trend analysis of the maximum water level in the Mekong river at Tan chau station

Year	x = i	max.WL m+MSL	ranked WL, y, m+MSL	Kx_i	Ky_i	D_i
1977	1	3.58	3.30	1	12	-11
1978	2	4.94	3.58	2	1	1
1979	3	4.10	3.58	3	16	-13
1980	4	4.61	3.61	4	17	-13
1981	5	4.68	3.64	5	13	-8
1982	6	4.40	3.71	6	11	-5
1983	7	4.18	4.10	7	3	4
1984	8	4.97	4.18	8	7	1
1985	9	4.32	4.18	9	10	-1
1986	10	4.18	4.30	10	19	-9
1987	11	3.71	4.32	11	9	2
1988	12	3.30	4.34	12	14	-2
1989	13	3.64	4.40	13	6	7
1990	14	4.34	4.61	14	4	10
1991	15	4.80	4.67	15	18	-3
1992	16	3.58	4.68	16	5	11
1993	17	3.61	4.80	17	15	2
1994	18	4.67	4.94	18	2	16
1995	19	4.30	4.97	19	8	11

Table 9 Trend analysis of the maximum water level in the Mekong river at Mi thuan station

Year	X =i	Max.WL, m+MSL	ranked WL, m+MSL	Kx_i	Ky_i	D_i
1977	1	1.68	1.66	1	19	-18
1978	2	1.96	1.68	2	1	1
1979	3	1.79	1.76	3	12	-9
1980	4	1.87	1.79	4	3	1
1981	5	1.87	1.85	5	11	-6
1982	6	1.88	1.85	6	14	-8
1983	7	1.89	1.87	7	4	3
1984	8	1.92	1.87	8	5	3
1985	9	1.89	1.88	9	6	3
1986	10	1.92	1.89	10	9	1
1987	11	1.85	1.89	11	7	4
1988	12	1.76	1.92	12	17	-5
1989	13	1.92	1.92	13	8	5
1990	14	1.85	1.92	14	10	4
1991	15	1.97	1.92	15	13	2
1992	16	1.92	1.92	16	16	0
1993	17	1.92	1.96	17	2	15
1994	18	2.13	1.97	18	15	3
1995	19	1.66	2.13	19	18	1

The following step is to find the stability of the variance and mean for the water level data.

F-test and t-test for stability of variance and mean

In addition to testing the time series for absence of trend they must be tested for stability of the variance and the mean. The same series investigated on trends will be subject to an F-test. The F-test will be carried out to see whether there is prove for a significant difference between the variance of the first half of the series (subset 1) and the second half (subset 2). The trend and the stability of the variance will be subject to the test for the stability of the mean. The T-test will be carried out to investigate whether there is prove for a significant difference between the mean of the subset 1 and the subset 2.

F-test for the stability of variance

The distribution of the variance ratio of the sample from a normal distribution is known as the F or Fisher distribution. The F-test will give an acceptable indication of stability of variance. Thus the test statically reads:

$$F_t = \frac{S_1^2}{S_2^2} \tag{3.4}$$

in which:
S_1^2 = variance of the subset 1
S_2^2 = variance of the subset 2

The critical region (rejection region), u, is bounded by

$\{0, F\{v_1, v_2, 2.5\%\} \text{ u } \{F\{v_1, v_2, 97.5\%\}$

in which: v_1 and v_2 are the respective number of degrees of freedom of the numerator and dominator, $v_1 = n_1 - 1$ and $v_2 = n_2 - 1$ with n_1 and n_2 are the number of observation in each subset.

The variance of the time series is stable, and one can use the sample standard deviation, s, as an estimation of the population standard deviation if:

$F\{v_1, v_2, 2.5\%\} < F_t < F\{v_1, v_2, 97.5\%\}$

The values of $F_{2.5\%}$ and $F_{97.5\%}$ can be derived from annex B.3
From table 13 and table 14 the observations are divided into two subsets as presented in table 10.

Table 10 Two subsets for calculating F_t and t_t for Tan chau station and Mi thuan station

Tan chau station				Mi thuan station			
i	Subset 1	i	Subset 2	i	Subset 1	i	Subset 2
1	3.58	11	3.71	1	1.68	11	1.85
2	4.94	12	3.30	2	1.96	12	1.76
3	4.10	13	3.64	3	1.79	13	1.92
4	4.61	14	4.34	4	1.87	14	1.82
5	4.68	15	4.80	5	1.87	15	1.97
6	4.40	16	3.58	6	1.88	16	1.92
7	4.18	17	3.61	7	1.89	17	1.90
8	4.97	18	4.67	8	1.92	18	2.13
9	4.32	19	4.30	9	1.89	19	1.66
10	4.18			10	1.92		

Subset 1 consists of 10 observations from 1977 to 1988 and subset 2 consists of 9 observations from 1989 to 1995. The results of the calculation of F_t for the maximum water levels in the Mekong river at Tan chau station and Mi thuan station are presented in table 11. From annex B.3 $F_{2.5\%} = 0.244$ and $F_{97.5\%} = 4.36$ when $v_1 = 9$ and $v_2 = 8$.

For Tan chau station:

$F_{2.5\%} = 0.244 < F_t = 0.613 < F_{97.5\%} = 4.36$, the variance is stable.

For Mi thuan station:

$F_{2.5\%} = 0.244 < F_t = 0.362 < F_{97.5\%} = 4.36$, the variance is stable.

T-test for the stability of mean

One can apply the t-test to data that belong to any frequency distribution. For t_t , the two sided critical region, u, is

$\{-\infty\ , t\{v, 2.5\%\}\}\ u\ \{t\ \{v, 97.5\%\}, +\infty\ \}$

with $v = n_1 - 1 + n_2 - 1$ degree of freedom.

The mean of the time series is considered to be stable if

$t\{v, 2.5\%\} < t_t < t\{v, 97.5\%\}$

$$t_t = \frac{X_1 - X_2}{\left[\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2} * \left(\frac{1}{n_1} + \frac{1}{n_2}\right)\right]^{0.5}} \tag{3.5}$$

in which:

X_1 = mean of the subset 1

X_2 = mean of the subset 2

n_1 = number of data in subset 1

n_2 = number of data in subset 2

S_1^2 = variance of subset 1

S_2^2 = variance of subset 2

The result of calculation t_t for the maximum water level in the Mekong river at station Tan chau and station Mi thuan are presented in Table 11.

For Tan chau station:

$t_{2.5\%} = -2.11 < t_t = 1.817 < t_{97.5\%} = +2.11$

The mean of the water level at n Tan chau is stable.

For Mi thuan station:

$t_{2.5\%} = -2.11 < t_t = -0.354 < t_{97.5\%} = +2.11$

The mean of the water level at Mi thuan station is stable.

Finally, the data of maximum water levels are accepted for making a hydrological analysis.

3.3 Hydrological analysis

In order to select the design water level for the dike design, a hydrological frequency analysis (HYFA) has been made with the extreme value type 1 (EVS) or Gumbel distribution (Fisher and Tipelt, 1920) by formula (3.6):

$$F(x_i) = e^{-e^{-y_i}} \quad (3.6)$$

Where: the reduced variate, Y_i, can be determined by formula (3.7):

$$Y_i = \frac{(X_i - c)}{a} \quad (3.7)$$

in which:

X_i = variance (water level in m)

c = the location parameter

a = the scale parameter

Table 11 The results of the calculation for the Tan chau station and the Mi thuan station

Tan chau station			Mi thuan station		
Parameter	Subset 1	Subset 2	Parameter	Subset 1	Subset 2
n	10	9	n	10	9
mean	4.4	3.99	mean	1.87	1.88
s	0.42	0.54	s	0.08	0.13
s^2	0.178	0.291	s^2	0.006	.017
v	9	8	v	9	8
Resulting calculation			Resulting calculation		
$F_{2.5\%}$	0.244		$F_{2.5\%}$	0.244	
F_t	0.613		F_t	0.362	
$F_{97.5\%}$	4.36		$F_{97.5\%}$	4.36	
$t_{2.5\%}$	-2.11		$t_{2.5\%}$	-2.11	
t	1.817		t	-0.354	
97.5%	+2.11		$t_{97.5\%}$	+2.11	

In terms of probability of non-exceedance or return period the Gumbel distribution is expressed by formula (3.8):

$$Y_i = -\ln[-\ln(F_i)] \tag{3.8}$$

in which:

Y_i = reduced variate

F_i = probability of non-exceedance

The value for F_i can be calculated by Gringorten' s formula (3.9):

$$F_i = \frac{i-0.44}{n+0.12} = 1 - \frac{1}{T} \tag{3.9}$$

in which:

T = return period in year

i = ranking in ascending order

n = number of data

Obviously, this method is simple and can also be applied in a graphical form. Extreme values of water levels are plotted versus the reduced variate. Based on the records of water levels in annex B.1 they are arranged in ascending order with increasing ranking number, next the probability of non-exceedance F_i, and then the reduced variate from F_i are calculated as presented in annex B.4 and B.5. The extreme water level (column 3) and the reduced variate (column 5) in annex B.4 and B.5 are plotted. The relationship water level - reduced variate is assumed to be linear. The GEV-1 curve fitted with plotting points is presented in figure 8 and 9. From the figure 8 and figure 9 the water levels for various return periods can be determined. Water levels corresponding to various return periods are also presented in table 12.

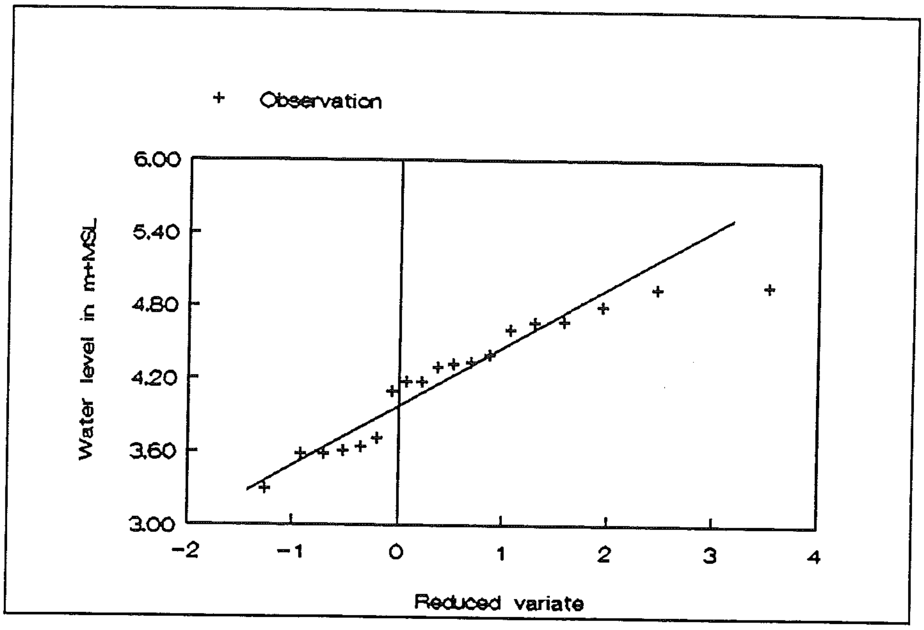

Figure 8 Gumbel extreme value Type 1 curve for the Tan chau station

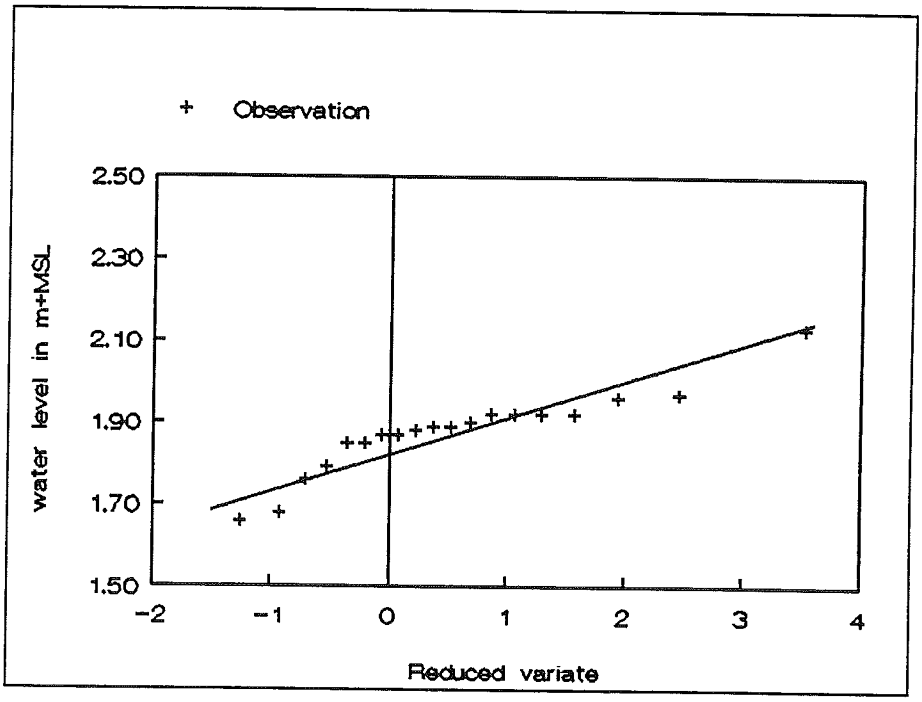

Figure 9 Gumbel extreme value Type 1 curve for the Mi thuan station

Table 12 Relation of water level to return period

Return period, year	Estimated water level at Tan chau station, m+MSL	Estimated water level at Mi thuan station, m+MSL
3	4.3	1.90
5	4.5	1.95
10	4.7	1.98
20	5.0	2.05
50	5.3	2.15
100	5.5	2.20
1000	6.3	2.40

The selection of the return period usually depends on the degree of structure or on the importance of the area to be protected. On the other hand, the selection of the return period is based on the economic analysis which deals with an investment cost and a damages. Optimal return period will be selected when a total cost of investment and damages is minimum as shown in figure 10.

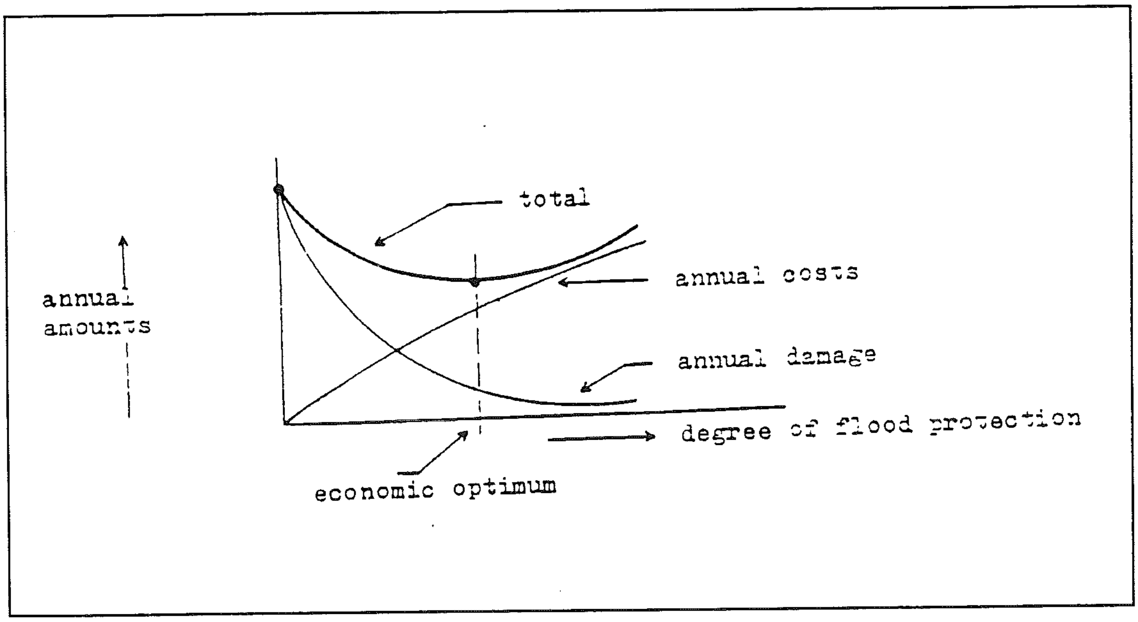

Figure 10 Selection of return period for dike design

As stated above the Plain of Reeds is an agricultural area and flood protection will be aimed at protection of one rice crop from the early August floods. Obviously, maximum water level in the Mekong river in August should be taken for determination of return period T_{aug}. Optimum return period T_{aug} is based on cost/benefits of august crop. As a result, the crest height of dike is found. Dike in the Plain of Reeds is submerged and repaired regularly. Therefore, the selection of return period has to deals with a dike repair or strength of dike. This selection is based on cost/benefits in repair which is taken from the annually maximum water level in the Mekong river. As a result, the return period T_{year} is found. From annex B.1 it is seen that annual maximum water levels in the Mekong river almost occur in September and October. It can be said that the yearly water level will be greater than the water level of August at the same return period. Therefore, the selection of return period is based on the yearly maximum water level in the Mekong river. In selection of return period attention should be paid to:

- strategy and importance of the Plain of Reeds.
- agreement of the Mekong committee which consists of four member-country: Cambodia, Laos, Thailand and Vietnam at present;
- the process of land reclamation: floods bring alluvial sediment to the fields. Thanks to the floods acidity easily flushed out from the field to the river Vaico West;
- if a choice for a high return period is made investments in works inside the Plain of Reeds will be high. A complication with large structures will be that the soil has a low bearing capacity;
- specific features of local people: the concept of living with flood is introduced. The local people are familiar to flood.
- environmental aspects;
- besides, according to the records of water level from 1945 to 1994 at Tan chau station it shows that percentage on indicated water level is given the followings:

  Water level $H < 4$ m : 24%

  Water level $H = 4.0$ to 4.5: 46 %

  Water level $H > 4.5$ m : 30 %

Based on the above reasons the selection of return $T = 3$ years will be appropriate. As a result, the design water levels for submergible dike construction based on the yearly maximum water level are:

at Tan chau: 4.3 m+MSL

at Mi thuan: 1.9 m+MSL

and design water levels at other places are determined by an interpolation.

This return period deviates from the return periods that are generally applied. A return period T = 10 years is generally is used when agricultural crop would have to be protected during the whole year. A return period T = 100 yreas is used when cities have to be protected. A return period T = 10000 years is used for the design of coastal dikes in The Netherlands due to importance of the protected area.

3.4 Criteria for dike design

By definition a dike is a hydraulic structure which may be of important significance for the country. Design activities have to rely on design criteria. In general, dike design criteria under submerged conditions are as follows:

- The scale (or degree) of dike: the dike along the Mekong river and the dike along the border with Cambodia are a type of main dike to protect an area of 629,200 ha. The area is located along a river with a discharge of more than 7,000 m^3/s. It is obvious that this is of great importance. Referring to procedures in QPTL.A.6-77 (dike classification in Vietnam), these dikes belong to the primary degree. However, the Plain of Reeds is an agricultural area and the dikes are submerged. For these reasons the dikes should be designed as dikes of tertiary or quartery degree (III or IV)

- Return period T: the return period T = 3 years in the Plain of Reeds as described above.

- Safety factor: for any constructions the safety factor has to be introduced. The safety factor depends on the degree of dike. In accordance with the degree of dike (III or IV) and return period T = 3 safety factor can be taken 1.05 in reference with the Regulations on design of earth dam, QPTL 60-70.

- Dike material: dike material is available locally and is clay or clay loam. To achieve a stability and minimum of filtration through the dike body, a density γ and optimum water content ω_{opt} of dike material should be:

for clay: γ = 1.55 to 1.56 ton/m^3, ω_{opt} = 25 to 26%

for clay loam: γ = 1.66 to 1.67 ton/m^3, ω_{opt} = 18 to 20%

- Safety distance: when a dike is constructed the pressure on ground will be increased which may cause sliding. A dike has to be built outside the limit of the sliding curve in river direction based on a calculation. On the other hand we have to reserve a certain distance from the dike foot for safety reasons. Referring to the dike law (1992) that within a distance of 50 m from the dike foot no stable constructions are allowable to built and for practical situation the safety distance is taken to be 50 to 100 m from the dike foot.

- Free board: Free board is not taken into account because of submerged dike.

- Preventive measures: this criteria is also under consideration. Erosion on the side slope of the dike surface is unavoidable due to overtopping. From an economic point of view and practical conditions grass planting will be applied to prevent erosion.

- Top width: usually a road is designed on top of a dike. Top width of the dike becomes then 5 to 7 m.

- Subsidence (settlement): Dike subsidence must be considered in the dike design because of its importance. The subsidence depends on the soil properties and height of dike. Under condition of the Plain of Reeds it may be about 30% of the height of dike.

Finally, the criteria for the dike design are summarized in table 13.

3.5 Dike design

Before completing the dike design a geological survey has to be conducted. Its objectives are to explain the features of dike foundation and to explore the characteristics of the dike material. Soil in the Plain of Reeds is clay, but clay loam has been found in some places. Their characteristics are presented in annex B.9 and use for further calculation. In dike design, it is necessary to know the reasons of dike failure in order to avoid it as presented in figure 11.

Table 13 Criteria for dike design in the Mekong delta under submerged condition

Order	Items	Estimation
1	Degree of dike	III or IV
2	Return period, year	3
3	Top width, m	5 - 7
4	Safety distance, m	50 - 100
5	Preventive measure	grass planting
6	Dike material	
6.1	Water content, %	
	for clay	25 - 26
	for clay loam	18 - 20
6.2	Density, kg/m^3	
	for clay	1,55 - 1,56
	for clay loam	1,66 - 1,70
7	Safety factor	1.05
8	Subsidence, %	25 - 30
9	Freeboard, m	0

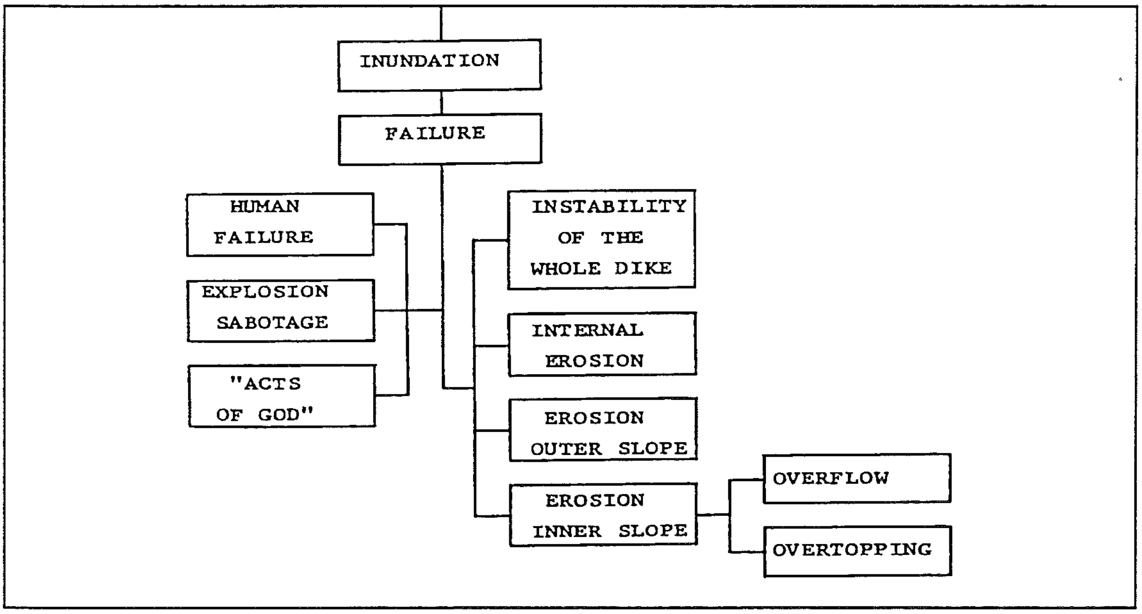

Figure 11 Reasons of dike failure

This study deals with technical aspects. From figure 11 it is seen that the dikes must be stable, no erosion outer and inner slopes, and no internal erosion.

Stability of dike:

The dike is calculated as a normal dike when water level in the Mekong river goes up in August but not reach the design crest. For this case, the program STABIL 5.1 was used which was developed by Verruijt (1990). The schematization for calculation is presented in figure 12.

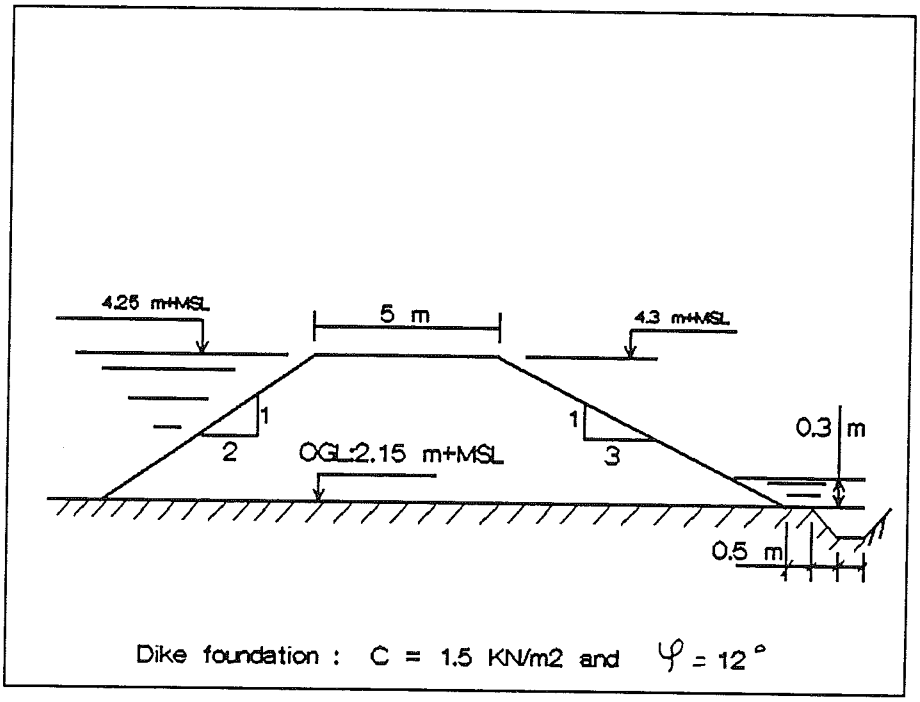

Figure 12 Schema for calculation of dike stability

The assumptions are made:

- water depth inside is 0.30 m above the field which is usually regulated to keep water in the field for flushing. It can be done by the structures through the dike as described above.
- slope stability depends on a value of side slope which is subjected to properties of dike material. The dike is submerged. There will be a overtopping. In order to limit erosion on the inside slope, it should be not too steep. So, outside slope is steeper than inside slope. For these reasons side slope in outside is 1:2 and 1:3 in inside.
- fixed slide point is at the dike foot and another point is at the ditch bottom.

- in design, the attention has to be paid to method of construction. In the Plain of Reeds the dike construction is completed manually, compaction is difficult available.
- only one layer of soil is applied for calculation by observation from canal excavation.

Finally, the program offers the smallest stability factor k_s for:
fixed slide point at dike foot k_s : 1.09
fixed slide point at ditch bottom k_s :1.10
Obviously, the stability factor for both slide points is greater than the factor recommended in criteria of dike design k = 1.05. Therefore, dike is stable.

Erosion outer slope:

Erosion outer slope usually is caused by affect of wave. The wave is common to accompany with the wind. In conditions of the Plain of Reeds there are no wind or very weak wind. i So, it is assumed that there is no erosion outer slope.

