HYDROLOGY AND WATER MANAGEMENT STUDY AT PT BHUMIREKSA NUSASEJATI PALM OIL PLANTATION

FINAL REPORT

Prepared by

MUSHAIRRY MUSTAFFAR
AYOB KATIMON
MUHAMMAD NASSIR HANAPI
RADZUAN SA'ARI

Faculty of Civil Engineering
Universiti Teknologi Malaysia
81310 UTM Skudai, Johor

Report Submitted to

KUMPULAN GUTHRIE BHD
Wisma Guthrie
21 Jalan Gelanggang
Damansara Heights
50490 Kuala Lumpur

HYDROLOGY AND WATER MANAGEMENT STUDY AT PT BHUMIREKSA NUSASEJATI PALM OIL PLANTATION

FINAL REPORT

Prepared by

MUSHAIRRY MUSTAFFAR
AYOB KATIMON
MUHAMMAD NASSIR HANAPI
RADZUAN SA'ARI

Faculty of Civil Engineering
Universiti Teknologi Malaysia
81310 UTM Skudai, Johor

Report Submitted to

KUMPULAN GUTHRIE BHD
Wisma Guthrie
21 Jalan Gelanggang
Damansara Heights
50490 Kuala Lumpur

EXECUTIVE SUMMARY

The hydrology and water management study in Bhumireksa Nusasejati Palm Oil Plantation was commissioned by the Kumpulan Guthrie Bhd. The objective of this study is to evaluate the hydrologic and hydraulic characteristics of the project area in relation to water navigation system of the existing canal. This study involved mainly field and hydrographic survey and investigation that include field data compilation and interpretation and hydraulic modeling exercise.

The major findings of this study can be categorised under three issues.

a.) Topography and peat depth configuration
b.) Water and water balance analysis
c.) Field demarcation system and canal water level control

Primary field data was collected between the periods of 15 July 2006 to 15 October 2006. These data include the topography of the areas adjacent to the canals, the bathymetry, peat depths, canal flow and water quality. Topography and bathymetry were determined using Global Positioning Satellite (GPS) and echo-sounding equipments. Peat depths were measured at fifty points along the navigable canals using a standard peat auger. Standard river gauging procedures were used in determining the water flow in the canals. The continuous water level was also monitored using automatic loggers. Rainfall and water table data were obtained from the estate managers. Modeling of the observed data was performed using the HEC-RAS software.

The study area is relatively flat, as depicted by the topographic data, with a difference of 2.5m in elevation. Based on the norm water demand of oil palm trees and run-off parameters, the hydrology analysis pertaining to water balance indicate that there is a surplus by considering the flow in the canal is free without any obstruction.

Two distinct flow conditions have been observed along the canals. The discharge at the main outlet 15 m^3/s during the wet season and 3 m^3/s during the dry season.

The demarcation of the study area is based on three (3) options, namely, A, B and C. These options were adopted based on the discussions with the senior managers and the senior engineer of the company. These options include the demarcation of the area into suitable sub-divisions, maintaining some of the existing structures and putting in place new water structures. It is anticipated that any one of the options would enable to achieve the objectives of the study. Verification of the modeling data has been performed by comparing them against observed values. Modeling results have shown that they follow the pattern of the observed parameters collected during the study.

After due considerations of the present conditions and existing water management practices Option A is recommended. When this option is in placed, the water level in the entire canal (both main and secondary canals) is sufficient to ensure navigability throughout the year. At the same time, the water level of the ground surface would be below 70 cm, i.e., an optimum condition for plant growth. Furthermore, the installation of the proposed scheme would also alleviate flooding woes to the majority of the area.

As with any design or schemes, flaws or weaknesses are inevitable and must be highlighted so that adequate and proper measures can be made or planned. Three significant weaknesses are anticipated with the proposed scheme. Firstly, isolated topographically low lying areas could be flooded during the wet season, thus, additional flood protection bunds may be required along KM2 to KM3 of the main canal and in areas beyond the proposed water-gates at KM8.5 and KM21. Secondly, the collapse of hydraulic structures on peat soil is a common phenomenon, simply due to the settlement of soil and erosion. Hence, a continuous monitoring on the hydraulic structures with potential eroding areas such as Spillway gate at KM 0 must be carried out to alleviate this problem. Furthermore, effort should also be made to reduce velocity of canal flow upon entering the spillway gate in a way to reduce the erosive forces. Finally, since the water level in the whole proposed system is highly dependent on the water level at the

KM 0 spillway crest, a series of continuous water level monitoring stations (preferably equipped with data loggers) should be established so that a continuous water level records can be obtained.

TABLE OF CONTENT

TABLE OF CONTENT Page

TABLE OF CONTENT

1. INTRODUCTION

1.1 Background of the Study

PT Bhumireksa Nusasejati is a 25,000 hectares oil palm plantation in Sg. Guntung, Sumatera which is owned by the Kumpulan-Guthrie Berhad. The plantation is divided into five (5) estates, namely, the Teluk Bakau Estate (TBE), Nusa Lestari Estate (NLE), Nusa Perkasa Estate (NPE), Mandah Estate (MDE) and Rotan Semelur Estate (RSE). The entire area is peat and is networked by a grid of dual-purpose man-made canals, i.e. as a mode of transportation and irrigation. The water input to these canals, which is at northern-most point, comes from the tidal Guntung River. The effects of the tides on the water level in the canals are apparent up to about 6 km inland. As a result, in areas not affected by the tide, the water levels in the canals vary significantly between the dry and monsoon seasons. This is because water is gained and lost through precipitation and evaporation respectively. Past experience has revealed that these inland canals run dry and are non-navigable during the dry season. However, during the monsoon season, the heavy rain-fall causes these canals to flood. Such unfavorable conditions affect yields of the crop as well as logistics.

1.2 Location of the Study Area

The study area lies between latitudes 0° 04' to 0° 15' North – South and longitudes 103° 29' to 103° 42 West – East . The area is shown in Figure 1.

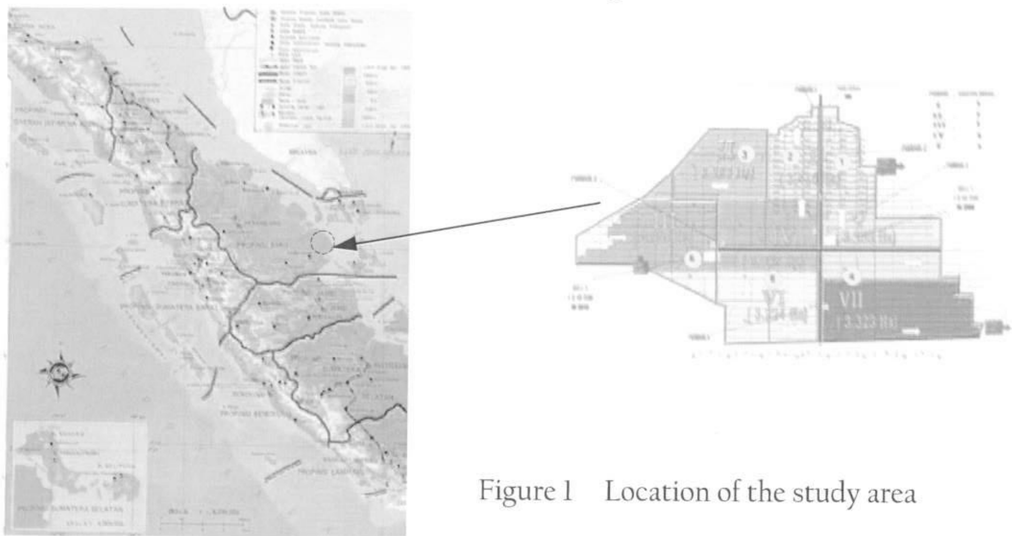

Figure 1 Location of the study area

2. AIM OF STUDY

To study and propose a water management system of the area to meet the followings conditions :-

a.) The depth of water level in the canals should be maintained so as to allow movements of vessels irrespective of the season.

b.) The water table of the entire area should be maintained at 75cm below the ground surface, as desired by the oil palm trees.

c.) The water management system (water level control in the canals and water table control in the field) system should not cause saltwater intrusion into the area.

3. SCOPE OF STUDY

In order to provide a conceptual design and specifications of the hydraulic structures required for a proper water level control in the canal so that it will be navigable by vessels, the following scope has been identified.

a) Establishing a topographic map showing the general landform of the project area

b) Providing peat depth profile of the entire area showing the peat depth spatial distribution

c) Generating the surface and channel bed drainage profile showing the invert pattern of the drainage flow

d) Collecting and analyzing of the relevant climatologic data as input to the hydraulic modeling purposes

e) Applying the hydraulic and hydrologic model using HEC-RAS model to estimate the drain water level during different weather condition for planning purposes

f) Field verification of the study finding through modeling approach using the observed data collecting during the study period

g) Preparing the Design Concept and Specifications of the required hydraulic structures to enable water level control in the drain

4. DURATION OF STUDY

The duration of the project has been decided to span over a period of three (3) months between 15 July to 15 October 2006. These dates were selected because the dry and wet seasons occurred between this period.

5. STUDY APPROACH

Discussions with the General Managers and Senior Engineer of the company initiated the study. After carrying out a desk study and a one day preliminary site visit to confirm the location and the boundary of the study areas, a conceptual problem solving approach was determined and comprehensive field investigation program were proposed. The main objective of the field investigation is to obtain a first-hand information on the hydraulic and hydrological data before a detail quantitative and modeling analysis are made. The works undertaken to achieve the objective are as outlined in the successive sections.

5.1 Topographic Mapping

A representative topographic map of the study area was established using an indirect information obtained from both hydrographic and peat depth surveys.

5.2 Peat Depth Profile

Fifty (50) peat depth measurements covering the entire project area were conducted using a standard peat auger. Based on these measurements a peat depth contour map of the study area was produced.

5.3 Drainage Flow

The flow condition of the drainage canal was measured using standard river gauging procedures. Two set of flow data covering two distinct flow regimes, i.e. during high flow (rainy season) and low flow (dry season) were collected. These flow data were used in the modeling works to verify the adequacy of water level in the drain for navigation purposes.

5.4 Water Table Data

Piezometric data supplied by the company were used to investigate the field water table fluctuations under different weather conditions. The objective of such procedure is to verify the adequacy of water table in the field to ensure optimum water table depths are met.

5.5 Rainfall Data

Rainfall data supplied by the company was used to obtain an overall wetness condition of the project area. Rainfall and water table depth relationships were established in order to obtain some ideas on the water table response to rainfall.

5.6 Continuous Drain Water Level

Two automatic water level loggers were installed at TBE and at the jetty adjacent to the Mill for more than three weeks to obtain the water level conditions in the main canal during one complete tidal cycle. The water level data obtained are used for simulation purposes as well as to estimate the tidal effect of the water level of the drain.

5.7 Quality of the Peat Water

The quality of water in the canal (especially pH) was determined using a quality water checker. The main purpose of this task is to reaffirm that the area is a peat basin (rain-fed basin).

5.8 Hydrographic Survey

A comprehensive hydrographic surveys covering most of the drainage canal network of the entire area were carried out. The surveys were carried out using satellite technology through GPS (Global Positioning System) particularly during the coordinate identification process. The outputs of the survey are in the form of channel bed profile, channel width & shape and water level profile. The information contain in these profile are indispensable variable for this particular study.

5.9 Hydraulic Modelling Study

All relevant data obtained from both ground survey and those provided by the company were used in the modeling aspect of the project. The main objective of this modeling work is to estimate the adequacy of water level in the drain under different weather conditions. The model was run to verify the importance of the dam at KM 0 as a key hydraulic structure in obtaining the desirable water level.

6. DATA ANALYSES AND RESULT

6.1 Physical Description of the Catchment

6.1.1 The Catchment

The project area is fully covered with moderate deep and decomposed peat soil. As such, the catchment area is categorized as an ombrothrophic peat basin or rain-fed basin in nature. The hypothetical diagram of a rain-fed peat basin found in the study area is illustrated in Figure 2. The unique characteristic of an ombrothropic peat basin is that the surface water inflow to the catchment is totally rely on rainfall even though a little ground water supply can be expected. As such, the peat water is acidic with pH values between 3 to 4.5. Under such field conditions, the management of the water level in the drainage is very much related to the temporal rainfall condition of the area. Unless the area is fully confined, that is, no outflows are allowed at all, the possibility of retaining water level in the drain would depend on the relevant hydraulics structures constructed along the drainage canal.

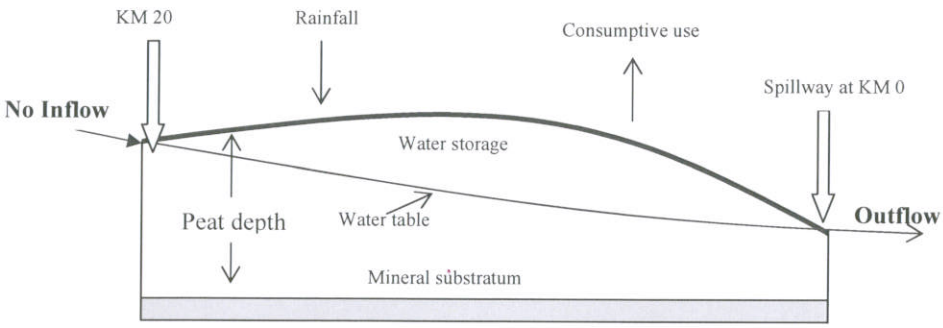

Figure 2. A hypothetical model of a 'rain-fed peat basin' of the project area

The total area of the drainage basin is 25,000 hectares but to date only about 16,577 hectares are planted. Figure 3 shows the division of the area into five different managerial schemes, namely Telok Bakau, Nusa Lestari, Rotan Semelur, Nusa Perkasa and Mandah. Table 1 lists the areas that have been planted to date.

