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WATER MANAGEMENT IN DEEP PEAT SOILS IN MALAYSIA

VOLUME 1 - MAIN TEXT

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Water Management in Deep Peat Soils in Malaysia

ABSTRACT

The study seeks to develop a field water management system for agriculture in peat soils in Malaysia, with an overall approach of integrating the engineering and agronomic aspects associated with crop production in deep peat areas. This includes the determination of soil physical parameters essential for field drainage design. The main experiments were carried out on a 10.9 hectare plot of land, initially drained 15 years earlier. The results were compared with data collected from a newly opened area and an area drained 40 years earlier.

The findings are

1) Comparison of basic data indicates that the lower and saturated peat deposits generally remain at their initial condition.

2) Moisture content of drained peat areas decreases with time. Rewetting potential is influenced by the initial moisture content before rewetting. Results indicate that as long as gravimetric moisture content, θ_m , is maintained in excess of 400%, irreversible drying may be avoided.

3) The moisture characteristic curve indicates minimal moisture differences between 5 and 15 bar. Therefore the wilting point of local peat can effectively be taken at a suction of 5 bar.

4) Although under similar conditions peat has a high water holding capacity than non peat soils, crops with rooting depths of less than 300 mm may still require irrigation if water table levels are not kept just below the root zone. Crops having such rooting depths include high value crops such as vegetables and flowers.

5) Within the same region, peat has a higher water holding capacity than the non peat soils but WT levels in the peat areas can drop very rapidly as a result of its relatively high hydraulic conductivity of around 5.5 m day^{-1}. The drainable porosity of around 0.38 indicates the substantial storage capacity of the peat soil.

6) The deeper the WT levels the higher the surface bearing capacity achieved. Ground bearing capacity of a fully decomposed peat with a watertable level at the surface can be as low as 5.3 kPa. At watertable levels of 1 m the bearing capacity is only about 50 kPa.

7) Subsidence rate can be very high, increasing with deeper WT levels but decreasing with time. Estimates of subsidence using shrinkage values, increases in ash content and consolidation constants confirmed existing records of Welch et al 1989 for areas drained over 15 years, giving rates varying from 15 mm yr^{-1} to 148 mm yr^{-1}.

9) The agronomic component of the study indicated the sensitivity of yield to moisture condition. Any water management system must take into consideration implications of WT levels not only on crop growth, but also on consolidation, bearing capacity, irreversible drying and subsidence. A water management model for pineapple has been proposed .

The conclusions are

1) Appropriate and adequate water management in crop production must be given due attention not only because of the environmental implication but also because its financial viability is very promising.

2) The implications of peat wastage rates on the economic viability of an agricultural project in peat areas must be analysed for the whole economic duration of the project.

3) If and when further reclamation of peatland becomes necessary, it should be considered in terms of the total perspective of water and land management, environmental implications as well as the created social implications at the end of the life span of the peat deposit.

4) Technically it is possible either to drain the peatlands and turn them into productive agricultural land or, if need be, to utilised the same technology to maintain wetland status of the area or pockets of the area.

5) An integrated body comprising of scientists, agronomists, foresters, conservationists, engineers and others must be set up to study and recommend a National Policy and Masterplan for peatland utilisation in the country.

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ABBREVIATIONS

A	ash content
AWC	available water capacity
BM	bench mark
C_c	compression index
D	height of the water level in the drains above the impervious floor
d	Hooghout's depth to the impermeable layer
DID	Department of Irrigation and Drainage
DOA	Department of Agriculture
dS	peat subsidence
e	void ratio
e_o	initial void ratio
F	fibre content
FC	Field capacity
g	gravity
GI	galvanised iron
GL	Ground level
G_s	Specific Gravity
h	difference in water table and water level in the drain
H_i	incremental depth of peat deposit
h_o	initial h
HP	Hydrological Procedures
h_r	relative humidity
h_t	h at time t
IPRS	Integrated Peat Research Station
K	saturated hydraulic conductivity

L	drain spacing
m	moisture content of soil sample
MARDI	Malaysian Agricultural Research and Development Institute
MSL	mean sea level
OW	observation wells
p	drainable porosity
p_f	final pressure
pF	log of suction (suction in cm)
p_i	initial pressure
PWP	permanent wilting point
q	drainage coefficient
r_t	tube radius
SEG_{60}	Sum of exceedence of water table above 600 mm (60 cm) for entire growth period - weekly values
t_{90}	time taken to reach 90% of the primary consolidation
WJIADP	Western Johore Integrated Agricultural Development Project
WP	wilting point
WT	water table
θ_m	gravimetric moisture content
θ_v	volumetric moisture content
ρ_d	dry bulk density
τ_s	the surface tension of water
ρ_w	density of water