Erosion inner slope:

From a hydraulic point of view the dikes in the Plain of Reeds are submerged, so it is necessary to check the erosion on inner slope when overtopping occurs. It is assumed that the dike in this situation is considered as broad crested weir. Discharge flows over the dike is estimated by formula (3.10):

$$Q=b.\frac{2}{3}.H.\sqrt{\frac{2}{3}.g.H} \tag{3.10}$$

Where:
Q = discharge over the dike, m^3/s
b = length of the dike, in this case it is assumed b = 1 m under consideration.
g = 9.81 m/s^2, acceleration of gravity.
H = 0.7 m, water depth above crest dike. This value is defined by the DUFLOW model (scenario 4 in section 4.3.3). By the DUFLOW model result the water level is 5.0 m+MSL. Design crest dike is 4.3 m+MSL.
Substituting the known values above into formula (3.10), it is found Q = 0.67 m^3/s.

However, critical depth y_c is defined by formula (3.11):

$$y_c=\frac{2}{3}.H \tag{3.11}$$

Where: H = 0.7 m as above

Critical velocity V_c is defined as below:

$$V_c=\frac{q}{y_c} \tag{3.12}$$

Where: q = 0.67 m^2/s = unit discharge from Q = 0.67 m^3/s with b = 1 m.
From formula (3.11) and (3.12) critical velocity V_c = 1.44 m/s. The dike is used in transport. The dike material is clay and very compacted. The permissible velocity V_p = 1.65 m/s for the very compacted clay (Pilarczyk, 1984). Obviously, V_c = 1.44 m/s < V_p = 1.65 m/s. Therefore, erosion on crest dike does not occur.

Now, it is necessary to check the erosion on inner slope with unit discharge above (q = 0.67 m^2/s). In this case a flow on inner slope of the dike is considered as flow in the steep grass channel. According to US soil conservation service (1954) V_p = 1.5 m/s. Obviously, shear velocity V_s is less than permissible velocity V_p. Shear velocity V_s is defined by formula (3.13):

$$V_s=\sqrt{g.R.S} \tag{3.13}$$

Where:
g = acceleration of gravity
S = 1/3 inner slope
R = hydraulic radius, m
It is assumed that hydraulic radius R = water depth y. Water depth y is defined from formula (3.14):

$$Q=\frac{1}{n}.R^{\frac{2}{3}}.S^{\frac{1}{2}}.y.b \tag{3.14}$$

Where:

$Q = 0.67\ m^3/s$, discharge

$n = 0.035$, Manning roughness, $m^{-1/3}.s$

$b = 1$ m taken for consideration

y = water depth on inner slope

Substituting these values into formula (3.16) and (3.17) it is found that $y = 0.15$ m and $V_s = 0.74$ m/s. Obviously, $V_s = 0.74$ m/s $< V_p = 1.5$ m/s, so erosion on inner slope can not occur.

Internal erosion

The reasons for internal erosion mainly depend on dike material, construction technology. So, it is careful to select a dike material and to inspect dike construction regularly.

Another consideration in dike design is calculation of settlement. The calculation of dike settlement is necessary to be carried in order to reach the design crest after certain time because the soil in the Plain of Reeds has the weak bearing capacity. The settlement is defined by Terraghi formula:

$$S=\frac{h}{C}.\ln\frac{\sigma_i+\sigma_a}{\sigma_i} \qquad (3.15)$$

in which:

h = depth of sublayer, m

C = coefficient of compressibility

σ_i = initial effective stress, KN/m^2

σ_a = actual effective stress, KN/m^2

The subsidence depends on two main factors: soil properties and height of dike. The soil is weak, it is better not to construct a high dike. The subsidence is carried out on the data in annex B.9 and the height of dike for the cross sections on the border with Cambodia and the Mekong river. It is found that the subsidence is 0.7 m and 0.3 m on the border and the Mekong river respectively. It seems to be reasonable to soil in the Plain of Reeds. From this result it may be said that the subsidence is about 30%. Therefore, the required height of dike is 2.85 m = 2.15 m (height of dike) + 0.7 m (subsidence) at construction phase in the border and 1.4 m (1.1 m + 0.3 m) in the Mekong river. It is common that the subsidence changes in time. Therefore, it can be said that at first decade overtopping can not occur because crest of dike is higher than designed crest. Furthermore, this height of dike will be used for calculation of earthwork of dike construction.

Based on calculation above the cross section of dike is presented in figure 13.

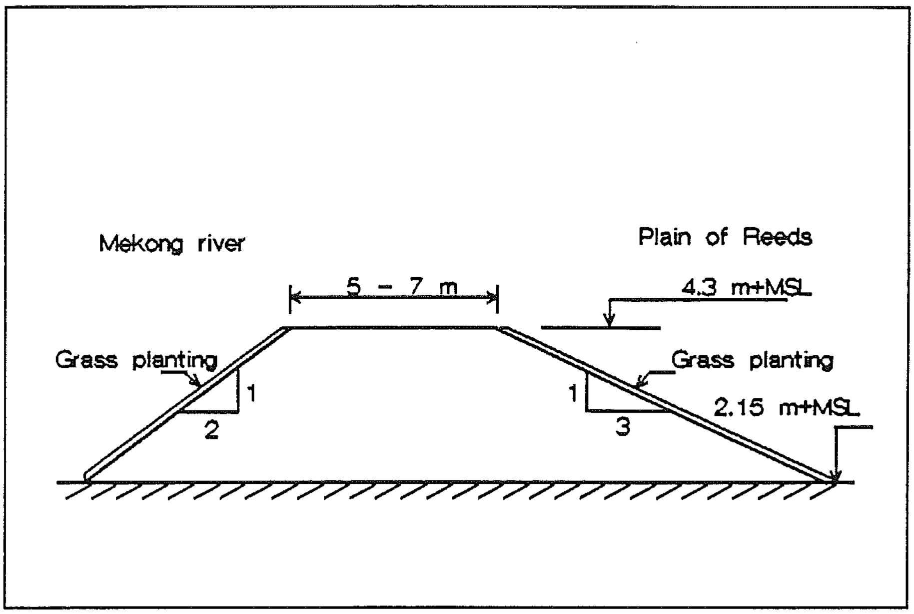

Figure 13 Typical cross section for submerged dike in the Mekong river

3.6 Economic analysis

Before carrying out the economic analysis it should be determined the alignment where the dike will be constructed. According to the investigation of 1994 flood distribution (annex B.6) it is seen that the flood in the Plain of Reeds is caused by flow from the border with Cambodia (Section 1) and from the Mekong river (Section 2). So dike has to be built at two sections mentioned above (see annex B.7). In section 1 water flows along the whole border with assumption of the same design water level. The dike will has also the same crest, 4.3 m+MSL. From the topography map the average elevation is 2.15 m+MSL. In calculation of the volume of earthwork the supplementary volume due to settlement is considered which includes in hight of dike. In this section topwidth of dike is taken as 5 m. The cross-section for calculation of earthwork in section 1 is presented in figure 14.

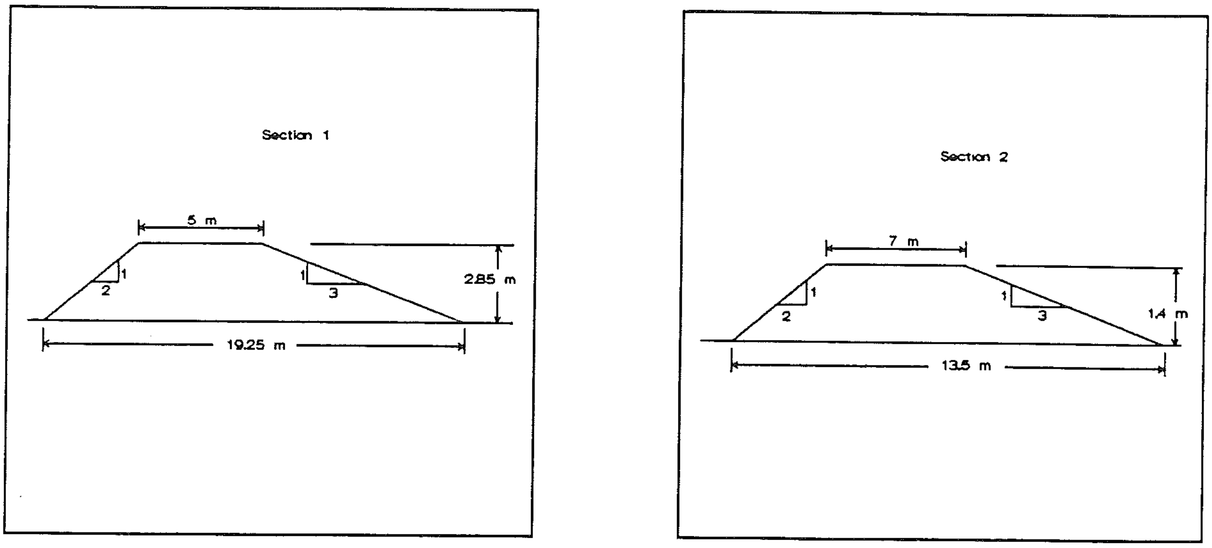

Figure 14 Cross-sections in section 1 and section 2 for the earthwork calculation

Volume of earthworks for dike construction is presented in table 13. In the section 2 the crest of the dike changes from the Tan chau station to the Mi thuan station and further to the mount. In this situation it is assumed that the dike crest and the ground elevation here are taken to calculate the volume of earthwork for section 2. The topwidth in this section is 7 m because it is a main road in the Plain of Reeds. The cross-section of this section for calculation is presented in figure 14. The calculation is presented in table 14. The dike construction is accompanied with the construction of culverts. These culverts have functions,firstly, to divert water for flushing the Plain of Reeds whenever flood water can not overtop the dike. Secondly, the structures prevent flood water from Cambodia to enter the Plain of Reeds at the beginning of flood season because water quality at this moment is poor with low value of pH, less than 6 (Nguyen,1995). The location of these structures is presented in annex B.7. The Section 1 consists of 4 structures. The Section 2 consists of 8 structures. In order to calculate the construction cost of these structures it is necessary to estimate the total width of these structures. It is assumed that the width of structure is the same width of canal where the structure will be constructed. Therefore, total width of all strutures through dikes is 180 m.

Table 14 Calculation of the volume of earthwork for dike construction

Items	Section 1	Section 2
Length, m	68,000	180,000
Water level, m+MSL	4.3	1.9
Average elevation of ground surface, m+MSL	2.15	0.8
Height, m	2.15	1.1
Subsidence, m	0.7	0.3
Topwidth, m	5	7
Upstream slope	2	2
Downstream slope	3	3
Volume, m^3	2,350,000	2,650,000

Cost calculation

Cost C_d for dike construction is defined by relation (3.16):

$$C_d = V * d \tag{3.16}$$

Where:

d = unit cost for 1 m^3 of earth, $13*10^3$ VND/m^3 (by tariff)

V = total volume for dike construction, m^3

Hence, $C_d = 13 * 10^3 * 5,000,000 = 65.0 * 10^9$ VND

Total cost of the structure construction C_s can be estimated as follows:

$$C_s = N * s \tag{3.17}$$

in which:

N = total amount of width of structures under dike

s = unit cost to complete 1 m width of structure, 1.2 $*10^9$ VND per 1 m width

Hence, $C_s = 1.2 * 10^9 * 180 = 216 * 10^9$ VND

Finally, total cost C will be:

$$C = C_d + C_s \tag{3.18}$$

$$= 65.0 * 10^9 + 216.0 * 10^9 = 281 * 10^9 \text{ VND or 26 million US\$}$$

Calculation of profit

The profit of the dike construction can be expressed in increase in area with a third crop (the autumn-winter crop) and no damages to rice crop by avoidance of early August floods.

- In terms of the autumn-winter crop: Based on the data in annex B.8 it can be assumed that area of autumn-winter crop will be increased by A = 20,000 ha which is about 12% of the total area under summer-autumn crop or about 25% of present area of the summer-autumn crop. Average rice yield of 11 years (1984 - 1994) is y = 2.2 ton/ha. According to the rice price r_p = 1.7 million VND/ton in 1995 total revenue R may be estimated by

$$R = A * y * r_p \tag{3.19}$$

$$= 20{,}000 * 2.2 * 1.7 * 10^6 = 74.8 \text{ billion VND}$$

However, in the dike design the return period T = 3 years. That means the actually total revenue R_a is estimated as below:

$$R_a = 2/3\ R = 2/3 * 74.8 = 49.9 \text{ billion VND}$$

In rice production the expenditures on land preparation, plant protection, fertilizer and seeds are relatively high. Real profit R_p is assumed as 25% of actually total revenue, the so real profit is

$$R_p = 0.25 * 49.9 = 12.5 \text{ billion VND}$$

- In terms of profit brought by avoidance of the early August flood: this value is estimated on an overall average in rice production during 11 years (1984 - 1994) for the summer-autumn crop. From annex B.8 the average area is 179,000 ha, average rice yield is 3.2

ton/ha. As described above, the harvesting is in August at the same time the flood occur. It is assumed that the reduction of rice yield due to flooding is 30% on the area of about 20% of total area of the summer-autumn crop (this is based on the cropping calendar). The return period T = 3 years, so the profit in this case will be only 33% of total profit due to dike construction. Therefore, profit P_f due to dike construction will be:

$$P_f = 170{,}000 \text{ ha} * 3.2 \text{ ton/ha} * 0.3 * 0.2 * 0.33 * 1.7 * 10^6 = 18.3 \text{ billion VND}$$

Total profit due to dike construction:

$$P_{total} = 12.5 + 18.3 = 30.3 \text{ billion VND or } 2.8 \text{ million US\$}.$$

Cost for dike maintenance

Cost for dike management Cm consist of regular maintenance cost of dike repair after flood. Due to submergence the cost for repair are relatively high. They can be taken as 7% of the construction cost for further calculation. This means

$$Cm = 0.07 * 281 = 19.67 \text{ billion VND/year}$$

Due to return period T = 3 years the probability of cost of repair management is 33%. So, required cost for dike maintenance will be estimated as below:

19.67 * 0.33 = 6.5 billion VND

Dike construction is funded by the Government, so economic analysis is carried out by duration of return of initial investment T. Value T is determined by relation

$$T=\frac{\text{Totalinvestment}}{\text{Totalprofit-dikemaintenance}}=\frac{281*10^9}{30.3*10^9-6.5*10^9}=11.8\text{years}$$

From the calculation of duration of return of investment of 12 years is acceptable. Usually, life time of the dike and the structure through dikes are up to 50 years or more. Therefore, investment for dike construction can be feasible.

Chapter 4

SOIL AND WATER MANAGEMENT

4.1 Drainage and irrigation requirement

For acid sulphate soil water management is the key factor to improvement (Dent, 1986), particularly in areas where lime can not be applied on a large scale. It can be modified in the way that appropriate irrigation and drainage is the key factor to open a new horizon of agricultural development on acid sulphate soils in the Plain of Reeds. If it will be done effectively as follows:

- increase agricultural production, especially rice. It is popular to implement in two ways: either by vertical extension or by horizontal extension. The higher yields, high crop intensities and increase in area can not be obtained without provision of adequate irrigation and drainage. Certainly, we do not forget to mention flood control and cultural practices. Adequate irrigation and drainage will provide security for sustainable development of agriculture;
- exploit new areas with a high potential for agricultural development as the Plain of Reeds. Under increasing population pressure, after reclaiming a new area resettlement of people from densely populated areas will take place.

Effective irrigation and drainage management is based on a theoretical and practical analysis of the water balance. The water balance in a rice field is written as below and is depicted in figure 15:

$$Wo + Wm + Wt + Wr = Wh + Wth + Wc \qquad (4.1)$$

in which:

Wt = Irrigation water supply (m^3/ha)

Wm = Effective rainfall (m^3/ha)

Wo = Initial amount of water in field (m^3/ha)

Wr = Amount of water for leaching (m^3/ha)

Wh = Evapotranspiration (m^3/ha)

Wc = Amount of water on field at end (m^3/ha)

Wth = Amount of drainage water (m^3/ha)

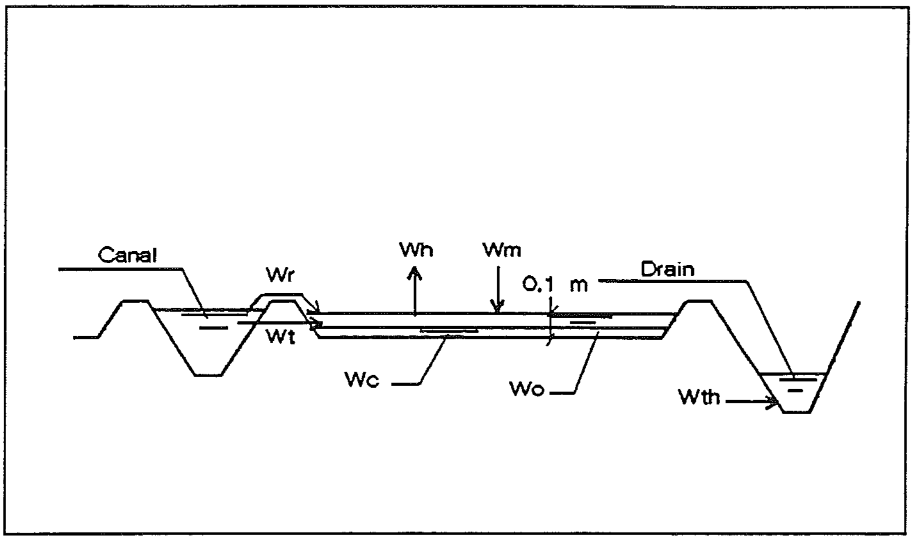

Figure 15 Components for the water balance in a rice field

Certainly, water which is needed to maintain a certain water depth in the rice field, maximum is 0.1 m, can be either irrigation water or rainfall. The calendar of rice cultivation is planned in accordance with the hydrological and climatological conditions. This is aimed at economizing water for agricultural development. The calculation of the water balance is done in this study. Data of 1994 which were available are used. The water balance was conducted on 3 fields with an area of 10 ha, 5 ha and 1 ha for field 1, field 2, and field 3 respectively. These fields are shown in figure 16.

Determination of the factors in equation (4.1):

- Wo = Wc = 0 means that irrigation is provided whenever it is required;
- Irrigation water supply Wt: irrigation provision depends on the stage of vegetation (annex C.1). Based on data on irrigation it can be seen that the required amount of water on soil

type P/S (field 1) is greater than on the developed acid sulphate soil. It may be only due to filtration because other conditions were controled. Irrigation for the winter-spring crop requires more water than for the summer-autumn crop because of lag of rainfall.

- Evapotranspiration Wh has been measured and is presented in annex C.2. It is shown that the total potential evapotranspiration is almost the same for both crops, 6,125 m^3/ha for the winter-spring and 5,884 m^3/ha for the summer-autumn crop;
- Effective rainfall Wm for the whole duration of growing period is taken from meteorological data at Tan Thanh station. This value is 510 m^3/ha for the winter-spring crop and 2,394 m^3/ha for the summer-autumn crop;
- Water for leaching Wr: some water is used for removal of toxic elements by pass-flow. Apart from that the amount of water also provides for leaching, 1,300 m^3/ha in the winter-spring and 2,400 m^3/ha in the summer-autumn. Finally, by equation (4.1) we can determine a total amount of drainage water Wth. The result of calculations is presented in Table 15.

Table 15 Water balance for rice field in 1994 (Duoc, 1994)

Crop	Wt (m^3/ha)	Wm (m^3/ha)	Wr (m^3/ha)	Wh (m^3/ha)	Wth (m^3/ha)
Winter-spring	6,350	510	1,300	6,125	2,035
Summer-autumn	3,850	2,394	2,400	5,885	2,759
Total	10,200	2,904	3,700	12,010	4974

It is seen in table 15 that the leaching in the summer-autumn crop is greater than in the winter-spring crop, 2,759 m^3/ha and 2,035 m^3/ha, respectively because there is a flushing by flood water at the beginning, the requirement on leaching becomes less. Meanwhile, more leaching is needed in the summer-autumn crop to remove the toxic elements which have been accumulated in the toplayer due to evaporation at the end of the winter-spring crop. Another reason is that possible time for leaching in the winter-spring is short. The experimental data in the project show that the irrigation module is relatively high, 1.53 l/(s.ha) (Duoc, 1994). Meanwhile in the North the irrigation module is only 1.2 l/(s.ha) (Thinh and Hai, 1991). The reason is high evaporation and use of the spring tide. The high irrigation module will require more investments. It is possible to re-reseach in order to reduce the irrigation module.

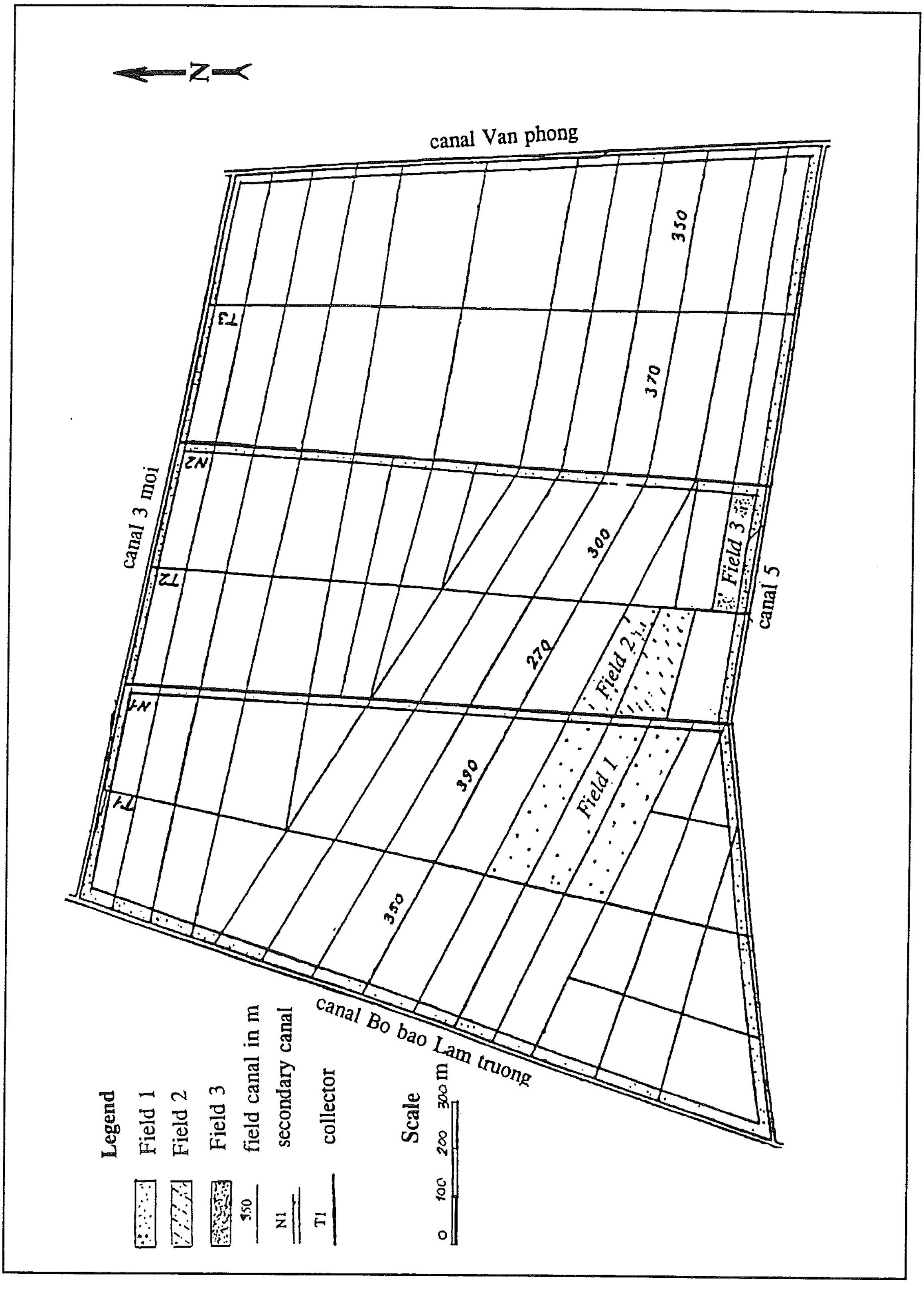

Figure 16 Lay-out of the canal network in the pilot project Tan Hoa

4.2 Alternatives

So far various methods of drainage for reclamation of acid sulphate soil have been carried out on the field in Vietnam. These are open drainage at Hai Hung province in the North (1980 -1985) and at Tan Thanh distrct, Long An province in the Plain of Reeds (1980 till now); mole drainage at Hai Hung province in the North (1985 - 1990) and subdrainage by the project VIE/86/001 funded by the United Nations Development Program at Thai Binh province in the North. The research results show that open drainage is the most suitable to conditions of Vietnam. The research activities in the South are aimed at optimum canal networks and techniques of leaching for reclamation of acid sulphate soil. These researches are in frame of state research topic with code 06.01.02.04 in the period 1980 -1985 and 06A.03.01 in the period 1985 - 1990. The research was carried on a small area and was successful. Based on the research results the following parameters for a tertiary drain are recommended and are tested in the pilot project Tan Hoa to gain appropriate technical specifications for planning and design activities under conditions of the Mekong delta:

- Distance between drains: 100 m, it deals with working possibilities of equipments on the field and to minimize the non-agricultural area under canal construction;
- Depth of drain: 1.0 m, it deals with the stability of the side slope of the canal and to try not to excavate too deep through the pyrite layer;
- Bottom width: 0.8 m, it deals with discharge under tidal conditions, method of completion and seepage;
- Side slope: 1:1, it deals with the stability to avoid sliding;
- Maximum length: 300 m, it deals with optimum size of field and avoid the stagnating water in the drain;
- Water level in the drain: $\geq$ 0.3 m-surface to create hydraulic head for leaching.

Before the construction of the canal network the land in the area was fallow, there were only a few canals. That is why only reed was grown because concentration of the chemical elements in the soil is very high (annex C.4). Especially, there were various types of soil in the project as mentioned in Table 17. Distribution of these soils is presented in annex C.5.

Table 17 Features of soil and its distribution in the project (Duoc,1994)

Type	Features	Area, ha	%
P/S	Alluvial on acid sulphate soil	39.4	13.98
S_1J_2	Developed acid sulphate soil, low acidity, jarosite appears at depth of 0.5 - 1.0 m-surface	43.6	15.47
SJ_2	Developed acid sulphate soil, mean acidity, jarosite appears at depth of 0.5 - 1.0 m-surface	44.4	15.76
SJ_1	Developed acid sulphate soil, mean acidity, jarosite appears at depth of 0.0 - 0.5 m-surface	67.8	24.06
SP_2	Potential acid sulphate soil,mean acidity, pyrite at 0.5 - 1.0 m-surface	56.0	19.87
SP_1	Potential acid sulphate soil, mean acidity, pyrite at 0.0 - 0.50 m-surface	23.4	8.30
TS	Soil affected by acid water	7.2	2.56
	Total	281.8	100

It can be said that the soil in the project as well as in the Plain of Reeds is rather complicated. In addition, there were no field canals/drains, the existing canals was in bad condition. Excavation of canals or improvement of existing canal was easy to completed. The parameters above seem to be accepted by the farmers (interview with farmer during fieldtrip to the project, 1996). It is evident that farmers have excavated canals in the fallow area nearby as done in the project. To change fallow land into cultivated land, by experiment, soil at the toplayer (0.0 - 0.20 m-surface) has to be puddled in order to solute toxic elements in the soil solution and discharge these elements. Puddling is done at water depth of 0.30 m twice before rice seeding planting. Puddling requires a large amount of water, 3,000 m^3/ha. Fortunately, the flood water is used. It has to be done when the flood water level is going down.

