DESIGNING OF A DRAINAGE SYSTEM IN A SWAMPY COASTAL AREA UNDER INFLUENCE OF TIDES

(A case study in the Secanggang Polder, Sumatra, Indonesia)

Major thesis presented in partial fulfilment of the requirements for the degree of Master of Science.

by

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	Secondary irrigation canal.
	Secondary drainage canal.
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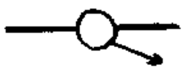
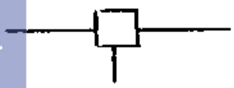
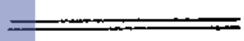
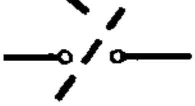
	Tertiary drainage canal.
	Main diversion structure (S)
	Tertiary diversion box stmucture.
	Roads.
	Bridges (B)
	Culvert (C)
	Spillway (Sw)
	Syphon (Sp)

b = bottom width of a canal - (m)

t = talud = side slope of a canal (vertical:horizontal)

i = longitudinal gradient of a canal (in cm/km)

v = velocity of water flow(m/sec)

Q = discharge (m^3/sec)

L = length of a canal (m)

h = height of water in a canal (m)

i.w.l = initial water level

t.w.l = terminal water level

Sect = canal section

S = structure used in irrigation terms

s = structure used in drainage terms

1. INTRODUCTION.

The Secanggang Polder is one of the 4 subareas in the Secanggang Project in the swampy coastal area near the city of Medan, in the Province of Northern Sumatra (Indonesia). The toal area is about 3600 ha, of which 3023 ha would be irrigated.

A preliminary design of the layout of the irrigation and drainage system has been made over the whole area of the Secanggang Polder. Owing to the lack of knowledge concerning the tidal movement, agricultural practices in the swampy coastal area relating with the water management, and estimation of a considerable amount of earthen work for drainage facilities, it is suggested to design in detail only a part of the area, which is the Secanggang drainage area, as a pilot project, while the rest of the area, which is the Sepucung drainage area remains in the preliminary design stage. The design has been made on a contour map of scale 1:10,000.

Irrigation will be supplied from the Sungai Wanpu via the Kotalama main canal with a total capacity of 4.8 m^3/sec at the main intake. The main canal will split into three secondary canals, namely, the Marbau secondary canal will supply 1434 ha with a total capacity of 2.2 m^3/sec, the Selotong secondary canal will supply 1112 ha with a total capacity of 1.7 m^3/sec, and the Pematangtinggi secondary canal will supply 414 ha with a total capacity of 0.6 m^3/sec.

The peak demand is determined by the water requirements during pre-saturation of the sawahs and amounts to 1.4 l/sec/ha.

On the basis of the available rainfall data and potential crop damage the drainage requirements of rice field have been taken at 30 mm per day, and the drainage requirements of upland have been taken at 75 mm per day (ch. 5.4.2).

The peak discharge is determined by these drainage requirements and the total area that should be drained taking into account that the gate will be open only during part of the day.

The peak discharge is determined by these drainage requirements and the total area that should be drained taking into account that the gate will be open only during part of the day.

A total volume of 378000 m^3 should be discharged in 10 hrs averaging a discharge of 10.50 m^3/sec, whilst the water level in the canals is allowed to increase from +6.10 m to + 6.40 m during the 7 hours that the gate is assumed closed, on the average. It has been estimated that a 10 m of the bottom width of the drainage sluice will be sufficient for the pilot area.

The north and west part of the area, must be bordered by dikes to prevent the influence of the high water especially during storms.

When the pilot project will be executed we recommend a program of the following observations:

- The records of the tidal movement should be done continuously. The recording station should be installed near the site of the future drainage sluice at the Secanggang and Sepucung rivers.

- Measurement of the subsidence during a number of years.

- Measurement of the salt concentration in the drainage canals along the dike.

- Measurement of the discharge passing the drainage sluice.

- Measurement of the inflow passing the main diversion structure SK 3, on a daily basis.

- A soil-mechanical investigation to determine the rate of the setting of the dikes.

- Investigation of the water level fluctuation in drainage canals and storage basin ("boezem") in relation to the management of the drainage sluices.

- Investigation of the possibilities of using the storage basin as fish culture ponds.

- Investigation of the need of keeping the storage basins and outlet at the proper depth (frequency of cleaning).

Further suggestions:

- Establishment of an agricultural pilot scheme emphasizing a better water management at the farm level.

- Establishment of farmer's associations in the pilot scheme relating with the operation and maintenance of the irrigation and drainage system at the farm level.

LOCATION OF PROJECT .

scale 1 : 8,155,000

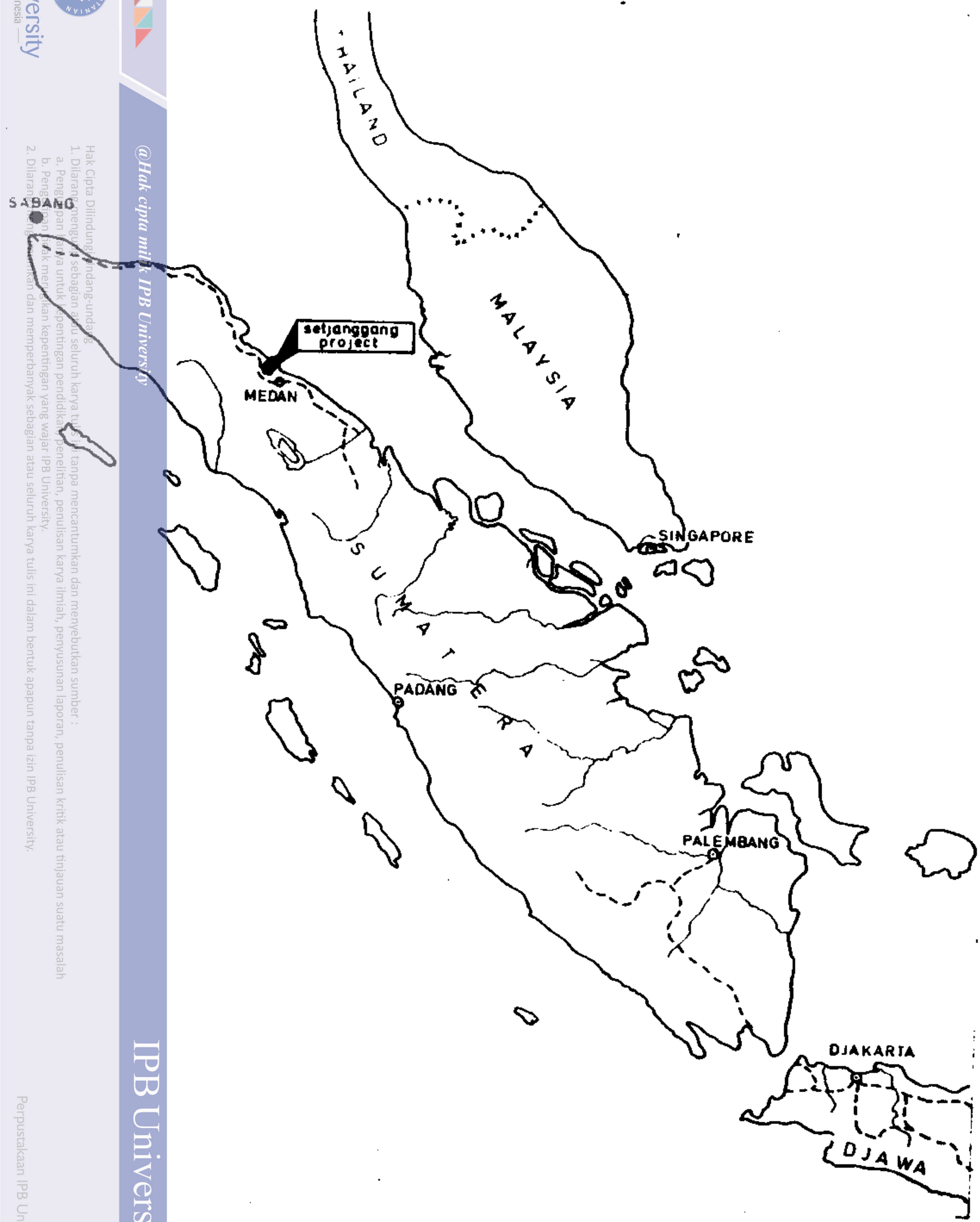


Fig. 1a

72 B.25.3/Ra.

2. GENERAL INFORMATION.

2.1 Location.

The project is located in the Province of Northern Sumatra of the Republic of Indonesia. It lies in the swampy coastal area 30 km north-west of the city of Medan and is bounded to the west by the river the Sungai Wampu. The area under study, the Secanggang Polder, is a part of a project area which has a gross hectareage of 14,490 ha and is subdivided into four subareas:

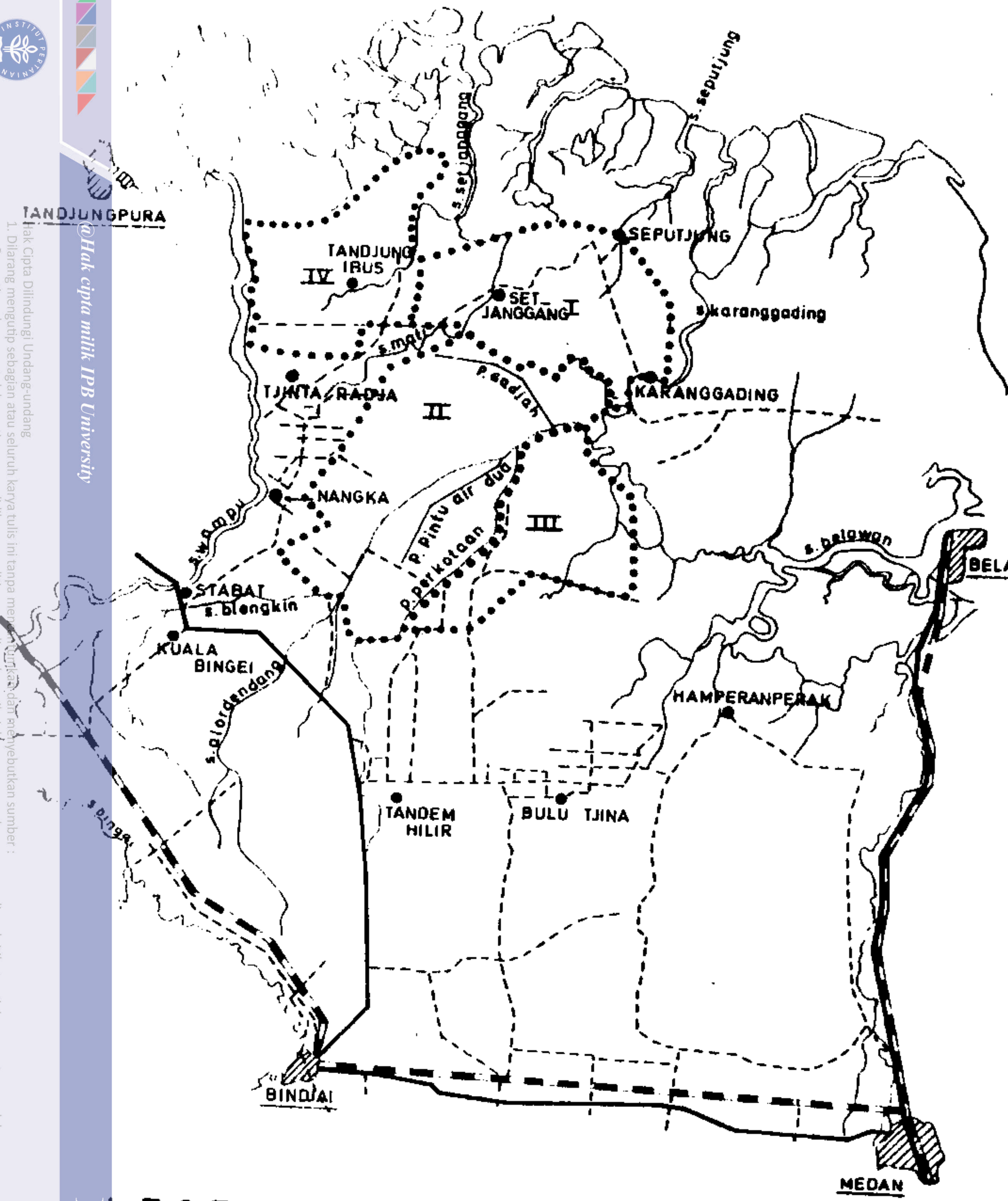
subarea I	: the Secanggang Polder, the area under study - - - - - - - - - - - - - - - -	3,600 ha
subarea II	: the Kota Lama area, the Lubuk Dalam area and the Paya Dendang area - - -	5,450 ha
subarea III	: the Telaga Tujuh Polder - - - - - -	2,750 ha
subarea IV	: the Kebun Kelapa Polder - - - - - -	2,690 ha

The location of the project is shown in fig. 1a and 1b.

2.2 Population.

The total estimated population living in the project area is given in table 1. An estimated 90% of the people are either fully or partly employed in agriculture. About 50% of the population in the project area are Javanese, while the remaining population is of Malay or Banjarese origin. The total population is increasing, not only through natural growth, but also by immigrants; the immigrants try to buy land - which is difficult - or apply for a license for cleaning a part of unused land for paddy production. The average size of a family is 6 persons, of whom 3 are potential farm workers.

scale 1: 200.000.



LEGEND

BOUNDARY OF PROJECT AREA

HIGHWAY

RAILWAY

SECONDARY ROAD

river

VILLAGE

Fig. 1b

Table 1. Distribution of the population over the subareas. (1968).

Subarea	number of population
I	8,100
II	24,500
III	13,200
IV	12,900
total	58,700

2.3 Climate.

2.3.1 Rainfall.

The climate is an equatorial rain climate. February and March are the driest months of the year. A short wet season occurs in May, after which the rainfall decreases slightly. The main wet season occurs in the period August - December. Daily rainfall records covering the years 1954 - 1967 are available at four stations in the environment of the project area. Monthly and annual averages of the precipitation of these stations are given in table 2.