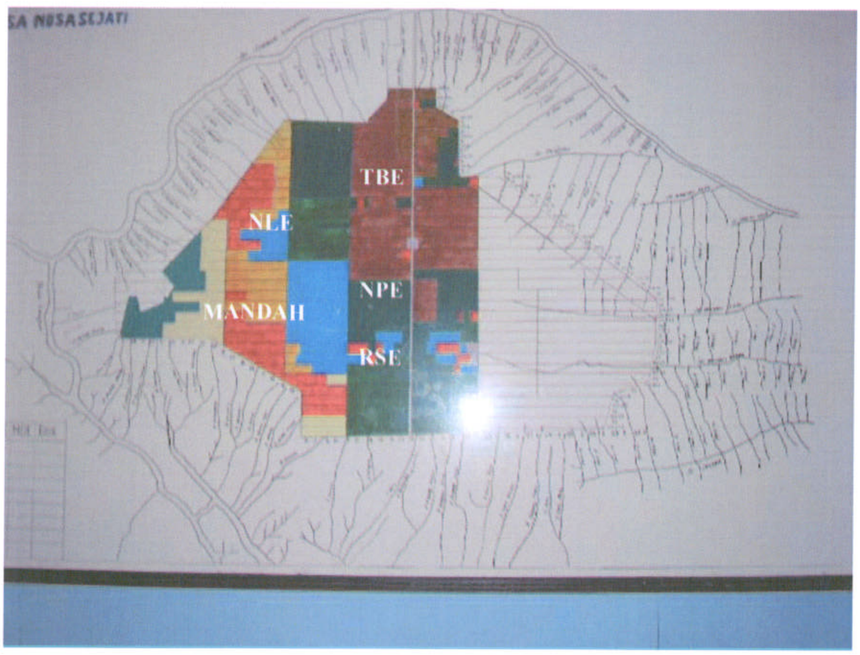

Figure 3. Estates of the project area

Table 1. Planted area of the estate

Name of Estate	Planted Area (Ha)
Teluk Bakau (TBE)	3459.00
Nusa Lestari (NLE)	3185.00
Rotan Semelur (RSE)	3461.00
Nusa Perkasa (NPE)	3347.00
Mandah (MDE)	3125.00
Total	16577.00

Total catchment area: 25,000 Ha

6.1.2 The Topography

In general, the topography of an ombrotrophic peat basin is relatively flat. The relief is extremely small and does not favour an overland flow process. With such reason, the rainfall-runoff process of the basin is basically governed by groundwater or subsurface flow. An indirect topographic survey has produced a representative topographic map of the project area. As shown in Figures 4 and 5, the reduced level (RL) of the highest point in the area is 4.5m from the mean sea level (MSL) and located at Mandah Estate while the lowest point is at the spillway with an RL of 2.0m MSL. The overall land slope is 0.0125 percent.

6.1.2 Existing Infrastructure

Two most important infrastructures associated to water level control in the project area are the man-made open canal and earth bunds & bridges. The canal system comprises of a 22 km long main canal and about 320 km long secondary canal. Based on the the total length, the canal density of the project area is about 22 m/hectare. At present, a spillway was built at the downstream end of the main drain and functions as the key water level controlling point of the project area.

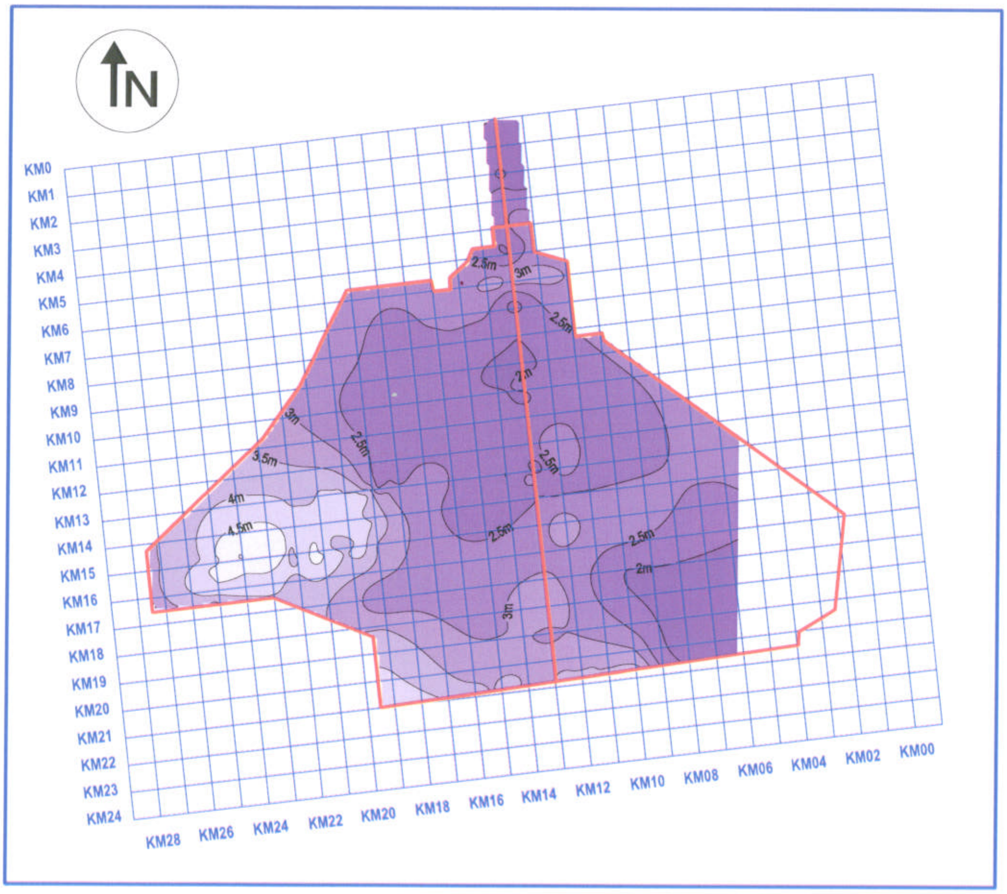

Figure 4. The topography of the project area of relatively flat

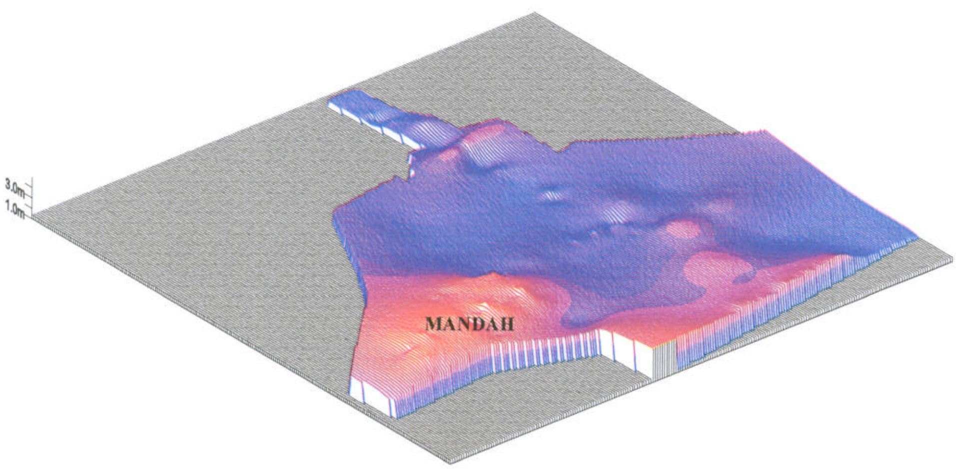

Figure 5. Digital Terrain Representation of the Project Area showing the peak point at Mandah estate

6.2 Hydrology

6.2.1 Rainfall

Rainfall plays the most important role in a rain-fed peat basin for a sustainable water management. The annual rainfall pattern of the study area during 1998-2005 hydrologic years is given Figure 6. The average annual rainfall is considerably high (higher than 2500 mm) which is typical to a peatland ecosystem in the tropics. Figure 7 shows the mean monthly rainfall of the study areas. Within the study area there is also a distinct variation in the spatial and temporal distribution of rainfall. This variation has shown some hydrologic heterogeneity between estates of the project area. Figure 8 is the mean monthly rainfall taken from all estates record. It clearly shows two distinct dry spell occurences in a year, which are January to February and July to September. It is expected that during these months water shortage would occur which may significantly affect the water level in the canal if a proper water level control is not placed.

6.2.2 Water Demand

In order to have an overall understanding of the hydrological water supply and demand of the area, the amount of water required or consumed by the palm trees is estimated. In practice, the maximum amount of water consumed by oil palm trees grown on wetland such as found in peat can be estimated using evaporation rate of a water body of about 4.0 to 4.5 mm per day.

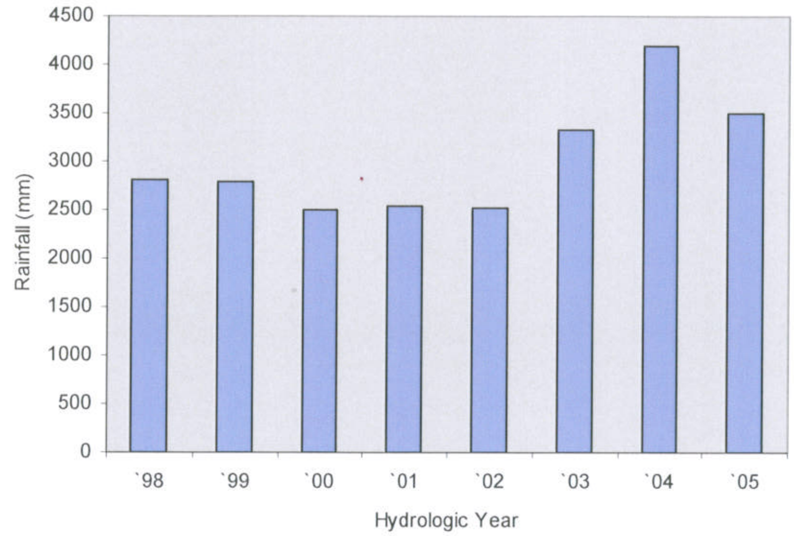

Figure 6. Annual rainfall pattern of the project area

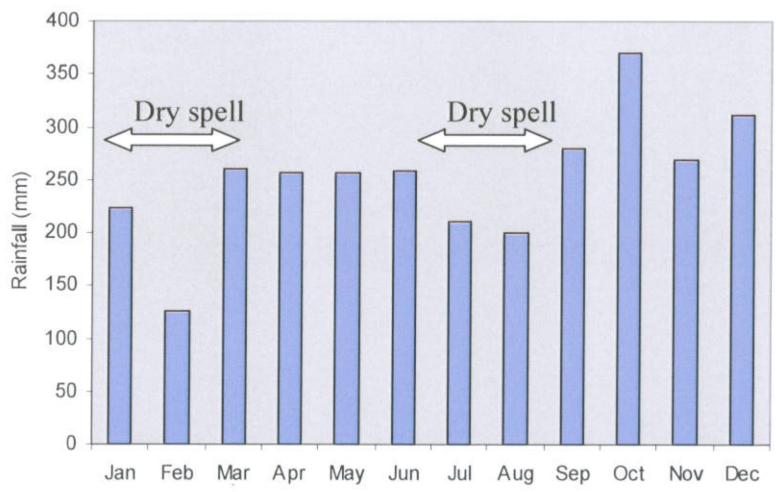

Figure 7. Mean monthly rainfall pattern

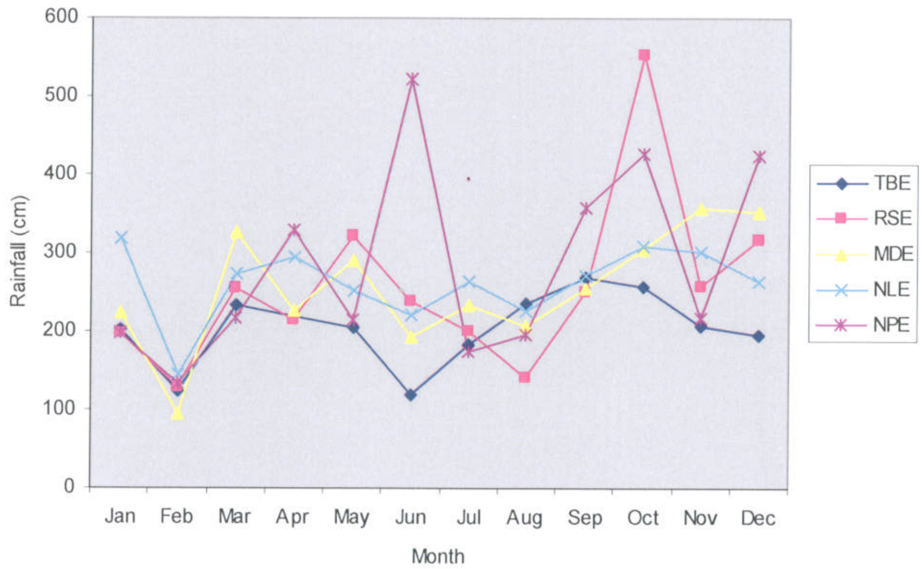

Figure 8 . Mean monthly rainfall pattern of the individual estates showing a spatial and temporal rainfall distribution

6.2.3 Catchment Runoff

The total drainage outflow of the catchment through the drainage canal system is recognised as runoff or the amount of water losses from the drainage basin during a specified period. In the case of an ombrothropic peat basin, during wet season, a rapid run-off rate is crucial to avoid field flooding. On the other hand, during a long dry spell, it is essential to minimise the rate of run-off in a way to retain the water level in the drain and the water table in the field. The amount of run-off can be estimated by multiplying the channel flow rate with time.