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CHAPTER 1 - INTRODUCTION

1.1 General

1.1.1 Research Identification

Malaysia has a total land area of about 33 million hectares of which an estimated 42% is suitable for agriculture (Cheong C.L., 1979). Peat soils cover an estimated 2.4 million hectares or 7.2% of the total land area (Md. Yusof, H., 1984). As of 1985, only about 10 % of these peat areas have so far been developed for agriculture (Anon, 1985i). Figure 1.1 shows the location of the peat deposits, both in Peninsula Malaysia, Sabah and Sarawak. As can be seen these are located along the coastal areas. These coastal fringes are essentially flat lands and are also population centres as well as industrial centres. The agricultural sector employs more than one third of the available manpower and contributes around a fifth to the gross national product and to the gross export value (Anon, 1986). It also significantly affects the manufacturing sectors. Such proximity, substantial hectarage on flat areas, and importance, therefore, ensures that these peat areas receive substantial focus.

Farming on peat areas has by necessity been preceded by drainage. Drainage schemes in Malaysia, especially those involving small scale farms comes under the purview of the Department of Irrigation and Drainage (DID) of Malaysia. Peat areas until recently were not actively pursued as agricultural land (Anon, 1973). In existing agriculture development on peat, drainage design is based on storm drainage criteria with some cognisance given to the organic nature of the peat. These include building drainage control structures in the secondary drains to prevent excessive drawdown as well as lowering the invert of concrete structures below design level to allow for the expected subsidence of the surrounding area (Salmah et al, 1989). However the design is heavily biased towards flood control and its alleviation. This is understandable considering the high average annual rainfall and the absence of soil physical design parameters required for field drainage designs. Thus the necessity and economic viability for detailed field drainage designs has not yet been tested.

Classified under HISTOSOLS by the USDA Soil Taxonomy System (Soil Survey Staff, 1975) peat was defined at the Second International Congress of Soil

Science, Russia, 1930, as an organic soil covering an area greater than 1 hectare, with a depth greater than 0.5 metres and containing less than 35% mineral content. Peat is made up of organic plant material in which its overall decomposition has been exceeded by deposition. Peat deposits can be found in hilly areas of continuous high humidity or in enclosed lowland basins. The peat types that are found in Malaysia and in most South East Asian regions are mostly the lowland, oligotropic, woody type and it is this type of peat (unless otherwise stated) that is being described in this thesis.

1.1.2 Location and Climate

Located between latitude 7°40' N and 0°50' N in South East Asia (Scott, D.A., 1989), Malaysia virtually lies within the equatorial belt. The country lies between longitude 99°35' E and 119°20' E and is made up of two parts, the peninsula states and the states of Sabah and Sarawak. The peninsula is almost surrounded by sea with the Straits of Malacca to the west and the South China Sea to the east. The states of Sabah and Sarawak are part of the island of Borneo and separated from the peninsula by the South China Sea.

Temperature differences between day and night are relatively small and constitute the main variation in temperature. The daily minimum temperature varies between 20°C to 25°C while the daily maximum is between 26°C to 33°C giving a daily average temperature of around 26°C. The difference in daily maximum and minimum averages around 7°C.

The climate has a very limited variation in solar radiation during the year. The total average hours of sunshine per annum is between 2000 to 2600 (Dale, 1964) increasing from south to north and from east to west. Departures from the mean annual values of sunshine vary from ±5 to ±13%.

The equatorial belt is the wettest of the major climatological zone with average annual rainfall exceeding 1500 mm. Because of Malaysia's maritime location, its annual average rainfall is much higher, generally between 1750 mm to 5000 mm. Rainfall distribution is dependent on location and is influenced both by the Northeast monsoon and the Southwest monsoon. In the project area the rainfall is fairly well distributed over the year (Figure 1.2).

Daily evaporation averages around 3 to 4 mm. and with annual total of around 1600 mm. There is a general decrease in evaporation with increasing distance from the coast and with increasing elevation. The monsoon also affected the evaporation rate with the winds associated with it bringing higher rates of evaporations.

The peninsula has a continuous high humidity with higher values on the coast. Mean average humidity generally exceeds 80% with daily humidity fluctuating between 55% and 75% rising to above 95% at night (Scarf, 1976, Nieuwolt, 1965)

Surface winds are generally light and stronger along the east coast. Average wind velocity ranges between 2.6 m s^{-1} to 0.7 m s^{-1} (Scarf, 1976).