An analysis was made of the rainfall data using all 42 available station years. From this analysis, rainfall-duration and drought-duration lines were drawn up for the periods February - April, i.e, the period with the lowest rainfall, and September - November, which is the period with the highest rainfall. The lines are presented in the figures 2a and 2b.

2.3.2 Other climatic data.

The most important other climatic data are listed in table 3. They include the monthly average temperature, humidity, sunshine duration and wind velocity. The data are averages over the years 1959 - 1962,

Table 2. Monthly average of the precipitation at four stations in the environment of the project area, period 1954-1967.

Month	Cintaraja	Kuala-bingei	Tandem-hilir	Bulucina	Average
January	101 mm	116 mm	131 mm	119 mm	116.8 mm
February	83	59	62	53	64.3
March	75	86	71	50	70.5
April	92	102	89	85	92
May	154	181	156	149	160
June	95	143	125	114	119.3
July	125	144	141	135	136.3
August	157	172	153	148	157.5
September	204	215	164	139	180.5
October	239	261	242	239	245.3
November	210	209	189	165	193.3
December	163	161	144	143	152.8
Year total	1692 mm	1849 mm	1667 mm	1539 mm	1638.6 mm

RAINFALL - DURATION LINES AND DROUGHT - DURATION LINES
FOR THE MONTHS OF FEBRUARY, MARCH, AND APRIL

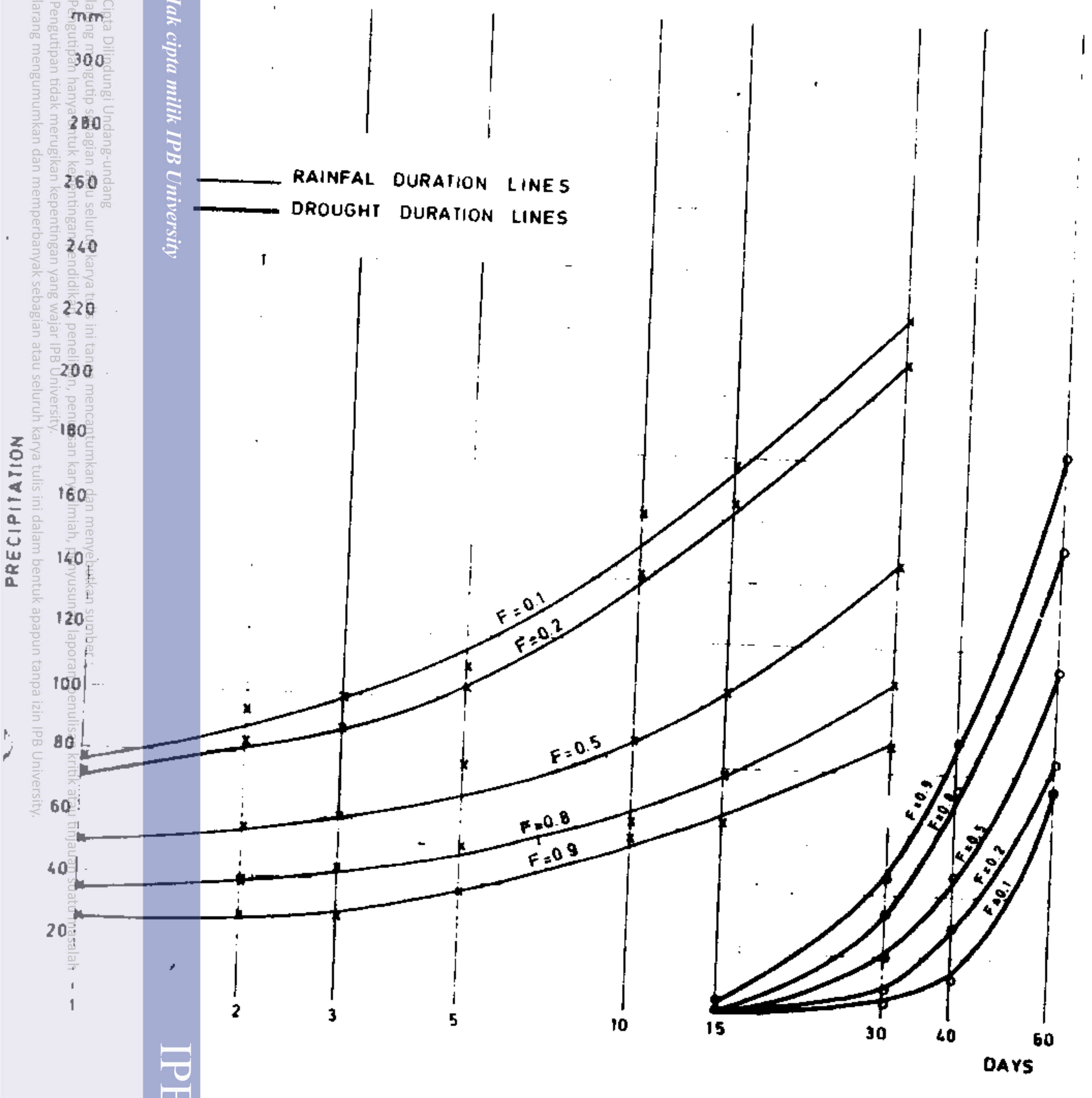


Fig 2a

FOR THE MONTHS OF SEPTEMBER, OCTOBER, AND NOVEMBER

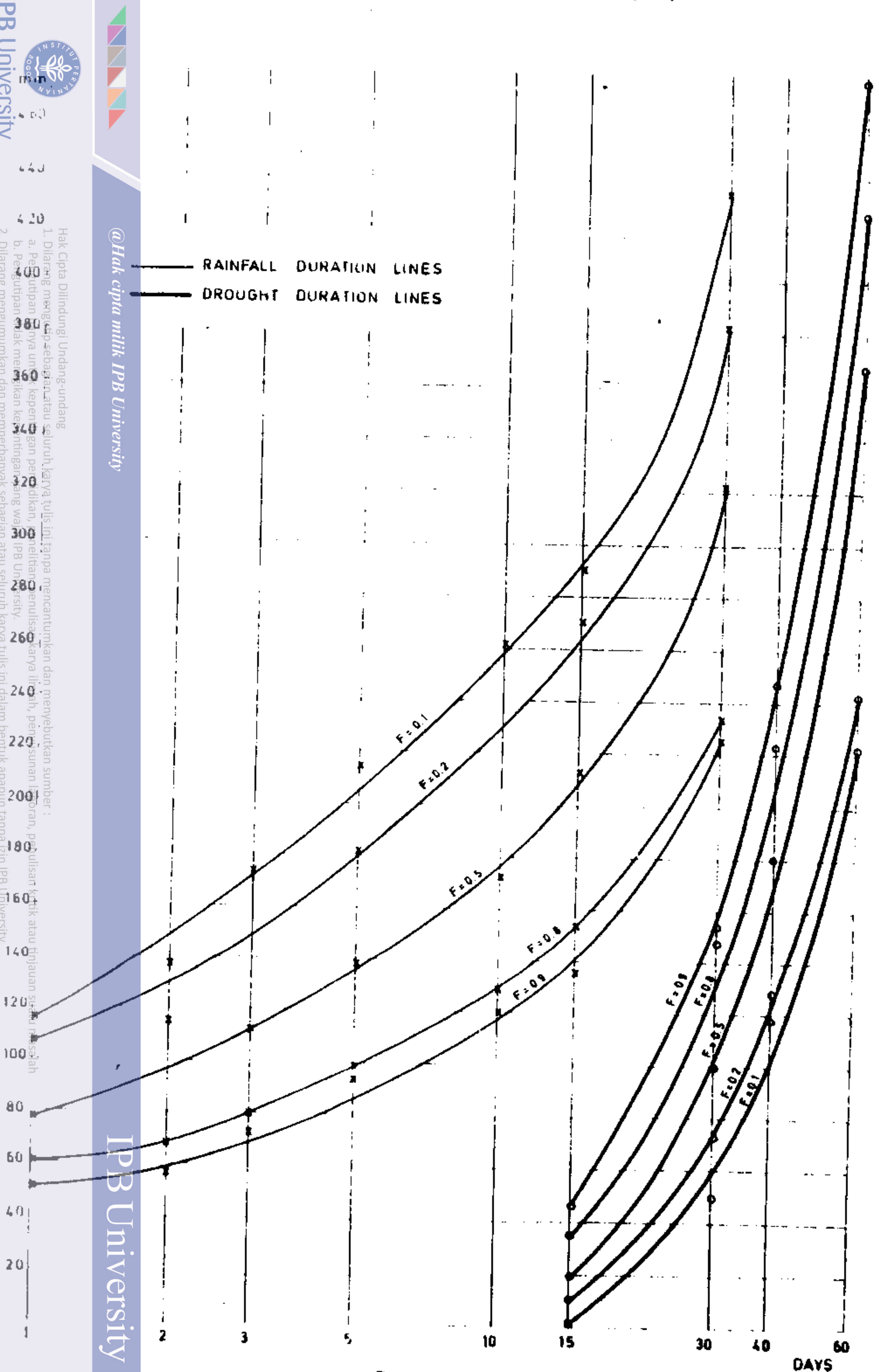


Fig. 2b

Table. 3. Monthly averages of temperature, relative humidity, sunshine-duration, wind velocity and (modified) Penman's evaporation(E_o), Evapotranspiration, daily averages of rainfall, and rainfall deficit and excess.

Month	Temperature °C	Relative humidity %	Sunshine duration %	Wind velocity (m/sec) at 2m high	Evaporation of a free water surface E_o (mm/day)	Evapotranspiration; $Ep = 1.1 \times E_o$ (mm/day)	Daily average of rainfall = R (mm/day)	Approximate rainfall deficit and excess; R-Ep (mm/day)
1	2	3	4	5	6	7	8	9
January	25.6	84	29	3.8	4.3	4.7	3.8	-0.9
February	26.2	83	42	3.5	5.1	5.6	2.2	-3.4
March	27.0	82	54	4.6	6.2	6.8	2.3	-4.5
April	27.3	82	51	4.5	6	6.6	3.1	-3.5
May	27.7	81	58	4.6	6.3	6.9	5.2	-1.7
June	27.9	81	58	3.1	5.6	6.2	4	-2.2
July	26.9	82	57	3.1	5.6	6.2	4.4	-1.8
August	26.8	81	50	2.9	5.4	5.9	5.1	-0.4
September	26.6	84	46	3.1	5.3	5.8	6	+0.2
October	25.9	86	36	3.2	4.8	5.3	7.9	+2.6
November	25.9	86	36	3.2	4.5	5	6.4	+1.4
December	25.9	85	31	3.6	4.3	4.7	4.9	+0.2

recorded at the weather station at Medan. The evapotranspiration of rice has to be assesed from the climatic data by using modified Penman's formula. The 6th column states the evaporation of a free water surface (E_o) of the modified Penman's formula and the 7th column states the evapotranspiration of rice (E_p) being calculated by introducing a crop factor f (the crop factor for rice is about 1.1), so $E_p = 1.1 \times E_o$.

The last column of table 3 gives the approximate daily rainfall deficit and excess figures during rice growing season. These figures have been derived from the difference between the daily mean rainfall of the four stations mentioned in table 2 and the daily evapotranspiration of rice in column 7. Although these figures give less accurate information, they clearly indicate the seasonal difference in the amount of water available for rainfed rice cropping and the need for supplementary irrigation during an appreciable part of the year when double cropping is envisaged. On an average, an approximate 8-month cumulative deficit of 558 mm alternates with a 4-month cumulative excess of 135 mm.

2.4 Topography.

The project consists of a flat area with little slope in which the natural levees of present or former rivers occur. The general slope of the area is in a north-eastern direction. The area has a mean height of 0.50 m above sea level or +6.8 m Ilaco level, whilst the riverine levee extend between 4 m and 1 m above mean sea level (+10.30 m and +7.30 m Ilaco level, respectively). Small rivers, drainage canals or tidal creeks intersect the area. Several villages are located in the project area linked by roads.

The largest topographical maps covering the project area at a scale of 1:50,000. Aerial photographs covering the project area, have been mounted into photomaps at a scale of 1:20,000. The above mentioned maps give the usual topographical information but no data with regard to the altitude of the land. For the subarea I, the Secanggang Polder, the photomap 1:20,000 has been controlled and enlarged to a scale of 1:10,000. The data of a topographical survey in subarea I are presented in a contour map, scale 1:10,000. (see ANNEX)

2.5 Soils.

The project area consists of riverine basins bounded on the north side by tidal flats and intersected by distinct natural levees of existing or former rivers. The Sungai Wampu and its tributaries have carried eroded materials from acid pre-Toba formations, from acid tuffs of the Toba eruptions and from andesitic and dacitic vulcanic rocks to the project area, which is thus fairly endowed with sediments containing mineral plant nutrients. Much of this material was reworked by tidal action in a brackish environment and enriched with organic matter from brackish swamp vegetation while the shore line progressed gradually towards the north-east. The sediments contain relatively large quantities of sulphides. Undoubtedly, this will result in extreme acidity if the land is deeply drained and aerated. Further inland this material is covered by sub-recent and recent riverine alluvium, which prevents the development of acidity in the marine subsoil. Besides, the marine deposits are saline, highly permeable and subject to subsidence.

A soil survey has been carried out resulting in a soil map of the project area (see ANNEX : Secanggang Polder, soil map). The system of the soil mapping legend is given in table 4. The textural classes are defined according to the March 1967 Supplement to the 7th Approximation.

The soil properties described above lead to the following conclusions:

- The groundwater table should be maintained as high as possible, sufficiently to prevent subsidence of the land surface and further oxidation of pyrites. Even during the ripening stage of the paddy

Table 4. System of the soil mapping legend.