6.2.4 Field Water balance

The field water balance of a rain-fed basin can be expressed using a simple formula as shown in Eqn (i) :-

$$R - Q - ET = \Delta S \qquad \text{.... (i)}$$

where R is rainfall, Q is runoff or drainage outflow, ET is the consumptive use and ΔS the water storage change in the body of peat material. Knowing R, Q and ET, the water storage in the basin can be estimated. Table 2 presents the estimated monthly water balance of the area. The analysis indicates the water supply and demand status considering the flow in the canal is free without any obstruction.

Table 2. Monthly water balance analysis

Month	Rainfall (cm) *	Potential water demand (cm)**	Potential water loss due to runoff (cm)***	Existing Storage (cm) ****	Water supply and demand status
Jan	22.2	12	2.6	100	Surplus
Feb	12.5	12	2.6	100	Surplus
Mar	26.0	12	16	100	Surplus
Apr	25.5	12	16	100	Surplus
May	25.6	12	16	100	Surplus
Jun	25.8	12	16	100	Surplus
Jul	21.0	12	2.6	100	Surplus
Aug	20.0	12	2.6	100	Surplus
Sep	27.9	12	2.6	100	Surplus
Oct	37.0	12	16	100	Surplus
Nov	26.8	12	16	100	Surplus
Dec	31.0	12	16	100	Surplus

* a long term mean monthly rainfall
** based on 4.0 mm perday potential evaporation
*** based on 15 m^3/s during wet and 3 m^3/s during dry
**** estimated from water body generated from peat depth

6.3 Hydraulic Characteristic of the canal

6.3.1 Flow Condition

Beside consumptive use, water loss of the project site is discharge at the spillway. One of the major problems encountered by the drainage scheme is the difficulty in controlling the channel discharge during dry period. Stream gauging works has been carried out during two distinct conditions, i.e. wet and dry season. More than 60 measurements for each condition covering 22 km main canal and several important secondary canals have been conducted. Figure 9 depicts the mean flow of the main canal. Two important flow conditions can be highlighted here.

Firstly, during the wet season, the overall discharge rate of the main canal is relatively large of $15m^3/s$. Maximum flow occurred at the spillway, reduced towards KM 12 and became constant from this point onwards. Secondly, during dry season, the channel flow is almost a constant along the whole length of the canal. This indicates that during dry season, the flow in the canal is due to the hydraulic gradient of its bed.

Hydraulically speaking, steady flows were occurred during the dry season while mixed flow (steady, unsteady and mixed) is observed during wet condition. These findings will be materialised in the modeling effort of this project. The average flow taken for simulation purposes is $15\ m^3/s$ for wet season and $3\ m^3/s$ for dry season respectively.

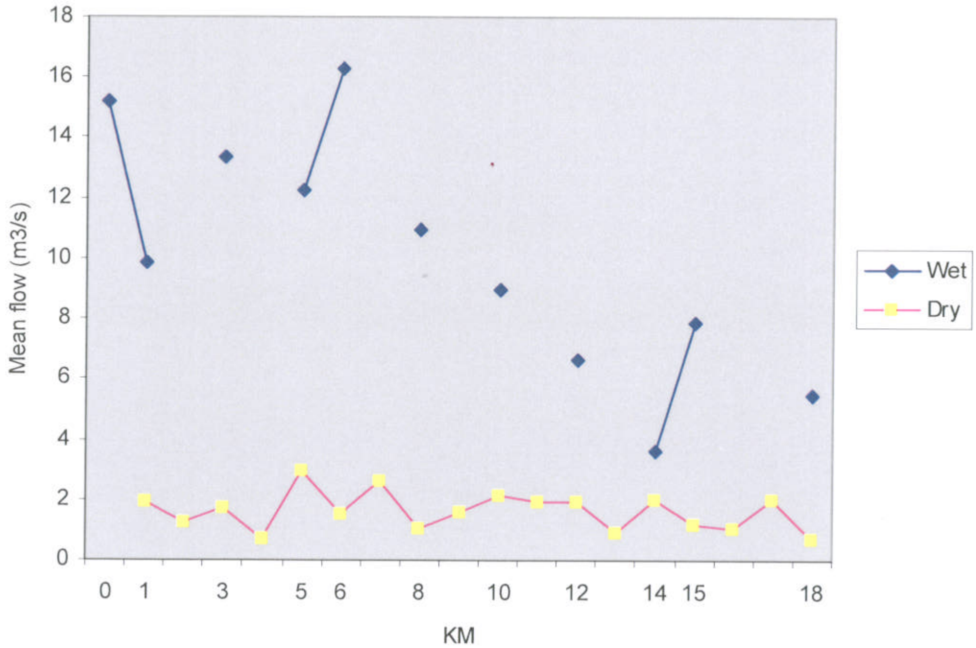

Figure 9. Flow variation along the main drain during wet and dry season

6.3.2 Canal Geometry

As man-made channels built on peat areas, the shape of the canals (side slope) is found to be irregular. The geometric shape of the canal, or more precisely, the cross-sectional area is one of the most important input parameter in the modeling works of this particular study. More than twenty (20) cross-sectional profile survey of the channel reaches along the main drain were measured. The typical channel shape is shown in Figure 10. As expected the shape is irregular with mild side slopes. The width of the main canal ranges from 20m to 38 m with the maximum width found at a reach close to KM 0.

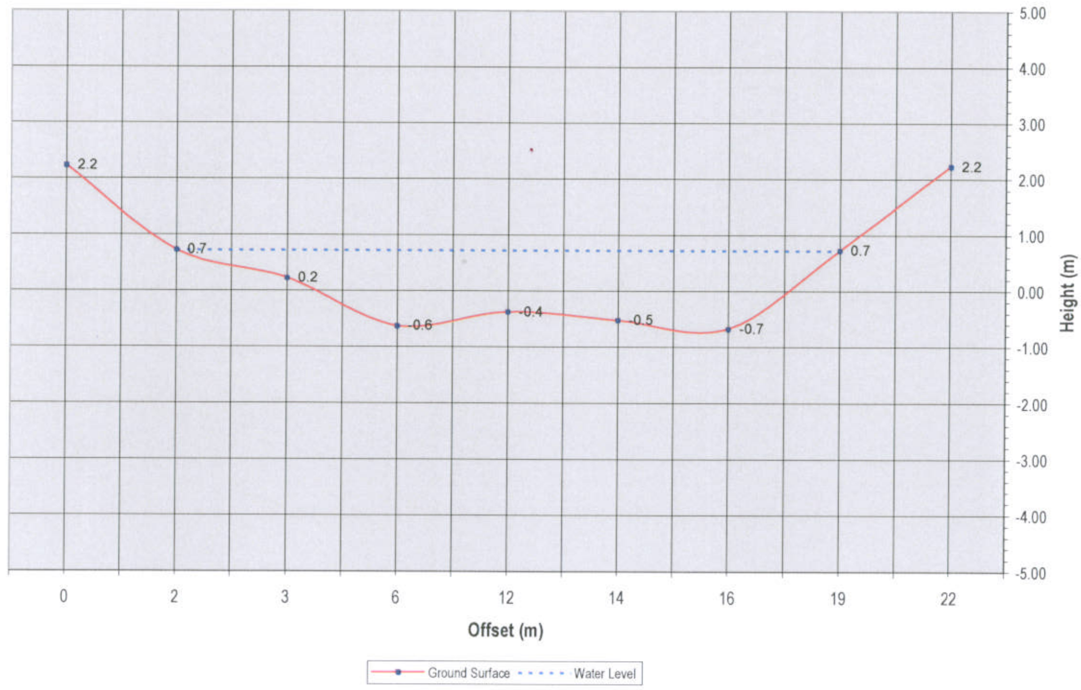

Figure 10. Typical shape of the main canal showing the uneven bed level and mild side slopes

6.3.3 Bed and Surface Water Profile

The flow in the drainage canal is basically governed by the bed profile of the channel, thus, the longitudinal profile of the surface water along the canal length. A detailed hydrographic survey has produced a comprehensive data for this particular hydraulic parameter to enable us to do detail analysis. Figure 11 shows the overall water surface profile of the main drainage canal in relation to channel bed profile and riverbank elevation. It is evident, the overall channel slope is extremely small of about 3.5 m per 20 Km or 0.02 percent. Under such hydraulic condition the water level in the drainage canal is supposed to be stagnant if no major outflow is allowed at the drainage end (KM 0) of the basin especially during dry season. During the wet season the drainage flow pattern can be visualized using invert of the drain as shown in Figure 12.

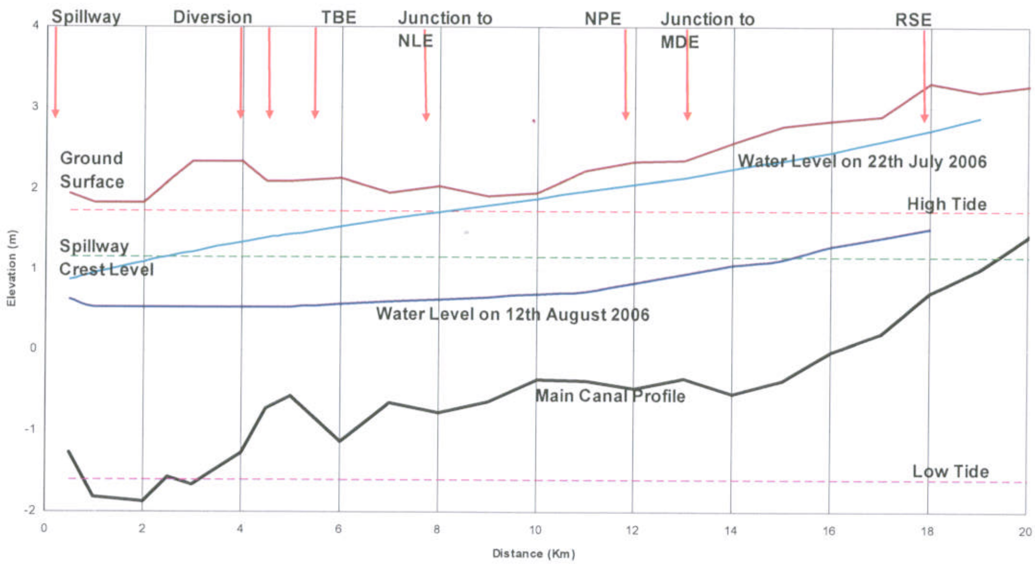

Figure 11. Channel bed, free water surface profile and ground surface of the main drainage canal

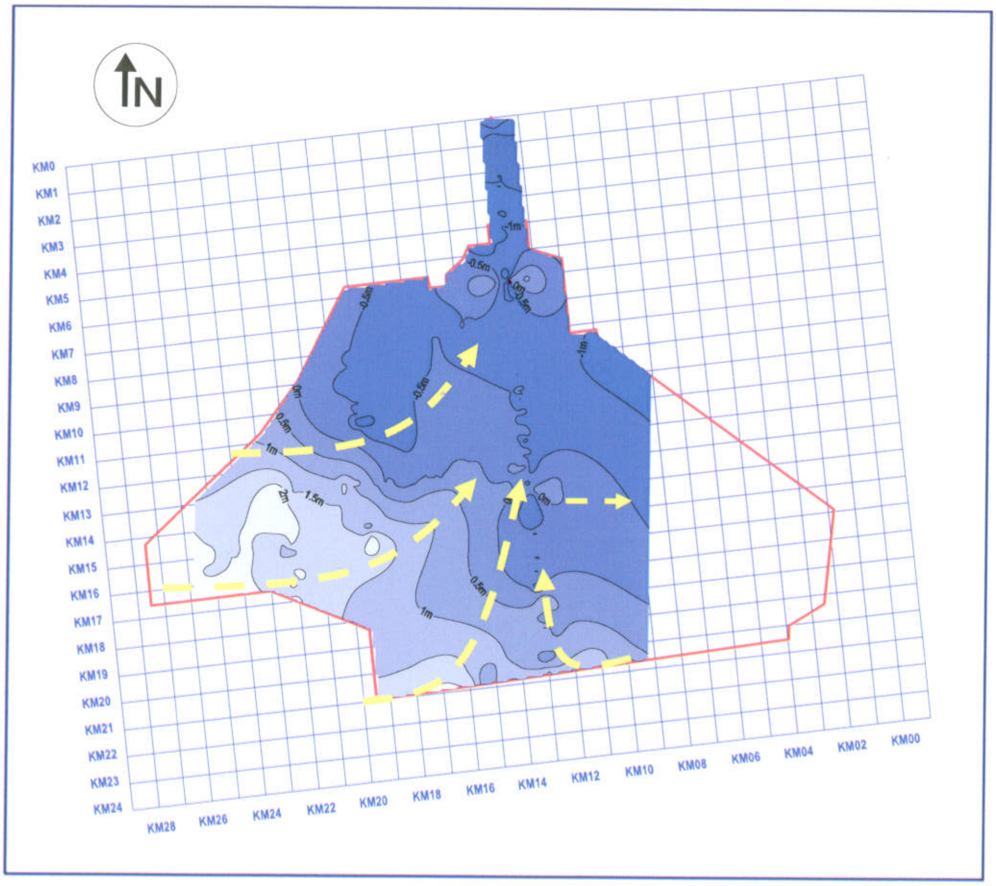

Figure 12. Invert level of the canal showing the potential direction of drain flow

6.2.4 Hydraulic roughness of the drainage canal

The smoothness of flow in the canal under both steady and transient state conditions is somewhat governed by its channel roughness or manning roughness, *n*. The roughness of the main canal was computed using standard manning equation and the geometric parameters (depth, cross-section area, width, wetted perimeter and hydraulic radius) of the drainage canal obtained during hydrographic and river gauging survey. Table 3 presents the summary of the computation. As shown, the channel roughness is in the range of 0.01 to 0.05 with a mean value of 0.03. These values are reasonably acceptable for an open channel built on peat areas and are comparable to the published values.