During leaching the difference between the water level in the canal and on the field (hydraulic head) and the coefficient of filtration have considerable effect on the removal of toxic elements. To increase the removal of toxic elements we can increase the hydraulic head when the coefficient of filtration is low or we can regulate the water level in the drain when the coefficient of filtration is high. It can be found by the Hooghoudt equation (4.2):

$$q = \frac{8*k*d*h+4*k*h^2}{L^2} \tag{4.2}$$

Where:

q = drain discharge, m/d

k = hydraulic conductivity, m/d

L = drain spacing, m

h = hight of ground water table above water level in drain, m

d = equivalent depth, m

Soil in the area is newly formed. A lot of cracks and remainders of trees have been found. An important factor which influences on the hydraulic conductivity is the formation of a ploughing foot layer. This layer is absent at present and will be formed in future after some years of cultivation. By determining the average of 11 samples the hydraulic conductivity is 0.005 m/day (Southern Institute for Water Resources Research, 1995). It is relatively low in comparison with other areas in the Plain of Reeds. Of course this value will decrease in course of time. Commonly, the water level in the drains is 0.30 - 0.40 m-surface on average at the beginning, then it falls down to 0.50 - 0.60 m or more for winter-spring crop and at the beginning of the summer-autumn crop. In contrast, the groundwater level has an increasing trend from the beginning of the summer-autumn crop and reaches field surface at the end of the summer-autum crop due to rainfall. Water level regulation is not available because there are no structures. Water levels in drains fully depend on the tide. Using the equation of Hooghoudt (4.2) it was found that the distance between drains would have to be 7 - 8 m. Obviously, in comparing the calculated drain spacing with the practical drain spacing there is very large difference 8 m and 100 m, respectively. Research on this difference should be carried out in future. If the calculated drain spacing will be accepted, field drains will be very densely. As a result, the non-cultivated area under canals/drains will be high, activities on the field met difficulties. Otherwise, if the practical distance between drains is accepted, the leaching can be not effectively provided. However, leaching occurs. As a result, toxic elements are removed out, soil is improved. The changes in chemical components are presented in Table 17. From Table 17 it is seen that Al^{3+} in both layers decreases, but SO_4^{2-} decreases in the top layer, and increases in the sublayer. It could be that SO_4^{2-} is accumulated in the sublayer. In general, the amount of Al^{3+} decreases by 12% and SO_4^{2-} decreases by 13%. From the value of Ec we have found that Al^{3+} decreased due to, firstly, solution of Al^{3+} in water and secondly, exchangeable Al^{3+}. Low hydraulic head results in removal of the toxic elements mainly from the toplayer.

Table 17 Changes of chemical components in soil in the summer-autumn crop in 1993 (Duoc, 1994)

Time	Soil depth, m	pH	Ec, μS/cm	Al^{3+}, ppm	SO_4^{2-}, ppm
Before leaching	0.0 - 0.3 0.3 - 0.5	3.4 3.3	1,432 1,672	1,731 1,890	1,980 2,310
After leaching	0.0 - 0.3 0.3 - 0.5	3.7 3.3	1,278 1,534	1,530 1,800	1,740 2,400

As described above flood also plays an important role in land reclamation. Thanks to flood toxic elements in soil are well diffused in flood water. Concentration of elements decreased considerably as presented in table 18.

Table 18 Changes of chemical components in soil by flood in 1993 (Duoc,1994)

Time	Soil depth, m	pH	Ec, μS/cm	Al^{3+} ppm	SO_4^{2-} ppm	Date
Before flood	0.0 - 0.3 0.3 - 0.5	3.52 3.16	1,270 1,120	1,687 1,811	1,700 1,800	15/7/93 15/7/93
After flood	0.0 - 0.3 0.3 - 0.5	3.81 3.32	983 917	1,161 1,711	1,230 1,672	15/11/93 15/11/93

To enhance the diffusion process after harvesting the summer-autumn crop the soil has to be ploughed in order to increase the area of surface exchange. From data in table 17 and table

18 it is shown that in reclamation of acid sulphate soil diffusion by flood seems to be more effective than leaching, for example, Al^{3+} decreases by 201 ppm in case of leaching and by 526 ppm by flood flushing. The main reason is water quality and solution of the toxic elements. Flood water quality is very good and is much better than the irrigation water in the summer-autumn crop. Chemical components of irrigation water in the project as below (Duoc, 1994):

pH = 4.87, Ec = 204 μS/cm, Al^{3+} = 1.19 meq/l and SO_4^{2-} = 157.5 mg/l

The specific feature for the Plain of Reeds is that all canals are connected to each other. The same canal can be an irrigation canal for one area and can be a drainage canal for other area. For this reason the effective of land reclamation has limitation.

Also from table 17 and 18 we can observe the storage of toxic elements by capillary rise from ground water/saturated zone when irrigation stop for harvesting,for example, Al^{3+} increased from 1,530 ppm to 1,687 ppm during June and July. Generally, after one year of reclamation soil in the project was improved and shows a positive trend as presented in figure 17 and 18.

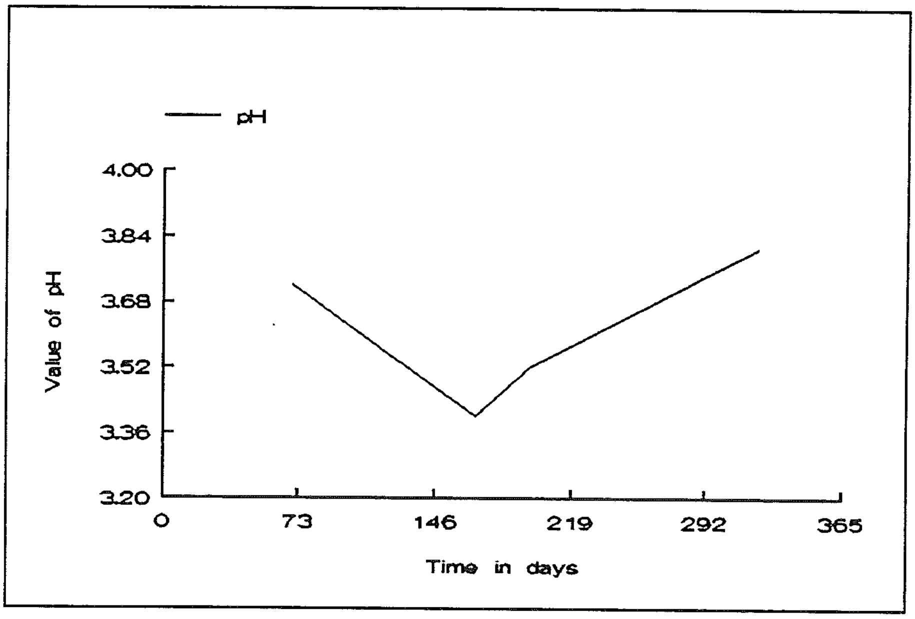

Figure 17 Change of value pH after 1 year of reclamation in the top layer in the area Tan Hoa in 1993

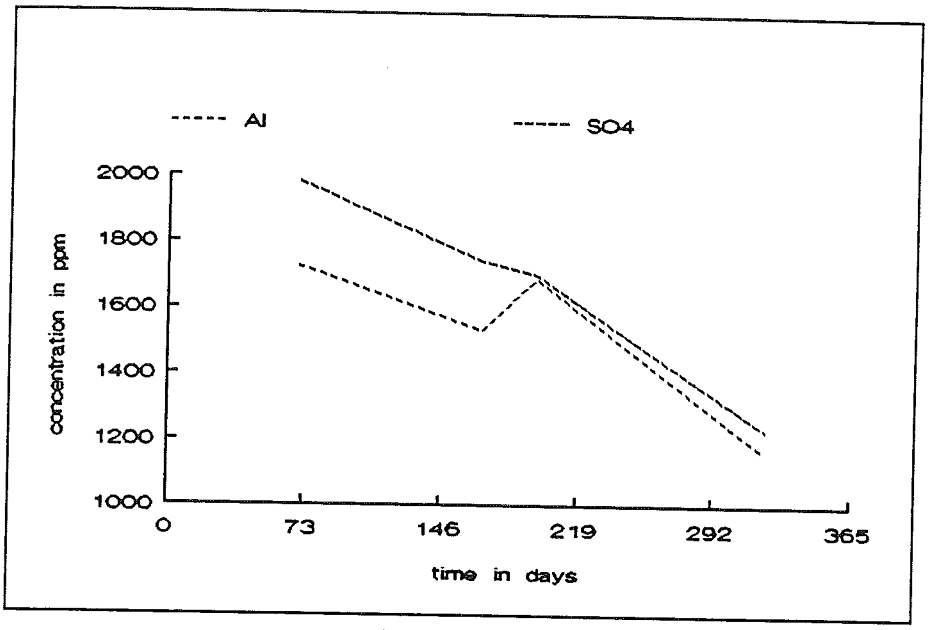

Figure 18 Change of Al^{3+} and SO_4^{2-} after 1 year of reclamation in the top layer in the area Tan Hoa in 1993

Based on the water quality in the irrigation canal and in the field drain we can also calculate the total amount of chemical components removed out from the soil by drainage. The calculation is carried out as follows (4.3):

$$RM = V * (Cd - Ci) \tag{4.3}$$

in which:

RM = total removed weight, kg/ha

Cd = concentration in drain, kg/m^3

Ci = concentration in irrigation canal, kg/m^3

V = volume of drainage water after calculated time, m^3

Following the available data we calculate for 1994, based on data of water quality in canal 5 and field drain as shown in figure 16 and annex C.3 and volume of drainage water in table 15 we have:

- For the winter-spring crop

$$RM = 2{,}035 * (0.0068 - 0.0048) = 4.1 \text{ kg/ha}$$

- For the summer-autumn crop

RM = 2,759 * (0.0059 - 0.0054) = 1.4 kg/ha

Then for the whole year

- RM = 4.1 + 1.4 = 5.5 kg/ha

Landreclamation of acid sulphate soil is closely related to the movement of the groundwater table. Under influence of floods the groundwater table reaches the soil surface from September to January (Figure 19). This phenomenon results in so-called secondary acidity.

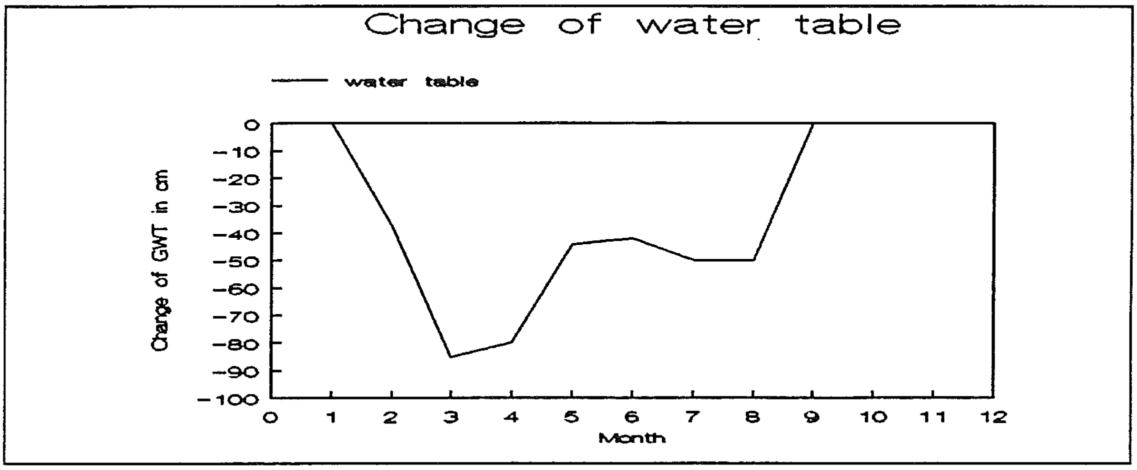

Figure 19 Change of the groundwater table in the area (Duoc, 1994)

Toxic elements in the ground water will be absorbed on the surface of soil particles in the top-layer to restrict the growth in the next season because concentration of soil solution in the saturated zone is very high (annex C.4). The change of the ground water creates the pyrite oxidation in some fields because pyrite is at nearly soil surface or not so deep. The pyrite oxidation starts in March when irrigation stops to harvest. Under the conditions in the area it takes a long time to make the soil suitable for agricultural development. To shorten the duration of landreclamation we should take opportunities of tide with construction of water control structures or irrigation water has to be supplied to the field for leaching when the water level in the drain is low in March till June. If the irrigation water is of good quality the duration of reclamation can be reduced (more detail in section 4.3).

Another aspect should be considered in the pilot project. This is land use. The whole area is used for rice cultivation. In the canal design attention should be given in such a way that the smaller the area under canals and roads is the better. Land use in the project is presented in table 19. From table 19 it is seen that the non-cultivated area accounts for only 6.7% of the total area of the project. This portion is acceptable and appropriate to conditions in the Mekong delta. It is rather higher than in the Red river delta, 5% (Duoc,1994). In terms of land size for farmer this is an actual problem. Initially, each farmer has about one hectare. Then some people have sold their land to the local people or people from neighbouring province of Tien Gang (Fieldtrip to the project, 1996). It is expected that the land size for farmers changes in future.

Table 19 Land use in the project (Duoc,1994)

Item	Area in ha	Percentage (%)
Cultivated area	262.88	93.3
Canals and roads	18.92	6.7

4.3 Analysis of alternatives

4.3.1 Simulation of acidity

Complete analysis and assessment of alternatives for land reclamation carried out on experimental plots requires a long time and a large amount of money. Due to financial and time limitations some questions involved such as what are the critical water levels for upwards unsaturated low carrying acids, toxic elements into the root zone, what will be the effects of drainage on development of cracks and associated oxidation process, etc. can not be known.

In recent years the Simulation Model For Acid Sulphate Soil (SMASS) (Bronswijk, 1992) has been developed and is a helpful tool for planing, design and engineering purposes. In the SMASS model the physical and chemical processes are described and are explained visible in numerical form of output data in time series. In other words, the introduction of the SMASS model provides the opportunity to focus on a quantitative analysis of several processes not be derived from the expert knowledge. With the help of the SMASS model we can predict completely the long-term or short-term effects of possible water management strategies like drainage and irrigation activities and leaching, on acidification and de-acidification of potential and developed acid sulphate soil in order to scope with the new land reclamation projects or rehabilitation projects.

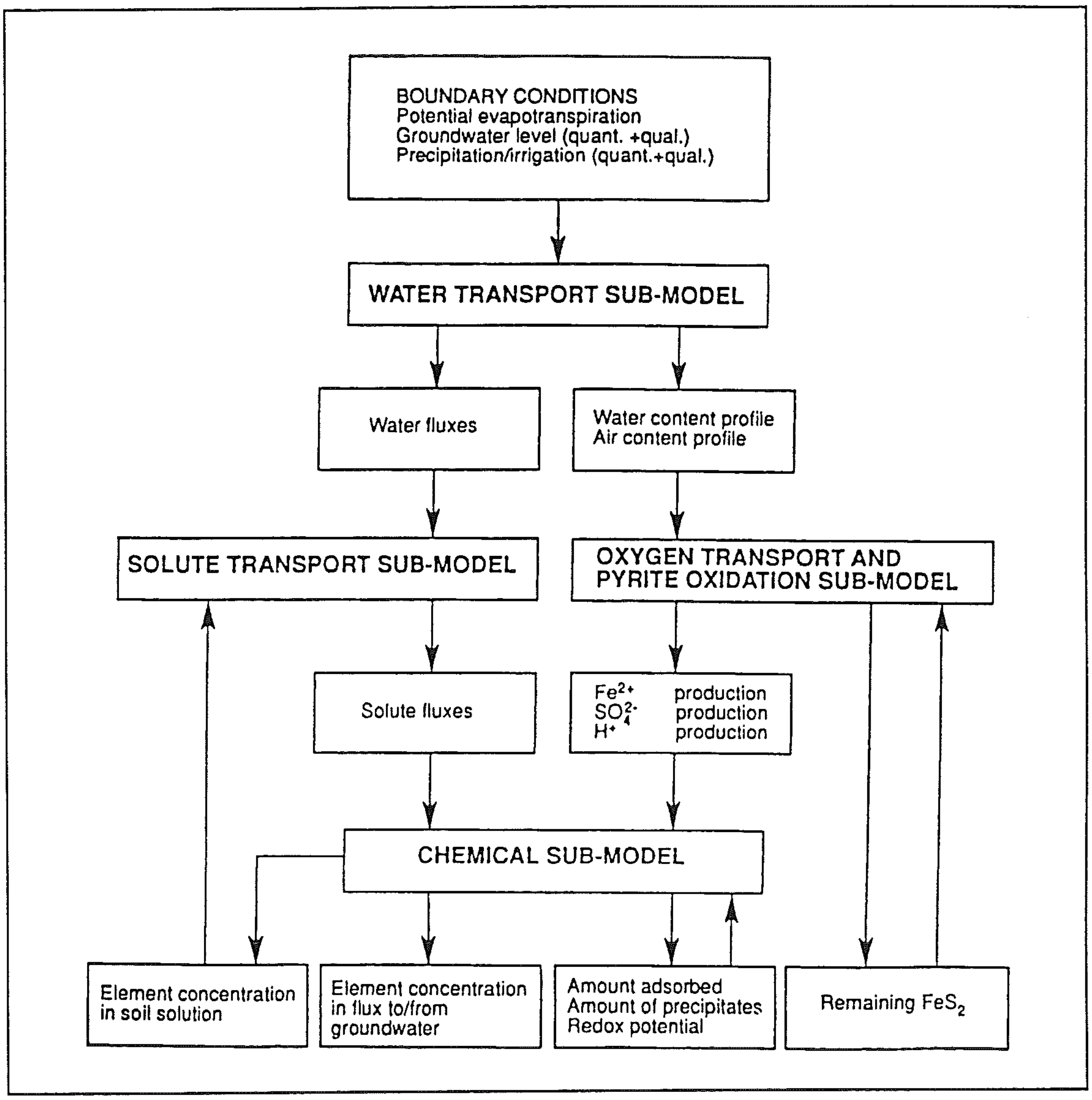

Figure 20 Structure of the SMASS model (Bronswijk, 1992)

The SMASS model has such great significance due to the logical consequences of physical and chemical processes taking place in the soil as shown in figure 20.

For the inherent features of the SMASS model we will use it to simulate the acidity in comparison with the field experimental data on the selected alternatives. It is no doubt that in analysis and assessment of land reclamation of acid sulphate soil the acidity (pH number) is considered to be one of the most important indicators. The acidity has significant effects on the growth of rice. The increase in pH number is favourable for rice. From chemical point of view the acidity has close interaction with $Fe^{2+}$and Al^{3+}. If the pH increases the content of ions $Fe^{2+}$and Al^{3+} certainly decreases. For acid sulphate soil the concentration H^+ theoretically is in equilibrium with concentration SO_4^{2-} by dissolution in water and ionizing of sulphuric acid H_2SO_4:

$$H_2SO_4 \rightarrow 2\,H^+ + SO_4^{2-} \tag{4.4}$$

This sulphuric acid is produced by the process of pyrite oxidation following the reactions (2.1) and (2.2). Then jarosite tends to hydrolyse (Do Van Dam and Ponds, 1972) according to the following reaction (4.5). From equation (4.5) it is possible to say that one of the reasons to cause acidity is a hydrolyse of jarosite.

$$KFe_3(SO_4)_2(OH)_6 + 3\,H_2O \rightarrow 3\,Fe(OH)_3 + K^+ + 2\,SO_4 + 3\,H^+ \tag{4.5}$$

The analysis shows that the magnitude of pH will depend on the following factors:
- The quantity of pyrite;
- Its oxidation rate;
- The rate of removal of soluble oxidation products;
- The neutralizing capacity.

In terms of the neutralizing capacity, calcium and exchangeable bases are important for acid neutralization in the short term, their reaction with sulphuric acid being virtually instantaneous. The remaining factors other than the quantity of pyrite can be controlled by water management measures (to discuss in next section) so that the value pH will be improved in a proper manner.

In order to run the SMASS model all input files (10 input files) should be filled with highly careful consideration in avoiding confusion. The input files are:

File 1: general input file
File 2: soil physical data
File 3: crop parameters as upper boundary condition
File 4: meteorological data as upper boundary condition
File 5: chemical data required for chemical equilibrium calculation
File 6: data necessary to define the bottom boundary condition of soil profile
File 7: information about the irrigation practice
File 8: initial water content and solute concentration in the soil profile
File 9: oxygen regime parameters
File 10: parameters used for the calculation of chemical equilibrium in subroutine EPIDIM

The results of the simulation are presented in 5 output files as below:

File 1: general output for water and solute data
File 2: calculated pH, pE and solute concentration in all compartment
File 3: calculated amount of absorbed component in all compartment
File 4: calculated amount of precipitates in all compartments
File 5: water and tracer balance data.

Regretely, some data necessary to fill the input files are not available due to either shortage in equipment of chemical analysis such as the pyrite content, precipitation component or missing in chemical analysis like HCO_3^-, etc. Pyrite content as well as precipitation components are important factors affecting acidity of soil. Component HCO_3^- participates in ion exchange. If these components are missing it will become difficult to run the SMASS model. In order to complete these missing data in practice we can accept data which are available from another place under similar conditions. It is known that the acid sulphate soils are in Kalimantan (Indonesia), in the Chao Phraya delta (Thailand) and in Malaka (Malaysia). However, the acid sulphate soil in Kalimantan (Indonesia) is the most similar to the Plain of Reeds (Vietnam) according to personal contact with people from the Southern Institute for Water Resources Research who just done studytour to Kalimantan in 1994. In addition, data from Kalimantan are available. So, in this case data from Kalimantan in Indonesia are used to fill the missing data.

We have found that the effectiveness of reclamation of acid sulphate soil depends on water management activities. If the water management is sufficient the land reclamation will be easy to complete at a large scale. Analyzing the factors effected on the possibility of land reclamation and considering the feasible conditions in Vietnam we know that irrigation water quality and water table are decisive factors. Water management strategies are based on these factors. Irrigation water quality deals with construction of seperate irrigation and drainage canals to avoid mixture of irrigation water with drainage water as in present situation. Irrigation should be water diverting from the Mekong river. Ground water table deals with constructions. The ground water table is only controlled by structures. It can be say that the lower the ground water table is the more investment requires. In the water management on acid sulphate soil in Vietnam the ground water table is lower than depth of root zone and pyrite is not alowable to expose the air. Irrigation water diverting from the Mekong river is of good quality as presented in table 20.

Table 20 Water quality in the Mekong river (Institute of planning and water management, 1993)

pH	Ec	Fe^{3+}	Al	Cl^-	Ca	Mg	Na	K^+	SO_4	H^+
6.7 to 7	210 to 265	0.3 to 0.4	0.4 to 0.7	8 to 9	0.6 to 1.1	0.07 to 0.3	0.1 to 0.8	0.03 to 0.04	0.2 to 0.5	0.67 to 1.4

Note: - all elements in meg/l and Ec in $\mu S/cm$

Water table deals with tide. Irrigation water quality in the Plain of Reeds is a question of interest. Irrigation water mix with drainage water. The mixture of irrigation and drainage water makes limitation for land reclamation and growing of rice due to poor water quality as presented in table 21.

Table 21 Water quality in the Plain of Reeds at Tan Thanh (Southern Institute of Water Resouces Research, 1993)

pH	Na	K	Ca	Mg	Fe2+	Al3+	SO_4	Cl
3.88	0.956	0.09	1.38	3.0	1.26	1.7	193	17

Note: all elements in meg/l

In accordance with strategies of water management for acid sulphate soils, canal and drain have to be separate. At present the water quality changes in space inside the Plain of Reeds from area near the Mekong river to area along the Vaico West river. In experiment it is difficult to carried out two alternatives at the same time. Thanks to the SMASS model it is easy to distinguish the effects of irrigation water quality on land reclamation. Hydrological factors and evaporation also effect on acid sulphate soil. Consequently, in dry season ground water table reaches pyrite layer. Pyrite oxidation occurs. In order to avoid this phenomenon it is necessary to control the water level in canal. Main crop in the area is paddy. Therefore, the ground water table is 0.15-0.2 m is appropriate and is controlled by building structures. Combining the effect of the water quality and the water table control we do SMASS model with water quality at present situation (so-called mixed water) and the water quality of the Mekong river in the same water table.

♦ **Scenario 1**: In this scenario it is assumed GWT = 0.20 m-surface for paddy. Variable is water quality in inputfile on irrigation practice. For analyzing the effects of leaching we are interested in value pH and concentration Fe^{2+} and Al^{3+}. These are main representatives for reclamation of acid sulphate soils. From the simulation result it is seen that value pH changes very slowly as shown in figure 21.

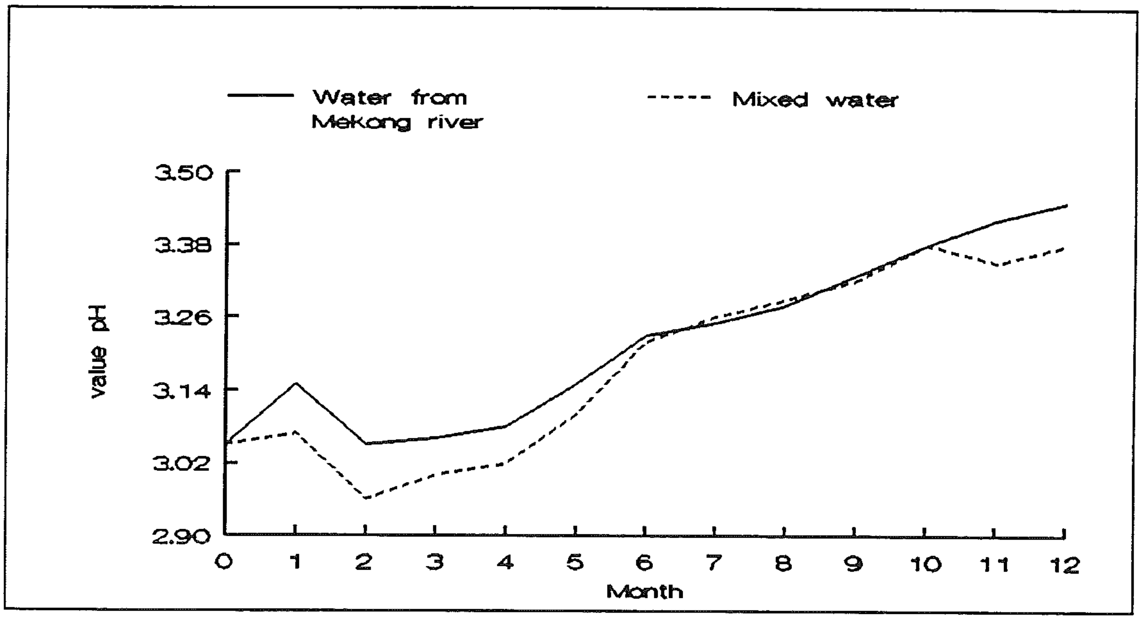

Figure 21 The effect of irrigation water quality on the change of value pH in top-layer, the ground water table = 0.2 m-surface

The change in pH almost develops in such a way that two lines are parallel in February, March, April and December. That means the better the irrigation water the higher value pH can reaches. By the way we can deal with a requirement on irrigation water quality. We know that water from the Mekong river is of good quality. In contrast mixed water is worst than that. But in the rainy months (July, August, September and October) the value of pH in two different irrigation water quality is the same one. It is sure that the more effective use of the rainfall is made the better the land is reclaimed. This problem deals with how to store more rainfall in the fields. On the other hand we have found that concentration Fe^{2+} and Al^{3+} change fast in first months as shown in figure 22 and figure 23, then slowly. This change shows that Fe^{2+} and Al^{3+} mainly exist in soluble form. This results in easy removing them out by pass-flow. In next months the concentration of Fe^{2+} and Al^{3+} changes due to exchangeable ions. It can be said that water quality considerably affects ion exchange. Based on the result of the SMASS simulations it is possible to say that high concentration of Fe^{2+} and Al^{3+} of acid sulphate soil in the Plain of Reeds is a soluble form. Therefore, it is not difficult to reclaim this soil if sufficient canal network is available and good water management is set up. It is clear that for reclamation of acid sulphate soil irrigation and drainage canal are necessary to be seperate with construction of appertaining structures. Depth of the ground water table is 0.2 m-surface seems to be feasible.