First two items	Third item	Fourth item	Fifth upto and including eighth item
Geomorphological unit	Drainage class	Predominant texture	Organic matter, salinity sulphur compounds
TO= terrace of older tuff	0= excessively drained	0 = sandy	d= mucky layer below 80cm
TY= terrace of young tuff	1= well-drained	1 = coarse loamy	m= mucky layer below 40cm
RL= river levee	2= moderately well-drained	2 = fine loamy	M= mucky layer thicker than 20cm, at the surface.
RB= river basin	3= moderately well-drained or imperfectly-drained	3 = fine clayey	
RA= riverine association	4= poorly-drained	4 = very fine clayey	s= $ECx10^3$ of root-zone groundwater > 2.5 mmhos in the dry season.
RR= riverbed	5= very poorly-drained	5 = fine over coarse	
RG= river gully	6= ponded	v = varying texture	S= noticeable sulphur compounds.
RM= riverine and marine		p = peat	
MF= marine tidal flat			
MR= marine beach ridge			

crop and after the harvest, the water table should not subside more than 50 cm below the surface of the land, especially in areas with soil properties of S, m, and M (see the meaning of the symbols in table 4 and the soil map 1).

- Canals and water courses should be brought into optimal condition to reduce the area with stagnant water especially during the growing season and to improve leaching of soils which presently accumulate noxious substances like sodium chloride (soils with symbol s) and sulphates (soils with symbol S).

- Higher groundwater table is also useful to prevent sea water intrusion from tidal creeks.

- Consequently, there will be no alternative other than the cultivation of lowland rice.

3. PRESENT AGRICULTURAL CONDITIONS.

3.1 Historic Development.

Dusun Bataks are reported to be the original inhabitants of the coastal plain. The first settlers came to the project area by the end of the nineteenth century; they were of Malay origin. From about 1900 onwards the tobacco companies started to release the basin soils to the local population and the smaller strips of the river levees. On the latter the new villages were built. Many Javanese estate labourers settled in the area as independent farmers after completion of their contract. Malay, immigrant Banjarese and Javanese farmers prepared the basin soils for the production of sawah paddy and planted fruit crops and vegetables on the levees. At present almost all the suitable soils are occupied, except those that are very low lying and those where soil salinisation prevents economic rice production.

3.2 Land Use.

The tidal marine flat soils are not used for agriculture, partly because they have not yet been cleared, partly because they are saline. On the riverine basin soils sawah paddy is grown during the main rainy season (August - January); during the off-season the land is usually left fallow. The riverine levee soils are used to grow tobacco in the case of estate lands. The remaining levee soils are used for housing and for the cultivation of fruit crops, such as coconut, banana and, to a minor extent, durian and rambutan, and for the cultivation of vegetables and food crops such as soybeans, green gram, cassava and sweet potatoes. The narrow transitional zone between levee soils and basin soils is sometimes used for sawah paddy, sometimes for maize or soybeans. The hectareages of the various subareas and the present land use are given in table 5.

Table 5. Present land use in the subareas in ha.

Land use	sub area I	sub area II	sub area III	sub area IV	Total project area
Sawah paddy	1270	3790	1980	2066	9106
Compound crops	595	1565	750	520	3430
Nipah	300	0	0	0	300
Tobacco	0	50	0	90	140
Forest, roads, canals and villages	1435	45	20	15	1515
Total gross area	3600	5450	2750	2690	14490

3.3 Farm Type and Farm Sizes.

The prevailing type of farm in the area is the smallholding, usually between one and two hectares in size, seldom larger than 5 ha. These farms are primarily prodiving paddy and fruit crops, much of which is used for subsistence purposes. A minor part of the Malay and Banjarese farmers has a nipah plot. Animal husbandary is of little importance. Most families have some chicken or ducks. Cattle is kept both for breeding purposes and animal traction and is regarded as a safe security against sudden crop failures and inflation. Buffaloes are found much less than cattle. The animals grase on the levees, but no special grasing grounds are available.

The average farm size was found to be 1.65 ha for Javanese farmers and 2.95 for Malay and Banjarese farmers and the median farm size 1.44 ha and 1.88 ha, respectively. Table 6 gives the average and median farm size of various crops in ha.

Table 6. Average and median areas of various crops in ha. (1968)

	Javanese		Malay & Banjarese	
	average area	median area	average area	median area
Paddy land cultivated	1.04	1.00	1.16	1.00
Paddy land not cultivated 1)	0.11	0.00	0.40	0.00
Fruit crops	0.46	0.40	0.89	0.32
Dry land crops	0.03	0.00	0.07	0.00
Nipah	0.01	0.00	0.43	0.00
Total	1.65	1.44	2.95	1.88

1) a small part of the paddy land is not cultivated, because of impeded drainage, salinization, or lack of money to pay hired labour.

Only a small part ofthe land is registered as a property. The greater part of the land is government owned. Only a few of the settlers have registered usufructuary rights. Depending on the quality of the soil, farmers pay land rent amounting from Rp 900 per ha to Rp 300 per ha or even less.

At present land fragmentation does not give rise to problems. The average number of plots is 2 or 3 on the smaller farms, 3 or 4 on the larger ones. About half of the paddy plots are less than 0.5 km away from the village, one quarter from 0.5 to 2 km and one quarter over 2 km. There is no acute shortage of paddy land, but plots given out are far from the villages (2 - 3 km) and often suffering from excess water, salinization and severe attacks by rodents and pigs. There is definitely a shortage of land on the levee soils. Prospective immigrants are given one hectare of land by the local authority, but no land on the levee soils.

3.4 Farmer's Activities and Income.

The life of the Secanggang farmer is governed by the weather. The most important crop, paddy, is transplanted before the onset of the heavy rains in October. During the monsoon the farmer, if he is not a craftsman, has little more to do but to look after his fruit crops, to weed, and to wait for the harvest time. The latter falls usually in the dry months of February and March, and the farmers usually need some help, either from friends and relatives, in mutual cooperation, or from hired labourers. After the harvest and threshing period many farmers work a few months as a casual labourer in nipah cultivation or in pole cutting in the mangrove forests.

The farmer's income is earned from crop cultivation, livestock and off farm labour. Table 7 gives the yields of and income from the main crops grown in the area and table 8 is giving the net household income of the farmers. With this income most farmers can just make ends meet and little is left for luxury consumptions.

Exhibit 1 gives an idea about the type of farming, income, expenditure and activities on a typical Javanese farm. The labour film shows, that there is a certain underemployment. However, the farm size is adjusted to the peak labour requirements of transplanting and harvesting, and work to fill the biggest gap from November to February is not available.

TABLE 7 - Yields of and income from the main crops grown in the area.

Crop	Yield per ha	Producer's price in Rp.	Gross production value per ha. in Rp.	Nett production value per ha. (excl. of labour) in Rp.	Number of labour days involved	Income per labour day in Rp.
Sawah paddy	1,600 kg	30 Rp./kg	48,000	45,000	200	225
Coconut 1)	6,000 nuts	6 Rp./nut	36,000	34,000	60	565
Bananas 1)	1,500 bunches	30 Rp./bunch	45,000	43,000	60	715
Maize	1,000 kg	15 Rp./kg	15,000	12,500	60	210
Soy beans	1,200 kg 2)	30 Rp./kg	36,000	33,000	120	275
Green gram	800 kg 2)	50 Rp./kg	40,000	37,000	120	310
Cassava	12,000 kg	5 Rp./kg	60,000	57,000	220	260
Sweet potatoes	10,000 kg	7,5 Rp./kg	75,000	72,000	250	290
Nipah 3)	18,000 atap sheets	1 Rp./sheet	18,000	17,000	150	115

1) The project area has an overproduction of coco-nuts and bananas.

2) These yields are only obtained on the levee soils (compounds); on the moderately well-drained sawahs, soy beans yield only 500 kg/ha and green gram yields about 400 kg/ha.

3) Nipah is made into roof and wall sheets; it can easily sold to tobacco companies for the roofing of curing barns.

Table 8.

Farmer's income
(1968)

	average net household income in Rp	median net household income in Rp
Javanese & others	64,600	61.690
Malay and Banjarese	89,820	56,620*
All farmers	81,300	56,880*

* the high income of a small group of Malay and Banjarese farmers causes the distribution to be skew and the average to be much higher than the median income.

Exhibit 1 - Typical Javanese farm

Family size, farm size, income, expenditure, labour film

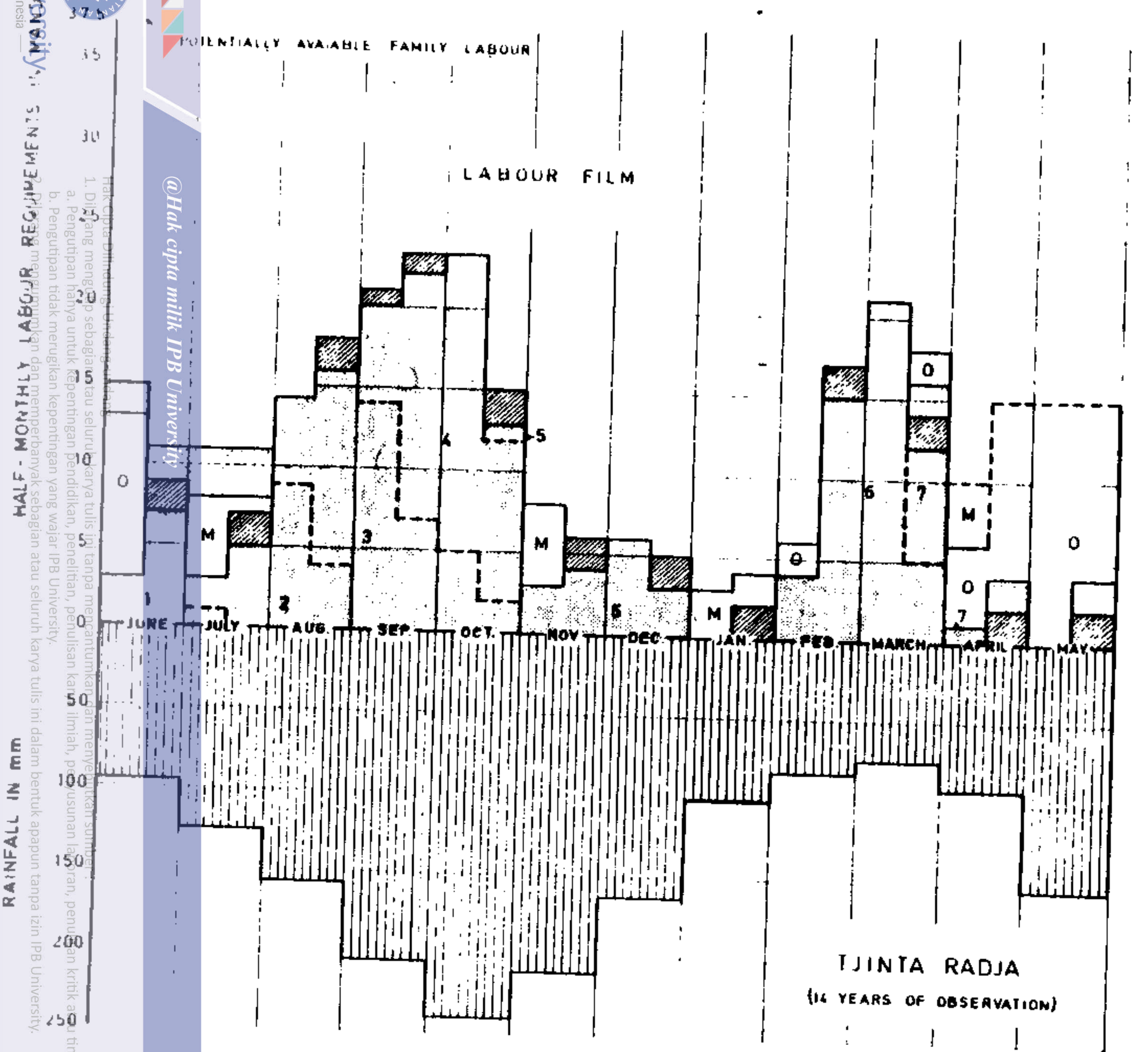
(May 1968: 1 US $ = Rp. 300)

Family: 6 persons, 3 adults, 3 children

Type of farming	Size of farm	Income in Rp.		Expenditure in Rp.	
Paddy land (sawah)	1.00 ha	From paddy (1,550 kg/ha)	43,000	Food (farm privileges)	40,000
Fruit crops	0.40 ha	From fruits	12,000	Food (bought)	7,000
Palawidja	0.12 ha	From palawidja	3,000	Clothing	6,000
Homestead plot	0.08 ha	From livestock and poultry	2,000	Taxes (including religious taxes)	5,000
		From off-farm jobs	9,000	Gifts	1,000
				Interest on credit	2,000
				Miscellaneous (travel, cigarettes, housing)	8,000
Total farm size	1.60 ha	Nett household income	69,000		69,000

Note: The typical Malay or Bandjarese farmer is not very different from his Javanese colleague. His total income may be somewhat lower because he has somewhat less livestock and hardly any palawidja. On the other hand, the Malay farmer makes about Rp. 4,000 a year on his nipah-plot.

Exhibit 1



Paddy cultivation	200 mandays	1. preparation dry nursery and sowing
Palawidja crops	15 mandays	2. preparation wet nursery 1st transplanting
Fruit crops	24 mandays	3. land preparation
O Work outside the farm	54 mandays	4. 2nd. transplanting
M Miscellaneous activities	40 mandays	5. weeding
Livestock	20 mandays	6. harvesting
	353 mandays	7. threshing

4. PRESENT DRAINAGE AND IRRIGATION.

4.1 Drainage.

Except for the minor area on the natural levees, almost all the soils of the lowlands have a poor natural drainage. Formerly, the northern and eastern parts of the project area were drained by canals with drainage sluices into the creeks with tidal fluctuations. They drained excess water at low tide, but closed at high tide to keep sea water out. At present, however, the tidal waters enter freely, the structures being out of order. The lands of the central, southern and western parts of the project area drain into the river Sungai Karanggading. Parts of this river have been canalized. However, bottlenecks give rise to flooding. The adjacent lands are hardly drained, though they are traversed by drainage canals. These drains are non-functioning and have non-functioning flood gates. There are two possibilities to drain the water in the area of subarea I (Secanggang Polder) namely at Sepucung and at Secanggang creeks by installation of sluices.