Table 3. Channel roughness, n, of the main canal

KM	Velocity (m/s)	Depth (m)	Area (m^2)	Discharge (m^3/s)	Width (m)	Wetted perimeter	Hydraulic radius	Slope	n
0	0.19	2.65	81.00	15.19	38.00	100.70	0.80	0.0001	0.03
1	0.10	3.50	94.74	9.84	38.00	133.00	0.71	0.0001	0.05
3	0.31	3.05	43.18	13.38	27.20	82.96	0.52	0.0001	0.01
4	0.04	1.45	43.18		22.50	32.63	1.32	0.0001	
5	0.23	2.50	53.97	12.26	25.60	64.00	0.84	0.0001	0.03
6	0.39	2.46	41.75	16.28	22.50	55.35	0.75	0.0001	0.02
8	0.32	2.35	34.70	10.95	21.90	51.47	0.67	0.0001	0.02
10	0.20	2.35	46.01	8.97	24.80	58.28	0.79	0.0001	0.03
12	0.17	2.22	39.20	6.65	22.80	50.62	0.77	0.0001	0.04
14	0.11	2.40	32.42	3.61	19.80	47.52	0.68	0.0001	0.05
15	0.17	2.30	46.14	7.89	31.00	71.30	0.65	0.0001	0.03
18	0.15	2.20	35.86	5.51	21.00	46.20	0.78	0.0001	0.04
								Mean	0.03
								Min	0.01
								max	0.05

7. WATER QUALITY

To obtain a general background of water quality of the drainage scheme, several water quality parameters has been measured using an automatic water quality checker. The result is presented in Table 4. Two most relevant water quality parameters in this study are the pH and Salinity. The pH value represents the acidity level of the peat water and salinity provide some information on whether the area is influenced by sea water. The salinity level of the drainage water along the canal is found to be nil (0) indicating that the area is not jeopardized by the sea water even during high tide conditions. The pH value is in the range of 3.8 to 4.2 which indicates that the area belong to a normal drained peat area under the category of peat bog or ombrotrophic peat or rainfed peat basin, earlier defined in this report.

Table 4. Water quality background of the drainage scheme

Point	Location	pH	Cond	Turb	DO	Temp	Sal
0	At spillway	4.8	0.2	4.5	0.2	28	0
0	River mouth	4.1	0.18	4	1	28	0
1	KM 0 - main	4.2	0.18	5	0.9	28	0
2	KM 1 - main	4.3	0.17	3	0.8	28	0
3	KM 3 -main	3.8	0.17	3	0.7	28	0
4	KM 4 - main	4	0.17	1	1.4	28	0
9	KM 5 -main	3.8	0.17	2	1	28	0
10	KM 8 - main	3.9	0.17	2	0.7	28	0
11	KM-12 before Mandah	3.9	0.17	1	0.4	28	0
12	KM-15	3.9	0.18	2	0.5	28	0
13	KM-18	4.1	0.19	4	1.1	29	0
14	KM-20 main	4.1	0.2	7	1.8	29	0

8. FIELD WATER TABLE

8.1 Mean monthly water table

The water requirement of the oil palm trees grown on peat areas rely on the water supply from water table capillary rise. For palm tress, the optimum water table depth of less of 75 cm from the ground surface is desirable. Field piezometric data (January to June, 2006) supplied by the estate management has been analysed to obtain the general perspective of the water table conditions in the field. As presented in Table 5, the average water table for the whole project area during January to June, 2006 was between

59 and 78 cm from the ground surface. The detailed mean monthly water table depth for all estates is given in Tables 6 to 10. As expected the lowest water table occurred during February to March where the mean monthly rainfall is minimum.

Table 5. Average water table depth of the whole project area during January-June, 2006

Month	Average water table (cm)
January	66.58
February	76.14
March	78.50
April	61.52
May	59.04
June	61.92

Table 6. Mean monthly water table and rainfall depth at Rotan Semelur Estate

Month	Water table depth (cm)				Average	Rainfall (mm)
	Div 1	Div 2	Div 3	Div 4		
January	30.6	29			29	1437
February	34.9	43			43	410
March		71		71	71	303
April		73	84.4	61	73	960
May	40.5	55	49	73	55	938
June	68.3	71	78.7	68	71	583
Average					57	

Table 7. Mean monthly water table rainfall depth at Telok Bakau Estate

Month	Water table depth (cm)				Average	Rainfall (mm)
	Div 1	Div 2	Div 3	Div 4		
January	36	52	31	52	43	909
February	69	68	51	72	65	45
March	92	83	48	57	70	54
April	77	44	40	41	51	481
May	67	45	53	53	55	505
June	64	56	44	55	55	245
Average					56.5	

Table 8. Mean monthly water table rainfall depth at Nusa Lestari Estate

Month	Water table depth (cm)				Average	Rainfall (mm)
	Div 1	Div 2	Div 3	Div 4		
January	177	174	173	171	174	1637
February	154	153	156	150	153	425
March	89	78		85	84	356
April	58	49		57	55	790
May	37	43		45	42	938
June	48	49		50	49	633
Average					93	

Table 9. Mean monthly water table rainfall depth at Mandah Estate

Month	Water table depth (cm)				Average	Rainfall (mm)
	Div 1	Div 2	Div 3	Div 4		
January					54.9	1641
February					60.7	425
March					91.5	336
April					67.6	675
May					75.2	938
June					77.6	523
Average					71	

Table 10. Mean monthly water table depth at Nusa Perkasa Estate

Month	Water table depth (cm)				Average	Rainfall (mm)
	Div 1	Div 2	Div 3	Div 4		
January	39	28	30		32	1240
February	68	56	53		59	8
March	95	80	54		76	285
April	48	90	46		61	101
May	91	68	44		68	238
June	60	63	49		57	293
Average					59	

8.2 Water table response to rainfall condition

To have a proper water management system in peat catchment, it is necessary to have a general understanding on the relation between water table and rainfall of the project area. Water table in the area closed to the main canal basically less responsive to rainfall because these areas are drained more efficiently. Under such condition, a large percentage of the rainfall quickly drained before it developed as the water table rise. The rainfall and water table relationship is presented in Figures 12 to 16.

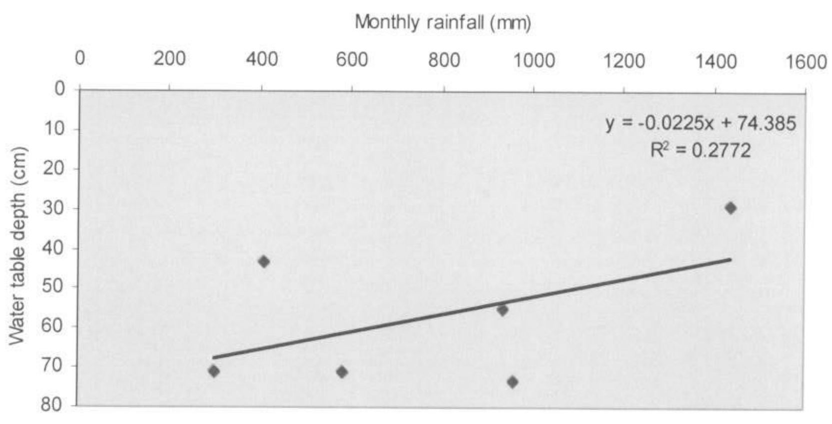

Figure 12. Water table response to rainfall at Rotan Semelur

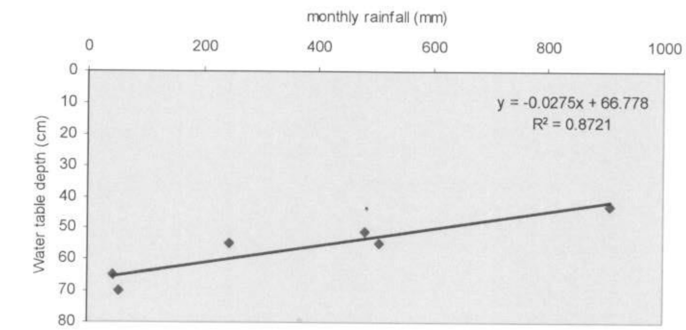

Figure 13. Water table response to rainfall at Telok Bakau

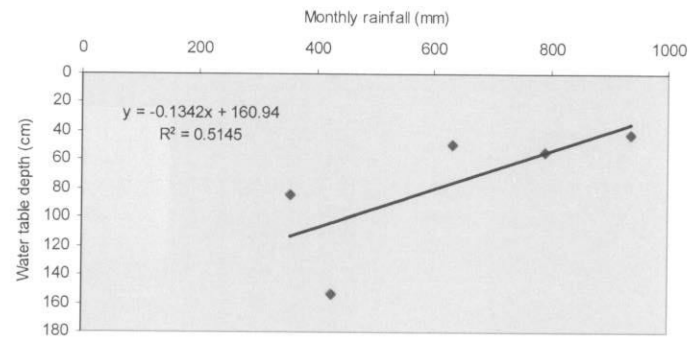

Figure 14 . Water table response to rainfall at Nusa Lestari

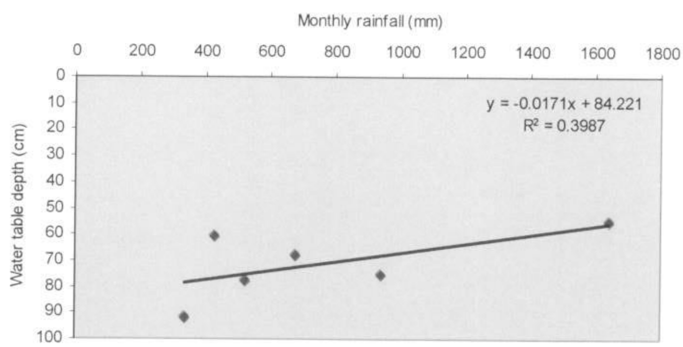

Figure 15. Water table response to rainfall at Mandah

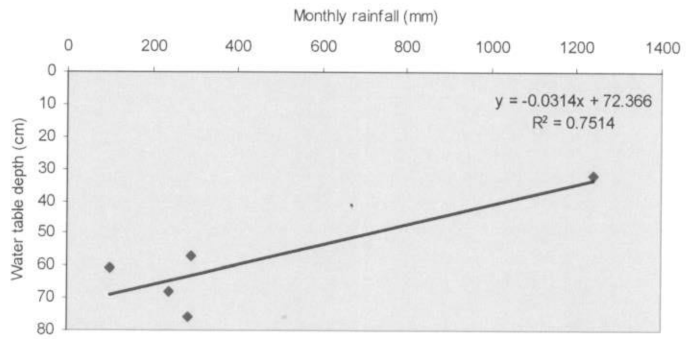

Figure 16. Water table response to rainfall at Nusa Perkasa

Table 11. Water table response to rainfall as indicated by statistic R^2

Name of Estate	R^2	Rate (mm water table /mm rainfall)
Teluk Bakau (TBE)	0.87	0.28
Nusa Lestari (NLE)	0.51	1.34
Rotan Semelur (RSE)	0.28	0.23
Nusa Perkasa (NPE)	0.75	0.31
Mandah (MDE)	0.40	0.17

Table 11 is the summary of statistic for water table-rainfall relationship. Referring at their rate of water rise due to rainfall, it is found that water table at Nusa Lestari area is more responsive to rainfall while Mandah is the least. It has to be expected that compared to Nusa Lestari, Mandah is located at higher elevation and the rate of water loss to the drain is faster.

9. PEAT DEPTH CONTOUR

The hydrology of a peat basin is directly related to the peat volume of the basin. The water level of the peat basin is controlled by its storage potential which is indicated by the peat volume. Peat depth survey using a standard peat auger was conducted to produce the peat depth configuration of the entire area. Fifty (50) peat depth auger measurements (500 Ha per auger) covering the entire area of the drainage scheme has been made to figure out the general peat depth profile of the area. Figure 17 shows the general peat depth contour of the area. Overall, the areas fall under the category of deep peat, but it should be expected that the thickness of the peat is reducing with time due to continuous decomposition processes. The deepest peat material (3.5 m thick) was found at Mandah while the least (0.5 m thick) was found at areas close to the downstream end the whole project area. As anticipated, the cross-sectional of the area showing a slight dome-shaped profile (Figure 18 and 19).