1.2 Problems in peat reclamation

1.2.1 Poor Accessibility and Subsidence

Malaysian peat is woody and has a very low bulk density averaging around 0.1 Mg m^{-3}. In its natural condition it is wet and waterlogged and has very poor bearing capacity. Its utilisation has to be preceded by drainage to allow accessibility and farming practices. When drained, its volume decreases resulting in subsidence. Subsidence following drainage involves a combination of three processes, namely

i. dewatering; where the loss of suspending fluid results in rearrangement of the soil particles into a more compact mass and on drying the shrinkage of the soil mass
ii. compaction and consolidation of the underlying layer as a result of farming practices and increase in over burden pressure and
iii. peat wastage as a result of oxidation/mineralisation of the organic material

Following drainage, water flows out of the deposit and the water table in the soil is lowered. The layer above the water table ceases to be in part suspension and rearranges itself into a tighter pack. The particles above the water table are no longer submerged and as a result the peat starts to dry out and in the process it shrinks. It not only shrinks, but because it has now lost its buoyancy the deposit above the water table exerts an increased overburden pressure on the lower deposits, consolidating it further. All this is reflected in the substantial initial subsidence of drained peat areas. Once drained, air is able to enter the deposit and continued decomposition is possible. This leads to further mineralisation of the deposit resulting in loss of matter. Thus the first process involves the reduction of moisture content in the peat deposit itself, the second process results in moisture loss of individual particles and in the third process, the peat mass itself reduces upon oxidation, all with resultant loss in volume.

Subsidence of peat has been recorded at 26 mm yr^{1} and 36 mm yr^{1} at two MARDI (Malaysian Agricultural Research and Development Institute) peat research stations (Md. Sharif et al, 1986). Detailed monitoring of peat subsidence in the south of Peninsula Malaysia over 15 years shows higher subsidence rates for the deeper deposits. The rates range from 15 mm yr^{1} for a deposit with initial depth of 2.4 m to 148 mm yr^{1} for a deposit of more than 6.1 m deep (Welch et al, 1989). A pineapple estate in Pontian recorded a subsidence of 1.3 m from 1967 to 1987 (Tay et al, 1987). Thus while it takes between 4000 to 5000 years for a peat deposit of 6 m deep to form (Anderson, J.A.R. 1974), at an average subsidence rate of 25 mm per annum, it can take only about 240 years for it to be depleted. If the subsidence rate is higher say at 50 mm per annum, the deposit of this depth could be depleted in the next 120 years. A shallow deposit of less than 3 m can be expected to be completely mineralised in less than half the time mentioned above. Already some parts of the Sungai Pinggan area, in Western Johore, previously about one meter deep 10 years ago, have now reached the acid sulphate layer. This in effect will declassify such areas from peat soils.

1.2.2 Poor Nutrient provider

The Malaysian peat is very acidic and deficient in essential nutrients (Md Sharif et al, 1986). The peats are underlain largely by marine clay and/or sand (Anderson, 1964, Ismail, 1984) and in some cases by potential acid sulphate soils. In potential acid sulphate areas, the lowering of the water table below the acid soil, will release the acid potential of the soils making them unsuitable for agriculture.

1.2.3 Changing Physical Properties

Peat physical properties such as bulk density, porosity, hydraulic conductivity are expected to change with drainage and with time. This is due to changes in the peat structure as a result of continued decomposition. The rate of decomposition is a function of climate, water management and cultivation practices. Appropriate water management and cultivation practices will only retard the process of decomposition and possibly lengthen the life of the peat deposit. The rate of subsidence may also change with time. The problems of farming on peat in Malaysia is further compounded by the presence of buried timber and tree trunks. All these changes will affect drainage design and ultimately the project economic viability.

1.2.4 Lack of Physical Design Data

Research work in Malaysia, quantifying peat properties in terms of agronomic requirements as related to nutrition has been prolific but with much less work on the physical side. Examples are work by Kanapathy (1975) on general and fertiliser requirements for maize, sorghum, groundnuts, etc, Dunsmore (1957) and Wee (1968) on pineapple cultivations, Chew (1982) on congo jute and kenaf, Cheong S.P. (1977) on oil palm. Ahmad et al (1975) considered peat for sago palm production while Bachik et al (1986) looked at rubber. In 1980 Tay submitted his research findings on the optimum water table requirement for pineapple in peat. These experiments were followed by other researchers studying optimum water tables for cassava and asparagus in lysimeters. Ismail (1984) looked into the physical properties such as changes in bulk density, fibre and ash with depth. A comprehensive inventory of the physical parameters and how they change with time and in varying moisture regimes is still however not available.