4.1.1 The tidal creeks.

The tidal fluctuations of the creeks are determining for the possibility of drainage by sluices and for the calculation of the dimentions of these sluices. Water levels in tidal creeks have been measured at two locations, viz. near Sepucung in the Sungai Sepucung Besar and near Tanjung Ibus in the Sungai Tanjung Ibus during the period 9th - 14th June 1966. The tide levels are shown in Fig. 3. Mean sea level is about 6.30 m ILACO level is about 1.50 m Belawan level.

4.1.2 The Sungai Karanggading.

The Sungai Karanggading carries water from the Sungai Alordendang and the Sungai Blengkin. The water-shed of the two last-mentioned rivers covers and area of about 13,300 ha. It has an even relief and an average slope of 0.05%.and it is well under vegetation.

Below the junction of the Sungai Alordendang and the Sungai Blengkim, the Sungai Karanggading has been canalized of 3 km and is called Parit Alordendang. The slope of the Parit Alordendang is 0,25 $^{o}/_{oo}$. From measured cross-sections, it was found that a discharge of 55 m^3/sec can be transported by the Parit Alordendang with a free board of 0.50 m. The water level is then 0.50 - 1.00 m above the surface level of the Lubuk Dalam area, the south western part of the subarea II. To prevent flooding, embankments have been constructed at both sides in which flood gates have been built. These flood gates do not function well, the embankments need repairs. According to local information, the capacity of the Parit Alordendang meets the requirements.

Downstream the Paritdendang, the river is called Sungai Karanggading. The stretch of the Sungai Karanggading from the Parit Alordendang to the entrance of the Parit Pintu Air Dua is about 4.5 km. The cross-section of the riverbed in this section is 40 m^2, the slope 0.25 $^{o}/_{oo}$. The capacity does not meet the requirements as according to local information the water overtops the dikes regularly. The level of the Kotalama area on the left bank side and the Payadendang area on the right bank side is low as compared to the river level and adequate drainage by gravity is not deemed to be possible.

The capacity of the Sungai Karanggading between the Parit Pintu Air Dua and the Parit Gajah is considerably less than in its previous sections. The cross-section of this part of the Sungai Karanggading is about 20 m^2, its course is winding and the slope only 0.05 $^{o}/_{oo}$. In this section tidal movement was observed. Frequent flooding was reported by the population.

The part of the Sungai Karanggading between the Parit Gajah and the Secanggang Polder has been straightened and widened again to a cross-section of 50 m^2. At the moment, no frequent flooding occurs in this stretch of the Sungai Karanggading because the flood water is disposed off into flood areas upstream. Tidal movement is strong and the water is salty.

From the south point of the Secanggang Polder up to the sea, the Sungai Karanggading becomes more or less a tidal creek.

4.2 Irrigation.

The introduction of artificial irrigation in the project area will make it possible to grow a second crop and to eliminate yield depression in the rainy season as a result of irregular rainfall. As source of irrigation water can be considered the river Sungai Wampu.

4.2.1 The Sungai Wampu.

The Sungai Wampu has a catchment area of approximately 3,750 km^2. Owing to the difference in rainfall in several parts of the catchment area and the lack of pronounced dry periods, the Sungai Wampu has a favourable minimum discharge. Rain may cause the discharge to rise rapidly up to approximately five times its minimum value. After rainfall the discharge falls back very rapidly to its minimum value. The minimum discharge has been calculated at approximately 240 m^3/sec and the maximum discharge at approximately 1,200 m^3/sec. At low discharges, the river water is clear and transports only a slight amount of silt. A much higher silt content is observed at very high discharges at which time, moreover, large quantities of floating dirt are being transported. Sedimentation of this material may result in a rise of the riverbed. Information about the highest and lowest water levels are presented in table 9.

Table 9. Stages of the Sungai Wampu.
(1968)

Location	Stage (in m. +Ilaco level) HWL	Stage (in m. +Ilaco level) LWL	Distance (km)	S_o in m. per km HWL	S_o in m. per km LW
Stabat	15.52	11.72			
			5.4		0.22
Nangka		10.55		0.24	0.23
			3.2		0.26
Cintaraja	13.45	9.73			

* Note: HWL = highest water level.
LWL = lowest water level.
S_o = slope of the water surface.

5. DESIGN CRITERIA.

5.1 General.

A main irrigation canal directly conveys the water from the main inlet or intake to one or more irrigation divisions, for example the Kotalama main canal supplies water to the Kotalama division and the Secanggang division. In the division areas the main canal branches into severall secondary irrigation canals and each canal conveys water to an irrigation zone. For example, in the Secanggang area, the Kotalama main canal branches into 3 secondary canals, namely the Marbau secondary canal, the Selotong secondary canal and the Pematangtinggi secondary canal, respectively will supply water to the Marbau zone, the Selotong zone and the Pematangtinggi zone (fig. 4a). A secondary canal branches into many tertiary canals and each canal will supply water to a tertiary unit, and the tertiary canal branches into several quarternary canals and each canal will directly supply water to the rice fields.

The following drainage systems can be distinguished, namely, internal drainage system and primary or main drainage system. The internal drainage system consists of tertiary drains, which drain off a tertiary unit, and secondary drains, which drain off several combined tertiary units or a total irrigation area. The secondary drains convey the excess water to a primary drainage system or directly to the sea. For example, the Sepucung secondary drain will drain off several tertiary units in the Marbau zone and a part of the Selotong zone which would be called the Sepucung drainage area (fig. 4b). The primary or main drainage system consists of drains, rivers and canals, which discharge floods, originating from higher situated areas, for the greater part non-irrigated, to the sea. For example, the Sungai Karanggading discharges floods originating from the surrounding areas of Tandunhilir, Kualabingei. the Lubukdalam area, the Telagatujuh area and the Payadendang area.

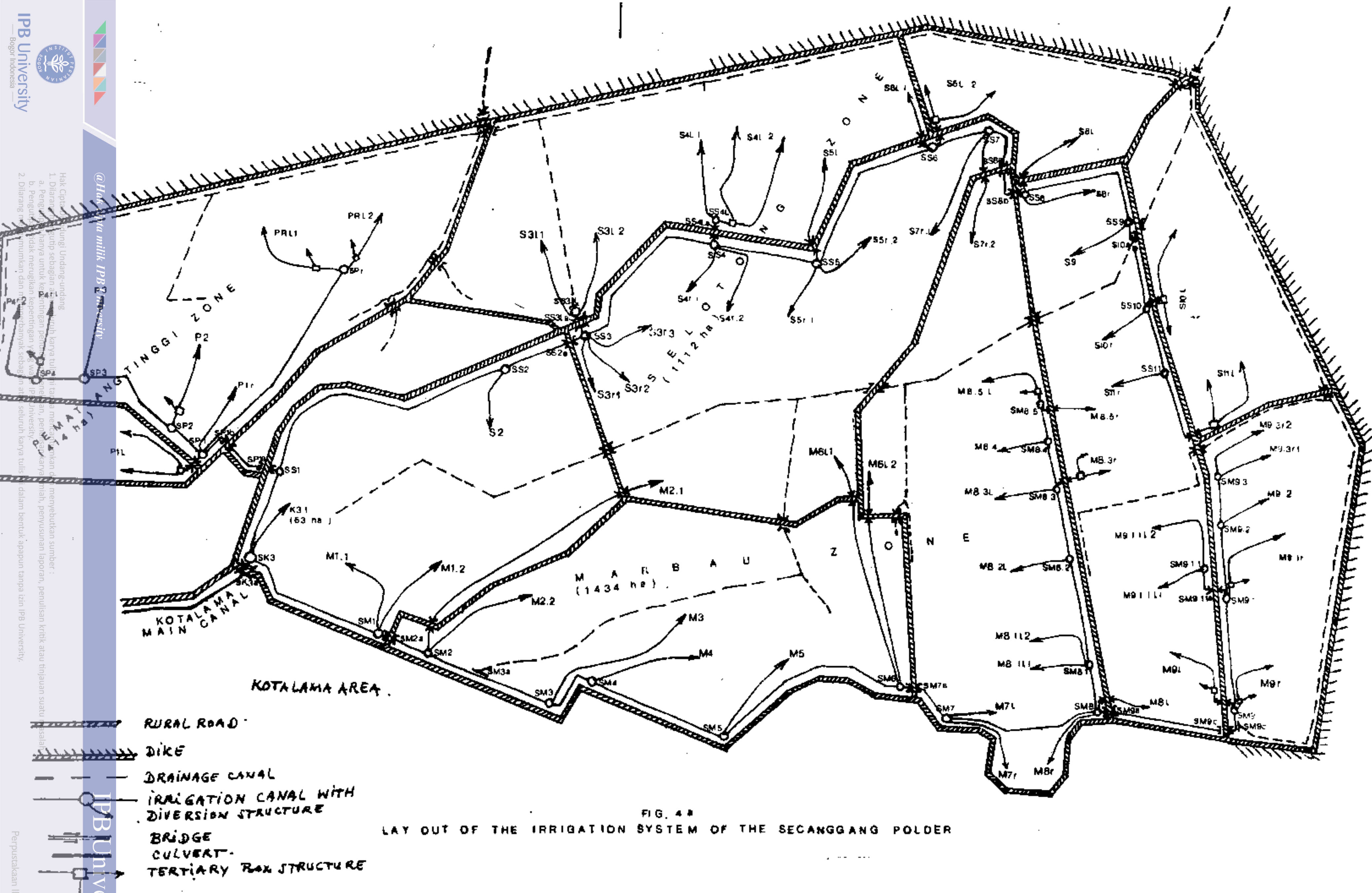


FIG. 4a

LAY OUT OF THE IRRIGATION SYSTEM OF THE SECANGGANG POLDER

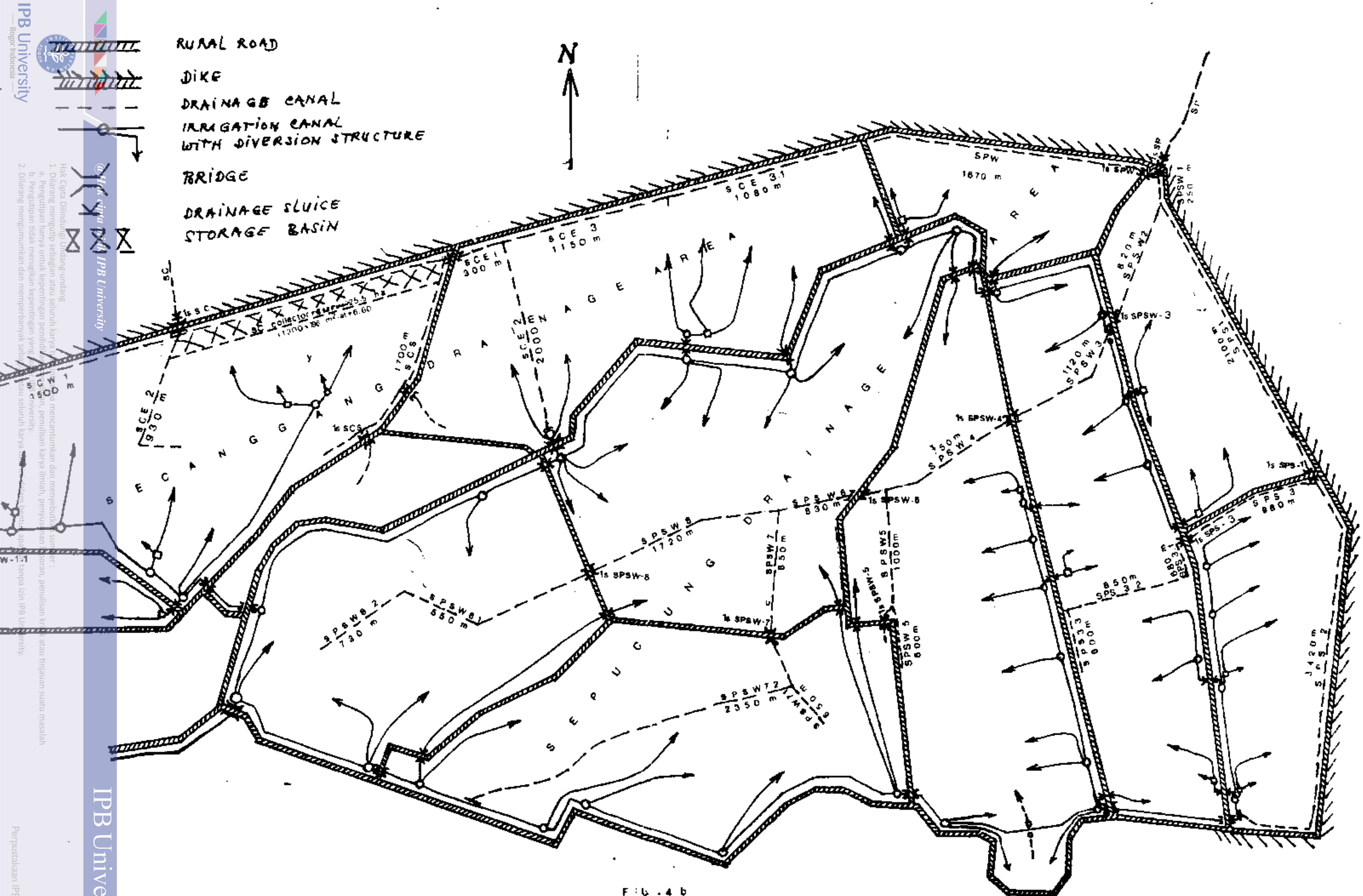


FIG. 4 b

LAY OUT OF THE DRAINAGE SYSTEM IN THE SECANGGANG POLDER

A contour map, scale 1:10,000 and also a topographical map, scale 1:200,000 will be used as basic data for the designing of the irrigation and drainage system in the Secanggang area. (SEE ANNEX)

5.2 Nomenclature.

In order to obtain a clear and easily adaptable nomenclature, the following conditions have to be met:

a. the indication has to be short,

b. the name has to indicate a structure, canal, drain or area,

c. it must be possible to add an extra structure without changing the existing system too much.