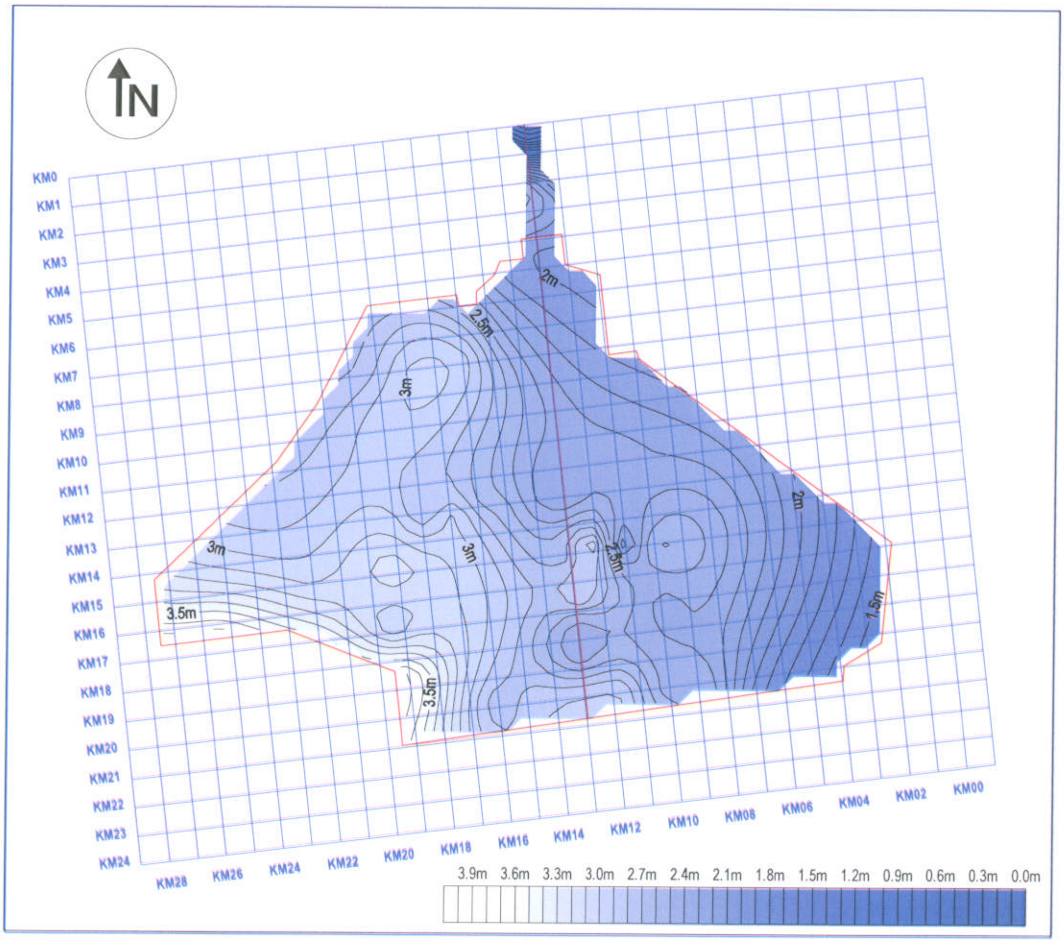

Figure 17. Peat contour of the project area

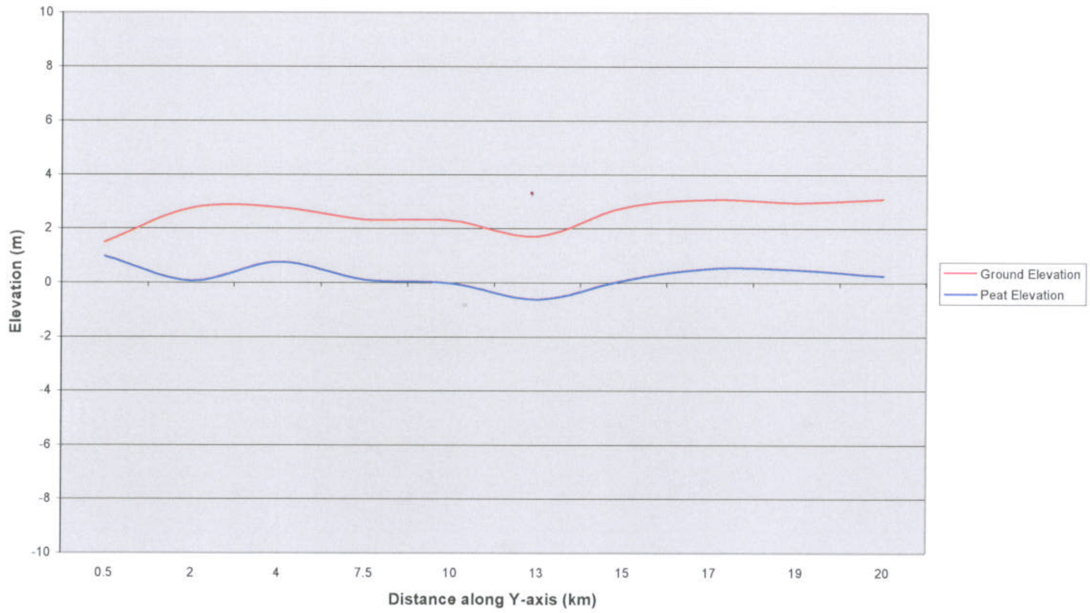

Figure 18. Cross-section Y-Y (North-North)

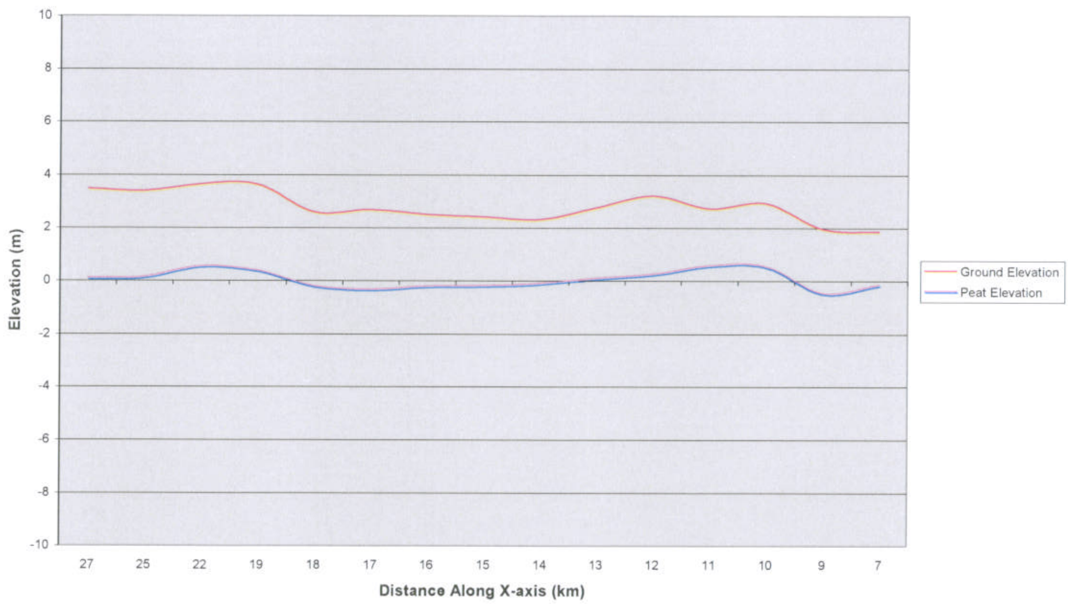

Figure 19. Cross-section X-X (East-West)

10. HYDRAULIC MODELLING AND SIMULATION

10.1. Introduction

The main purpose of this modeling work is to estimate the surface water profile in the canal under different weather condition. Knowing the surface water profile of the canal would help the estate management to foresee the possible problem associated to canal flow particularly for transportation purpose. The output of the modeling exercise will be used in decision making for canal water management.

10.2 The Hydraulic Model

The hydraulic model used is the HEC-RAS computer program. The HEC-RAS performs one dimensional water surface profile calculation for steady, gradually varied flow in natural or constructed channels. The computations began at the upstream end (KM 20) of the study reach and proceed cross section by cross section to the lower end of the reach (KM 0). The required input parameters of the model are the river reach, geometric shape, roughness coefficient and bank stations. A major assumption is that the flow through various reaches is steady, i.e. depth, velocity and discharge remained constant with time at a particular location on the canal.

10.3 The Modelling Process

The model was run by taking into account two different situations, namely, free-flow and control-flow. Apart from these situations, three options were also considered in the modeling of the water level. These options, which are designated as A, B and C, are derived from the physical parameters obtained from the ground survey and current management practice.

10.3.1 OPTION A

For this option, all existing infrastructures are maintained. Nevertheless, additional minor hydraulic structure such as a new spillway at KM 8.5 east is required. Table A provides detailed specification of the option.

Table 12. Field specification under Option A

Field Demarcation System	Hydraulic Structure Needed	Role of the structure
The whole project area is considered as belonging to one water management scheme except, Mandah. Due to the distinct topographical feature, the water level control in Mandah is independent from the main canal.	Spillway at KM 0 (Mill)	The key water control structure of the whole area. The water level at the spillway crest should be used as an indicator to the overall water level in the main drain.
	Spillway at KM 8.5 East	This spillway is meant for emergency in case an extra ordinary wet weather occurred to avoid the downstream area from flooding
	A permanent Dam with water gate at the main outlet at KM 0 (Mill)	The key function of this structure is to block the drained water from leaking especially during dry season. It must constructed is such a way that completely impermeable. The excess water due to extreme wet season should be channel via the spillway situated close by.
	Earth dam at KM 14, 18, 19, Nusa Lestari and Mandah (existing)	The main function of these small dams across the secondary drain is to minimize flow from the secondary canal to the main canal. These dams are not functionally meaningful if the water level in the main canal can be kept high
	New Mill at KM 14	To serve the upper part of the project area
	Dredging works at KM 16-21	To increase the maximum possible water depth of these particular stretch

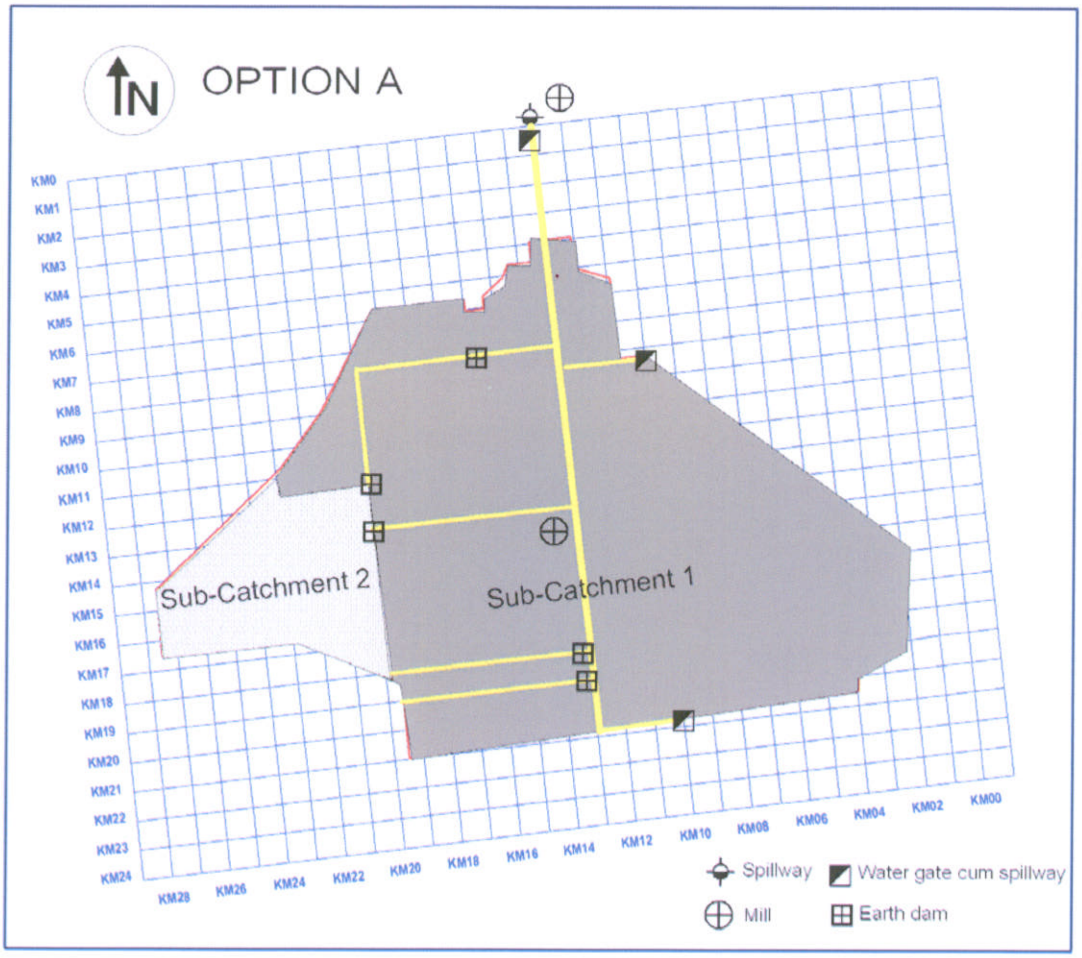

Figure 20. The proposed field layout under OPTION A

10.3.2 OPTION B

This option is quite similar to Option A. The only extra is that sub-catchment 2 (originally covered Mandah only) is extended to cover some part of Rotan Semelur Estate. In other words, these areas are considered merged and go under one water management system. The rationale of this merger is that such area fall under the same degree in topography. To accomplish this task and to ensure a sufficient water level control in sub-catchment 2, as shown in Figure 21 an additional dam is required at KM 13 and KM 18 of the secondary canal.