1.2.5 Environmental Factors

It has been recognised that drainage of peat areas will bring irreversible changes to the peat area and its ecosystem. The continued process of decomposition to completion arises through chemical reaction of oxygen with the peat material and biochemical action of bacteria and other animals on the peat substrate. The deposit will only stop decomposing if it is returned to its initial condition of complete saturation or if the entire organic content has been fully decomposed and utilised. Drainage therefore marks the beginning of the end of the peat deposit.

Any man made project that utilises natural resources has an impact on the ecological system. The effect of the possible total destruction of 2.4 million hectares in Malaysia (and a possible 16 million hectares in neighbouring Indonesia) of peat ecosystem may have distinct and irreparable consequences on local as well as global climatic factors. The fact remains however that these peat areas can be turned into profitable agricultural land despite their inherent infertility. Already thousands of families are depending on peatland agriculture for their livelihood.

Reclamation of peatland should be considered in terms of the total perspective of water and land management, environmental implications as well as the created social implications at the end of the life span of the peat deposit.

As drainage marks the beginning of the end of peat deposits, an optimum design strategy is needed to ensure peat deposits are to be fully utilised. This research attempts to identify this optimum design strategy.

1.3 Research Objectives

The primary objective of the study is to develop a field water management system for agriculture in peat soils in Malaysia taking into consideration all its inherent properties.

Other secondary objectives in relation to the above are to identify ways of

i. minimising aeration stress in wet periods
ii. minimising moisture stress during dry periods
iii. minimising the peat wastage rate
iv. providing an adequate bearing capacity for farming activities including mechanical operations

1.4 Scope

The study was largely confined to a 10.9 hectare plot at the Integrated Peat Research Station (IPRS), MARDI, Pontian. This particular area, Figure 1.3, was initially opened around 1971 but was later left under secondary growth. Where necessary and for comparison purposes tests were carried out on peat deposits in the surrounding areas.

Specific aspects investigated in this study include

i. determination of Malaysian peat physical properties such as hydraulic conductivity, drainable porosity, water table drawdown, water table shape, capillary fringe, rate of capillary rise and rewetting potential
ii. changes in moisture content, bulk density, fibre and ash content with depth following drainage
iii. field experiments on cassava and pineapple with different water table depths
iv. bearing capacity of peat soil at different water table depths
v. consolidation properties of the peat soil
vi. three dimensional analysis of subsidence of a peat plot area over a 4 year period
vii. field drainage system requirements for Malaysian peat

The overall approach was to bring together the engineering and agronomic aspects associated with crop production in deep peat areas. The final analysis takes into account the present drainage system of the whole area in general and the peat area in particular and the results of the study are assessed within the context of these systems.

CHAPTER 2 - REVIEW OF LITERATURE

2.1 Water Management in Peat

2.1.1 General

Peat land crop production is similar in many respects to crop production on other types of wet land and soils. Drainage is required and aeration stress and moisture stress for crop production must be minimised. The difference with peat is the added dimension that is brought about as a direct result of the organic nature of the peat soil which tends to waste away. Peat soil in its natural state has very low bearing capacity which can be improved by lowering the water table. Low water tables however, not only improve bearing capacity but accelerate the rate of decomposition and therefore increase the peat wastage rate. For minimum moisture stress and minimum peat wastage rate the water table has to be kept as high as possible, where as for minimum aeration stress and adequate bearing capacity the water table has to be kept as low as possible. Thus water management in peat areas involves an economically viable and delicate balance of these two opposite requirements in order to optimise crop production.

2.1.2 Non Tropical Peat Areas

Peat deposits in temperate areas are either of the lowland type or that of the raised bogs. In Ireland the blanket peats along the coast are highly gelatinous and have very low permeability of approximately 0.01 m day^{-1} (Galvin, 1972). These peats vary in depth from 1.5 m to 6 m and have water tables varying from ground level (GL) to 250 mm below GL. In this blanket peat, analysis showed that the critical depth for drains is 1 m with deeper drains creating a region of reduced hydrostatic pressure in the deposit close to the drains. The large release of gas in this region of reduced pressure results in further reduction of permeability as the gas bubbles clog the pores. The raised bog peats have permeabilities of approximately 0.8 to 0.16 m day^{-1}. At 1 m depth, drain spacing in the area would have to be 5 m apart and drainage would be expensive using conventional methods. Reclamation of this type of peat for grassland has been effective by proper surface grading and planing.