In the last couple of decades before the Second World War, the system of Ir. van Rosse was used, of which a description is given in the "Waterstaatsingenieur", 1913 - no.4. This system has been adapted to the Indonesian language with some improvements.

5.2.1 The irrigation system.

- The main canal is mostly named after the supplying river, or after the area it supplies. For instance the North Wampu main canal or NW main canal, which originates from the river Wampu to the north direction.
  Another example: the Kotalama main canal, which supplies the Kotalama irrigation area.

- A secondary canal is mostly named after a village situated in the secondary unit. For instance the Selotong secondary canal (from SK 3, SS 1, SS 2 ,...., SS 11) is named after the village Selotong, which is located in this secondary unit.

- A canal is divided into sections, in which the capacity stays the same. For instance section Marbau 2 usually is written as St..M2, which means the section of the secondary canal Marbau between the diversion structure M1 and M2..

- The diversion structures close off the sections. They are named after the upstream section, but the letters St (St = section) is changed into S (for S = structure). For instance SM2, is the diversion structure at the end of the section St.M2..

- Structures between the diversion structures (culverts, bridges, aquaducts, drop structures, spillways etc.) are named after the section in which they are situated, also starting with an S. and followed by a small letter in such a way that the most upstream structure starts with "a", and the structures situated farther downstream, have the letters b,c, etc. added. For instance SS8b,, is the second structure in the section St.SL8 of the canal Selotong situated between the diversion structures SS7 and SS8.

- Tertiary canals are named after the diversion structure from which they receive their supply water, but with a small letter, without an S, and where applicable with an indication l,r, and m (l = left, r = right, m = middle), seen in a downstream direction, standing in front of the diversion structure. In case there are more than one tertiary unit at one hand side of the diversion structure, numbering is started from upstream, to downstream direction. For instance s7r2, is the tertiary canal which supplies water from the diversion structure SS7 and discharges to the right hand side, number 2 from the upstream to the downstream direction.

- A tertiary unit receives the same name as the tertiary canal, but the first letter is a capital letter. For instance the tertiary unit S5r/, receives its water from the tertiary canal s5r2, which is the right hand outlet from the diversion structure SS5, situated in the secondary canal Selotong.

5.2.2 The drainage system.

- Usually all existing water courses have been named by the local people. If the water courses are used for drainage canals, the local names have also to be used. For instance the SC secondary drainage canal or the Secanggang secondary drainage canal, is named according to the farmer name of the river Secanggang. In case new secondary drainage canals, are installed, the drains can be indicated with a capital letter, e.g. A,B,C etc. or by the direction or the location of the canals in respect to the existing canals. For instance the SCE secondary drainage canal is the Secanggang East secondary drainage canal which is located on the East side of the Secanggang area.

- A drain is divided into sections, in which the capacity stays the same. For instance SPSe 4, which means the fourth section, starting from the downstream end, of the drain SPSc (=the Sepucung Southeast secondary drainage canal).

- Structures in the drains are numbered in a upstream direction, starting at the downstream end. They are indicated with an "s" (for structure = bangunan = b), a capital letter, which is the same as the drain in which the structure is situated, and a number, to indicate the section of the drain, in which the structure is situated. For instance 1sSPSe 4 is the first structure in drain SPSe, section 4.

5.3 Peak Demand During Irrigation.

The peak demand determines the required capacity of the irrigation system. It occurs during the periods of land preparation, for off-season from the middle of February to the end of March (40 days) and for main season from the middle of August to the middle of September (30 days).

Prior to both periods, the water is let off the fields two weeks before harvest. Consequently, when land preparation starts, the field has been allowed to dry during 6 – 9 weeks and the upper layer of the soil must be resaturated. On the well-consolidated alluvial clay soils, the water depth should be kept within the range of 5 – 15 cm. But in practice it is often found necessary to manipulate with the water on the field to facilitate tillage of the soil, and to drain off some water which must be replaced afterwards. Therefore, it is recommended that allowance be made for the use of 15 cm of water to establish the water layer in the fields at the start of the irrigation period.

At the start of the irrigation period, all the water will be used for the saturation of the fields. As the saturation period goes on, an increasing part of the irrigation water is needed to compensate for evaporation, percolation and field losses and less water becomes available for saturating new fields. Towards the end of the period, nearly all the water is used to maintain the water layer in the area.

For the calculation of the peak demand the method of van de Goor and Zijlstra (1968) has been followed.

$$I = \frac{M \cdot e^{\frac{MT}{S}}}{e^{\frac{MT}{S}} - 1}$$

I = Field water requirement during the land preparation (mm/day). This is the peak demand to be calculated.

M = Water requirement in order to maintain the water layer in the already saturated fields (Evaporation, Percolation, field losses) (mm/day).

S = Depth of water requequied for presaturation and establishment of the water layer (mm).

T = Duration of the land preparation period (days).

For the Secanggang area, the peak demand has been found as follows:

M is estimated at 8.6 mm/day and it consists of:

a. Evaporation from a free water surface. These values have been given in table 3. For off-season, February - March, this value is about 6 mm/day.

b. Percolation losses. These losses, as the soil has been puddled and also due to the high groundwater table, can be neglected.

c. Field losses. These losses are estimated at about 30% of the gross irrigation supply during this period at the tertiary inlet structure.

S is estimated at about 280 mm and it consists of:

a. a water layer of 150 mm.

b. 90 mm of water for the saturation of the upper soil layer.

c. 5 mm of water for the nurseries. They cover about 10 per cent of the area and are cultivated first. Water needed for the nurseries are estimated 50 mm, which results into a water gift of 5 mm over the whole area.

d. field losses. These losses consist of losses during the presaturation period, during the period of building up the water layer and distributional losses counted at the tertiary inlet structure together were estimated at 35 mm.

With the help of the date for the off-season (February - March the peak demand calculated at the tertiary inlet structure is as follows:

$$I = \frac{8.6 * e^{\frac{8.6 * 40}{280}}}{e^{\frac{8.6 * 40}{280}} - 1} \text{ mm/day} = 12.14 \text{ mm/day or}$$

about 1.4 l/sec/ha. During this period, rainfall is scanty and often of no inportance as can be seen from the rain-fall-duration graphs in Ch. 2.3.1. With this water supply, 40 percent of the area can be saturated during the first ten days of the period, 30 percent during the second ten days, 20 percent during the third ten days and 10 percent during the last 10 days period.

For the main-season (August - September), the value of M becomes 7.7 mm/day, with a calculated evaporation of 5.4 mm/day and losses of 30% of the gross supply, and the value of T is 30 days. The value of S remains the same (280mm). With the new values of M and T, the peak demand calculated at the tertiary inlet structure, for the main-season, is 13.70mm/d. From the rainfall analysis in Ch. 2.3.1, one can find that a 30 day rainfall is 60 mm or more during nine out of ten years. Assuming that about 60% of this rainfall is effective, the average rain water supply during the period of 30 days is 1.20 mm/day. From the value of the calculated peak demand of 13.70 mm/day, 1.20 is supplied by rainfall and therefore the peak demand remains the same. The duration of the land preparation period becomes shorter when the effective rainfall exceeds 1.20 mm/day.

5.4 Drainage Requirements.

5.4.1 Crop damage due to temporary high water levels.

Perfect drainage is often not physically or economically feasible and a compromise needs to be reached between cost and damage averted taking into account that submersion damage to rice is most severe at the panicle-formation and heading stages. These are called critical stages.

Table 10 illustrates the information of the maximum tolerable submersion at the critical stages from various rice growing countries.

Table 10. Maximum tolerable submersion during the critical stages in various countries.

Countries	submersion height (mm)	maximum submersion days (days)	Remarks
Malaysia (MATSUSHIMA, 1962)	400	8	yield decline 35%
India (ANONYMOUS, 1971, NAGARAJAN 1973)	300	7	
Chao Phya (Thailand) (ANONYMOUS, 1972)	162	3	
Vietnam (ANONYMOUS, 1968)	250	2 - 3	
Japan (FUKUDA & TSUTSUI, 1973)	300	1 - 2	

Van de Goor (1974) has come to the conclusion

a. that the permissible increase in water level will usually not be more than 50 - 150 mm, and

b. that the period of this increase will be tolerated may range from a few hours to a few days.

Since the initial water level is normally 50 – 150 mm, the maximum permissible depth would be at most 300 mm, but normally 200 mm, tolerated for , say, two days.

From the discussion it can be concluded that the temporary high water level for the Secanggang Project will be taken at 160mm, tolerated for 3 days, as about the same value of that used in Thailand.

5.4. 2 Determination of the drainage capacity.

The drainage capacity or drainage modulus (Dm) is based on the amount of rainfall which may cause undesirable flooding during critical stage of rice growth in periods lasting 1, 2, 3, 4, 5 or more (n) days and expected to occur once in 1, 2, 3, 4, 5 ....10 or more (T)years. The rainfall duration line of September, October and November, given in Ch. 2.3, will be used to determine the drainage capacity in the Secanggang Project. A 5 – year return period (f =0.2) and a 10 – year return period (f = 0.1), with cumulative rainfall during 9 or 10 days 'period, are used for the calculation of required drainage capacity. It is assumed that seepage or runoff from adjacent area is negligible or will be compensated by euapotranspiration and percolation.

Based on these figures, two rainfall periods have been conceived with 110 mm on the first day, 20 mm on the second day, etc, for f = 0,2 and 120 mm on the first day, 30 mm on the second day, etc, for f = 0,1. These figures have been listed on table 11 (the second column). On each rain period two values of drainage capacity are super imposed. The two values of 25 mm / day and 30 mm / day are used as listed in the third column. In the fourth column excess water in the field is calculated by subtracting cumulative drainage from the culülative rainfall. In this calculation normal water depth is taken at 70 mm as generally it is difficult to maintain the water depth at less than this value due to the minor differences in land

Table 11. Cumulative rainfall and drainage in the Secanggang area.

Day	Cumulative rainfall (mm)	Cumulative drainage (mm) 25mm/day	30mm/day	Excess water in the field(mm) (2-3a)	(2-3b)	Water layer (mm) normal	total	depth
1	2	3a	3b	4a	4b	5	6a (4a+5)	6b (4b+5)
			Once in 5 years (F = 0.2), 9-day rainfall					
1	110	25	30	85	80	70	155	150
2	130	50	60	80	70	70	150	140
3	150	75	90	75	60	70	145	130
4	165	100	120	65	45	70	135	115
5	180	125	150	55	30	70	125	100
6	190	150	180	40	10	70	110	80
7	200	175	210	25	0	70	95	70
8	210	200	240	10	0	70	80	70
9	220	225	270	0	0	70	70	70
			Once in 10 years (F = 0.1), 10-day rainfall					
1	120	25	30	95	90	70	165	160
2	150	50	60	100	90	70	170	160
3	170	75	90	95	80	70	165	150
4	190	100	120	90	70	70	160	140
5	210	125	150	85	60	70	155	130
6	220	150	180	70	40	70	140	110
7	230	175	210	55	20	70	125	90
8	240	200	240	40	0	70	110	70
9	250	225	270	25	0	70	95	70
10	260	250	300	10	0	70	80	70

levelling. To the figures in the excess water column, the water present on the field, which is at the normal depth of 70 mm, should be added. These quantities represent the resulting total water layer on the field which should meet with the permissible depth of submergence (160 mm) during less than 3 days. With a recurrence period of 10 years (f = 0,1) and a drainage capacity of 25 mm/day, the permissible depth would be surpassed for more than 3 days and damage to the crop would occur too often. To be on the safe side, therefore, a drainage capacity for the design criterion of 30 mm/day or 3,5 l/sec/ ha. is proposed for rice fields.

From the column of daily cumulative rainfall in a 10 - year return period. One can also estimate the drainage module for uplands, which take up about 10% of the total area. Due to only small amount of rain water that can be stored in the ground (soil) and also to greater gradient of the terrain implying the quicker time of run off, the design criterion of 75 mm per day or 8.7 l/sec ha is proposed for the uplands.

Sometimes the secondary drainage system has also to drain off the overflow from the spillways situated in the dikes of the secondary irrigation canals. The discharge of these spillways have been taken up in the computation of the capacity of the secondary drainage systems.

5.5 Canal Dimensions.

After the design discharges and the available gradients of the canals have been determined, the dimensions are calculated with Manning formula:

$$Q = K_M \cdot A \cdot R^{2/3} \cdot I^{\frac{1}{2}}$$

where:

Q = design capacity (m^3/ sec).

K_M= Manning roughness coefficient ($m^{1/3}$. sec^{-1}).

A = wetted area (m^2)

R = hydraulic radius (m).

I = slope of water surface (^{o}/oo).

The flow velocity depends on the topographical conditions, the soil properties and the required capacity. The velocity in irrigation canals under normal conditions, for quarterary canals should be smaller than 0.30 m /sec, for tertiary canals should be smaller than 0.50 m/sec., and for main and secondary canals should be smaller than 0.70 m/sec, to prevent erosion, but they should be more than 0.20 m/sec, for all canals in order to avoid sedimentation. Preferably the velocity of the main and secondary canals should be between 0.50 - 0.70 m/sec. The flow velocity of drainage canals under normal conditions, for quarternary and tertiary canals should not be more than 0.50 m/sec because of the soil conditions in Secanggang area, whilst the velocity of secondary drainage should not be more than 0.60 m/sec. Table 12 shows further information concerning all parameters used in computing canal dimensions based on the local conditions of Secanggang area.

Preferably the longitudinal slope of the canals should follow the slope of the terrain as much as possible. Due to the soil condition, deep drainage should be avoided and the ground water table should not subside more than 0.50 m below the ground surface. Temporarily higher groundwater table is allowable due to the conditions that the drainage sluice is closed during high tide, which is about 14 hours per day. In principle no dikes are designed along the tertiary and small secondary drains. Where possible the soil from the excavation will be used for making road beds and dikes. As the transportation of the soil to another place is very costly the design should take these aspects into account. All rice fields which are directly draining into the canals will do this by cutting the dikes or by using pipes.