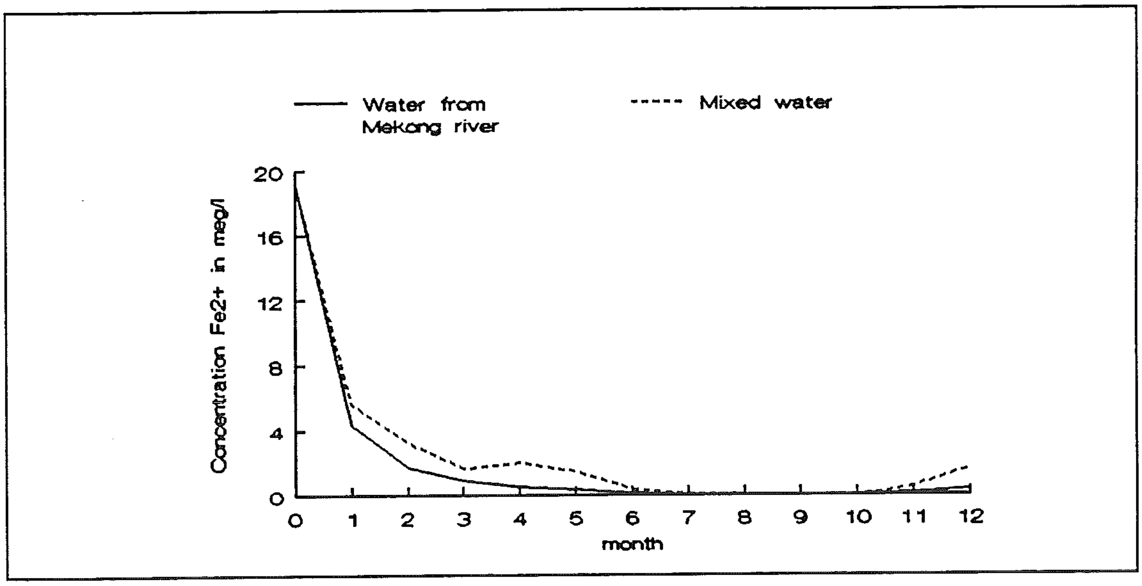

Figure 22 The effect of irrigation water quality on removal out of Fe^{2+} in top-layer in reclamation of acid sulphate soil, the ground water table = 0.2 m-surface

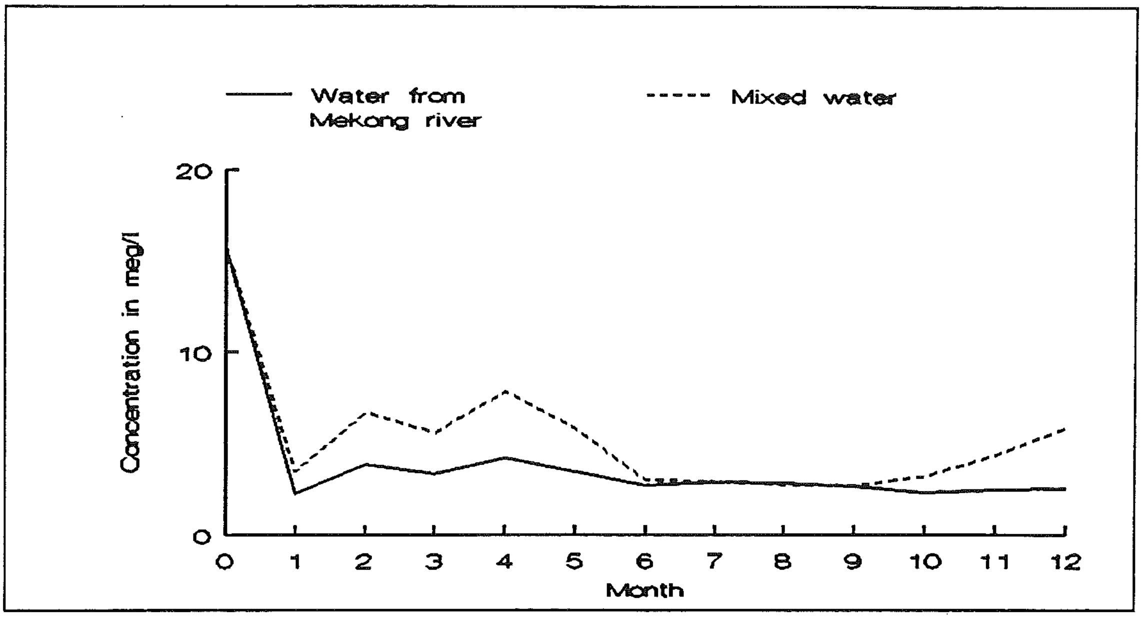

Figure 23 The effect of irrigation water quality on removal out of Al^{3+} in top-layer in reclamation of acid sulphate soil, the ground water table = 0.2 m-surface

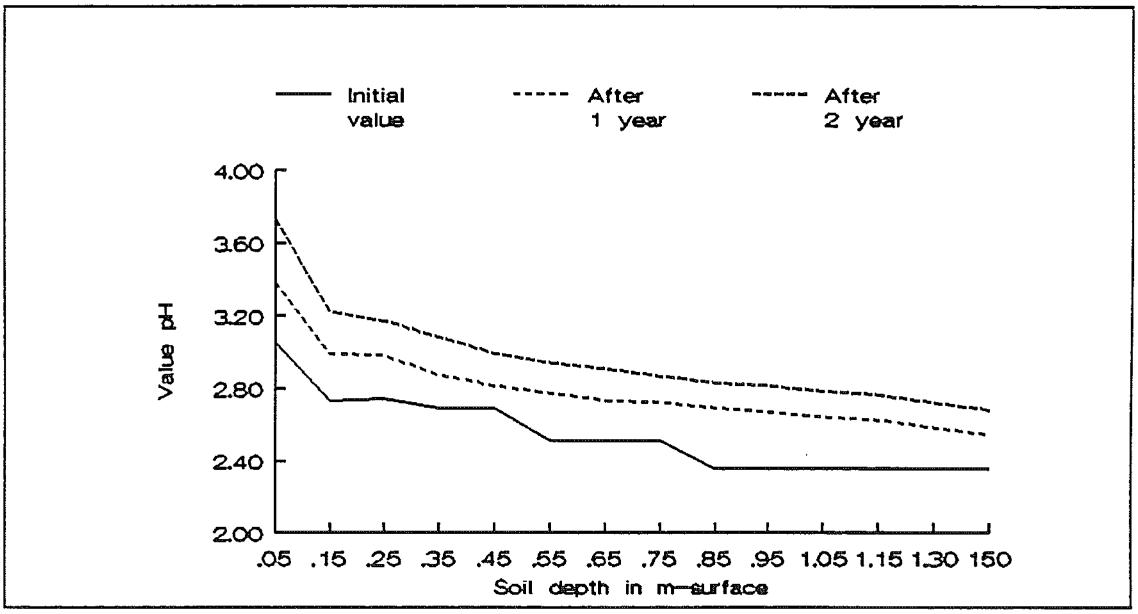

Figure 24 Change pH in soil profile in reclamation course in time

♦ Scenario 2: The objective of this scenario is the prediction of the duration for land reclamation. By leaching the concentration of toxic elements varies in time. Obviously, the simulation result of certain year is considered as inputdata for next year simulation.

In accordance to present situation we select mixed water and GWT = 20 cm-SS for consideration. The change pH in compartments is homogenous and slowly too as presented in figure 24. Each year value pH increases only by 0.35. According to boundary value proposed by Can tho University pH $\geq$ 4 for used rice varieties it will take at least 3 years to reclaim. From second year concentration Fe^{2+} and Al^{3+} change slowly (annex C.6 and Annex C.7).

♦ **Scenario 3**: The objective of scenario is aimed at assessment of present water management, GWT varies in time as presented in figure 19. Due to GWT is lower than depth of pyrite layer, pyrite oxidation occurs and causes negative effect on land reclamation. So, acidity as well as Fe^{2+} change slowly. It can take about 8 years to reclaim. Such variation of GWT is not good for land reclamation. Appropriate water management is needed for acid sulphate soil. Example for this is presented in annex C.8 and C.9 for comparison. In addition, by result simulation of this scenario we could compare it with data available from field experiment in table 22.

Table 22 The difference in pH between SMASS simulation and available experimental data

Date	Soil depth in m-SS	Experiment	SMASS
15 July 1993	0.0 - 0.3	3.52	3.15
	0.3 - 0.5	3.16	2.8

This difference can be due to:
- In SMASS there is no consideration of flushing, in contrast in experiment flushing was applied in April;
- It is possible that pH by SMASS is measured by pH_{H2O} and pH in experiment is measured by pH_{KCl}. Value pH_{KCl} is always greater than pH_{H2O};
- It is possible that the pyrite content which is taken from the Kalimantan (Indonesia) is rather higher than in the Plain of Reeds.

The other question of interest to be solved is the ground water table. This problem deals with construction of structures. In this scenario (scenario 4) we will simulate with the same irrigation water quality, but with different water table, assumed that GWT = 0.2 m and 0.4

m. The result is presented in figure 25 and figure 26.

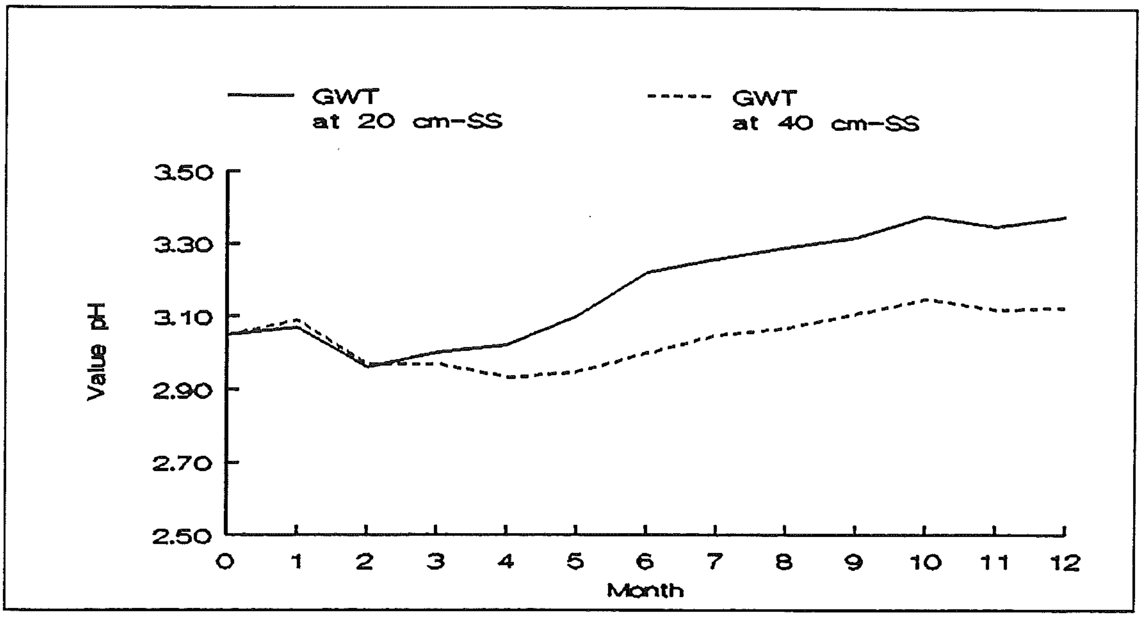

Figure 25 The effect of the ground water table on the change of value pH in top-layer in the same irrigation water quality

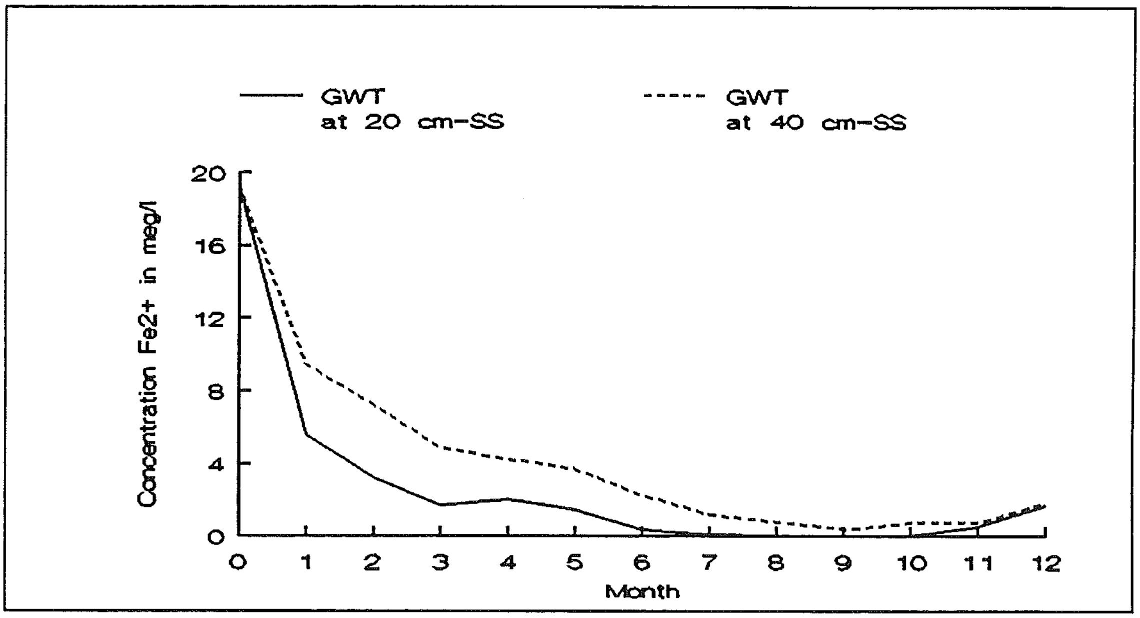

Figure 26 The effect of the ground water table on the change of concentration Fe^{2+} in top-layer in the same irrigation water quality

The result simulation shows that the depth of the GWT considerably effect on removal of toxic elements. The deeper GWT the less toxic elements can be removed out. This effect is an question of interest. Analyzing 3 cases of the GWT the depth of the GWT at 0.2 m-SS sounds appropriate. The conclusion can be drawn that in reclamation of acid sulphate soil in the Plain of Reeds the ground water table is at not so deep.

Limitation of the SMASS model

Looking at data in input files we have found that the drain spacing or hight of water table above the water level in drain is absent. In order to use effectively the SMASS model in water management strategies we should combine it with the Hooghoudt equation.

4.3.2 Simulation of field soil and water management

As presented in the previous section the magnitude of pH in soil depends significantly on the rate of pyrite oxidation and the rate of removal of soluble oxidation products (toxic elements). It is clear that the pyrite oxidation and the rate removal of toxic elements again depends on water management.

The rate of pyrite oxidation

Based on the soil characteristic of the study area the pyrite is distributed at a depth of 0.5 m onwards from the soil surface in an area of 56 ha. During the dry season (December to April) the water level in drain drop to 0.8 m or more below the soil surface. Evaporation is high as to 10 cm/day. Consequently, pyrite oxidation with possible relative long duration can occurs (figure 27). But in the dry season there is a winter-spring crop in turn it is necessary to irrigate, except during the time of harvesting. Duration during which there is no water on the field surface is short in accompanying with the cropping calendar. For these reasons actual time of pyrite oxidation can be short. On the other hands it is seen in figure 25 the removal of toxic elements has limitation due to the water table at soil surface.

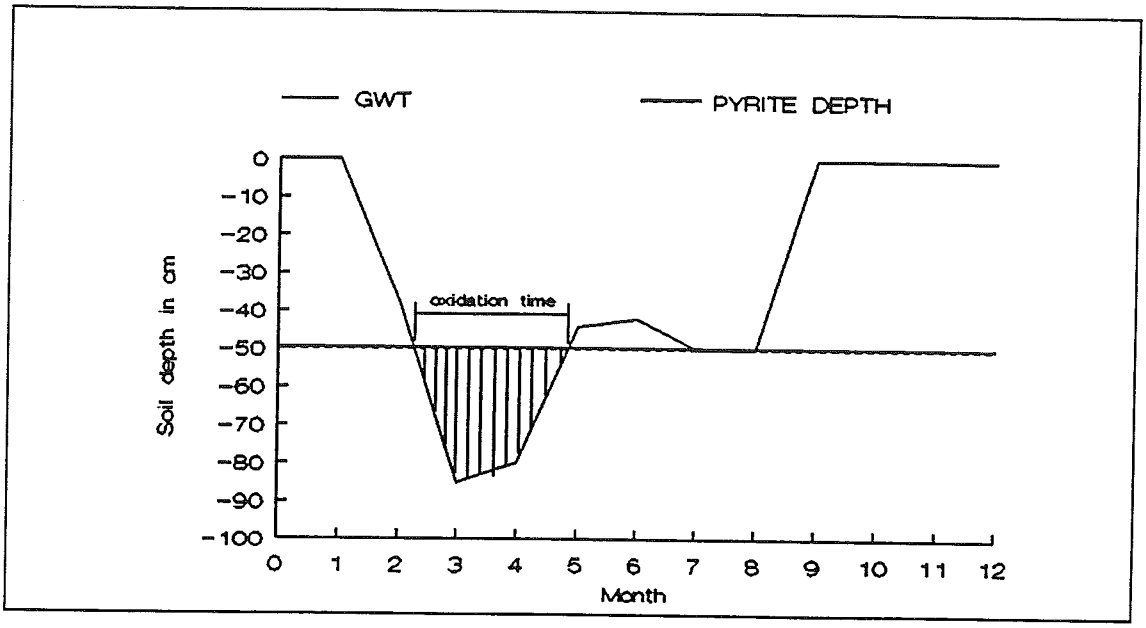

Figure 27 Duration of pyrite oxidation in relation to the GWL

Especially, during the dry season cracks are observed on the field surface with width of 0.4 cm on average, maximum to 1.5 cm. In principle, the cracks stimulate the air to enter into the soil. In combination of the fact that if the ground water level is low and cracks are formed the pyrite oxidation process occur at high rate. The pyrite oxidation process will have a positive impacts only if the leaching is adequate and the drainage system is under good working conditions. In contrast, the pyrite oxidation will have a negative impacts e.g the pH number will be decreased when the leaching is insufficient. In this case we should control the ground water level in order to eliminate the pyrite oxidation.

The rate of removal of toxic elements

Toxic elements are often in form of ions (H^+, SO_4^{2-}, Fe^{2+}, Al^{3+}..) and removed by drainage water. The rate of removal of toxic elements is closely related to drain discharge as calculated above. The more the drain discharge is flowed out the more the elements may be removed. It is clear that problems specific to acid sulphate soil is a calculation of drain spacing by using the Hooghoudt formula (4.2). Open drain are the most popular in the Plain of Reeds as well as in the whole Mekong delta.

The evidence is that the increase in drain discharge after forming the cracks has been observed on field experiment on acid sulphate soil at Hai Hung province in the North. The leaching will be improved. It is expecting that the k-value will be increased for the soil in the Plain of Reeds in future. Then we found that to control the hight (h) of water table above water level in drain is closely related to the main system and outlet The drainage in the Plain of Reeds is by gravity under the tidal conditions. Pumped drainage is not found in practice at present. Due to drainage by tides control structures should be constructed to control flow in the drain. It is clear that in principle when the tide is going up automatic hydraulic gates will be closed to lead to storage of the drainage water in the drains. The water depth of storage after one tidal circle is estimated as below(4.6):

$$h=\frac{q*L*t_s}{b} \tag{4.6}$$

Where:

h = increase of water depth due to storage, m

q = drain discharge, m/d

L = drain spacing, m

t_s = time of storage taken from tidal curve, day

b = width of water surface, m

By Darcy equation:

$$q=k*h*\frac{dh}{dx} \tag{4.7}$$

By integral of Darcy equation (4.7) yields

$$q*x^2=k*h_x^2-k*h_c \tag{4.8}$$

Where:

h_x = hight of water table at distance x from drain (m)

q = drain discharge (m/d)

k = hydraulic conductivity (m/d)

h_o = hight of water table taken as equivalent depth in Hooghoodt equation above reference datums (m)

Obviously, this increase in water depth in the drain results in more or less changes of the ground water table. The determination of position of water table before and after storage is based on the formula (4.8) that is derived from the Darcy equation (4.7) and are completed in tabular form (annex C.10). The results of calculation are presented in figure 28. In figure 28 it is seen that there are a little changes of water table at small distance far away from drain because of low k-value and laminar flow in soil. Besides that it could be said that the control structure is large enough to evacuate all drainage water in time. In practice, sometimes the water table in drain rises due to certain reason such as rain, error in management etc. Duration for this rise is not allowable too long. It is sure that the rice plants growing along the drain of field will get a high yield than in the centre of the field.

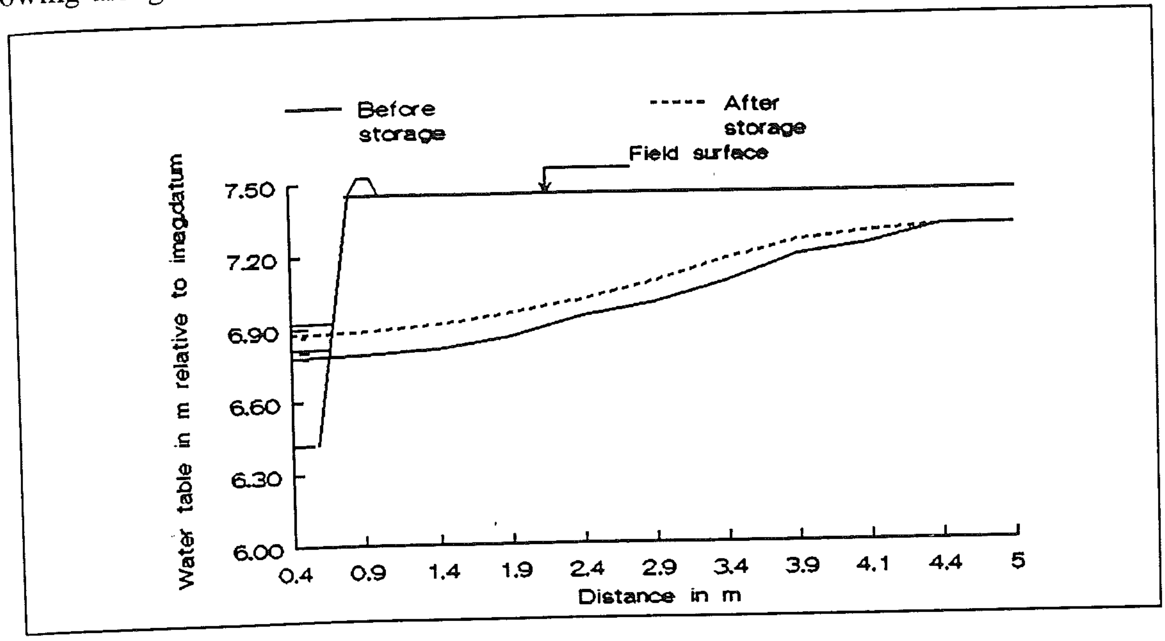

Figure 28 Changes of the water table before and after water storage in open drain

4.3.3 Simulation of the main system

All the systems in the Plain of Reeds are related directly or indirectly to the Mekong river and Vaico West river. The main systems play a decisive role in successful development in the area. It is easy to realise that if the water level in the Vaico West river is low, the drainage capacity of main system will increase, the more drainage water will be discharged into the river. In the other hand, if the water level in the Mekong river is high, it will be easy to command the irrigated areas by gravity or this water level will create maximum possible source for irrigation by application of pump with low head. The rivers are considerably under the influence of tide, especially in the dry season when the discharge is low. Therefore, the determination of when and how long the water can enter into or be discharged from. The water management system is of important significance. Then we can determine the scale of the hydraulic structures and the network at field level. Besides that, in case of the Plain of Reeds we can also consider the reduction of negative impacts due to removal of toxic elements from the acid sulphate soil by flushing. That means to improve the quality of drainage water by mixing it with water from the Mekong river in the main system. These problems can be analysised with the DUFLOW model. The DUFLOW model is a hydrodynamic model and based on two basic equations for unsteady flow (ICIM,1992):

* Equation of conservation of mass

$$B*\frac{dH}{dt}+\frac{dQ}{dx}=0 \tag{4.9}$$

* Equation of conservation of momentum

$$\frac{dQ}{dt}+g*A*\frac{dH}{dx}+\frac{d(\alpha Qv)}{dx}+\frac{g|Q|Q}{C^2*A*R}=b*\gamma*w^2; \tag{4.10}$$

Where

t = time (s)

x = distance as measured along the channel axis (m)

H(x,t) = water level with respect to reference level (m)

v(x,t) = mean velocity (m/s)

Q(x,t) = discharge at location x and at time t (m^3/s)

R(x,t) = hydraulic radius of cross section (m)

A(x,t) = cross section flow area (m^2)

b(x,t) = cross section flow width (m)

B(x,t) = cross section storage width (m)

g = acceleration due to gravity (m/s^2)

C(x,H) = coefficient of De Chezy ($m^{0.5}/s$)

w(t) = wind velocity (m/s)

Φ(t) = wind direction (°)

ϕ(x) = direction of channel axis in degrees, measured clockwise from the north (°)

γ(x) = wind conversion coefficient (-)

α = correction factor (-)

Running the DUFLOW model the attention has to be paid to the canal network in the Plain of Reeds. The existing canal network will be more densely in the future. In adition, the existing canals will be dredged in order to increase their capacity. For example, during the period of 1985-1994 the total volume of dregding of feeding canals and primary canals was 7.89 million m^3 and excavation of new feeding canals and primary canals was 10.84 million m^3 and upto 1990, 7.7 million m^3 in the period 1991-1995. Due to this earthwork water levels and discharge in canals have changed significantly. For example, duration of flooding decreased to some 2 months. The DUFLOW model is used for the present situation while the canal network, rivers and the sea have close interactions. It is very difficult to run separately for any channel. For this reason the DUFLOW model was set up to run for the whole Plain of Reeds in combination with unique entity of canals, river and sea.

Considerations for running the DUFLOW model

Data for cross-sections and longitudinal sections

Data for the cross sections and longitudinal sections are available from the general survey of the river-canal network for the whole Mekong delta (Southern Institute for Water Resources Research, 1995). Canals inside the Plain of Reeds are relatively stable in cross-section and have no bottom slope. Otherwise the cross section of the Mekong river and the Vaico West river are unstable. Cross section and bottom crest in both rivers change in space from place to place. This condition more or less affects on hydraulic regime in the rivers. Dimensions of cross sections are complicated too. In order to get a high accuracy we should fill cross section step by step following the survey data. In the DUFLOW simulation the assumption is made that bottom width and surface width are taken into account. The number of cross-sections in both rivers plus sections of canals inside is very large and exceeds allowable number (maximum to 250) for the DUFLOW model, so some sections are combined.

Discharges and water level as boundary conditions

From the records of the Mekong river in 5 years (1990-1994) at the Tan chau station (annex

C.11) the discharge in April and September in 1993 are taken for consideration. April and September are representative for the dry and the wet season. Besides, we have records of water levels at another places as controlled nodes for calibration of the simulation result of simulation. The water level (tide) in the South China sea is the lower boundary condition and considerably affects the water level in the rivers and in the canals. The coastal line of Vietnam is about 3,000 km long and refers to different tidal zones. Both rivers are in the same tidal zone. The tidal data are available from the Vung Tau station (near estuary of the Mekong river). In simulation discharge has to be at same point of time with the tide. That mean tide is selected April and September as shown in annex C.12 and annex C.13.

Rainfall and evaporation

In the DUFLOW simulation rainfall and evaporation are ignored.

Structures

There are no structures except two salty intrusion prevention structures in the Vaico West river.

Schematization

Based on the canals network, river and sea we made a schematization as presented in annex C.14.

Output: Output in the DUFLOW model is presented in tabular and graphic form for water level at node/route, discharge and velocity in section/route. Output depends on the interest of user.