In the Netherlands peat reclamation since the 11th century has lowered the surface of the land from a few metres above the mean sea level (MSL) to a few metres below it. Where peat is still present land use has been converted, during the 15th century, from arable cultivation to grassland. Presently these existing peat areas are now 1 to 2 metres below MSL and are served by parallel ditches with water levels at 300 mm to 400 mm below GL. There is a tendency to lower the water levels to between 400 mm to 800 mm below GL to increase its bearing capacity. Water in the ditches is regulated by being pumped into the arterial system by either diesel or electric pumps (van der Molen, 1981).

Peatland farming in the Wash in England began during the Roman times. Its utilisation accelerated in the 17th century with the construction of drainage systems by the Dutch engineer, Vermuiyden. Substantial subsidence arises as a result of the effective drainage and to date the drainage system comprises of two systems, the high level drains for draining the water to the sea and the low level system for lifting water out of the field drains into the main drains. Wind mills were initially used for pumping the water, these were followed by steam, diesel and present day electric pumps. The difference between the field and the embankments of the high level drains in some areas can be as much as 6 m (visit to Ely, 1986). Records of subsidence from the Holme post from 1848 to 1932 gives a value of 3.5 m. The surface soil has also now nearly reached the subsoil as indicated by its lighter colour. Smith (1969) estimated that the loss of about 600 mm of peat depth in the 30 years from 1969 to around the turn of the next century will convert 75% of existing peat soil into skirtland. In the Somerset Levels in South West England, it was observed that some areas utilise small automatic diesel pumps to control the water levels in the field ditches (Taunton visit, 1986 and ADAS, 1985). The field ditches act as reservoirs. As the water level in the field ditch rises above the maximum design level, the pump is automatically triggered and water is pumped from the field ditches into the laterals and stopped when it reaches the minimum design level in the field ditches. Both levels are controlled by float sensors. This allows sufficient outfall at all times for water to drain from the field into the field ditches.

New Zealand has peat soils exceeding 180,000 hectares. In these areas the main drains were designed to meet the general requirements similar to drains in mineral soils. Field drains are provided either in the form of ditches, 350 mm deep and spaced at 10 metres, or by subsurface pipes. In woody peats, pipes are not installed due to the presence of buried timbers making trenching difficult. Mole drains are favourable in reasonably consolidated peat with no buried timbers. Although agriculture on New Zealand peat can be worthwhile (Van der Elst, 1978, and Wallace, 1978) alternative uses are being looked at such as wildlife habitats, recreational areas and scientific research (Cheyne, 1978 and Mcdowal, 1978). Thomson, 1978 stresses the need for a peatland "suitability survey" and for large scale and long term planning.

2.1.3 Tropical Peat Areas

The Florida Everglades in the United States of America, is a continuous body of subtropical peat exceeding 800,000 hectares (Shih, 1980) with depth ranging up to 3.7 m. The area was initially drained by gravity systems in 1909. Laterals were provided at intervals of 0.8 km with farm ditches spaced between 400 to 200 metres apart. The closer spacings were for vegetables or truck crops. Mole drains at depths of around 760 mm and spaced between 3.7 m to 4.6 m were used for subdrainage and subirrigation purposes. Using a 150 mm diameter mole foot, holes of approximately 114 mm diameter were formed that lasted for five to eight years (Clayton et al, 1942). The first few years of effective drainage resulted in a subsidence rate, in some areas, of about 150 mm per annum. The gravity system became ineffective as a result of the subsidence and the subsidence rate itself, then, levelled off. It increased again, albeit at a slower rate, when pumping was introduced. Most pumps in use are reversible, water being pumped only when needed, thus controlling the water level during the dry periods. With continued subsidence, it is expected that the Everglades which are underlain by sedimentary limestone will be too shallow for agriculture by 1990 (Stephens, 1969). Shih, 1980 proposed some modifications to the water management which included

i. seepage control between the main canal and the adjacent field in the form of a field ditch. The field ditch, constructed to bed-rock should discharge seepage water into the laterals.
ii. land forming either in the form of land grading, land levelling or land smoothing to correct uneven ground elevations. This allows for better water control during subirrigation and subdrainage as well as improving surface irrigation and drainage.
iii. aquaculture system for crops that can withstand wet and flooded conditions.