Here, like in the irrigation canals, the sections of the drainage canals will have constant dimensions. The drain water entering the drainage canal from the bordering lands is taken into account in determining these dimensions.

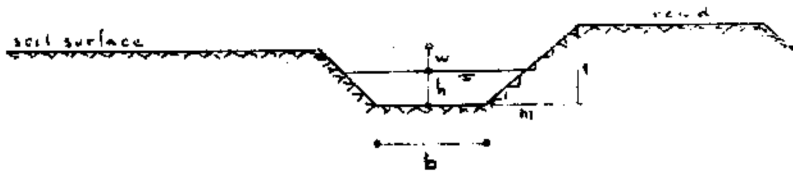
Table 12. Basic information for calculating canal dimensions.

Irrigation canals

Design capacity of the canals (m^3/sec)	K_m ($m^{1/3}sec^{-1}$)	V in normal condition (m/sec)	t 1 : m	n = b/h	Embankment: Freeboard W (m)	Embankment: dike width (m), without inspection road	Embankment: dike width (m), with inspection road
Quarternary Q < 0.20	25	0.20-0.30	1	1 (b > 0.20)	0.10-0.20	0.30-0.50	-
Tertiary Q < 0.05	40	0.20-0.50	1	1 (b > 0.30)	0.30	0.60-0.75	-
Main and secondary							
Q < 0.5	40	↑	1	1 - 2	0.40	1.50	-
Q = 0.5 - 1	45		1.5	2 - 2.5	0.50	1.50-2.00	↑
Q = 1 - 2	45		1.5	2.5 - 3	0.60	1.50-2.00	
Q = 2 - 3	45		1.5	3 - 3.5	0.60	1.50-2.00	
Q = 3 - 4	45	0.50-0.70	1.5	3.5 - 4	0.60	1.50-2.00	5.50
Q = 4 - 5	45		1.5-2	4 - 4.5	0.60	2.00	
Q = 5 - 10	47.50		1.5-2	4.5 - 6	0.75	2.00	
Q = 10 - 25	50	↓	2	6 - 7	0.75-1.00	2.00	↓

Drainage canals

Design capacity of the canals (m^3/sec)	K_m ($m^{1/3}sec^{-1}$)	V in normal condition (m/sec)	t 1 : m	n = b/h	Embankment: Freeboard W (m)	Embankment: dike width (m), without inspection road	Embankment: dike width (m), with inspection road
Quarternary Q < 0.20	25 - 30	< 0.50	1	1 (b > 0.30)		-	-
Tertiary Q < 0.05	35	< 0.50	1	1 - 2 (b > 0.50)	-0.15-0.20 from soil surface	-	-
Main and secondary					(below soil surface)		
Q < 0.5	35	↑	1	1 - 2	-0.20-0.30	-	-
Q = 0.5 - 1	40		1.5	2 - 3	-0.20-0.30	-	-
Q = 1 - 2	40		1.5	↑	-0.20-0.30	-	-
Q = 2 - 3	45	less than	1.5 -2		-0.30-0.40	-	↑
Q = 3 - 4	45	0.60	2	3 - 15	-0.30-0.40	-	5.50
Q = 4 - 5	45		2		-0.30-0.40	-	
Q = 5 - 10	47.50		2	↓	-0.40	-	
Q = 10 - 25	50	↓	2	>15	-0.40	-	↓



6. LAYOUT OF THE IRRIGATION, DRAINAGE AND ROAD SYSTEM.

6.1 Designing of Irrigation and Drainage System.

The Secanggang Polder is irrigated from the northern supply canal, the Kotalama main canal, originating from the dam structure in the Sungai Wampu located near Nangka, a little town in the project area (see fig. 1b). The Kotalama main canal enters the area in the south-west, there, at the last structure of the main canal (SK3), the canal splits into two secondary canals, these are the Marbau secondary canal and the Selotong secondary canal, At the first structure of the Selotong secondary canal (SS1), the canal has a branch, that is the Pematangtinggi secondary canal. Tertiary turnout structures will be installed along the secondary canals to irrgate the tertiary units. All the tertiary turnout structures will be provided with Romijn weirs, for each branch one or more in order that distribution of the supply over the different canal branches is easy to regulate. The area that will be served by the Marbau secondary canal is about 1434 ha and consists of 29 tertiary units. The area that will be served by the Selotong secondary canal is about 1112 ha and consists of 24 tertiary units. The area that will be served by the Pematangtinggi secondary canal is about 414 ha and consists of 8 tertiary units. That means the total area that will be served by the Kotalama main canal will be 3023 ha (including one tertiary unit K3.1 of about 63 ha) and consists of 62 tertiary units. Fig 4a gives schematic map of the irrigation system.

Drainage is effected by two sluices, one at Sepucung in the north-west of the village of Secanggang. Due to lack of information and data concerning the Secanggang river, just from the observation from a contour map with a scale of 1:10,000, the place 1.5 km to the north-west of the village of Secanggang is selected for the location of the drainage sluice in the Secanggang drainage area. The Sungai Mati will be dammed by a dike across the river and a connection made with the

Sungai Wampu. Then the area to the south-west of the Secanggang Polder, the area of Cintaraja, can be disregarded as the information about the area relating to the Sungai Mati is not available.

As the gates are only open during part of the ebb tide, as will be discussed later based on a total 14-hour close and a 10-hour open design, a considerable amount of water will have to be stored in drainage canals and in a collector "reservoir" near the gates. As a considerable amount of work is involved, including the excavation of soil for drainage canals and the storage reservoirs and the installation of the drainage sluice. Therefore, it is advisable to select the Secanggang drainage area as a pilot project to obtain further information and data concerning a drainage system in a coastal plain area under influence of tide. All the experience and knowledge obtained from this pilot project will be very useful for a better solution in the similar work in the future, for example in the Sepucung drainage area. The area that will be drained off by the Sepucung drainage system is about 2450 ha (2260 ha rice fields and 190 ha uplands) which consists of the area of the Marbau zone and a part of the area of the Selotong zone, the other part of this area will be drained off by the Secanggang drainage system (pilot project area). This area is about 960 ha (760 ha rice fields and 200 ha upland) and consists of the area of the Pematangtinggi zone and a part of the area of the Selotong zone. Figure 4b gives a schematic map of the drainage system. A detailed layout of the irrigation and drainage system is shown on map 2, scale 1:10,000.

A dike will be built along the north and the east, boundary of the polder, to protect the area inside the polder against floods which are caused by heavy rains during high water tides.

6.2 Irrigation Layout.

Eighteen main diversion structures will be built along the Marbau secondary canal, which implies that there are also 18 canal sections along this canal. The Selotong secondary canal will have 14 main diversion structures but will have only 12 canal sections, including one canal supplying a tertiary unit located far from the diversion structure (section S111), and not including small sections (S31 and S41) which will be counted during the design of the diversion structures SS4, SS41, SS5, SS51 and closing structures. The Pematangtinggi secondary canal will have 5 main diversion structures and also 5 canal sections. Length and dimensions of the canal sections of the secondary canals and crossing structures are listed in table 13 (see legend of symbols and abbreviations).

From the main diversion water will be delivered to one, two or three tertiary units via measuring devices, Romijn type. Only one tertiary unit (K3.1) which is directly supplied from the main diversion structures at the end of the Kotalama main canal.

6.2.1 Available head of irrigation water and canal capacity.

In order to determine the required water level upstream of the tertiary turnout (inlet) structure and in the secondary or main canals, three conditions should be considered.

1. Maintenance costs should be kept to minimum. These costs are lowest when the water level is below ground level.

2. To minimise the construction costs, the amount of fill and excavation should be more or less equal.

3. The water level has to be sufficiently high to irrigate the highest area in a tertiary unit.

These three conditions contradict each other, so a compromise will have to be found.

a. Table 13. LENGTH AND DIMENSION OF SECONDARY IRRIGATION CANALS AND STRUCTURES.

Name of Canal	Section	I.A (ha)	Q (L/sec)	L (m)	b (m)	h (m)	i °/oo	v (m/sec)	t	w (m)	i.w.l (+1LACO)	t.w.l (+1LACO)	STRUCTURES				
													Name	Type	L (m)	Ø, b (m)	Z (m)
MARBAU	M1	1434	2151.00	1150													
	M2	1339	2009	400									SM2a	B		5.50	0.05
	M3	1147	1721	750													
	M4	1075	1613	450													
	M5	1026	1539	850													
	M6	974	1461	1650													
	M7	823	1235	600									SM7a	B		5.50	0.05
	M8	761	1142	1450													
	M8.1	369	554	400													
	M8.2	272	408	850													
	M8.3	202	303	550													
	M8.4	107	161	400													
	M8.5	67	101	350													
	M9.	557	536	1000									SM9a SM9b	B B		5.50 5.50	0.05 0.05
	M9.1	260	390	800									SM9c	Sw		-	-
	M9.11	77	116	420									SM9.1.1a	C			0.05
	M9.2	131	197	600													
	M9.3	89	134	400													

b

Table 13. LENGTH AND DIMENSION OF SECONDARY IRRIGATION CANALS AND STRUCTURES.

Name of Canal	Section	I.A (ha)	Q (L/sec)	L (m)	b (m)	h (m)	i °/oo	v (m/sec)	t	w (m)	i.w.l (+1LACO)	t.w.l (+1LACO)	STRUCTURES Name	Type	L (m)	Ø b (m)	Z (m)
SELOTONG (S)	S1	1526	2289	680													
	S2	1112	1668	1350									SS2a	B		5.50	0.05
	S3	1045	1568	650									SS3La	B		5.50	0.05
	S4	788	1182	1280									SS4La	C			0.05
	S5	591	887	850													
	S6	468	702	900													
	S7	369	554	350													
	S8	288	432	450									SS8a SS8b	B B		5.50 5.50	0.05 0.05
	S9	230	345	1100													
	S10	192	288	650									SS10a	Sp			0.05
	S11	100	150	500													
	S11L	68	102	750													
PEMATANG TINGGI (P)	P1	414	621	650									SP1a SP1b	B B		5.50 5.50	0.05 0.05
	P2	214	321	250													
	P3	161	242	800													
	P4	98	147	300													
PEMATANG TINGGI RIGHT (PR)	PR	106	159	1720													

The available head between the secondary irrigation canal upstream of the tertiary turnout structure and the ground surface amounts to 0.45 m. This is specified as follows:

a.	water layer on rice field		0.10 m
b.	head losses from quarternary canal to rice field		0.05 m
c.	head losses in quarternary division box		0.02 m
d.	conveyance losses in tertiary canal, i x L m		0.05 m
e.	head losses in tertiary division box		0.02 m
f.	head losses in culvert		0.05 m
		H =	0.29 m
g.	head losses in Romijn measuring device ± 1/3 H	=	0.10 m
		h =	0.39 m
h.	variation in water level ± 0.12 h	=	0.05 m
	or rounded off 0.45 m.		0.44 m

These figures imply, if the ground level is about + 6.60 m ILACO level, the water level in the secondary canal upstream of the tertiary turnout structure should be at least + 7.05 m ILACO level.

With an initial water level of + 8.75 m ILACO level at the SK3 structure and 10.10 km long with 4 crossing structures (3 bridges and one is culvert), the Marbau secondary canal will have an average of longitudinal gradient of 0.15 ^{o}/oo. With the same initial water level and 9.5 km. long with 5 crossing structures (3 bridges, one syphom and one culvert), the Selotong secondary canal will have an average of longitudinal gradient of 0.15 ^{o}/oo. The Sematangtinggi secondary canal will have enough longitudinal gradient, which is about 0.67 ^{o}/oo.

As the sertiary turnout structures should be designed for a capacity of 1.4 l/sec./ha. To account for losses in the secondary canals these canals should be given a capacity of 1.5 l/sec/ha. With a given capacity of 1.6 l/sec:/ha in the main supply canals, an efficiency of the project, which is the total efficiency from the main inlet structure to the fields, of 56% will be obtained.

6.2.2 Size of tertiary units.

For a better water management, during operations and maintenance, the maximum size of a tertiary unit should not be larger than 100 ha. Only occasinally larger units are allowed, but these units should preferably, not exceed 120 ha. In the Secanggang Polder there is only one tertiary unit which is more than 100 ha, that is the tertiary unit M 2.1 2 having 111 ha. On the other hand, by decreasing the size of the tertiary units, the costs for execution, operation, and maintainance will be slightly higher. Small tertiary units are found 11 ha (S4r1), 12 ha. (S3r1), 14 ha (M81), 16 ha (S5r2), and 17 ha (SPr). With the total of irrgated area of 3023 ha and the total of 62 tertiary units (the Marbau canal: 29 units, the Salotong canal: 24 units, the Pematangtinggi canal: 8 units, and one unit K3.1), the average of the tertiary unit will be 48.76 ha. All the tertiary units and canals are listed on table 14.

To prevent water theft from one unit to another clear boundaries between the units have to be established. If no clear boundaries exist (i.e. rivers, roads, railways, water courses etc.) a drainage canal or irrigation canal has to be constructed along the boundary. The property of one family (farmer) will also contribute to the shape and size of the tertiary units, besides, the topographycal conditions of the area. Each hectare, which is about the property of one family has its own field inlet, With the basic figures 200 x 50 m^2, 250 x 40 m^2, 300 x 35 m^2 and only occasionally 400 x 25 m^2 and 500 x 20 m^2, the distances between irrigation ditch (tertiary or quarternary) and drainage ditch (tertiary or quarternary) are arranged from 200, 250, 300 m and only occationally 400 to 500 m as shown on map 2.

6.3 Drainage Layout.

At first a preleminary layout of the drainage system was designed taking into consideration only the topography of the land the possible irrigation and road system (Fig. 4 b).

a. Table 14. MARBAU AREA - LENGTH AND DIMENTION OF TERTIARY IRRIGATION CANALS AND STRUCTURES.