Scenario 1 for discharge in April at present situation (dry season)

♦ Boundary condition

- Lower boundary condition is created by the water level in the sea in a times series: this boundary condition is given at nodes 36, 40, 152, 156 related to the Mekong river and node 75 related to the Vaico West river. All these node refer to the South china sea and have the same magnitude as shown in annex C.12.

- upper boundary condition is given as discharge: this condition deals with all discharge outflow and inflow. Outflow at node 146, inflow at nodes 1 as main inflow of the Mekong river, node 46 and 51 as inflow from Cambodia and nodes 70 as inflow of the Vaico East river. Discharge at node 1 is 1,270 m^3/s which is taken from annex C.10. Discharge at node 146 is 440 m^3/s which is taken about 35% of discharge at node 1 because discharge at node 1 is 19,800 m^3/s, discharge at node 146 is 8,000 m^3/s (Le, 1995). Discharge at node 70 is 75 m^3/s which is taken under consideration of operation of reservoir Dau Tieng in dry season. Discharge at nodes 46 and node 51 are asummed 15 m^3/s where two small rivers from Cambodia flow in.

♦ Result of simulation:

- Water level in the Mekong river is presented in annex C.15
- The water levels at node 1 at Tan chau, node 18 at Mi thuan and node 91 at Hung thach inside the Plain of Reeds are considered as representative results. The difference in water level between the simulation result and the observations (Hydro-meteorological service department, 1995) at nodes above as belows:

Node	Simulation results	Observation	Difference
	m+MSL	m+MSL	m
1	0.86	0.81	0.05
18	1.05	1.02	0.03
91	0.14	0.10	0.04

From the data above the difference between the simulation result and observation is 0.03-0.05 m. Results of simulation are greater than observations while firstly, some canals inside the area is not taken into account; secondly, outflow in some canals also are not taken into account. Therefore, if missing canals and outflow/inflow are improved we will get more accurate results. This difference shows that the present channel network can be accepted for further consideration. Generally, in April with such discharge the irrigation by gravity is not possible, even at the lowest place. Pump is required to irrigate rice summer-autumn crop. Besides, the simulation result shows that the water level in the Mekong river and the Vaico West river is considerably affected by the tide, for example, as far as 220 km in the Mekong river. In order to save the energy consumption farmers have to irrigate their fields during the spring tide. In addition, the water level inside the Plain of Reeds varies by the tide. Viewing the discharge at section it is realized that the control structures should be installed at outlets/inlets under tidal condition.

Scenario 2 for the discharge in September (wet season) at the present situation

♦ Boundary conditions

- Lower boundary: sea water level of September at nodes above as shown in annex C.12.
- Upper boundary: discharge at nodes above instead of September as below:

Node 1:	18,700 m^3/s
Node 146:	7,800 m^3/s
Node 70:	500 m^3/s
Node 46:	50 m^3/s
Node 51:	50 m^3/s

♦ Result of simulation

- Water level in the Mekong river is presented in C.16
- The difference between the simulation result of water level and reading at controlled nodes as below:

Nodes	Simulation m+MSL	Oservation m+MSL	Difference m
1	4.00	3.61	+ 0.39
18	1.88	1.90	- 0.02
91	1.51	1.47	+ 0.04

The reason for the differences can be, firstly, as in the previous scenario; secondly, it may concern overflow of the bank of the Mekong river and overflow of canal banks. It is possible that storage width is not full to take for consideration. In reality in the Plain of Reeds there is a flow, very slowly when flood occurs. For this reason the water level at node 1 is high. The comparison of the simulation result with the observation at control nodes shows the logically stable consequence (annex C.17 and annex C.18). In this scenario the tidal affects is only observed at short distance about 60 km from the Mekong river mount. Actually, the larger discharge in the river the less the tide affects on the water level. From the simulation result in term of water level we can also determine the water depth of flooding at any place of interest.

Scenario 3 for discharge in September with completion of dike construction and structures through the dike are closed. The objective of this scenario is to determine the effects of dike construction.

♦ Boundary conditions as in scenario 2

♦ Results of simulation: Obviously, when the dikes have been constructed and structures through the dike are closed all water flows in the Mekong river. This results in an increase in water level in the river. In this scenario it is possible to determine the rate of increase in water level in the Mekong river for few days. Due to limitation of the memory of the computer, in order to run the DUFLOW model it is accepted that the simulation result of first day is the initial condition for the next day. The simulation result shows that the rate of increase 0.2 m on first day and in second day the increase in water level is only 0.15 m at node 1. After 2 days the water level at node 1 reaches 4.35 m+MSL and at node 18 water level is 1.98 m+MSL. The different increase in water level in these two days can be due to overtopping at somewhere. This trend continues if discharge in river does not decrease (annex C.19). From this scenario it is clear that the Plain of Reeds is a retention reservoir. It is seen that the larger the discharge in the river the higher the water level rises. Thanks to the simulation result we are easy to determine the effected area caused by the dike construction.

Scenario 4 for discharge in September with a submergible dike. The objective of this scenario is aimed at determination of the variation of water level due to submerged dike.

♦ Boundary condition as in scenario 2, we only change the discharge at node 1 and node 146. The discharge in 1994 (annex C.10) is taken into accout because the 1994 flood is big flood in the Plain of Reeds with discharge = 22,200 m^3/s at node 1 and discharge at node 146 is 8,880 m^3/s.

♦ Consideration: in this scenario it is accepted that all structures are closed, overtopping starts when the water level in the Mekong river and the water course on border with Cambodia reaches the crest of dike.

♦ Results of simulation: In this scenario of course the water level is lower than the water level in scenario 3 (annex C.20) with the same discharge, for example Q = 18700 m^3/s. By records on the water level and discharge at node 1 (Tan Chau station) we found that large flood in the Mekong delta happened in 1994. Using the DUFLOW model with assumption of the same lower boundary condition and Q = 22200 m^3/s the water level at node 1 reaches around 5.0 m, and the readings in water level is 4.67 m. The comparison of two these water levels shows that submerged dike causes a little increase in water level, only about 0.35 m. This result seems appropriate in comparison with data of NEDECO (after Report on bank protection of the Mekong river, 1995). Therefore, it can be said that the submerged dike is reasonable for flood control.

Scenario 5 Application of the DUFLOW model for structure and canal design.
Function of structures are designed to control flow in the irrigation and drainage canals. Overviewing the present situation of acidity/acid sulphate soil it deals with water management. One of main activities of water management is to eliminate the critical part in the plain of Reeds. Critical part is area of pH < 4 defined at the end of dry season and at the beginning of the wet season. Based on the data of investigation on acidity distribution in 1994 and 1995 the critical part is located at low part, near the Vaico West river. It is no doubt that all acid water is stored here due to poor drainage. This results in that critical part is expanded in all directions and account for about 55% of total area of the plain of Reeds due to rainfall and water from the Mekong river. This consequence effects directly on rice summer-autumn crop. To eliminate this part more water has to be supplied and improved drainage capacity. Related to this part two outlets at the Vaico West river have been constructed in 1992/1993, increase of drainage capacity through these structures has limitation. Another way is that acid water is evacuated either to the Mekong river or to the Vaico West river. Staring point for consideration are water level at node 98 (centre of critical part), node 28 (at the Mekong river) and node 59 (at the Vaico West river). From the simulation result of the DUFLOW model it is seen that water level at nodes above is effected by tide. In comparison of difference in water level at node 98 and node 28 with the difference in water level at node 98 and node 59 (annex C.21) with distance node 98 between node 28 (31,250 m) and distance between node 98 and node 59 (8,937 m) it is found that friction slop in direction to the Vaico West river is greater than that in direction to the Mekong river. Hence, drainage water should be discharged out into the Vaico West river. In drainage sometimes friction slop is one of requirements, the steeper friction slop the better

evacuation of water. In combination of water level in canal with ground surface by the IDRISI in the dry season the machinery irrigation has to be applied due to water level below ground surface about 0.5 m. In order to increase the value pH more water (supplementary discharge) has to be supplied to the area, then to evacuate them out. Supplementary discharge Q_s is determined from formula (4.11):

$$C=\frac{C_s\cdot Q_s+C_d\cdot Q_d}{Q_s+Q_d} \tag{4.11}$$

Where:

C = permissible concentration in water which is discharged out into collector, meg/l

C_s = concentration in supply water, meg/l

C_d = concentration in drainage water, meg/l

Q_d = drainage discharge, m^3/s

Q_s = supplementary discharge, m^3/s

In this case it is assumed expected value pH = 4.2, initial pH = 3.85 and pH = 5.25 in supplied water according to investment on acidity in 1995. Incoming and outcoming discharges have been found by the DUFLOW simulation for dry season. Another assumption is that 40% of supplementary discharge pass through canal between node 98 and 59. From formula (4.11) Q_s is found as below

$$4.2=\frac{3.85*28.27+5.25*Qs}{28.27+Qs}$$

We found that Q_s = 9.42 m^3/s and discharge in section 229 is 6.1 + 0.4 * 9.42 = 9.868 m^3/s. Dimension of this section is found in integrated solution in accordance with the entire area. In water management canals and structures are considered two man-made factors and has close interaction each other. In present canal network in the Plain of Reeds is very complicated. It is of course difficult to implement too much structures. The construction of structures will meet the following difficulties

- a large amount of finance is required,
- soil has very weak bearing capacity,
- constrain the boat passing, boat is main mean of transport.

Therefore, the question now deals with canals. In order to supply more water to the critical part it is possible that firstly, new canal can be excavated, secondly, increase of dimension of canal. In fact, canal networks in the plain of Reeds is densely, so it is better to improve the cross section under selected canal. The requirements for canal selection:

- flood water is evacuated fast to reduce the duration of flooding.
- total volume of earth work is minimum.
- suitability to existing situation e.g bottom crest, bottom width and relief.
- inlet is located at high place where water level is high to command the area and good water quality available.

For this purpose the DUFLOW model is used in case of dry season. First of all, water level at nodes 3, 6 and 8 as the beginning of separate feeding canals is taken into account. The simulation result (annex C.22) show that the variation of water level between these nodes is small, not significant. So, it is better to choose node 6 for further use. The existing canal deal with dredge, enlarge and dredge/enlarge in accordance with technology of completion. At present earth work of main canals is completed by machinery e.g dredger and excavator. Canal is not necessary to dredge so deep that causes slide of bank and to enlarge too wide due to limitations of excavator. The duration of flooding of two month is more or less effected on agricultural production. If the duration of flooding decreases it is expected that more area under three crops will be grown. Flooded area is located in central part. In short, decrease of duration of flooding and irrigation/drainage is main factors for agricultural development. For the reasons above sections 88,89,90,91,92 under dredge; sections 161,162,163 and 164 under enlarge; and sections 93,94,95,96,97,98,99 and 229 under dredge/enlarge will be used for calculation. Another important factor infected on water management in the critical part is tide. Also the simulation result by the DUFLOW model shows that drainage is not effective if the structure will not built. Visually, the difference area of upper part (outcoming water to the river) and area of lower part (incoming water from the river) on curve of discharge is small. Therefore, construction of structure is necessary. Using the DUFLOW model the dimension of structure and sections are found. Dimension of selected sections are presented in table 23.

Table 23 Dimensions of sections before and after improving

section	Before improvement			After improvement		
	Bottom width,m	Bottom crest, m+MSL	Q m^3/s	Bottom width,m	Bottom crest, m+MSL	Q m^3/s
88	20	-3.0	29.7	20	-3.5	41.2
89	20	-3.0	21.9	20	-3.5	32.3
90	20	-3.0	14.3	20	-3.5	19.1
91	20	-3.0	11.6	20	-3.5	17.7
92	20	-3.0	14.7	20	-3.5	21.4
93	20	-3.0	18.7	25	-3.5	36.5
94	20	-3.0	18.9	25	-3.5	36.4
95	20	-3.0	18.1	25	-3.5	34.6
96	20	-3.0	18.5	25	-3.5	34.7
97	20	-3.0	20.1	25	-3.5	35.9
98	20	-3.0	21.7	25	-3.5	37.5
99	20	-3.5	14.7	25	-3.5	18.5
111	20	-3.5	13.2	25	-3.5	16.7
161	20	-3.5	24.1	25	-3.5	30.3
162	20	-3.5	23.5	25	-3.5	30.8
163	20	-3.5	18.5	25	-3.5	28.1
164	20	-3.5	17.2	25	-3.5	25.5
229	7	-2.0	6.1	8	-3.0	11.1

Dimensions of outlet structure in the Vaico West river as below:
- Width in m: 8
- Sill level in m+MSL: -3.0
- Maximum capacity in m^3/s: 12.48

From table 23 it is seen that discharge in section 229 and through the outlet is greater than estimated discharge. It can be accepted due to safety factor of flood. Now another aspect, change in water level due to supplementary discharge is considered. From the simulation result it is found that the water level in the critical part has a little increase as presented in figure 29.

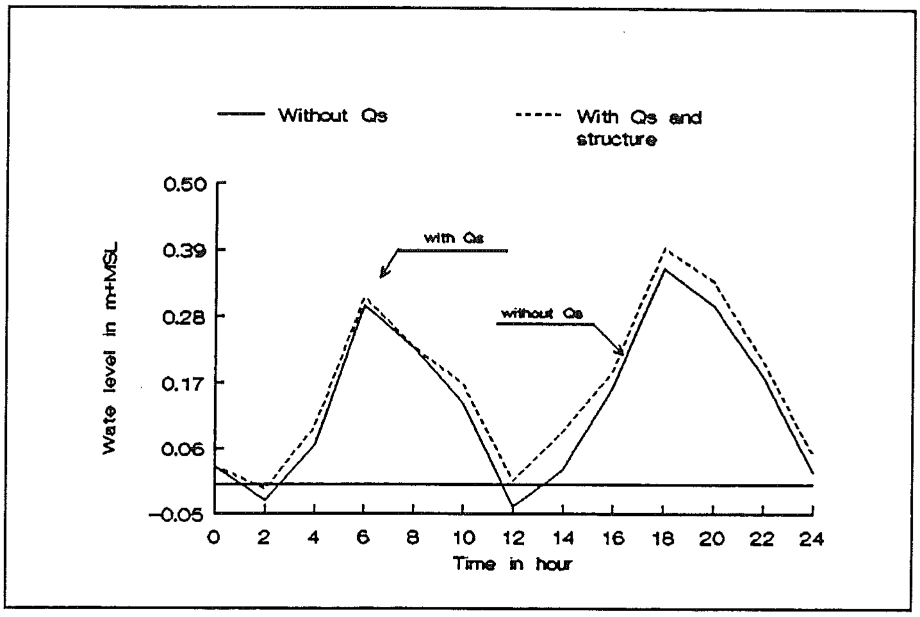

Figure 29 Changes of the water levels at centre of the critical part before and after the improvement of the water management system.

It can say that this increase has no effect on crops in the area. Apart from that increase in discharge results in enhancing the reclamation of acid sulphate soil and avoiding the negative impact due to reclamation of the acid sulphate soil.

4.3.4 Application of geographical information system (GIS)

At present the geographical information system (GIS) is widely used in fields of human activities. The importance of the GIS is expressed in some definitions such as by Eastman (1987), Aronoff (1991) and Brower (1993). GIS is rapidly becoming a standard tool for management of natural resources and it is used to assist decision makers by indicating various alternative development plan and has a capacity to model the potential income for series of development scenario (Brower,1993). Obviously, the most important characteristics of GIS is the utilization of capacity of spatial analysis functions. The objectives of data is to extract useful information to satisfy the requirements or objectives of decision makers. The IDRISI

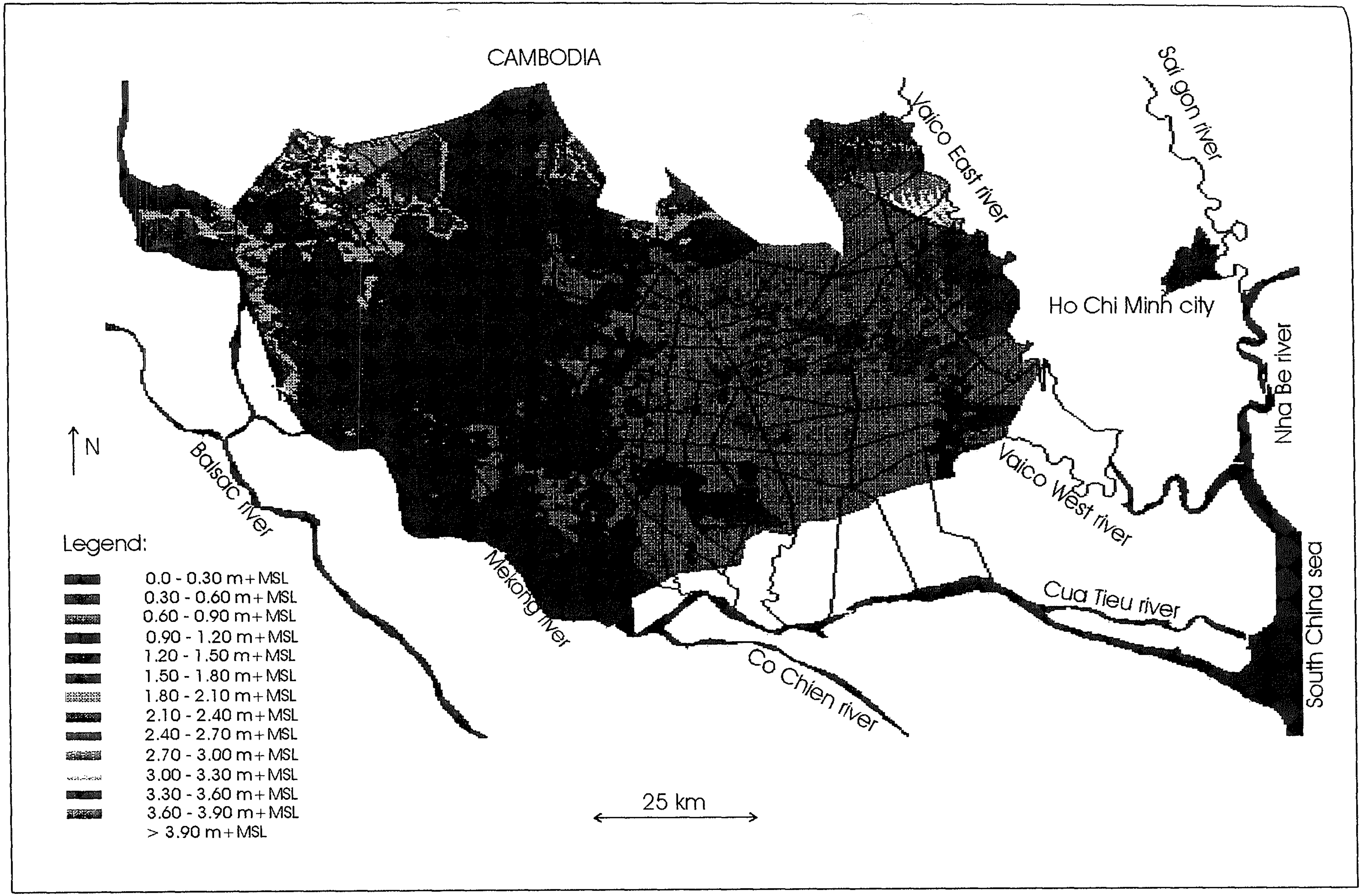

Figure 30 Digital elavation map of the Plain of Reeds, Vietnam

is one of the GIS program modules. The IDRISI has been developed by the school of Geography at Clark university (USA) and is applied in over 80 countries around the world. The IDRISI program modules is popular to apply to planning, designing and management of project. This is not a single computer program, but a collection of over 100 program modules that may be linked by a unified menu system. IDRISI runs on most microcomputers based on the Intel 8086, 80286, 80386 and 80486 (or later) family of microprocessor chips running MS-DOS 2.11 or greater. The IDRISI is recommended to use with hard disk of minimum requirement of 512k and EGA, VGA and 8514/A graphics adaptor. For the IDRISI all modules can be assessed from the IDRISI menu system by using the mouse or cursor keys to move highlight bar and pressing return or clicking the mouse once to select a module. Another way to run with IDRISI is by typing commands directly, just at the MS-DOS prompt. The first module required to run IDRISI is ENVIRON module because each module reads the environment file. ENVIRON allows one to specify various characteristics about the program environment, but most critically, the name of the disk drive and directory that contain the database to be used. These data have to be collect from the real objects in order to storage, manage and display a raster images, next to analysis the raster images. Data input is completed in many ways such as keyboard entry, digitizing, scanning and loading existing data file. Keyboard entry is very commonly used in practice and this method of data input is very time consume. Especially, it is easy to make mistake. Within this study data is input by keyboard entry. From this point it can say that the expertise is needed either in input data or in finding the errors. Data in the IDRISI are stored in data files as image file, vector file and attribute values files. From these input files the modules lineras, polyras and interpol are used to convert vector files of lines, polygons and points to a representation. Each vector files can present its own image file in combination with INITIAL module because INITIAL module creates new image with a constant value. Furthermore, we can check the result by using DOCUMENT module. DOCUMENT module creates and updates documentation file accompanying the IDRISI image,vector and attribute values files automatically. In order to view the image the module COLOR should be run. It is possible that the error is easy to find out when the image is not proportional to real condition. In fact a single image is not useful to assess. In this case some images have to unit a general image with help of modules OVERLAY or CONCAT. The other modules also are used in completion of general image are RECLAS and ASSIGN. RECLAS module reclassifies the data stored in image or attribute values into new integer categories. ASSIGN module is used to create new image by linking the geography of feature defined in an image file with attribute defined in an attribute values file in order to eliminate area outside of the Plain Reeds. In short, potentials of the IDRISI is very great, of which only few modules are used. However, images by the IDRISI are useful for further consideration.

Output

- By using module AREA: actual area of the plain of Reeds is 629,200 ha, total its area by IDRISI is 629,616 ha, the error percentage in this case is very small as only 0.13%. It can say that the more accurate the result is derived the more figure/map of object is required.
- In combination of digital elevation map from point vector file with river system from polygon vector file, then canal network from line vector file a general map of the Plain of Reeds is available as presented in figure 30. From this map it is easy to see that the relief is very flat and depressed in West-East and North-South direction. The lay-out of canal network is completely appropriate. Irrigation water is diverted from the Mekong river and drainage water is discharged into the Vaico West river. It is evident that the design of canal network for new project is effective to complete when the IDRISI modules are used. Otherwise, in the area with existing canal network the IDRISI modules are used to consider for updating and modernization. That means either structures or dredging/enlarging canal should be done.

4.4 Economic analysis

Engineering is the art of applying science to the optimum conversion of the resource of nature to benefit man (New Encyclopaedia Britannica 1975). Basis for this engineering is an economic analysis. The economic analysis must be done for any project. From the economic analysis it is possible to determine the positive or negative effects of the proposed alternatives. Economic evaluation of a project is to compare the benefit and cost (ratio B/C). In any case this ratio of greater than 1 is considered as positive. In terms of finance the internal rate of return (IRR) is determined as well. IRR must be greater than compound interest rate. In the economic analysis it is necessary to deal with the countries economy. In Vietnam investments on construction of main canal networks is financed by the Central government or provincial authorities. Field canal networks are excavated by farmers involved. They can borrow money from the bank. In the economic analysis some approaches are assumed:

- The life of service of canal networks could be taken 10 years after completion in 1992.
- Compound interest rate is 18%/year (1.5% per month in 1992).
- All costs are taken for 1 ha under consideration and based on costs consumed in 1993.
- Rice yield over the entire life of service of canal network is constant.

Cost

- Initial cost: the initial cost is a cost which is needed to constructed canal and field levelling. The total cost for construction of canal networks and levelling in the area is 775,8 million VND per net area of 240 ha (Duoc, 1994). Therefore, the cost for one ha is 3.2 million VND.
- Yearly operation and management cost and water fee: the cost mainly consists of water fee because farmer run field canals. Yearly operation and management cost is assumed 0.1 million VND. The yearly water fee is expressed in kg of rice per ha. The water fee is different for different area. In our case the yearly water fee is low, 400 kg/ha or 0.4 million VND (rice price is 1.10^3 VND/kg in 1993). Therefore, yearly cost for water fee, operation and management is 0.5 million VND.

Benefit

As described above the area is functioned with 2 rice crops per year. On the average rice yield is 4 ton/ha per the winter-spring crop and 3 ton/ha per the summer-autumn crop. The rice yield continues to increase in coming year when the soil is improved (annex C.23). Actual benefits are estimated by total incomes minus production cost. Production cost consists of land preparation, seeds, fertilizer, plant protection,labour and irrigation. Estimation of these costs are in annex C.22. Obviously, benefit for the winter-spring crop:

4,000 kg * 1.10^3 VND/kg - 2,150 kg * 1.10^3 VND/kg = 1.85 million VND

in which:

4,000 kg = average rice yield in the winter-spring crop in the area

2,159 kg = total cost which were paid in rice production (annex C.24)

1.10^3 VND/kg = rice price in 1993

benefit for the summer-autumn crop:

3,000 kg * 10^3 VND/kg - 1,800 kg *10^3 VND/kg = 1.2 million VND in which:

3,000 kg = average rice yield in the summer-uatumn crop

1,800 kg = total cost which were paid in rice production (annex C.24)

1.10^3VND/kg = rice price in 1993

Annual benefit: 1.85 million VND + 1.2 million VND = 3.05 million VND.

Calculation of the economic analysis is presented in annex C.25. From the calculation the ratio B/C = 3.1 at compound interest rate of 18%. IRR is so high that IRR is about 40%.

The B/C ratio and IRR are high because the area has no structures. In addition, it can predict that if structures will be build the ratio B/C and IRR will be less. At this stage the project is feasible and can be applied on large scale.

4.5 Technical specifications

Land reclamation of acid sulphate soil is being an actual problem for increase in agricultural production. It is recognized that the only way for this is appropriate water management. For this purpose methods of soil drainage such as pipe drainage (project in Thaibinh province in the North, combination of mole drainage with open drainage in Hai hung province in the North and open drainage in both North and South. It can say that acid sulphate soil is closely related with clay. This soil has very low coefficient of filtration. Based on research-experiment the open drainage is most appropriate to conditions in the Mekong delta as well as to conditions in the Plain of Reeds in particular. Technical specifications has to be based on experiment. From the experiment results derived in the project the technical specifications are introduced which deals with economic analysis and feasibility. The technical specifications are useful and necessary for planning and designing activities. Thanks to the technical specifications farmers also can make their decision to invest to field construction. The specifications are outlined in table 24.

Table 24 Technical specifications for field construction under conditions in the Mekong delta

Number	Specifications	Value
1	Dimension of canal	
1.1	Depth, m	1.0
1.2	Bottom width, m	0.8
1.3	Side lope	1
1.4	Water level in canal below field surface	>=0.3
1.5	Maximum length, m	<300
1.6	Distance between drains, m	100
2	Cost for canal construction and field levelling, million VND	3.2
3	Field levelling	
3.1	Average volume, m^3	350
3.2	Distance of soil removal on average, m	50
4	Water management	
4.1	Drainage, m^3	
4.1.1	Water for leaching in the winter- spring crop	1300
4.1.2	Water for leaching in the summer-autumn crop	2400
4.2	Irrigation	
4.2.1	Irrigation supply, m^3	
	In the winter-spring crop	6300
	In the summer-autumn crop	3800
4.2.2	Maximum irrigation module, l/s.ha	1.53
5	Portion of uncultivated area, %	7

Note: Cost of field construction estimated by rice price 1993

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

The Plain of Reeds is of great agricultural potential for economic development of Vietnam. This area is being an important rice cultivation area. But flood occurs every year. The flood causes significant damages to local people and the Government. Under pressure of increasing population and rice production flood control is an actual problem of interest. Therefore, a dike system is absolutely necessary to be constructed to protect against flooding.

The floods in the Plain of Reeds are not only caused by the flow from the Mekong river, but also by flow from the border with Cambodia. So, dikes have to be constructed along the Mekong river and along the border with Cambodia.