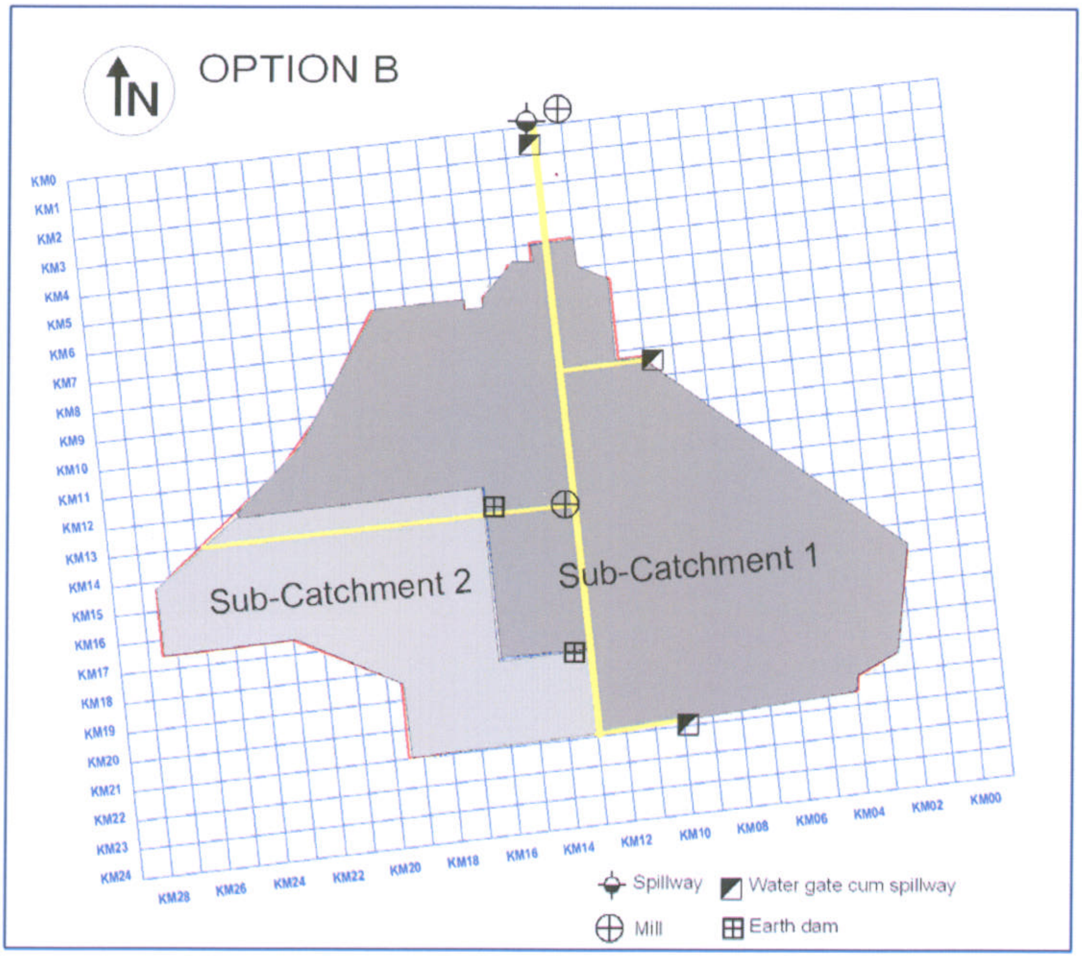

Figure 20. The proposed field layout under OPTION B

10.3.3 OPTION C

This option is a more simple approach in the sense that the whole area is equally divided into two sub-catchments, i.e. the upper catchment (sub-catchment 2) and lower catchment (sub-catchment 1). In other words, the existing peat basin is converted from a single basin system into two sub-basins system. Accordingly, the main canal is divided into two sections and each section will have its own command areas. Hypothetically, this option is workably possible for relative flat area such as found in peat basin. The advantage of this option is that it is simple and may require minimum number of additional hydraulic structure. The main structure required is a proper regulated dam across the main drain at KM 14. This dam will become the drainage end control of Sub-catchment 2 and ideally a new mill should be constructed in this area.

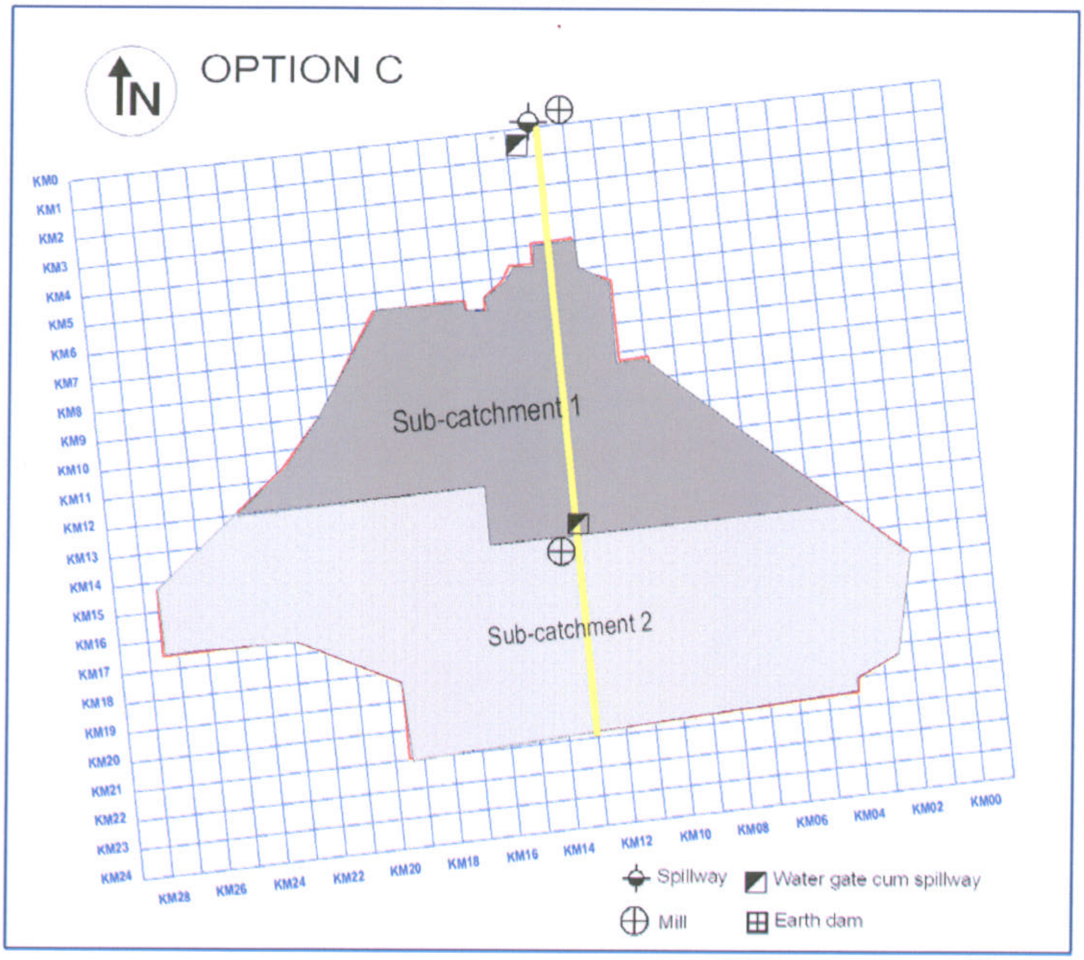

Figure 21. The proposed field layout under OPTION C

10.4 The Modelling Results

The conceptual field demarcation models earlier discussed were hydraulically verified using HEC-RAS software. The major output is in the form of water level in the main canal under various weather conditions (non-critical condition during rainy season and worse condition during dry spell). The model result was then compared to the observed values for calibration purposes. Subsequently, apart from the existing infrastructures, additional works is required to improve the canals' serviceability.

10.4.1 Observed Water Profile

Figure 22 shows the water level profile along the main canal and secondary canal at KM 21 in relation to invert level, spillway at KM 0 and ground level. The following points can be highlighted :-

a) A sudden change of the invert level at KM 18 and 21
b) Water level during no flow condition (red line) can be achieved provided dam at KM 0 is completely closed
c) Spillway crest (green line)
d) Water flow observed 12 August 2006 is lower than the anticipated flood water level
e) Invert level is representative to ground level

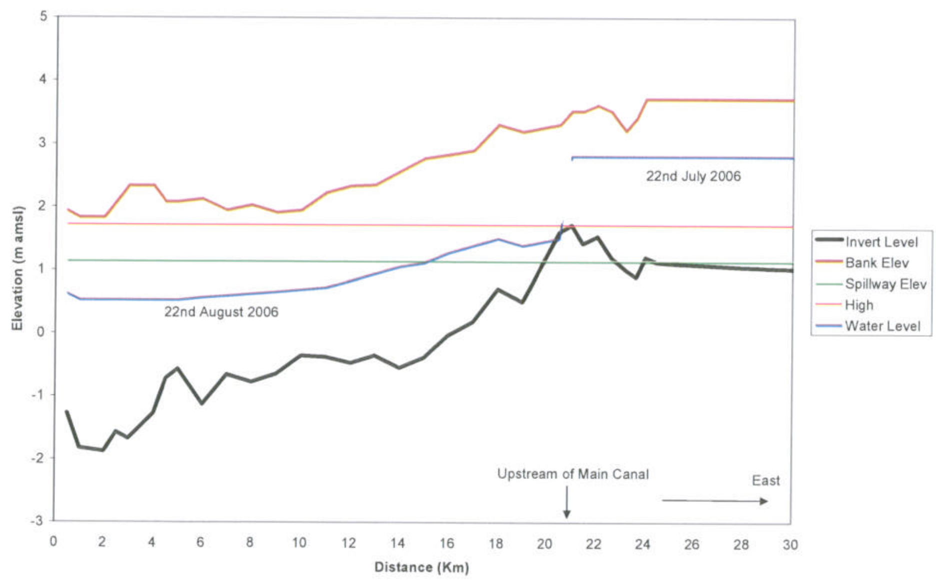

Figure 22. Observed surface water profile during wet (22 July, 2006) and Dry (12 August, 2006)

Figure 23 shows the water level profile in along the secondary canal at MANDAH in related to invert level, spillway at KM 0 and ground level. The followings can be deduced from Figure 23 :-

a.) Gradual flow observed within Mandah

b.) Water level from KM 0 to Mandah junction is below the flood level

c.) The difference of water level depicted between Mandah's junction at KM13 on the main canal and Mandah's office is due to the fact that the topography is higher

d.) On 12 August the water level in Mandah's canal network was naturally higher

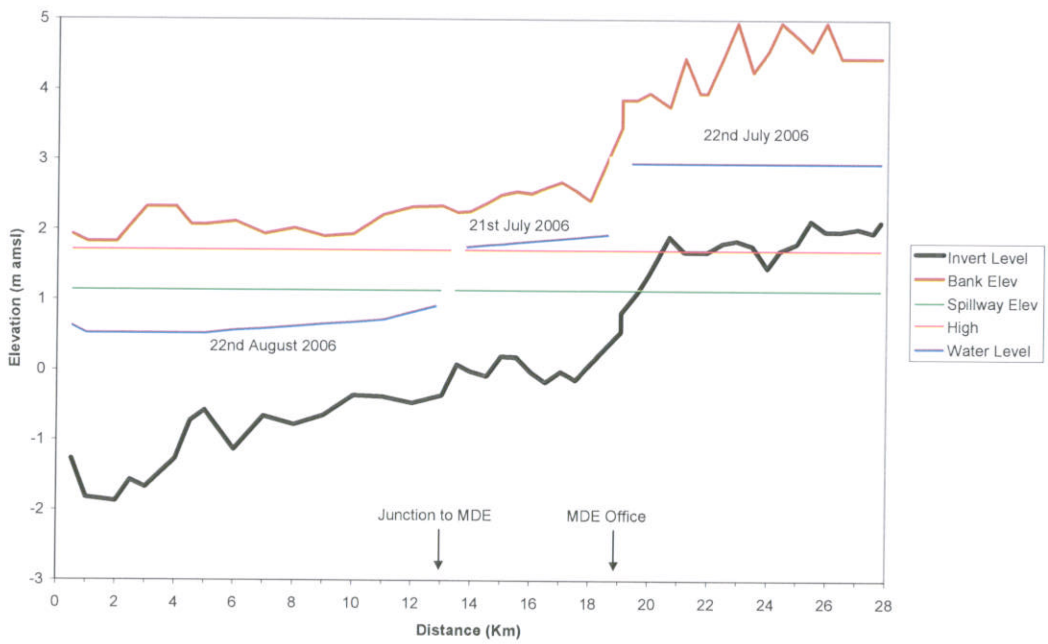

Figure 23. Observed surface water profile during wet (22 July, 2006) and Dry (12 August, 2006) at MANDAH

Figure 24 shows the water level profile along the secondary canal at NLE is related to the invert level, spillway at KM 0 and the ground level. Points that can be highlighted from Figure 24 are :-

a.) water level is adequate below spillway crest and high water level

b.) water is contained within the area with proper check structures

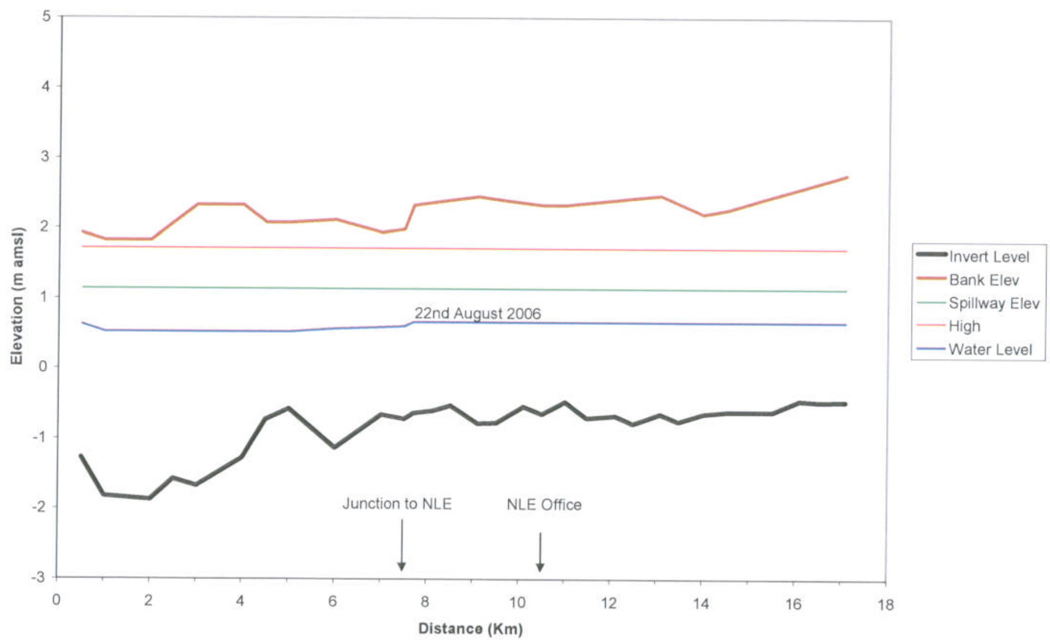

Figure 24. Observed surface water profile during Dry (12 August, 2006) at Nusa Lestari