Tertiary units	Name of tertiary canals	I.A. (ha)	Q (l/sec)	L (m)	b (m)	h (m)	i (°/oo)	v (m/sec)	t	i.w.l.	t.w.l.	Structures			
												type	L (m)	b (m)	z (m)
M111	m111	36	50												
M112	m112	59	83												
M211	m211	81	113												
M212	m212	111	155												
M3	m3	72	101												
M4	m4	49	69												
M5	m5	52	73												
M611	m611	78	109												
M612	m612	73	102												
M71	m71	29	41												
M7r	m7r	33	46												
M8r	m8r	21	29												
M81	m81	14	20												
M8.111	m8.111	65	91												
M8.112	m8.112	32	45												
M8.2	m8.2	70	98												
M8.31	m8.31	48	67												
M8.3r	m8.3r	47	66												
M8.4	m8.4	40	56												
M8.51	m8.51	35	49												
M8.5r	m8.5r	32	45												

b. Table 14. MARBAU AREA - LENGTH AND DIMENSION OF TERTIARY IRRIGATION CANALS AND STRUCTURES.

Tertiary units	Name of tertiary canals	I.A. (ha)	Q (l/sec)	L (m)	b (m)	h (m)	i ($^{o}/_{oo}$)	v (m/sec)	t	i.w.l.	t.w.l.	Structures			
												type	L (m)	b (m)	z (m)
M91	m91	48	67												
M9r	m9r	49	69												
M91.111	m9.1.111	34	48												
M9.1.111	m9.1.111	43	60												
M9.1r	m9.1r	52	73												
M9.2	m9.2	42	59												
M9.3r1	m9.3r1	48	67												
M9.3r2	m9.3r2	41	57												

Table 14. SELOTONG AND PEMATANGTINGGI AREA-LENGTH AND DIMENSION OF TERTIARY IRRIGATION CANALS & STRUCTURES.

Tertiary units	Name of tertiary canals	I.A. (ha)	Q (l/sec)	L (m)	b (m)	h (m)	i (°/oo)	v (m/sec)	t	i.w.l.	t.w.l.	Structures			
												type	L (m)	b (m)	z (m)
K3.1	k3.1	63	88												
S2	s2	67	94												
S3.r1	s3.r1	43	60												
S3.r2	s3.r2	67	94												
S3.r3	s3.r3	12	17												
S3.l1	s3.l1	73	102												
S3.l2	s3.l2	58	81												
S4.r1	s4.r1	11	15												
S4.r2	s4.r2	51	71												
S4.l1	s4.l1	65	91												
S4.l2	s4.l2	69	97												
S5.r1	s5.r1	62	87												
S6.r2	s5.r2	16	22												
S5.l	s5.l	45	63												
S6.l1	s6.l1	31	43												
S6.l2	s6.l2	68	95												
S7.r1	s7.r1	28	39												
S7.r2	s7.r2	53	74												

d. Table 14. SELOTONG AND PEMATANGTINGGI AREA-LENGTH AND DIMENTION OF TERTIARY IRRIGATION CANAL AND STRUCTURES.

Tertiary units	Name of tertiary canals	I.A. (ha)	Q (l/sec)	L (m)	b (m)	h (m)	i (°/oo)	v (m/sec)	t	i.w.l.	t.w.l.	Structures			
												type	L (m)	b (m)	z (m)
S8.r	s8.r	17	24												
S8.1	s8.1	41	57												
S9	s9	38	56												
S10.1	s101	52	73												
S11r	s11r	32	45												
S11l	s11l	68	95												
P1l	p1l	59	83												
Plr	plr	35	49												
P2	p2	53	74												
P3	p3	63	88												
P4	p4	62	87												
P5	p5	36	50												
PR1	pr1	43	60												
PR2	pr2	63	88												

The Secanggang drainage area was then studied in more detail to determine the influence of the tidal curve on the discharge regime of the drainage sluice. As will be treated in the next chapter a storage basin ("boezem") has to be projected to store temporarily the drain discharge during high tide when the sluice gates are closed.

This storage basin will occupy about 25.5 ha at soil surface (+ 6.60 m ILACO level), with the bottom at + 5.00 m ILACO level. The land occupied by the total drain canal system will be about 40 ha in total which is about 4% of the total drainage area of 960 ha (760 ha rice land and upland).

Together with the land occupied by the irrigation canals and the roads and polder dike this uncultivated area will be less than 10% of the total land which is still acceptable in these circumstances. Length and dimensions of the drainage canals are listed in table 15. Because the land is about flat secondary canals and most tertiary canals will contribute to the storages capacity. Secondary canals will have the ditch bed at + 5.00 ILACO level, bed width varies from 3 to 6 m, talus 1:2, tertiary canals will reach to + 5.60 m ILACO level with bed width of 1 m, talus 1:1. The storage basin will be about 1300 m long and 190 m broad and is situated near the drainage sluice in the lowest part of the Secanggang drainage area.(see ANNEX)

The excavated earth from the storage basin and most secondary canals will be used for the surrounding polder dike and the heightening or construction of the rural roads in the area. The excavated earth from the tertiary canals will be used where necessary for the embarkments of the irrigation canals, for land levelling and the strengthning of the "bunds" of the rice fields.

6.3.1 Peak discharges and storage capacity.

In general the expected or calculated peak discharges expressed in a discharge criterion will determine canal dimensions and the size of

a. Table 15. LENGTH AND DIMENSION OF SECONDARY DRAINAGE CANALS AND STRUCTURES.

Name of Canal	Section	D.A (ha)	Q (L/sec)	L (m)	b (m)	h (m)	i °/oo	v (m/sec)	t	w (m)	i.w.l (+1LACO)	t.w.l (+1LACO)	STRUCTURES Name	Type	L (m)	b (m)	Z (m)
CECANGGANG (SC)	SCE3.1	146	511	1080	3.00,	0.7	0.03	0.18	1:2		6.14	6.17					
	SCE3	211	739	850	6.00	0.55	0.03	0.21	1:2		6.11	6.14					
	SCE2	135	473	2000	3.00	0.7	0.03	0.17	1:2		6.11	6.17					
	SCE1	346	1211	300	6.00	0.8	0.03	0.23	1:2		6.10	6.11					
	SCW1.1	74 (50)	694	1200	5.00	0.65	0.03	0.20	1:2		6.15	6.19					
	SCW1	184 (50)	1073	1500	6.00	0.75	0.03	0.22	1:2		6.10	6.15					
	SCW2	143	801	930	3.00	0.70	0.03	0.17	1:2		6.10	6.13					
	SCS	(150)	525	1700	3.50	0.40	0.20	0.38	1:2		6.10	6.44					
	Tertiary canals	à 25	88	16000 (14 x 1143)	1.00	0.50	0.09	0.25	1:1		6.20	6.30					
	SC storage basin	760 (200) (up-land)	4400	1300	1.90	1.30	0.00	-	1:2		6.10	6.10					

b. Table 15. LENGTH AND DIMENSION OF SECONDARY DRAINAGE CANALS AND STRUCTURES.

Name of Canal	Section	I.A (ha)	Q (L/sec)	L (m)	b (m)	h (m)	i °/oo	v (m/sec)	t	w (m)	i.w.l (+1LACO)	t.w.l (+1LACO)	STRUCTURES Name	Type	L (m)	b (m)	Z (m)
PUCUNG (P)	SPSW8.2	114 (30)		730													
	SPSW8.1	212 (30)		550													
	SPSW8	474 (80)		1.720									1s SPS W.8	B			
	SPSW7.2	183		2.350													
	" 7.1	139 (25)		650													
	" 7	381 (25)		850									1 s SPS W.7	B			
	SPSW6	965 (140)		830									1s SPS W.6	B			
	SPSW5.1	277 (15)		800													
	SPSW5	437 (15)		1000													
	SPSW4	1455 (165)		750									1s SPS W.4	B			
	SPSW3	1565 (165)		1120									1s SPS W.3	B			
	SPSW2	1565 (190)		820 820													

c. Table 15 LENGTH AND DIMENSION OF SECONDARY DRAINAGE CANALS AND STRUCTURES.

Name of Canal	Section	I.A (ha)	Q (L/sec)	L (m)	b (m)	h (m)	i °/oo	v (m/sec)	t	w (m)	i.w.l (+1LACO)	t.w.l (+1LACO)	STRUCTURES Name	Type	L (m)	b (m)	Z (m)
SEPUCUNG (SP)	SPSW1 (190)	2150		250													
	SPS3.3	115		600													
	SPS3.2	153		850													
	SPS3.1	234		680													
	SPS3	253		980									1s SPS .3	B			
	SPS 2	212		3400													
	SPS 1	585		2100									1s SPS 1	B			
	SPW	110		1870									1s SPW	B			
	SP	2260 (190)		100									1s SP	DRB			

the drainage sluice or gate (s). According to the determined criteria for rice fields and uplands (ch. 5.4.2), the total discharge requirement of the Secanggang drainage area can be calculated as :

rice lands:	760 ha * 30 mm/day	=	228000 m^3/day
uplands:	200 ha * 75 mm/day	=	150000 m^3/day
			378000 m^3/day

or 15750 m^3/hr or 4.38 m^3/sec

Discharge by gravity flow will, however only be possible at low tides. The drainage gate will be closed when the level of the outside water (h_o) will be higher than that at the inside (h_i).

Analysis of the tidal fluctuations presented in fig. 3 shows that for constant h_i = +6.30 m ILACO level the gates would be closed, on the average, during 12 hrs 10 min and open for 11 hrs 50 min in 24 hrs. For a constant h_i = 6.40 m ILACO level these values would be 8 hrs 20 min closed and 15 hrs 40 min open. This is measured at the Sepucung gauge. Table 16 shows the rather irregular distribution over 6 * 24 hrs = 144 hrs for these two assumptions.

The inside water level will not stay constant, however, when the gates are opened, but will lower first slowly when $h_i - h_o = z$ is small, then faster when z increases and then decreasing with z till $h_i = h_o$ and the gates have to be closed.

The exact periods that the gates will be opened and closed can not be directly determined because the decrease of h_i depends on Q which depends on the inside conditions (dimensions of storage basin, canals and drainage modules), the outside conditions (dimensions of outlet channel and the tidal curve) and the dimensions of the gate(s) A = b * h = b * h_i. This interdependancy between Q and h_i requires that it should be assumed one of the two to calculate the other and then check if the assumption was right.

Table 16. Open and closed periods for 6 x 24 hrs. = 144 consecutive hours (Sepucung gauge, June 1966) per two constant levels. (From Fig. 3)

At 6.30 m		At 6.40 m	
Closed	Open	Closed	Open
	3.5		4.0
5.3		3.8	
	4.0		5.1
6.8		5.8	
	8.6		9.1
5.8		4.0	
	3.0		4.9
7.1		5.8	
	8.9		10.2
15.7		5.1	
	9.6		4.2
7.2		4.5	
	4.3		4.2
4.0		5.5	
	8.9		7.0
7.1		1.2	
	5.7		7.3
3.9		5.8	
	7.9		10.7
6.7		5.9	
	6.6		8.5
3.1		2.4	
			10.6
			7.8
73.0	71.0	50.10	93.9
12.17 hrs	11.83 hrs		
		8.35 hrs	15.65 hrs.

Average in 24 hrs.

To tackle the problem a first approximation was made by assuming a regular regime in which the gates were 7 hrs closed + 5 hrs open + 7 hrs closed + 5 hrs open in 24 hrs. It was further assumed that during the 7 hrs closed the inside water level h_i would rise from about 6.10 m to about +6.40 (fig.6).

On these assumptions the dimensions of drainage canals and storage reservoir were designed. Figure 5 shows the water storage (m^3) against the elevation of the water level in the polder (h_i). It should be kept in mind that due to the flat topography all secondary and most tertiary drainage canals will contribute to this storage capacity and are included in the storage capacity calculations. The storage capacity in the rice fields is excluded here, because this has been taken into account in the discharge criterion. For levels > 6.00 m the relation is almost linear, for levels < 6.00 m the relation is curved. This means that a unit discharge, say 15750 m^3/hr will give differences in the rise of the water level dependant on the initial water level as shown in table 17. For example, the volume that has to be stored in 7 hrs = 110250 m^3 will give:

a	rise	of	32 cm	from	initial	level	6.10 m	gives	6.42 m
"	"	"	35 cm	"	"	"	6.00 m	"	6.35 m
"	"	"	37 cm	"	"	"	5.90 m	"	6.27 m
"	"	"	39 cm	"	"	"	5.80 m	"	6.19 m

This implies that the lower the initial level a more than proportional time will be needed to reach a certain (maximum) level, in this case 6.40 m.

In view of the rather irregular sequence of high and low tide levels this is a rather important information for the determination of the dimension of the drainage sluice.