Dike construction deals with the entity of the region and consideration of environmental impacts. The concept of living with floods is introduced. The submerged dike is accepted with the return period T = 3 years. This is proved by the DUFLOW. A dike is an hydraulic construction of significant importance. The dike computations deals with conditions of working. Under conditions of the Plain of Reeds the outside slope in the Mekong river is 1:2 and inside slope in the Plain of Reeds is 1:3. The dike in the Plain of Reeds is submerged, so to avoid the erosion on the side slopes grass planting is introduced. Besides, maintenance and inspection should be carried out regularly.

In conditions of the Mekong delta in general and in the Plain of Reeds in particular floods play an important role the in reclamation of acid sulphate soil. The flood water is used for flushing toxic elements that accumulated in the top-layer in the dry season due to capillary and storage in canals. However, by this way some fertile material is removed. This problem is necessary to re-consider.

The lay-out of open field drains with a spacing of 100 m is too wide while the hydraulic conductivity and hydraulic head are low. This results in low effectiveness in removal of toxic elements by leaching. In reclamation of the acid sulphate soil in the Plain of Reeds the irrigation water quality is of importance. Good irrigation water quality enhances the removal of toxic elements and to reduce the duration of reclamation. As proved that in reclamation of acid sulphate soil canal and drain should be seperate. The SMASS model shows that it takes about 3 years of reclamation with water which is diverted from the Mekong river, meanwhile it is 8 years with mixed water as at present. Under conditions of the Plain of Reeds the potential acid sulphate soil should be kept lower the groundwater table to avoid pyrite oxidation. In accordance with the water management strategies it is better to keep the ground water table at 0.2 m-surface.

In order to reduce the duration of flooding in the Plain of Reeds for a third crop and to eliminate a storage of acid water in low part some canals must be enlarged or dredged to increase their capacity and a structure in the Vaico West river has to be build to avoid backflow into the Plain of Reeds from the Vaico West river. The DUFLOW model offers the required dimensions for canals and structure

The drainage in the Plain of Reeds is affected by tide. When structures are introduced this results in water storage in the open drains, consequently, the water level will increase. This increase is small and does not affects the growth of plants.

The irrigation module q = 1.53 l/(s.ha) is relatively high. This results in high investments in canal construction and structures. It is necessary to re-research the appropriate methods of water management in order to reduce the irrigation module.

The relief in the Plain of Reeds is very flat and is clearly divided into two part. It is possible to study with a geographical information system (GIS) the appropriate water management strategies on acid sulphate soil for each part.

Chemical and physical changes in acid sulphate soil in the Plain of Reeds are very complicated processes. The reclamation of acid sulphate soil changes natural environment, affect human habitat, etc. So, it is necessary to continue to study the dynamics and consequences. These are application of the DUFLOW model in propagation of acid water, water management strategies in relation to pyrite conditions to find out the best alternative foe the Plain of Reeds.

Finally, the sustainable agricultural development in the Plain of Reeds fully depends on water control activities.

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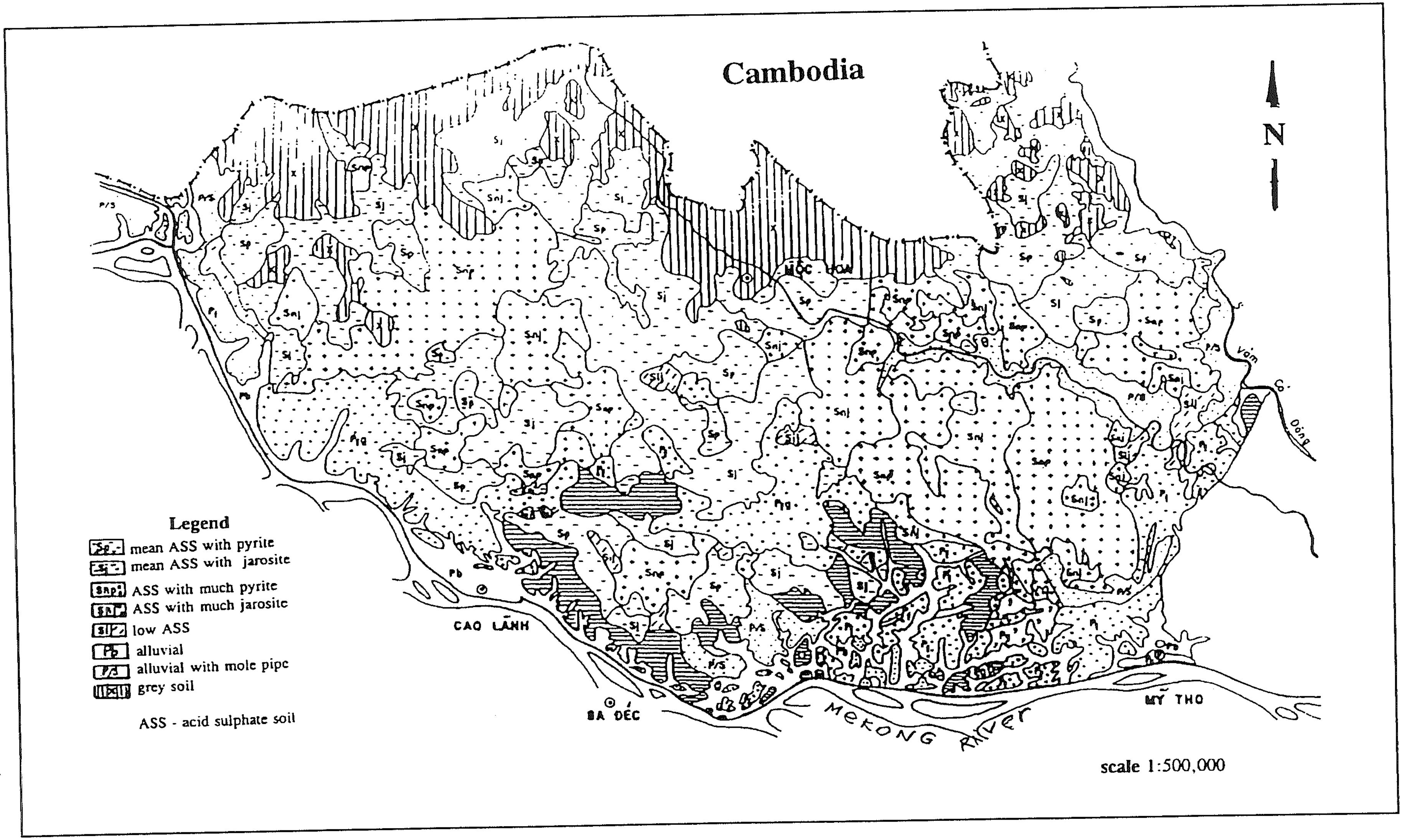
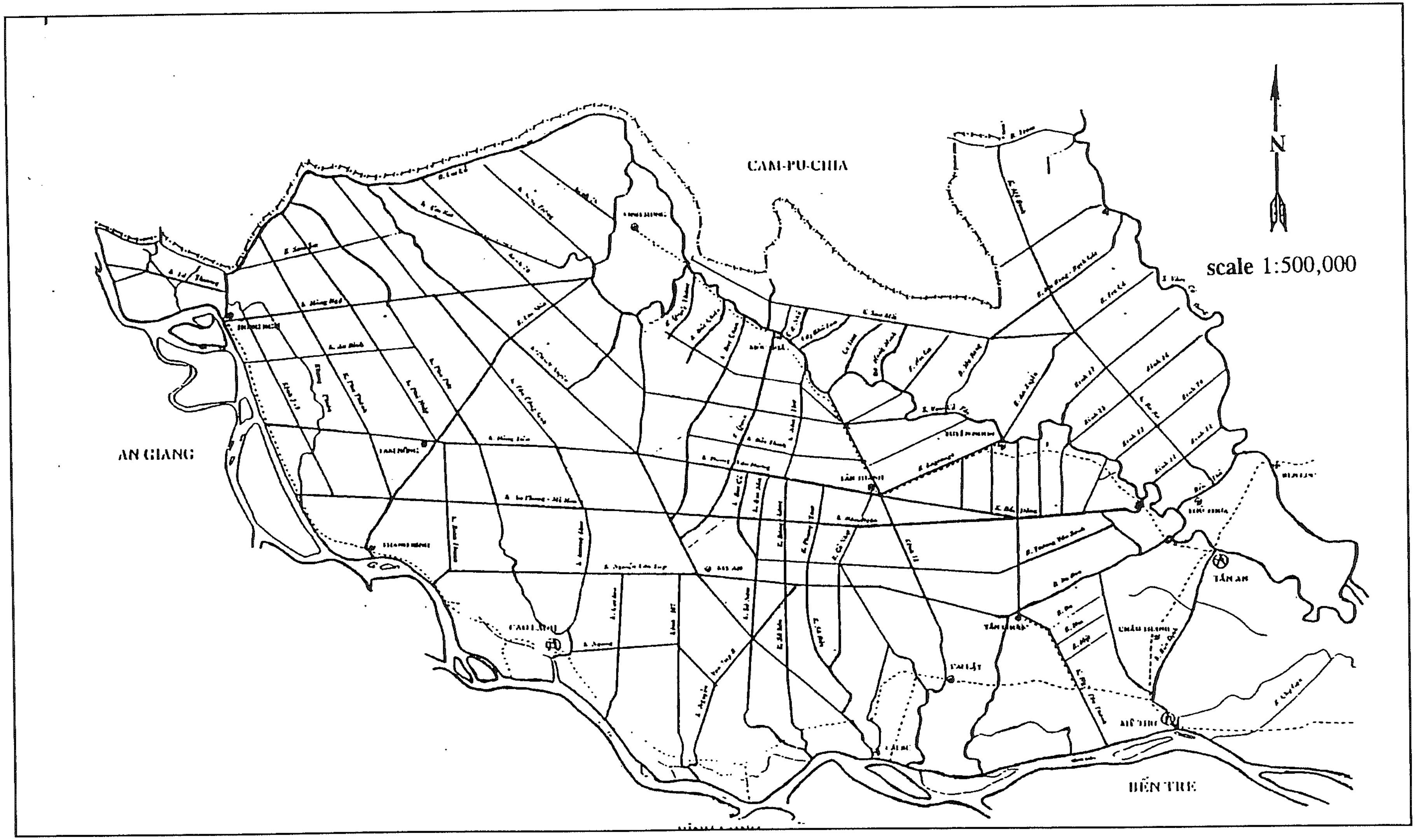
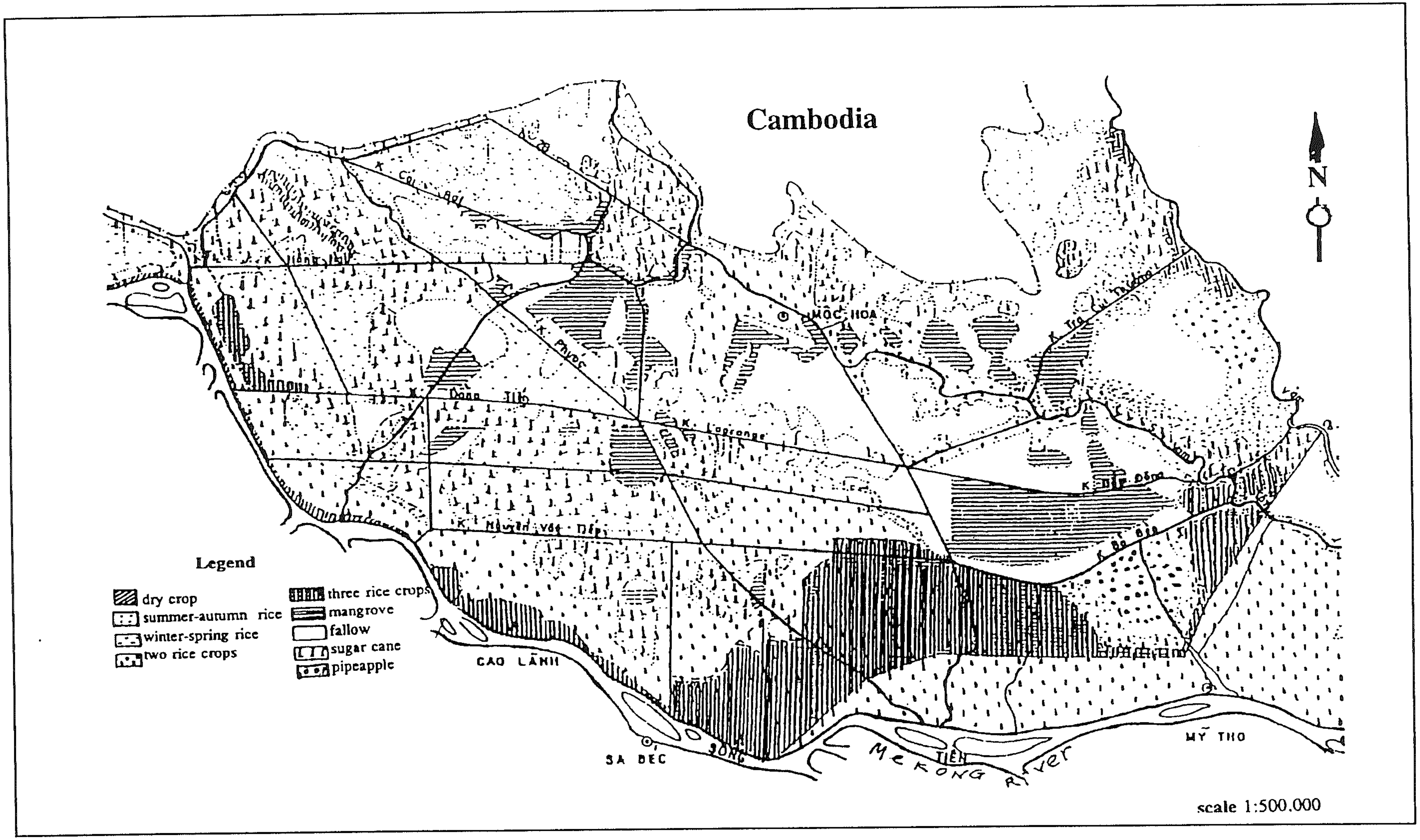
ANNEXES



Annex A.1 Soil map of the Plain of Reeds (source: Final Report on research topic 06A.03.01, 1991)



Annex A.2 Canal network in the Plain of Reeds (source: Report on investigation of the Plain of Reeds, 1995)



Annex A.3 Land use in the Plain of Reeds (source: Report on investigation of the Plain of Reeds, 1995)

Annex B.1 Annual maximum water level of the Mekong river at Tanchau and Mi thuan hydrological stations (1977 - 1995)(Hydro-meteorological Service Department, 1995)

Year	Tan chau station		Mi thuan station	
	Water level, m+MSL	Date of occurance	Water level, m+MSL	Date of occurance
1977	3.58	16/9	1.68	15/10
1978	4.94	4/10	1.96	17/10
1979	4.1	27/8	1.79	7/10
1980	4.61	23 & 24/8	1.87	27/9
1981	4.67	13/10	1.87	13/11
1982	4.4	23/10	1.88	2/11
1983	4.18	23/10	1.89	5/14
1984	4.97	12/9	1.92	25/10
1985	4.32	29/9 & 4/10	1.89	13/9
1986	4.18	21/9	1.92	3/11
1987	3.71	14/9	1.85	18/10
1988	3.30	26/9	1.76	29/8
1989	3.64	21/10	1.92	17 & 18/10
1990	4.31	10/9	1.85	4/11
1991	4.80	12/9	1.97	25/10
1992	3.58	2/9	1.92	26/10
1993	3.61	16/9	1.90	20/9
1994	4.67	23/9	2.13	17/10
1995	4.30	9/10	1.66	21/10

Annex B.2 Percentile points of Student t-distribution t{v, p} for a 5% level of significance (two-tailed) (de Laat,1995)

$p = P(t \leq t_p)$	0.025	0.975
v		
4	-2.78	2.78
5	-2.57	2.57
6	-2.54	2.54
7	-2.36	2.36
8	-2.31	2.31
9	-2.26	2.26
10	-2.23	2.23
11	-2.20	2.20
12	-2.18	2.18
14	-2.14	2.14
16	-2.12	2.12
18	-2.10	2.10
20	-2.09	2.09
24	-2.06	2.06
30	-2.04	2.04
40	-2.02	2.02
60	-2.00	2.00
100	-1.98	1.98
∞	-1.96	1.96

Annex B.3 Percentile point of the Fischer-F distribution $F\{v_1,v_2,p\}$ for 5% level of significance (two-tailed) (de Laat,1995)

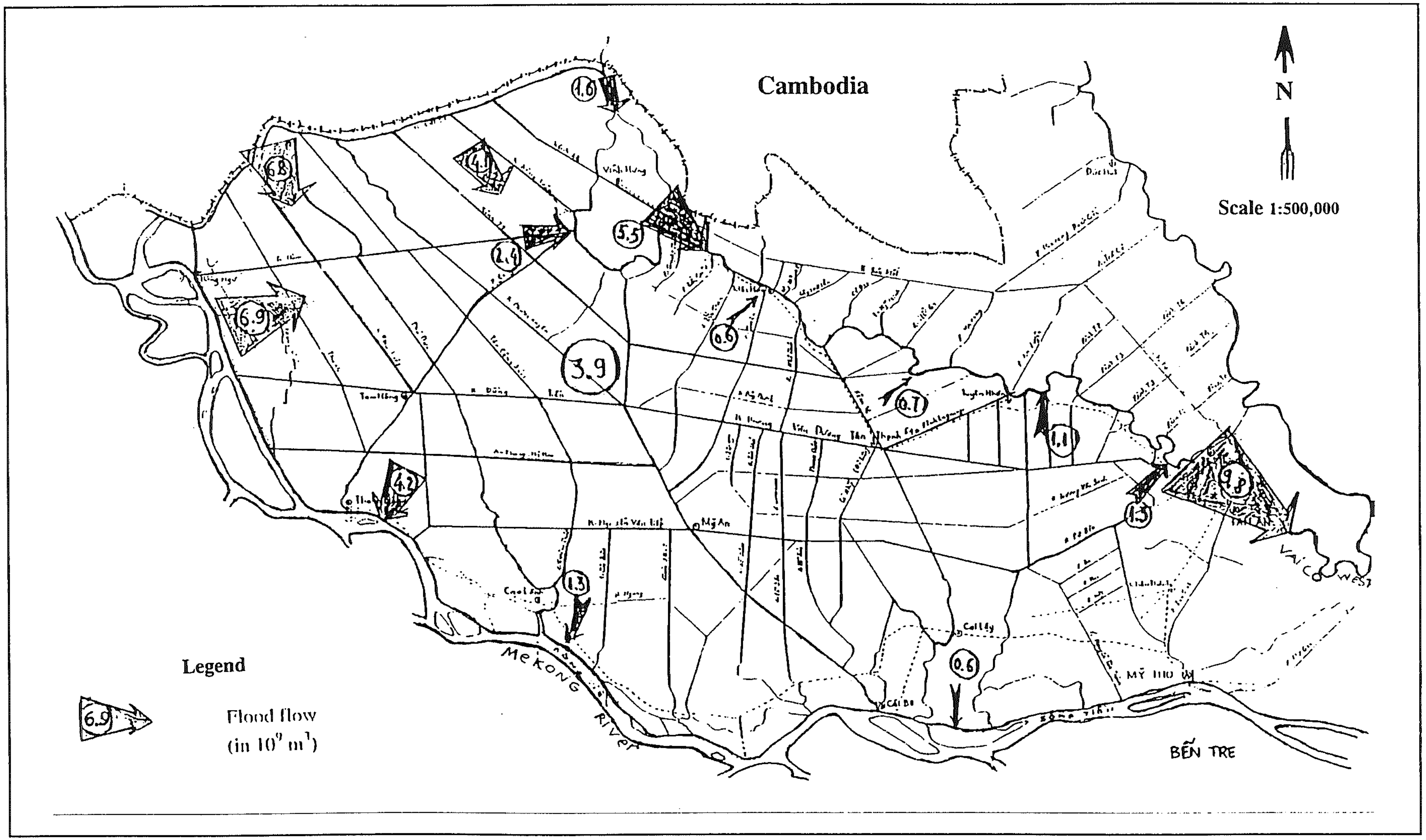
$p=P(F<=F_p)$	v_1	4	5	6	7	8	9
0.025 0.975	v_2:5	0.107 7.39	0.140 7.15	0.169 6.98			
0.025 0.975	6		0.143 5.99	0.172 5.82	0.195 5.70		
0.025 0.975	7			0.176 5.12	0.200 4.99	0.221 4.90	
0.025 0.975	8				0.204 4.53	0.226 4.43	0.244 4.36
0.025 0.975	9					0.230 4.10	0.248 4.03
0.025 0.975	10						0.252 3.78

Annex B.4 Gumbel extreme value analysis based on annual maximum water levels at station Tan chau

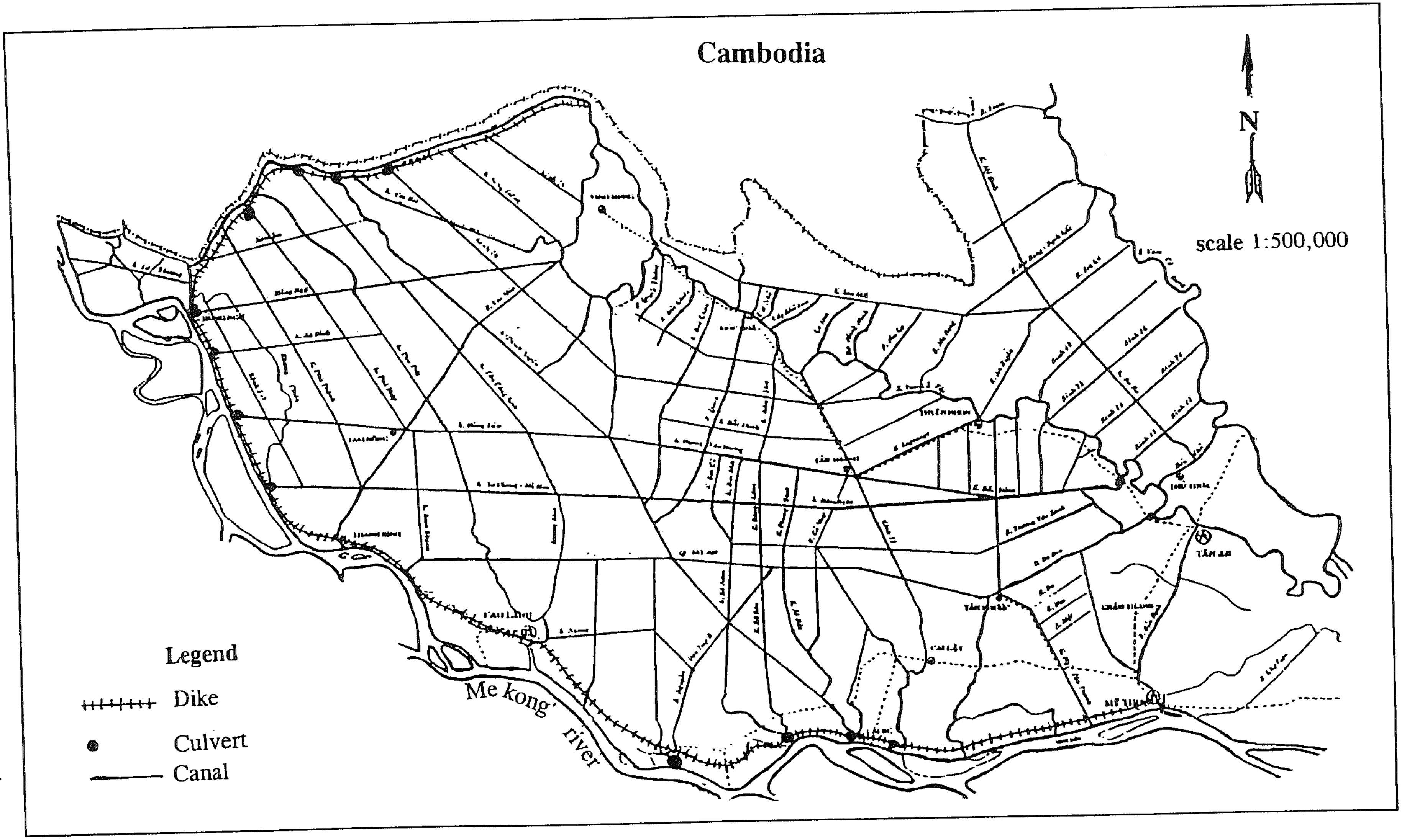
Year	Water level in m+MSL	Rank	$F_i=\frac{i-0.44}{n-0.12}$	$y_i=-\ln[-\ln F_i]$
1977	3.58	3.30	0.029	-1.26
1978	4.94	3.58	0.082	-0.92
1979	4.10	3.58	0.134	-0.70
1980	4.61	3.61	0.186	-0.52
1981	4.68	3.64	0.238	-0.36
1982	4.40	3.71	0.291	-0.21
1983	4.18	4.10	0.343	-0.07
1984	4.97	4.18	0.395	0.07
1985	4.32	4.18	0.448	0.22
1986	4.18	4.30	0.50	0.37
1987	3.71	4.32	0.552	0.52
1988	3.30	4.34	0.605	0.69
1989	3.64	4.40	0.657	0.87
1990	4.34	4.61	0.709	1.07
1991	4.80	4.67	0.761	1.30
1992	3.58	4.68	0.814	1.58
1993	3.61	4.80	0.866	1.94
1994	4.67	4.94	0.918	2.46
1995	4.30	4.97	0.971	3.53

Annex B.5 Gumbel Extreme value analysis based on annual maximum water level at station Mi thuan

Year	Water level in m+MSL	Rank	$F_i=\frac{i-0.44}{n-0.44}$	$y_i=-\ln[-\ln F_i]$
1977	1.68	1.66	0.029	-1.26
1978	1.96	1.68	0.082	-0.92
1979	1.79	1.76	0.134	-0.70
1980	1.87	1.79	0.186	-0.52
1981	1.87	1.85	0.238	-0.36
1982	1.88	1.85	0.291	-0.21
1983	1.89	1.87	0.343	-0.07
1984	1.92	1.87	0.395	0.07
1985	1.89	1.88	0.448	0.22
1986	1.92	1.89	0.50	0.37
1987	1.85	1.89	0.552	0.52
1988	1.76	1.90	0.605	0.69
1989	1.92	1.92	0.657	0.87
1990	1.85	1.92	0.709	1.07
1991	1.97	1.92	0.761	1.30
1992	1.92	1.92	0.814	1.58
1993	1.90	1.96	0.860	1.94
1994	2.13	1.97	0.918	2.46
1995	1.66	2.13	0.971	3.53



Annex B.6 The 1994 flood distribution in the plain of Reeds (Nguyen, 1995)



Annex B.7 Location of dike and structures through dike in the Plain of Reeds

Annex B.8 Rice production of the Plain of Reeds from 1984 to 1994 (Le, 1995)

Year	Yearly production			winter-spring crop			summer-autumn crop			autumn-winter crop		
	A (ha)	Y (t/ha)	P (thousand ton)	A (ha)	Y(t/ha)	P(thousand ton)	A (ha)	Y T/ha)	P(ton)	A (ha)	Y (t/ha)	P (ton)
1984	226,160	3.1	708.7	78,240	5.0	393.5	74,510	3.1	230,840	73,410	1.1	84,310
1985	281,480	3.2	916.7	92,740	5.0	462.3	97,240	3.2	306,880	91,500	1.6	147,500
1986	299,540	3.3	997.7	114,110	4.8	546.4	115,110	2.9	332,150	70,320	1.7	119,070
1987	307,160	3.6	1,105.0	117,880	5.0	583.9	99,780	3.4	342,930	89,500	2.0	178,350
1988	395,900	3.6	1,421.7	161,000	4.7	753.5	147,570	3.4	495,640	87,330	2.0	172,570
1989	463,000	3.7	1,751.7	196,000	4.7	921.9	188,000	3.4	635,440	79,000	2.0	158,360
1990	481,400	4.0	1,922.0	230,000	4.8	1,100.0	193,800	3.6	700,000	57,600	2.1	122,000
1991	490,135	3.8	1,848.6	232,046	4.7	1,079.3	233,683	3.1	732,973	24,406	1.5	36,330
1992	509,358	4.3	2,168.4	234,675	5.1	1,207.7	231,870	3.5	820,588	42,813	3.3	140,127
1993	573,293	4.0	2,313.9	272,243	4.5	1,236.5	240,012	3.7	881,553	61,038	3.2	195,799
1994	602,144	4.3	2,590.3	276,766	5.0	1,393.4	249,306	3.7	927,256	76,072	3.5	269,609