10.4.2 Modeled Water Level Profile

Figure 25 shows the water level profile in along the main canal obtained from the model in relation to the invert level, spillway at KM 0 and ground level. It can be deduced form Figure 25 that :-

a.) during low flow the water level in the main canal is adequate provided the dam at KM 0 is properly managed

b.) KM 15 to KM 18 need minor dredging

c.) KM 18 onward need major dredging

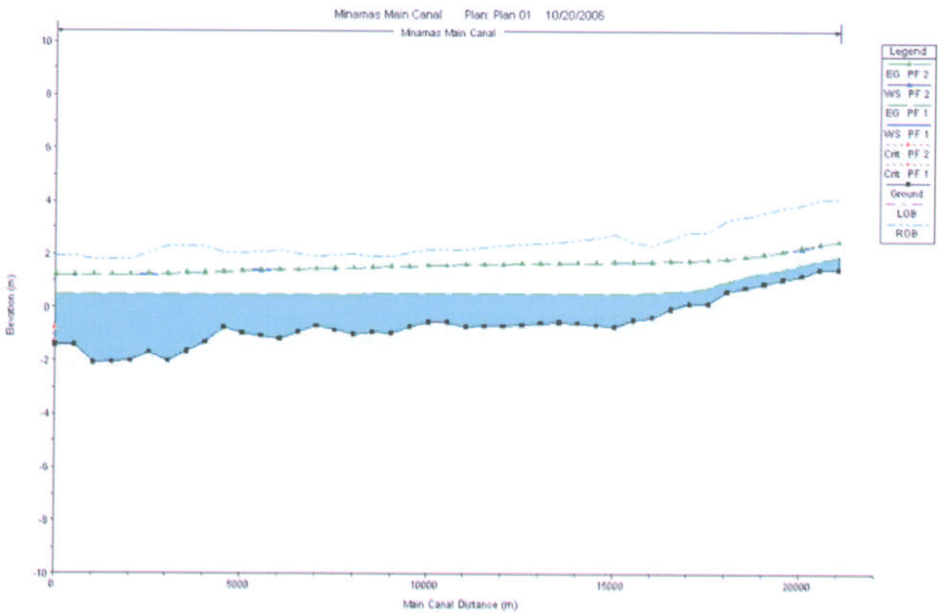

Figure 25. Modeled (verified) surface water profile along the main canal during low flow condition (without dam)

Figure 26 shows the water level profile along the main canal obtained from the model in relation to the invert level, spillway at KM 0 and ground level, if the dam is properly closed. It is evident from Figure 26 that :-

a.) flow in the main canal is adequate all the time (see Figure 25a)

b.) potential flooding at the downstream end- probably need pumping station to accerelate water discharge.

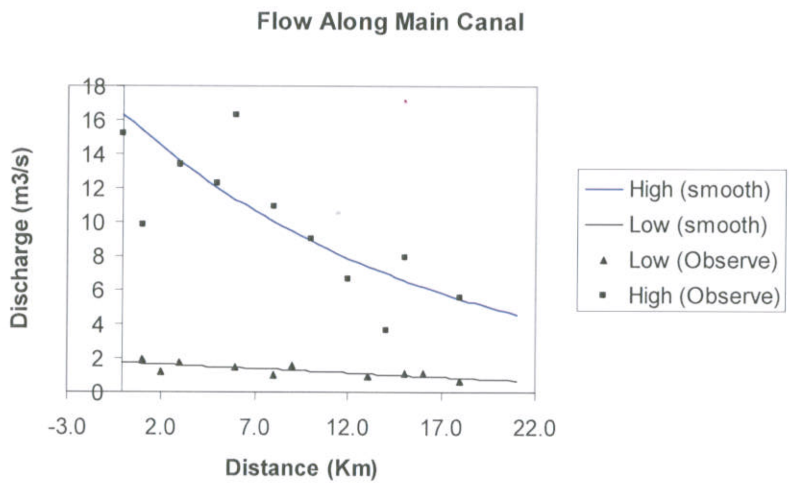

Figure 25 a. Flow Along the main Canal

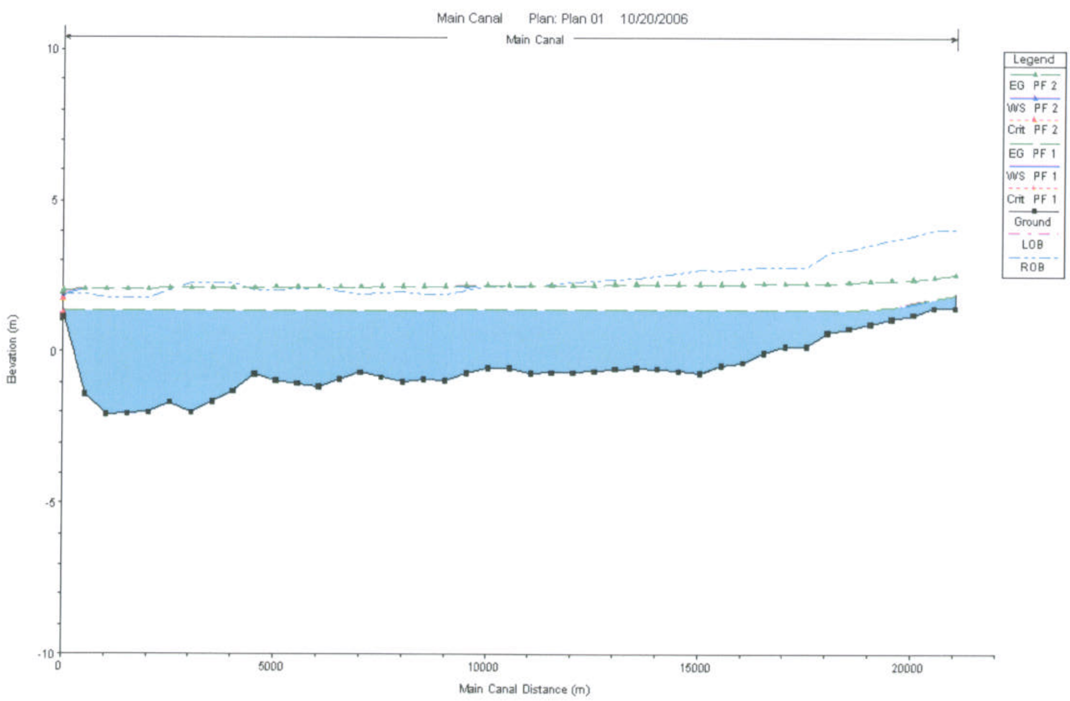

Figure 26. Modeled (verified) surface water profile along the main canal during low flow condition (with dam)

11. THE PROPOSED WATER MANAGEMENT PLAN

Considerations of the various topographic and hydraulic aspects of the study area and with the aid of computer modeling, indicate that the field layout in Option A is deemed to be the best option to be adopted. Full implementation of Option A would achieve the following objectives.

5.1 The water level in the entire canal (both main and secondary canals) is sufficient to ensure navigability throughout the year.
5.2 The water level of the ground surface is below 70 cm, i.e., an optimum condition for plant growth.
5.3 The possibility of flood occurring during heavy rainfall is minimal.

Nevertheless, it is should also be noted that, while objectives (a) and (c) are highly achievable, objective (b) is subjected to the undulation of the ground surface.

The following sections elaborate the relevant issues pertaining to Option A. The discussion excludes Mandah estate due to the followings :-

a) Mandah's elevation is significantly higher than that of the other estates. Thus, it is logical to isolate the estate's water management system from the rest forming a stand alone system.
b) If the drainage network in the Mandah estates is to be connected to the rest of the drainage system, its areas would face over drainage problem due to the lower invert level of the existing canal, which is 2m above the mean sea level.

12. FOLLOW-UP ACTION UPON ADOPTION OF THE PROPOSED PLAN

Upon the adoption of field layout Option A, the following actions are required.

a) Dredging work at KM 16 to 21

As recommended, to improve the canal navigability in the northern part of the area, dredging work is required at the main canal from KM 16 to KM 21. Table 13 provides the proposed dredging depth for every 100m interval and subsequently the estimated volume of dredged materials, assuming the average canal width is 25m. About 100,000 m^3 of dredged materials is involved. Figure 27 shows the practical guide to dredging works for ensuring adequate depths. The adequacy of dredging depths can easily be monitored via the tide pole located at Rotan Semelor Estate Office at KM 18 (RSE). As the proposed invert level of the dredged canal is to be 3.8m below 0m mark of the tide pole, the amount of dredge depth required can be easily computed by subtracting the present water level depth of the canal.

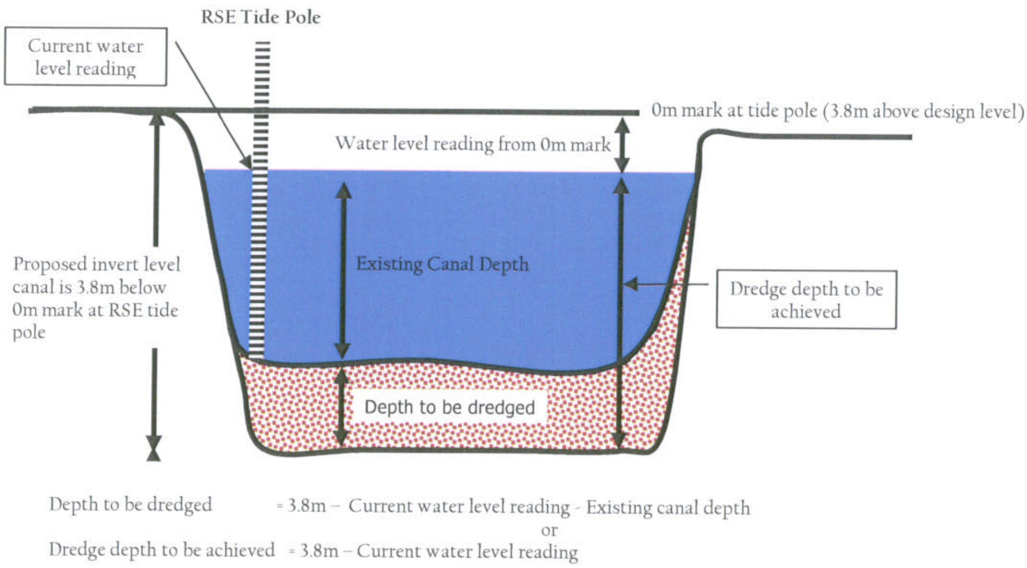

Figure 27. Canal dredging monitoring technique

Table 13. Estimated dredge volume required at KM 16 to KM 21

Chainage (Kilometre)	Existing Inverted Level (m)	Design Invert Level (m)	Proposed Dredge Depth (m)	Average Canal Width (m)	Area	Section Volume (m^3)	Cumulative Volume (m^3)
15.3	0.1	-0.5	0.6	25	16.2	-	-
15.4	0.0	-0.5	0.5	25	13.0	1458	1458
15.6	-0.4	-0.5	0.1	25	2.2	526	3051
15.8	-0.1	-0.5	0.4	25	10.6	518	3666
16.0	-0.4	-0.5	0.1	25	2.5	148	4367
16.2	0.2	-0.5	0.7	25	17.0	1116	5877
16.4	-0.5	-0.5	0.0	25	0.9	71	6823
16.6	-0.3	-0.5	0.2	25	5.1	664	7942
16.8	-0.2	-0.5	0.3	25	7.2	1131	10095
17.0	0.0	-0.5	0.5	25	12.9	849	11509
17.2	0.3	-0.5	0.8	25	20.6	1504	14133
17.4	-0.3	-0.5	0.2	25	5.3	1221	17342
17.6	0.3	-0.5	0.8	25	19.9	2097	21421
17.7	0.7	-0.5	1.2	25	29.8	2485	23907
17.8	1.1	-0.5	1.6	25	40.9	3532	27438
17.9	0.5	-0.5	1.0	25	25.7	3328	30766
18.0	0.4	-0.5	0.9	25	23.3	2449	33216
18.2	0.7	-0.5	1.2	25	30.0	2662	35878
18.3	0.6	-0.5	1.1	25	26.6	2826	38704
18.4	0.4	-0.5	0.9	25	22.4	2447	41150
18.5	0.3	-0.5	0.8	25	21.2	2181	43331
18.6	0.4	-0.5	0.9	25	22.3	2177	45508
18.7	0.7	-0.5	1.2	25	28.9	2561	48069
18.8	0.5	-0.5	1.0	25	24.7	2682	50751
18.9	0.6	-0.5	1.1	25	27.6	2616	53367
19.0	0.5	-0.5	1.0	25	25.9	2675	56041
19.1	0.6	-0.5	1.1	25	27.3	2658	58700
19.2	0.6	-0.5	1.1	25	28.1	2767	61467
19.3	0.6	-0.5	1.1	25	27.4	2776	64243
19.4	0.6	-0.5	1.1	25	28.0	2772	67015
19.5	0.7	-0.5	1.2	25	29.9	2894	69909
19.6	0.6	-0.5	1.1	25	28.2	2902	72811
19.7	0.8	-0.5	1.3	25	33.3	3074	75885
19.8	0.0	-0.5	0.5	25	12.6	2295	78180
19.9	0.2	-0.5	0.7	25	18.2	1541	79721
20.0	0.3	-0.5	0.8	25	19.8	1900	81621
20.1	0.6	-0.5	1.1	25	26.9	2334	83955
20.2	0.9	-0.5	1.4	25	34.5	3068	87023
20.3	0.9	-0.5	1.4	25	34.3	3439	90462
20.4	1.3	-0.5	1.8	25	44.4	3935	94397
20.5	1.4	-0.5	1.9	25	47.5	4594	98991
20.6	1.6	-0.5	2.1	25	52.6	5002	103993
21.0	1.6	-0.5	2.1	25	52.5	5253	109245

b) Alteration to the existing spillway at KM 0

As stated in the previous section and illustrated in Figure 28, the crest height at spillway KM 0 (existing spillway) is to be increased by 20cm as a mean of water conservation measure in the canal during dry season. Such decision is further strengthen by recent observations (January, 2007) which indicates that the ideal water level at the spillway is about 20 cm above the existing concrete beam. Under the same it was also observed that the water level is 1.0 m below the loading ramp (platform) and the banks of the canal for the entire drainage scheme is between 0.5 m to 1.0 m from the water level.