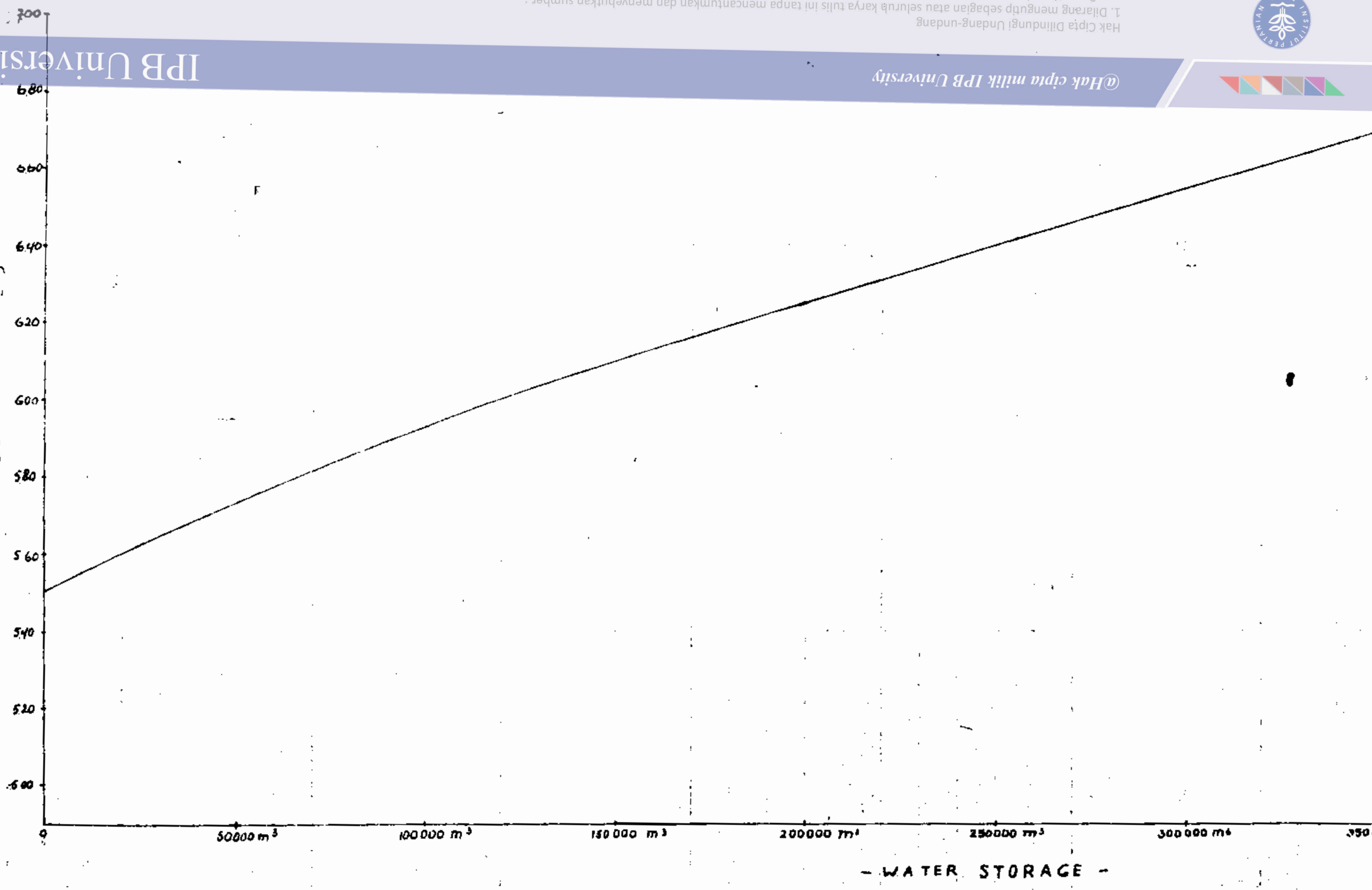


FIG 5 STORAGE CAPACITY CURVE

Table 17. Discharge duration, volume to be stored and resulting water level dependent on initial water level.

Discharge duration hrs	Tobe stored (m^3)	Water level where storage initiated from			
		+ 6.10	+ 6.00	+ 5.90	+ 5.80 ILACO
0	0	6.10	6.00	5.90	5.80
1	15750	6.15	6.06	5.96	5.86
2	31500	6.20	6.11	6.02	5.92
3	47250	6.25	6.16	6.07	5.98
4	63000	6.30	6.21	6.12	6.03
5	78750	6.35	6.26	6.17	6.09
6	94500	6.39	6.30	6.22	6.14
7	110250	6.42	6.35	6.27	6.19
8	126000	6.45	6.39	6.32	6.24
9	141780	6.49	6.43	6.36	6.29
10	157500	6.53	6.46	6.40	6.33
11	173250	6.56	6.50	6.44	6.38
12	189000	6.60	6.53	6.47	6.41
13	204780		6.57	6.51	6.45
14	220880		6.61	6.54	6.48
15	236250			6.58	6.52
16	252000			6.62	6.56
17	267750				6.60

6.3.2 Dimensions of the drainage gates.

In the first approximation it was assumed that the inside water level would rise from +6.10 m to +6.40 m ILACO level in 7 hours and the storage basin has been designed accordingly. The amount of water stored (110250 m^3) and the amount of drainage water coming down during the time that the gates are open (78750 m^3) have to be discharged in maximal 5 hrs. he discharge capacity of the gates can be calculated with

$$Q = c\,A\sqrt{2\,g\,z} \quad \text{, in which}$$

c = a constant $\approx$ 0.80.

A = the wet profile = b * h (m^2).

z = loss in head permitted between upstream and downstream of the gate (m).

g = gravity constant = 10 m/sec^2.

Q = discharge in m^3/sec.

For z the difference between inside and outside water level $h_i - h_o$ is taken, both are not constant. Assumed that h_o will decrease according to the tidal curve. The behaviour of h_i will depend on Q, that is on the dimensions of the gate.

Supposed that the bed width of the sluice at +5.00 m ILACO level is 10 m, divided over 5 or 7 gates of 2 or 1.5 m width each, the Q can be determined if further assumed that $h = h_i$ and h_i is determined with the aid of the relation: volume versus elevation given in fig.5, the storage capacity curve. To facilitate calculations the relation is taken as straight and that starting at initial h_i = 6.40 m for each lowering of 3 cm an amount V of 10000 m^3 water is released from the storage.

Because of the continuity condition, the volume V released from storage in a certain time plus the drainage modulus D_m = 4.38 m^3/sec has to be equal to the discharge Q out of the gates:

$$\frac{V}{t} + D_m = Q_{in} \text{ must be equal to } Q_{out} = c * b * h_i\sqrt{2g(h_i - h_o)}$$

The time t, needed to lower the inside water level h_i with 3 cm is estimated. At the same time t, h_o is read from the tidal curve and thus z and consequently Q_{out} can be calculated and compared with $Q_{in} = \frac{V}{t} + D_m$ for the same t. With a few trials $Q_{in} = Q_{out}$ and we can proceed with the next step of lowering h_i with 3 cm, estimate t and compare till $Q_{in} = Q_{out}$.

For a hypothetical tidal curve based on the first approximation 7 hrs closed, 5 hrs open, 7 hrs closed, 5 hrs open and h_i levels between 6.40 and 6.10 m these calculations are given in table 18. The curve of h_i can then be drawn in fig. 6 starting from h_i = 6.40 m will end 4 hrs 40 min later at a level of 6.02 where $h_i = h_o$ and the gates have to be closed.

In this time there has been discharged

12 * 10000 m^3 + 1 * 3300 m^3	=	123300 m^3	released from storage
and 4.65 * 15750 m^3	=	73237 m^3	coming down (D_m).
Total	=	196537 m^3	

This is indeed more than 189000 m^3, the total amount to be drained in 12 hours.

According to the calculations presented in table 17 the inside water level will rise then to about 6.39 m in ± 7 hrs 20 min. This level is fairly close to the initial level and it can be concluded that for this tidal curve the first try fits remarkably well. If this had not been the case trials with another b and other initial water levels had to be calculated through to bring the conditions in balance.

Table 18. Comparation of Q_{in} and Q_{out} according to $\frac{Vst}{t} + D_m = Q_{in}$

and $Q_{out} = 3.6 \times b \times h_i \sqrt{Z}$.

Σt (min)	t (min)	D_m (m^3/sec)	V_{st}/t (m /sec)	Q_{in} (m^3/sec) ≈	Q_{out} (m^3/sec)	$Z = h_i - h_o$ (m)	height of water h_i	h_o
0	0	0	0	0	0	0	1.40	1.40
14	14	4.38	11.90	16.28	15.60	0.10	1.37	1.27
25	11	4.38	15.15	19.53	20.18	0.18	1.34	1.765
34	9	4.38	18.52	22.90	22.62	0.23	1.31	1.08
43	9	4.38	18.52	22.90	24.16	0.28	1.28	1.005
51	8	4.38	20.83	25.21	25.46	0.32	1.25	0.93
59	8	4.38	20.83	25.21	25.77	0.35	1.21	0.86
67	8	4.38	20.83	25.21	25.31	0.36	1.18	0.825
75	8	4.38	20.83	25.21	25.01	0.37	1.15	0.785
83	8	4.38	20.83	25.21	24.36	0.87	1.12	0.755
92	9	4.38	18.52	22.90	23.51	0.34	1.09	0.75
103	11	4.38	15.15	19.53	19.83	0.27	1.06	0.79
118	15	4.38	15.49	15.49	14.60	0.16	1.03	0.875
131	13	4.38	4.27	8.65	8.99	0.06	1.02	0.96

Comparison of Q_{in} and Q_{out} according to

$$\frac{Vst}{t} + D_m = Q_{in} \text{ and } Q_{out} = 3.6 \times b \times h_i \sqrt{Z}$$

b = 10 m.

V_{st} = volume released from storage

t = time

D_m = drainage modulus.

gatebed = 5.00 m+ILACOLEVEL

h_o = tidal height at time t

h_i = upstream water level at time t(above gatebed)

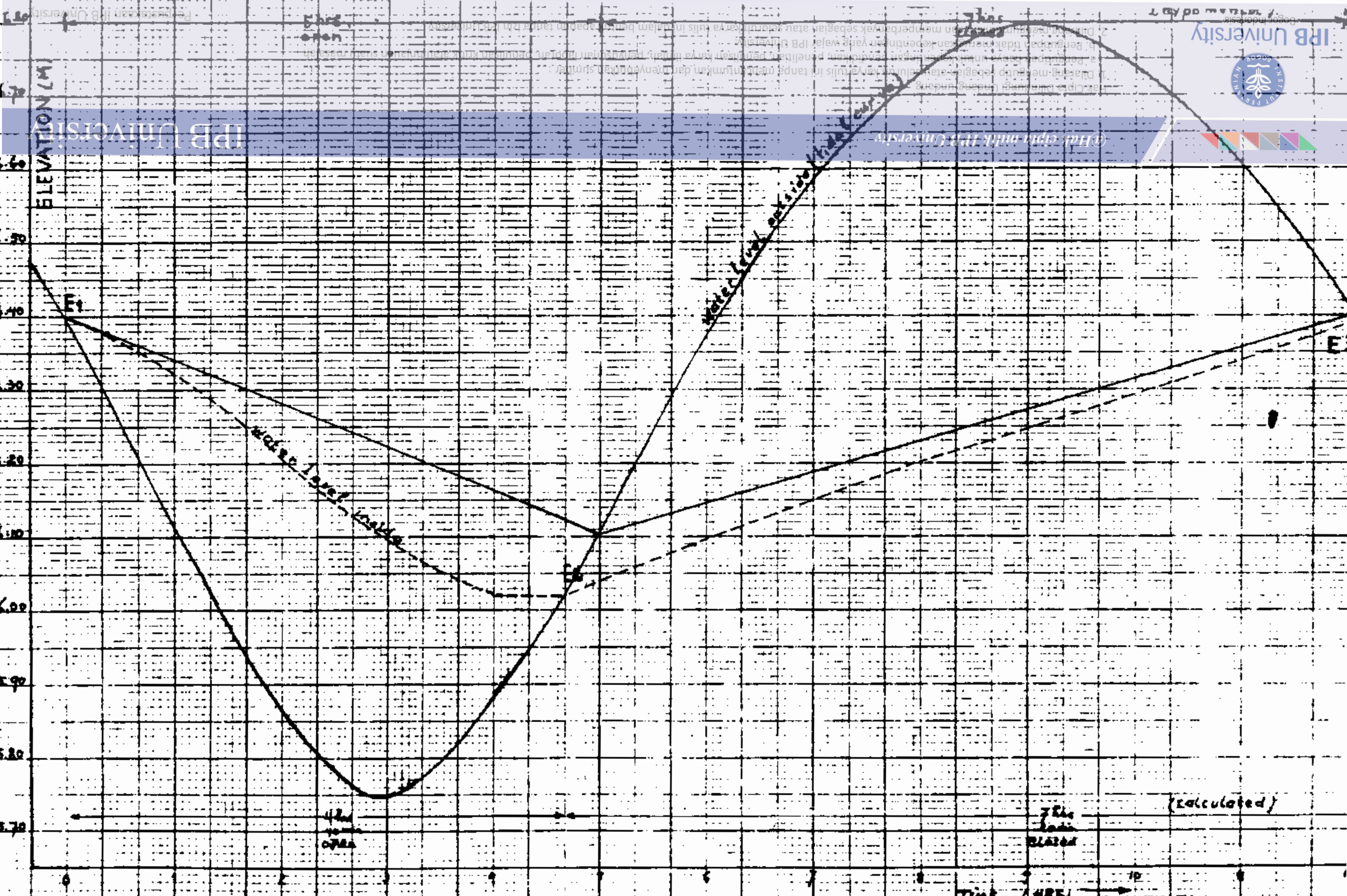


FIG. 6 CALCULATED WATER LEVEL FLUCTUATION (DOTTED LINE) COMPARED WITH HYPOTHETICAL CONDITIONS (FULL LINE)

The next step would have been to adapt the above described method of reconstructing the water level fluctuation inside polder to the given tidal regime (fig.3). The highly irregular fluctuations with periods that the gates will have to stay closed up to 16 hrs and possibly more imply that:

1. the storage capacity has to be more than doubled.
2. the sluice have to be widened with a factor 3 to 4 to meet the requirement that sufficient water can be let out also in the shorter periods that the gates are open.
3. the storage basins need not be so deep because only the volume above lowest tide is effective. To keep development of water plants low, however, the depth of more than 1 m is chosen.

7. EPILOGUE.

The fluctuation of the water level in a reclaimed swampy area under influence of tides is of utmost importance to the evaluation of the drainage design. This the more so if the acceptable range of fluctuation is very limited as in the given case were:

- the almost flat topography,
- the low elevation above mean sea level,
- the presence of potential acid sulphate soils,
- the subsidence hazard of peat layers

dictate a carefully executed drainage system.

The method described in this thesis, although rather elaborate provides a much better insight into the processes involved and thus a way to evaluate a drainage design on its consequences than the straight line approach given in :

> Drainage of Agricultural Land, by officials of the Soil Conservation Service, U.S.D.A., 1973.

The method as presented is still based on rather simple assumptions. For instance the assumptions that $h = h_i$, and $z = h_i$ - tidal curve need further investigation. Nevertheless this method makes it possible to reconstruct the water fluctuation upstream of the gate and when necessary indicate possible improvements in design.

It is a pity that lack of time has made it impossible to elaborate the method further. It seems that the rather laborious computations can be programmed for a computer, so this disadvantage can be overcome.