Note: A - area, Y - yield, P - production

Annex B.9 Characteristics of soil used in dike construction (Nguyen, 1979)

Type of soil	Liquid limit, %	Plastic limit, %	Plastics, %	Organic matter, %	Compaction		Coefficient of filtration, m/day	Fiction angle, °	Cohesive factor, KN/m²	Dry density, kg/m³
					$\rho_{d(max)}$, kg/m³	Optimum moisture content, %				
Clay	47 - 52	25 - 28	19 - 22	8.5 - 9.0	1,55 - 1,60	25 - 26	10^{-7} - 10^{-5}	9 - 13	1.5 - 2.2	1,37
Clay loam	33 - 40	20 - 24	11 - 15	9.0 - 9.5	1,60 - 1,70	18 - 20	as above	as above	as above	1,31

Annex C.1 Irrigation supply by pumps to field in 1994

Irrigation	Winter-Spring crop			Summer-Autumn crop		
	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
1	3,000	1,500	300	3,000	1,500	300
2	6,000	3,000	600	6,000	3,000	600
3	6,000	3,250	600	10,500	4,500	600
4	9,000	4,500	900	10,000	5,000	1,000
5	9,500	4,500	900	10,000	5,000	1,000
6	10,000	5,000	1,000			
7	10,000	5,000	1,000			
8	11,000	5,000	1,000			
m^3/ha	6,450	6,350	6,300	3,950	3,800	3,800

Annex C.2 Rice evapotranspiration for whole period of vegetation

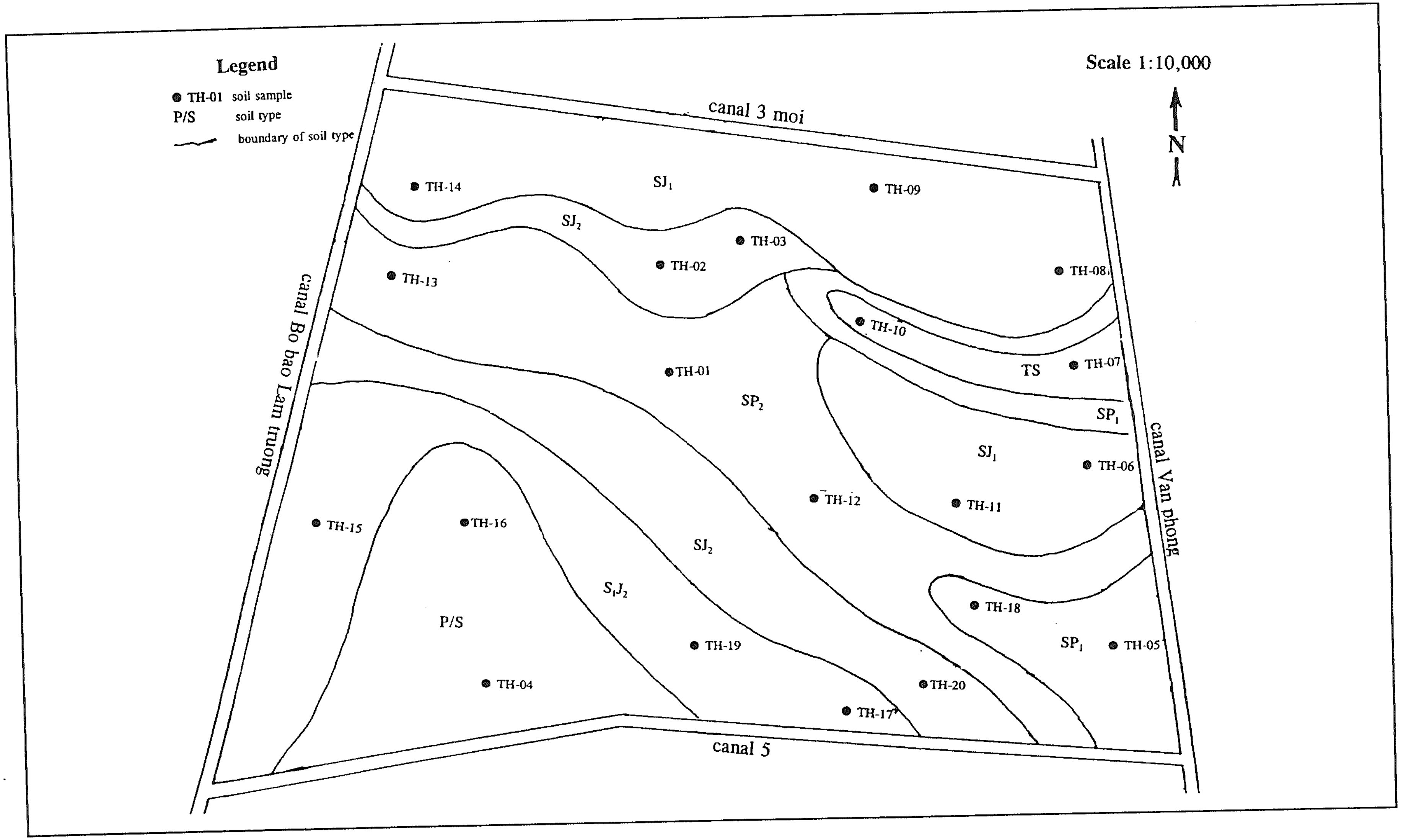
Crop	Stage of growing	Number of days	Time		Evapotranspiration, mm/day	Total Evapotr. mm
			from	to		
Winter-spring	1	25	20/11	15/12	4.0	100
	2	13	16/12	28/12	6.2	80.6
	3	18	29/12	15/1	6.7	120.6
	4	24	16/1	8/2	7.8	187.2
	5	17	9/2	25/2	7.3	124.1
						621.5
Summer-autumn	1	25	10/3	3/4	6.6	165
	2	13	4/4	16/4	7.5	97.5
	3	18	17/4	5/5	6.6	118.8
	4	24	6/5	29/5	5.3	127.2
	5	17	30/5	16/6	4.7	79.9
						588.4

Annex C.3 Water quality in canals in the area in 1994 (Duoc,1994)

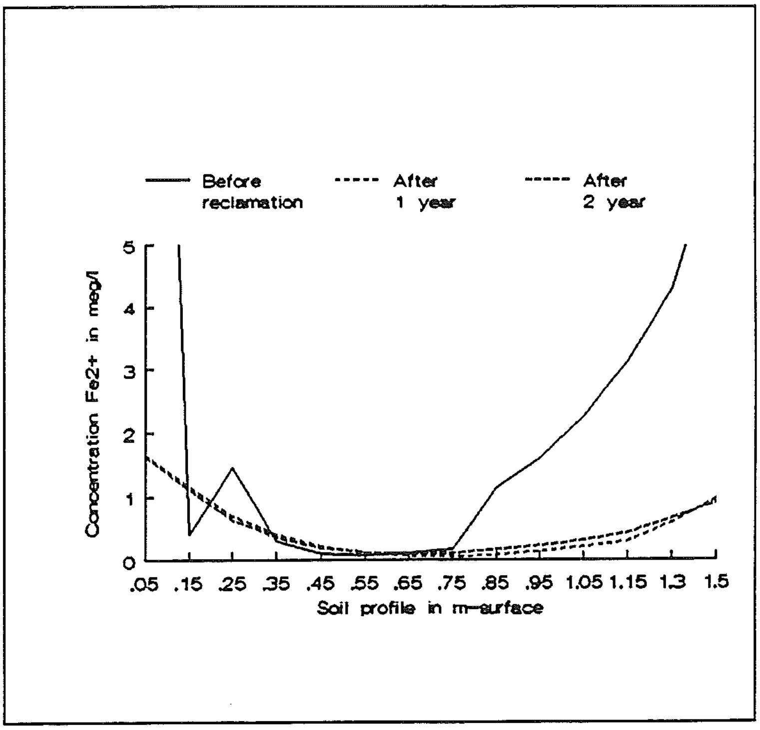
Crop	Location of water sample	pH	Ec (μS/cm)	Al^{3+} (meg/l)	SO_4^{2-} (mg/l)
Winter spring	Canal 5	6.1	169	1.6	161.3
	Canal BobaoLamtruong	5.1	250	1.8	184.5
	Canal 3 moi	4.5	287	2.2	182.5
	Canal Van phong	5.2	302	2.0	183.0
	Field canal	5.0	345	2.0	207.0
Summer autumn	Canal 5	4.9	204	1.8	157.5
	Canal BobaoLamtruong	4.2	285	2.0	189.0
	Canal 3 moi	4.5	298	2.4	244.5
	Canal Van phong	5.0	252	2.3	252.0
	Field canal	4.4	208	2.0	191.5

Annex C.4 Chemical components of soil in the project (Duoc,1994)

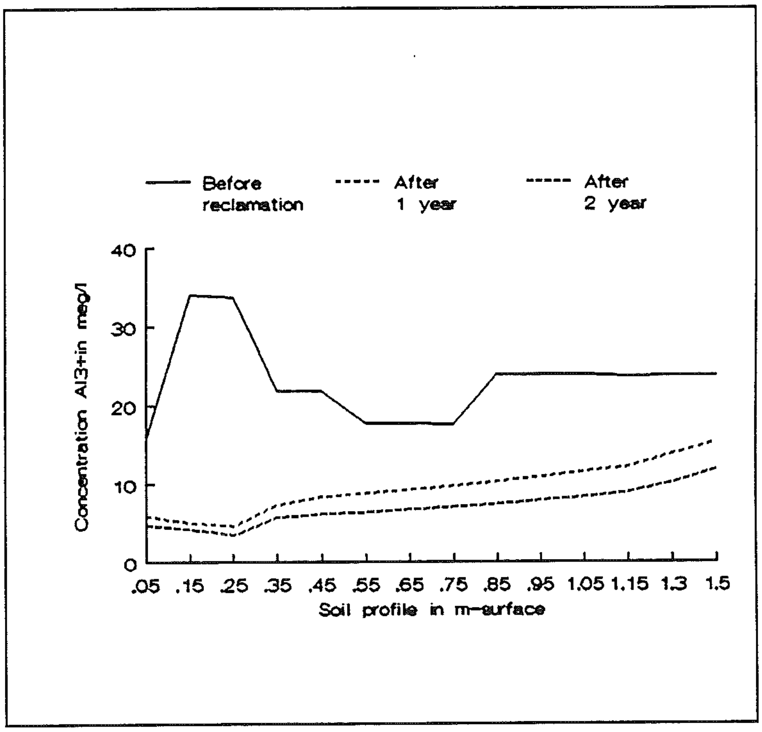
Soil profile	Soil type	Soil depth (m-surface)	Organic matter(%)	Ec us/cm	Ca^{2+} meq/meg	Mg^{2+} meq/100g	SO_4^{-2} ppm	Fe^{2+} ppm	Fe^{3+} ppm	Al^{3+} meq/100g	pH
TH-16	P/S	0.0-0.3	3.6	0.64	3.00	4.19	3750	194	399	6.0	3.47
		0.3-0.6	0.371	0.88	3.00	5.99	2100	125	62	9.0	3.25
		0.6-1.3	0.654	0.81	2.50	5.10	5000	212	100	14.0	2.82
		1.3-1.6	12.0	3.35	2.94	5.76	26750	1719	748	21.0	2.46
TH-13	SP_2	0.0-0.3	8.37	0.9	1.05	1.23	6250	534	116	16.0	3.05
		0.3-0.5	4.98	0.63	1.20	1.56	4100	266	219	14.0	2.83
		0.5-0.8	2.44	0.95	1.55	2.22	5000	324	137	15.5	2.61
		0.8-1.6	18.0	3.77	2.34	4.02	35100	2739	116	24.0	2.30
TH-05	SP_1	0.0-0.35	21.7	0.15	1.70	2.47	14250	447	170	15.0	3.22
		0.35-0.7	19.6	1.30	1.70	2.55	21750	447	267	15.8	2.73
		0.70-1.6	15.6	3.71	2.30	3.45	28500	1554	1884	21.0	2.25
TH-19	S_1J_2	0.0-0.2	3.07	0.37	2.04	1.87	4100	130	404	10.5	3.64
		0.2-0.4	1.95	0.37	1.45	1.73	3125	246	166	14.0	2.83
		0.4-0.75	1.38	0.66	1.60	2.22	4100	233	92	12.5	2.71
		0.75-1.7	6.68	1.51	1.70	2.55	16750	825	437	13.5	2.64
TH-03	SJ_2	0.0-0.2	10.0				10000	330	592	15.5	2.78
TH-08	SJ_1	0.0-0.2	9.81				6600	233	835	13.0	2.62
TH-10	TS	0.0-0.2	19.5				16500	288	631	13.0	3.09
TH-15	S_1J_2	0.0-0.2	12.6				4600	311	223	5.0	3.51
TH-20	SJ_2	0.0-0.2	7.7				4000	155	136	15.0	2.99



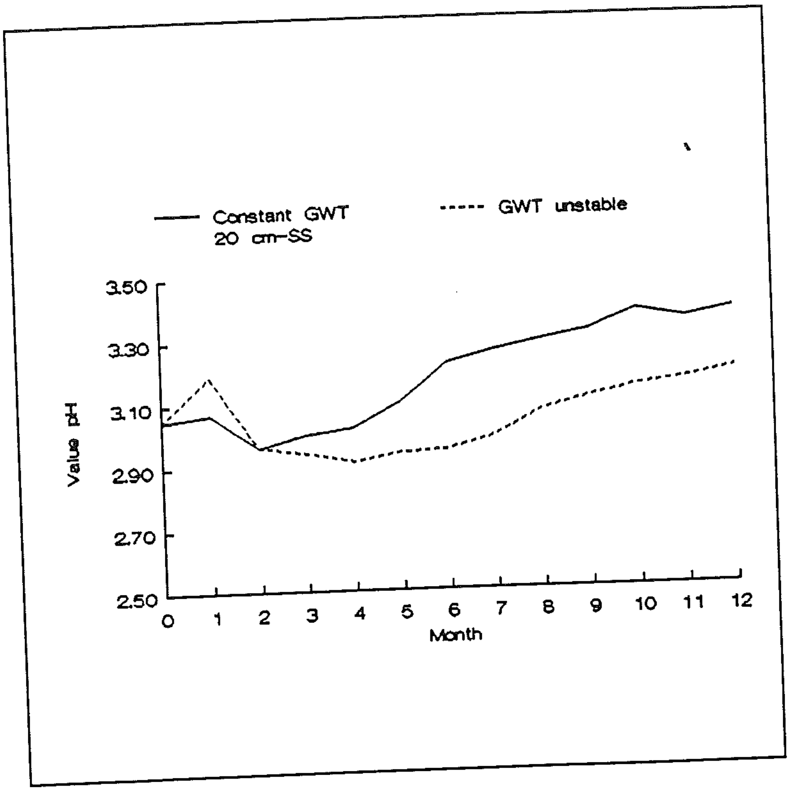
Annex C.5 Soil map of the pilot project Tan Hoa



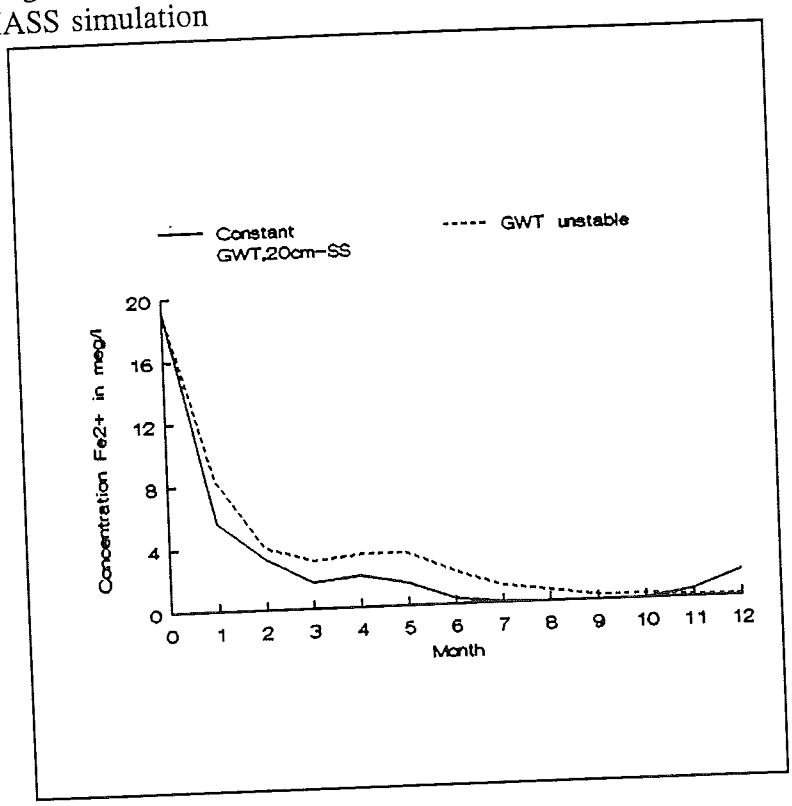
Annex C.6 Change of concentration Fe^{2+} in compartments in reclamation course in time by the SMASS simulation



Annex C.7 Change of concentration Al^{3+} in compartments in reclamation course in time by the SMASS simulation



Annex C.8 Change of pH-value in top-layer in relation to the ground water table by the SMASS simulation



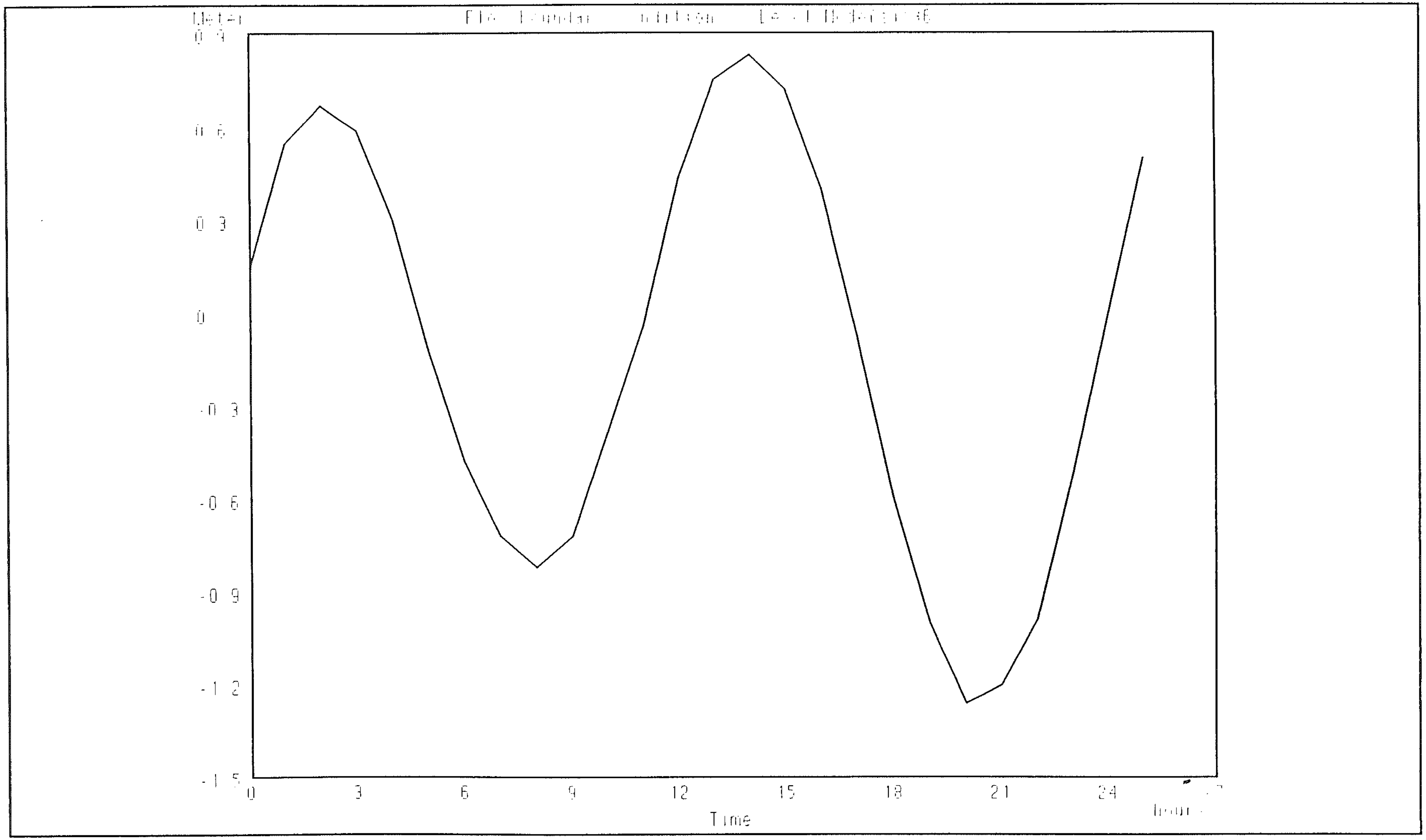
Annex C.9 Change of concentration Fe^{2+} in top-layer in relation to the ground water table by the SMASS simulation

Annex C.10 Calculation of the ground water table due to storage in drain

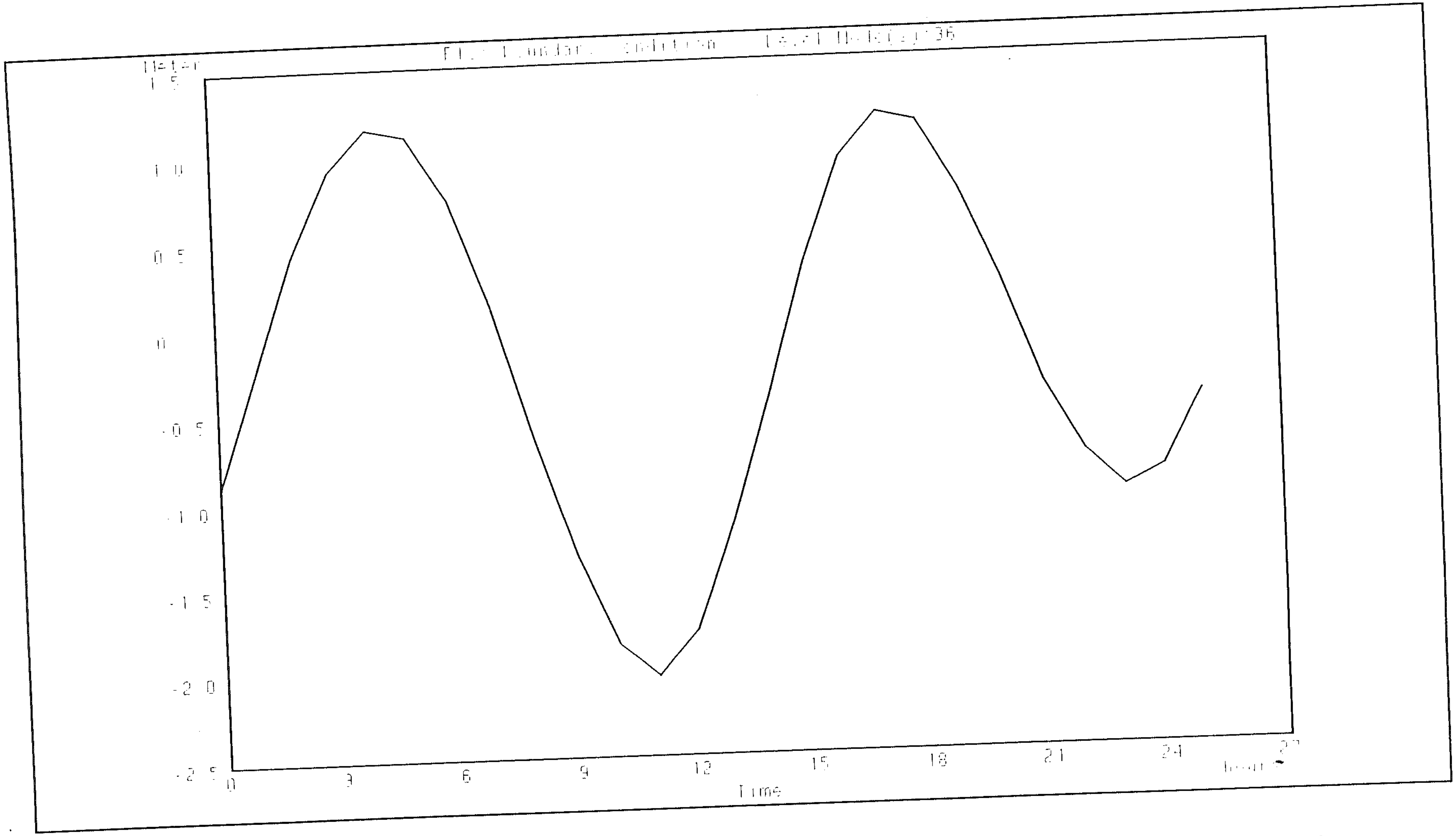
Distance from drain, m	Water table before storage relative to imag. datum, m	Water table after storage relative to imag. datum, m	Calculated values
0.0	6.67	6.88	q = 0.0023 m/day
0.5	6.788	6.888	k = 0.005 m /day
1.0	6.81	6.913	d = 1.0 m
1.5	6.86	6.955	a = 0.1 m
2.0	6.94	7.01	h = 0.5 m
2.5	6.99	7.174	h_o = 6.78 m
3.0	7.079	7.278	D = 9 m
3.5	7.184	7.32	
3.7	7.23	7.32	
4.0	7.3	7.32	

Annex C.11 Monthly dicharge (m^3/s) in the Mekong river at Tan chau station (Hydro-meteorological service department, 1995)