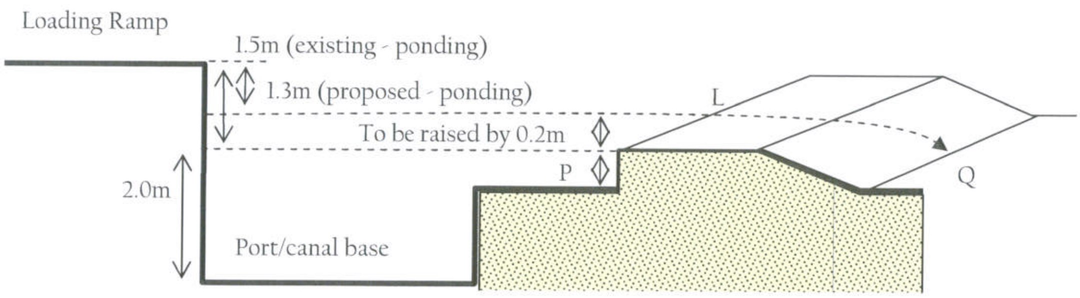

Figure 28. Alteration to existing spillway crest at KM 0

c) Construction of water gates cum spillways at KM 0, 8.5 and 21

During the construction of the spillways, one most important parameter to be seriously considered is the setting of the spillway crest to agree with the water levels in the canal and factory loading ramp. As illustrated in Figure 29, the spillway crest of both existing spillway and water gate at KM 0 must be set to the same elevation.

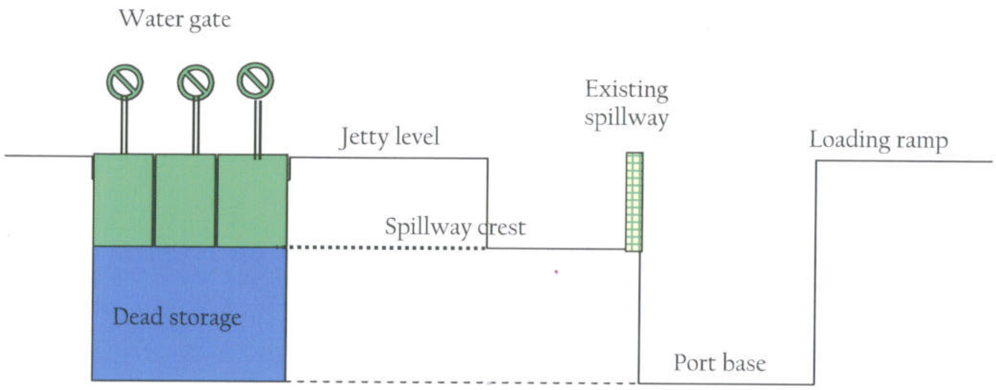

Figure 29. Visualization of spillway crest with respect to loading ramp

Upon completion of the relevant infrastructures proposed under Option A, the execution of the follow-up actions listed below is essential.

a) Dam at KM4.5 on the main canal should be removed to ease mobilisation within the plantation area.

b) Dams at KM13.5, KM18 and KM19 can be removed if the water level difference between the primary and secondary canals is less than 10 cm. Under such situation, the invert level of the secondary canals would be at 0 m above mean sea level. On the contrary, the invert level of the secondary canal at KM 21 is relatively high, i.e., between 0.5 to 1.7 m above mean sea level.

c) Spillway at the dam near Mandah office need to be re-build so as to allow adequate water flowing out of the area to prevent flooding in the Mandah Estate during heavy rainfall.

13. THE PROPOSED CANAL OPERATIONAL MAP

Figures 30 and 31 provide the proposed canal operational plan for the entire scheme during dry and wet seasons respectively.

During dry season all water gates must be completely closed and no outflow is allowed. During wet season all gates must also be closed with outflow only through spillways. During extreme wet season (flooded) the gate is to be opened at maximum capacity in order to provide extra flow out of the plantation areas. Conversely, the spillway at Mandah must be closed at all time regardless of the season.

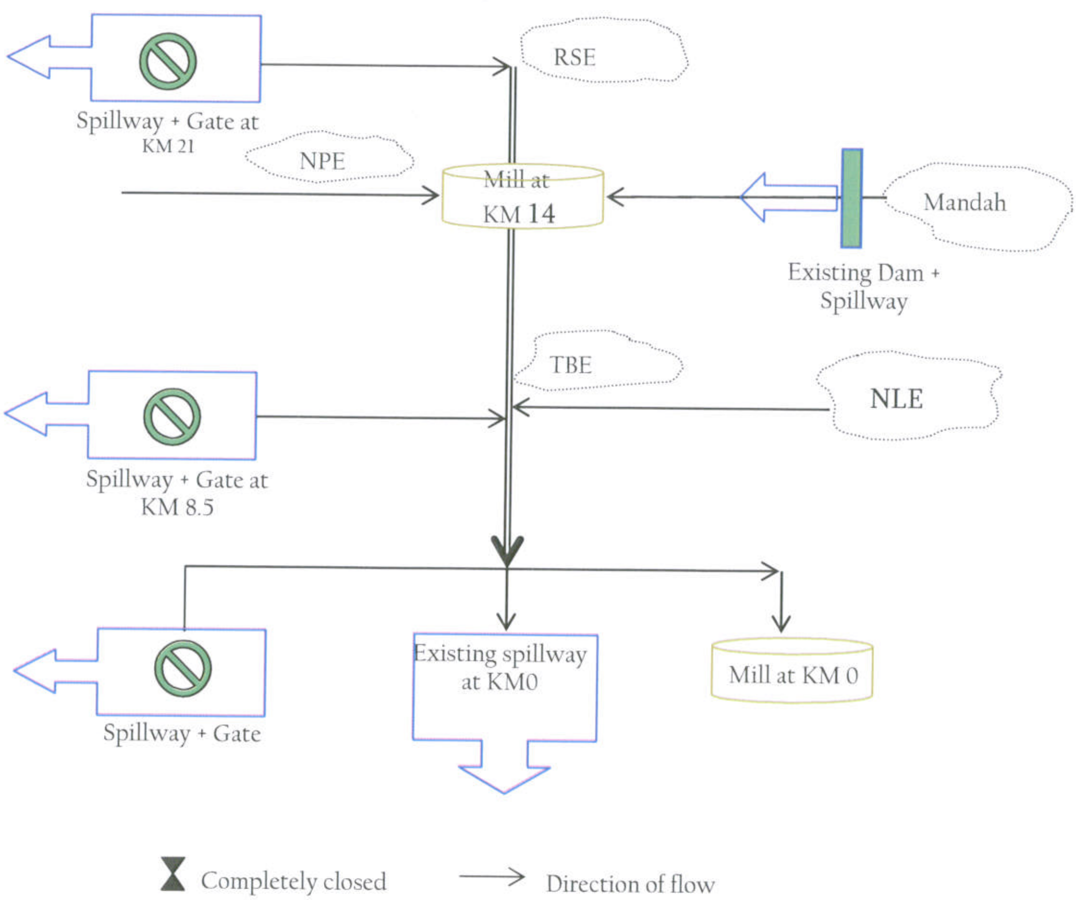

Figure 29. Proposed canal operational map during dry season

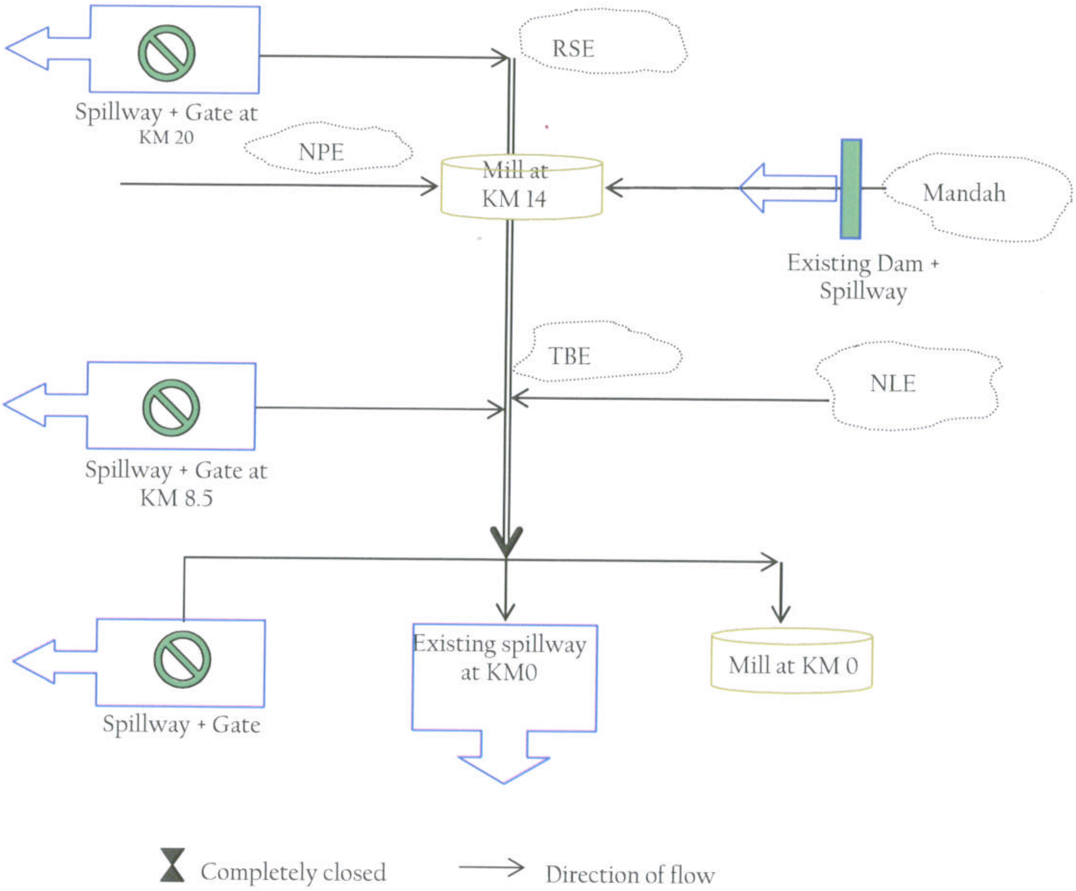

Figure 30. Proposed canal operational map during wet (flooded) dry season

14. POSSIBLE WEAKNESSES OF THE SYSTEM

Even though this study yielded a proposed system sympathetic to the existing hydrologic and topographic conditions, it is far fetched to claim that the proposed system is free of possible flaws. The followings list the probable weaknesses that could be envisaged.

a). The areas along the main canal at KM2 to KM3 are topographically low lying spots and are naturally prone to flooding. The tendency of these areas getting flooded during the wet season is great. Therefore, additional flood protection bund may be required along the KM2-3 of the main canal. A similar scenario is observed in areas beyond the water-gates at KM8.5 and KM21.

b). Construction of hydraulics structures on peat areas is very tedious in the sense that the soil is very loose and unstable. Hanging structures which eventually collapsed are common occurrence in peat areas. Such occurrence is basically due to the settlement of soil and erosion. Under the high flow condition with a strong velocity, bank erosion is more serious which can cause the structures to collapse. To navigate such problem, a continuous monitoring on the hydraulic structures with potential eroding areas such as Spillway gate at KM 0 must be carried out. Effort should also be made to reduce velocity of canal flow upon entering the spillway gate in a way to reduce the erosive forces.

c). Upon adopting the aforementioned field layout plan, the whole canal operational plan is now very much depended on the water level of the spillway at KM0. Ideally, knowing the crest's water level depth at spillway KM 0 would provide the general background of water level in the entire canalization system of the whole area. To verify whether such concept works, a series of water level monitoring stations (preferably equipped with data loggers) should be established so that a continuous water level records can be obtained.

15. CONCLUSIONS

An investigation on the water management scheme at PT Bhumireksa Nusasejati has been carried out. Appropriate and relevant primary field data has been collected and acquired from the company.

Three proposed options, namely, A, B and C were presented. However, Option A is recommended based on present conditions and water management practices. Full implementation of the proposed option would mean that the water level in the canals can be maintained at a level navigable by vessels. Furthermore, the proposed option would result in the water table of the entire area to be maintained at a level desired by the oil palm trees. With the aid of existing structures, the construction of proposed water structures would also ensure that saltwater intrusion will be kept at bay.

Modeling output obtained using HEC-RAS is validated and verified using observed data collected during the study period. As discussed in earlier sections, they are in agreement with the observed data obtained. This is to show that the assumptions adopted during the modeling process are sensible.