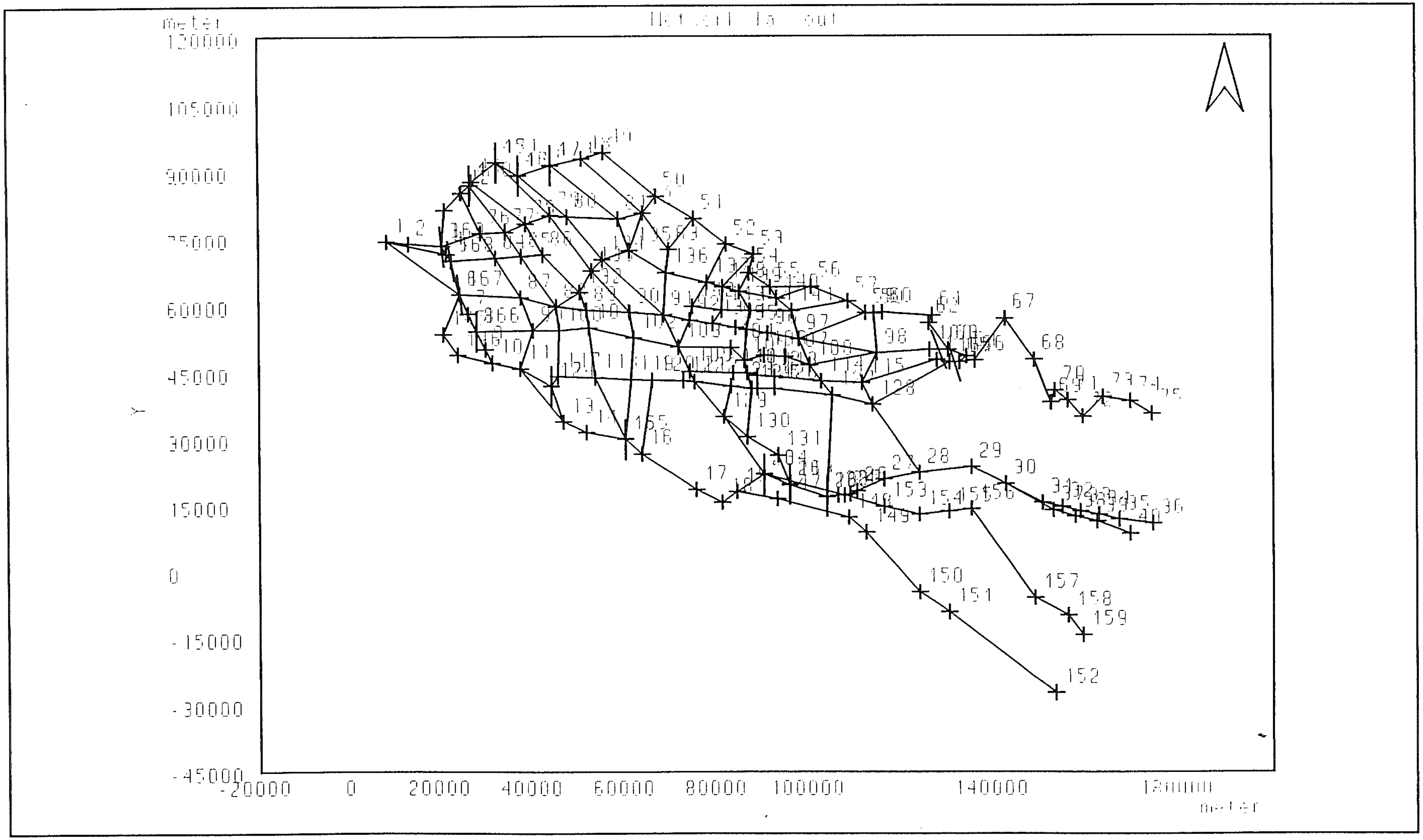
Month Year	January	Feb.	March	April	May	June	July	August	Sept.	October	Nov.	Decem
1990				1,790					21,300	19,900		
1991									22,700	20,300		
1992				2,320	2,730	5,820			17,900	16,400	12,000	
1993				1,270	1,860				18,700	15,300	10,900	
1994				1,890	2,140			20,000	22,200	19,300	13,000	



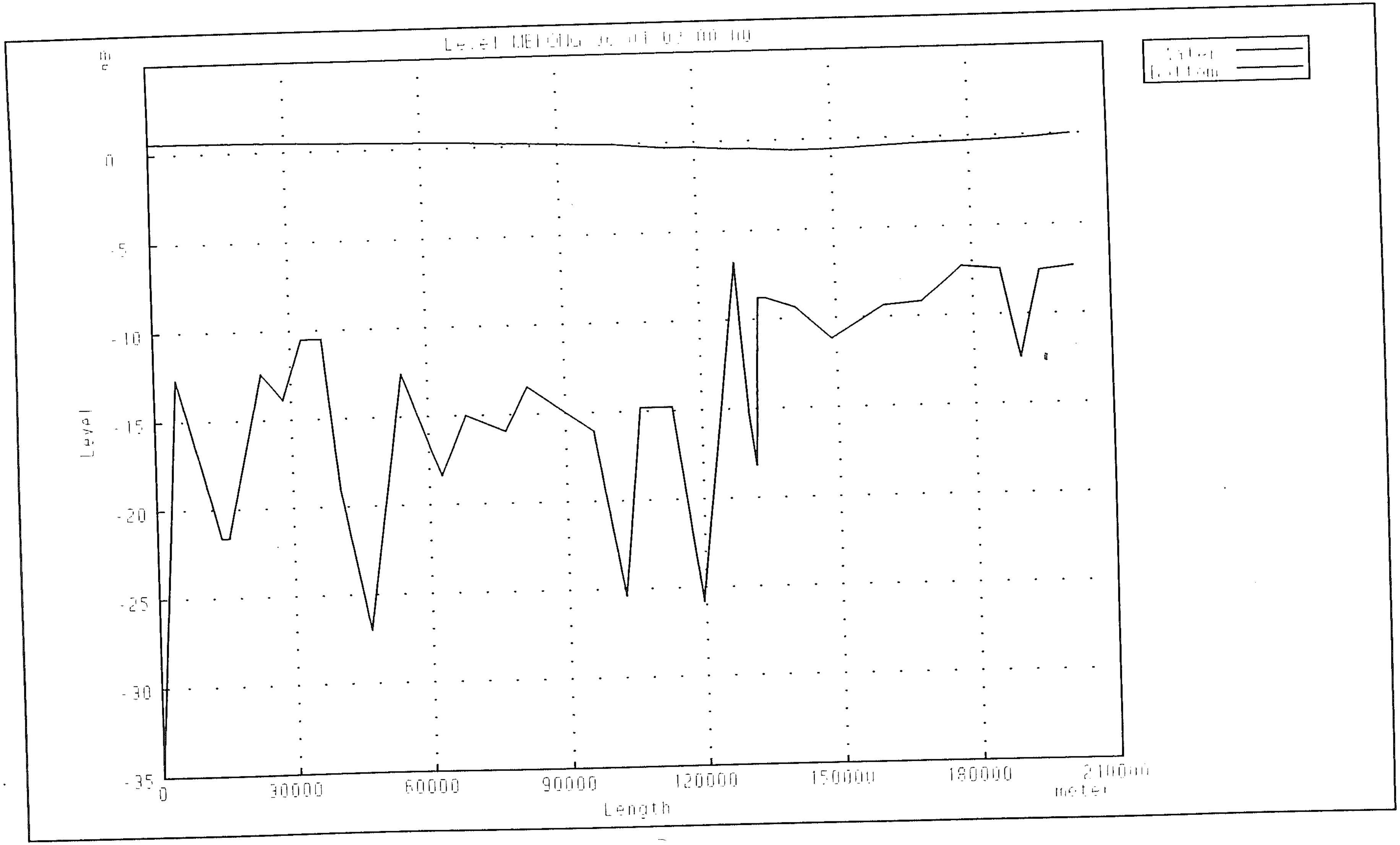
Annex C.12 Tidal curve in the South China sea at node 36 in April from Vung Tau station (Hydro-meteorological service department, 1995)



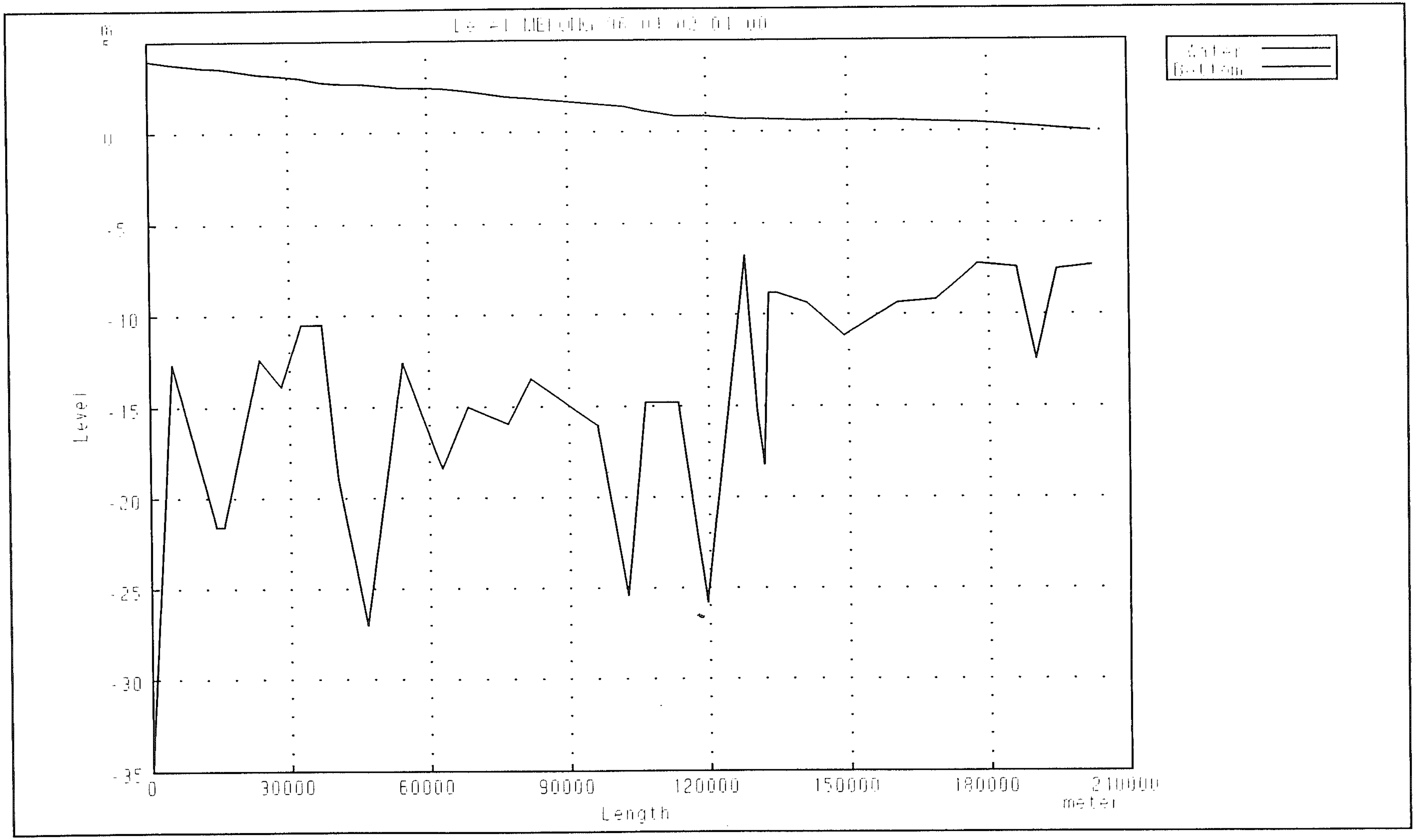
Annex C.13 Tidal curve in the South China sea at node 36 in September from Vung Tau station (Hydro-meteorological service department,1995)



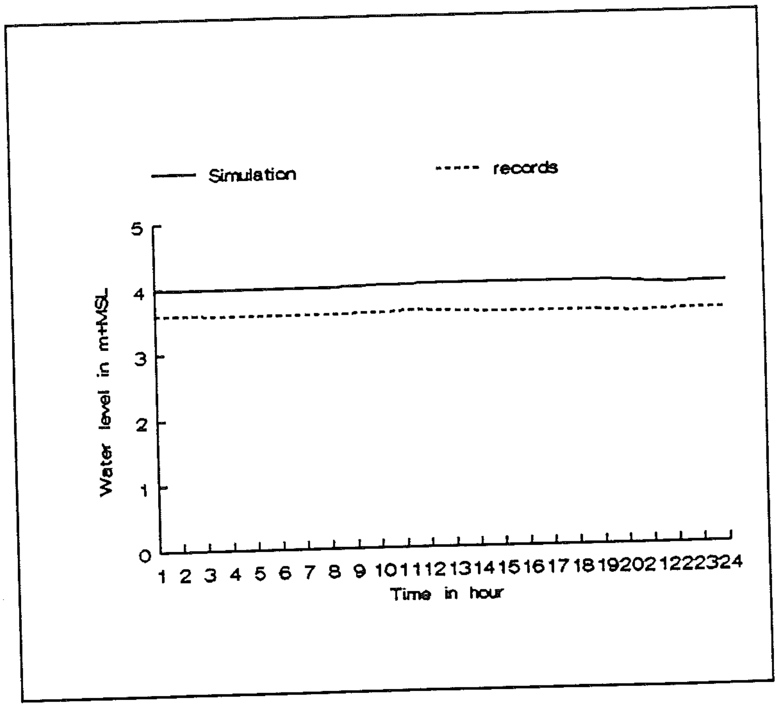
Annex 14 Schematization of canal network in the Plain of Reeds



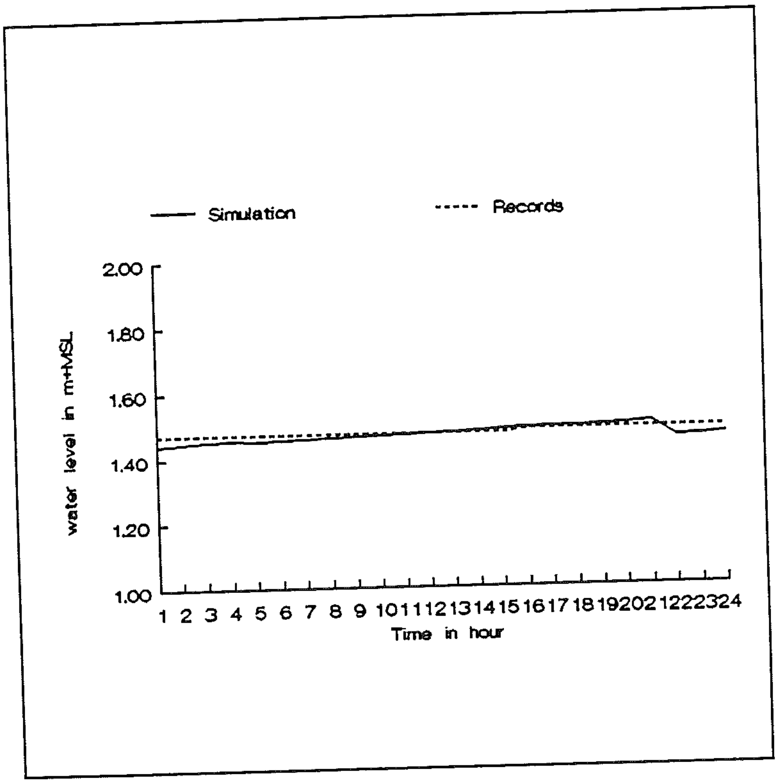
Annex 15 Water level in the Mekong river in April 1993 by the DUFLOW model



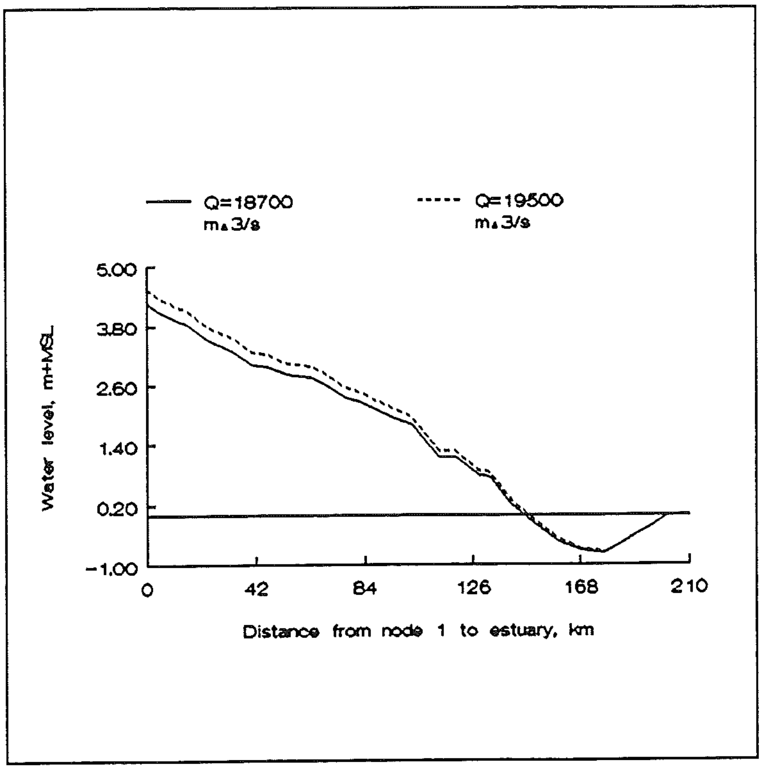
Annex 16 Water level in the Mekong river in September 1993 by the DUFLOW model



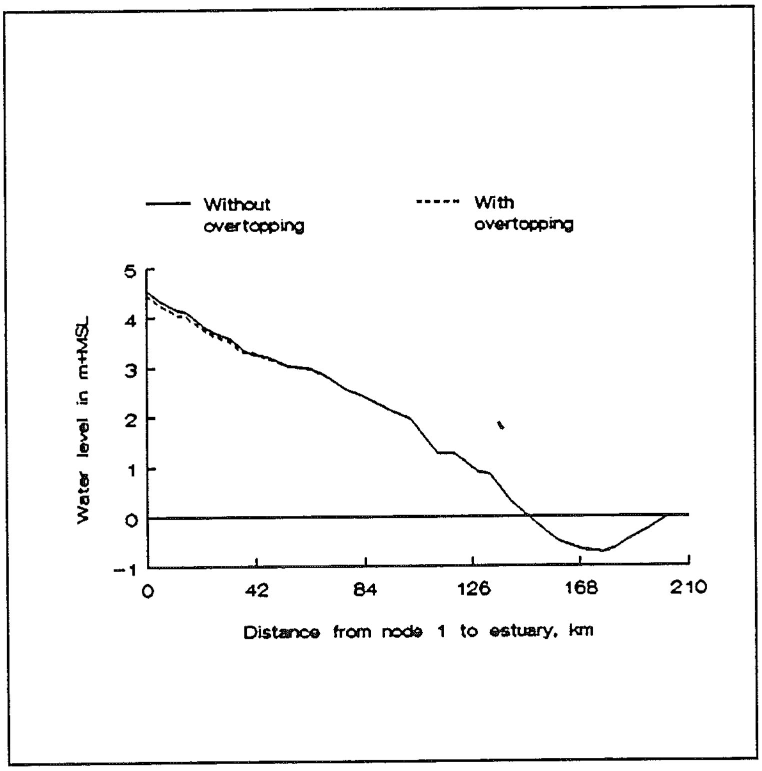
Annex C.17 Comparision of the water level between the simulation result with the reading at node 1 in the Mekong river



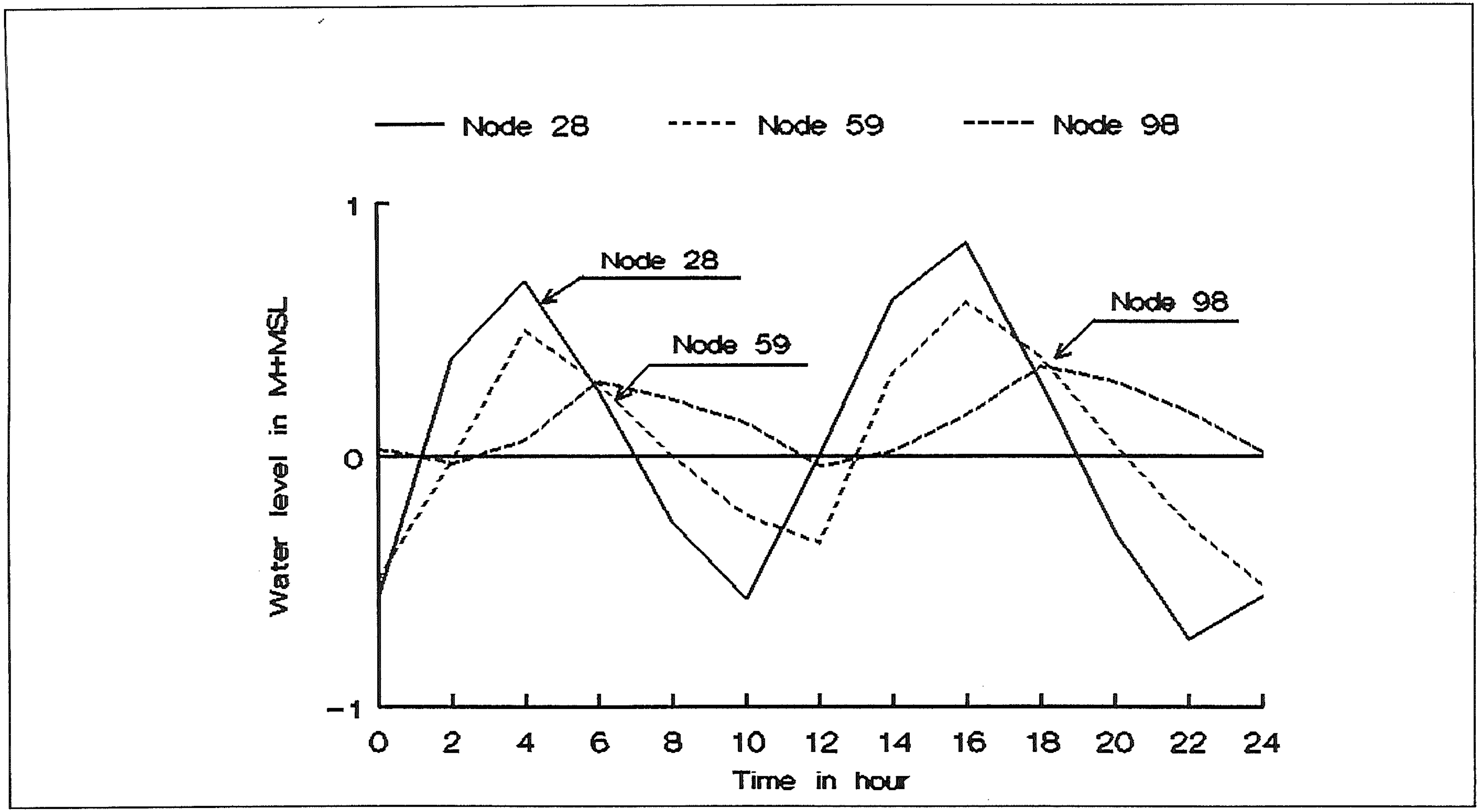
Annex C.18 Comparision of water level between the simulation result with the reading at node 91 (inside the Plain of Reeds)



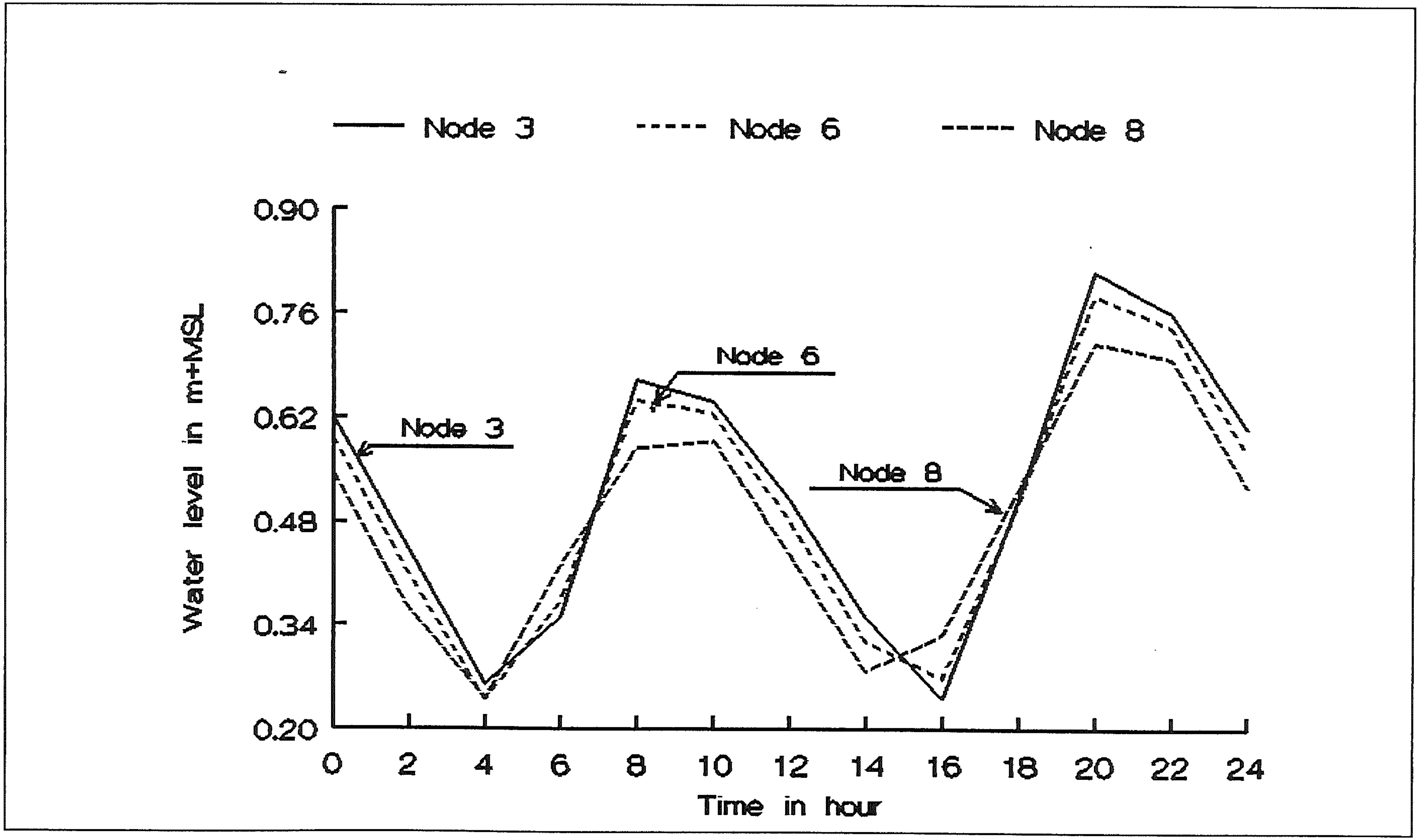
Annex C.19 Relation between discharge in the Mekong river and dike construction by the DUFLOW model



Annex C.20 Water level in the Mekong river with and without overtopping by the DUFLOW model



Annex C.21 Relation of the water level inside the critical part with the outlet (node 28) and outlet in the Vaico West river by the DUFLOW model



Annex C.22 Water level in the Mekong river at nodes of interest in the dry season by the DUFLOW model

Annex C.23 Rice yield in the pilot project Tan Hoa (fieldtrip,1996)

Year	Winter-spring crop, ton/ha	Summer-autumn crop, ton/ha
1992	0	0
1993	1.9	0
1994	2.9	1.7
1995	4.2	2.4

Annex C.24 Costs in rice production

Cost Crop	Land preparation	Seeds	Fertiliser	Plant protection	Labour	Irrigation	Total
Winter-spring	450	200	550	300	300	350	2150
Summer -autumn	200	200	550	200	350	350	1800

Note: Cost unit equivalent to 1 kg of rice. 1 kg of rice is 1.10^3 VND (1993 price)

Annex C.25 Calculation of economic analysis

Year	Period	Invest cost	O&M cost	Total cost	Disc. factor	Disc. total cost	Benefit	Dicount. benefit
91-92	-1	3.2	0	3.2	1.18	3.776	3.05	3.599
92-93	0	0	0.5	0.5	1	0.5	3.05	3.05
93-94	1	0	0.5	0.5	0.845	0.423	3.05	2.577
94-95	2	0	0.5	0.5	0.718	0.359	3.05	2.190
95-96	3	0	0.5	0.5	0.608	0.304	3.05	1.854
96-97	4	0	0.5	0.5	0.516	0.258	3.05	1.574
97-98	5	0	0.5	0.5	0.437	0.218	3.05	1.333
98-99	6	0	0.5	0.5	0.37	0.185	3.05	1.128
99-00	7	0	0.5	0.5	0.314	0.157	3.05	0.958
00-01	8	0	0.5	0.5	0.266	0.133	3.05	0.811
01-02	9	0	0.5	0.5	0.225	0.112	3.05	0.686
02-03	10	0	0.5	0.5	0.141	0.071	3.05	0.430
						6.496		20.190

Note: all cost in million VND