A peat pilot scheme of 970 hectares in the Mediterranean climate of Alicante and Valencia in Spain (Gil Sanchez et al 1982) is being drained by a system of laterals designed at spacings according to the hydrological soil characteristics. Water from the main drains is discharged by pumps into the main water courses. The whole area is protected by a dike. Irrigation is supplied on demand using a sprinkler system.

The Indonesian lowland peats cover an estimated 26.3 million hectares (Driessen et al 1975). The reclamation and drainage of these peat is still in its early stages. Gravity drainage is employed in the peat domes for the cultivation of perennials such as coffee, citrus, coconuts, oil palm and rubber. A visit in 1988 to a commercial coconut plantation on the east coast of Sumatra, first drained in 1985, identified the provision of gravity drainage and water controls through a system of laterals and multiple wooden weirs. These laterals were also used as waterways for the transport of both farm inputs and outputs. Where reclamation is for transmigration purposes areas suitable for rice growing have been included and this is usually in shallower peat of less than 2 m thick (Hardjoso, 1987).

2.1.4 The Malaysian Experience

Most of the peat wetland areas in Malaysia are in the lowland flood prone areas. As such the priority factor in developing such areas is to ensure a flood free environment that can guarantee a reasonable standard of living for the farmers in the area. At the time of the Western Johore Integrated Agricultural Development Project (WJIADP) appraisal in 1973 (Nesadurai, et al, 1973) peat deposits in Malaysia were still looked upon as a deposit that should be used up as fast as possible so that the underlying mineral soil, expected to be more fertile, can then be economically utilised.

With these two factors in mind, i.e. a flood free environment and quick removal of the peat deposit, it was therefore understandable that drains in the peat area in WJIADP, Phase I and II, were designed using criteria heavily influenced by the requirement for a flood free environment. The design provides an arterial system catering for storm drainage and uses 1 in 5 years return period, 72 hour storm duration for secondary drains and 1 in 25 years return period, 72 hour storm duration for the primary drains. This equates to discharges of 10 l/s/ha and 21 l/s/ha for storms with return periods of 5 years and 25 years respectively. The drain cross sections were designed in such a way that the primary drainage channels together with their embankments can retain peak flows of the 25 year storms whilst the actual cross sections excluding the embankments can cater for the 5 year peak flows (Anon, 1985i). Another major consideration was to ensure crops were able to withstand flooded conditions without yields being adversely effected. As cocoa and coffee are more susceptible to flooding than oil palm, the respective surface drainage criteria adopted for each is 8 l/s/ha and 6 l/s/ha respectively. Field drains were recommended to the farmers to be constructed at distances of 40 m to 100 m. These drains are in most cases not deeper than 700 mm, with a bed width of 1 m and usually run along the boundaries of the farmers land (Anon, 1985i).

As cross sections of the drains were designed to cater for the respective design peak storm discharges, the drains at other times are therefore effectively oversized. Controls are provided to prevent excessive drainage during dry periods but there is difficulty in ascertaining the appropriate time for gate closures. As dry periods occur on a regional basis it is difficult to channel water from within the region into the peat area. To take into account future subsidence, invert levels in control structures have been depressed between 300 to 450 mm below design levels. The actual rate of subsidence was not available at project commencement and in the event has been under predicted. Thus problems previously not encountered such as hanging control structures and bridges occurred within a few years after project construction. Other problems such as cracks in pavements and walls of buildings also emerged. It has since also become known that potential acid sulphate soil underlies substantial areas of peat deposit on the west coast of Peninsula Malaysia and that on the east coast the deposit is underlain by sand.

2.2 Peat soil

2.2.1 General

Peat is made up of accumulated remains of undecomposed and partially decomposed plant material and is not a spatial or temporal single homogeneous substance. Peat deposits occur in any type of climatic zone and can be found either in hilly areas of continuous high humidity or in enclosed lowland basins. The single common factor in all peat occurrence is the presence of moisture. In its natural condition peat has a high water table, frequently reaching the ground surface. Peat deposits have been classified into various groups according to the field of study that the deposit is subjected to and the different needs that the peat will serve. Table 2.1 lists some of the common names under which the deposits have been grouped. Under the USDA Soil Taxonomy System (Soil Survey Staff, 1975), peats are grouped under Histosols, and are further classified into sub-order, great group, sub group, family and series. In general the suborders of Histosols are defined by the moisture regime and by the degree of decomposition.

The peats found in Malaysia are mostly the lowland types and have been described as topogeneous, ombrogeneous and oligotrophic peat. Topo because it occurs in basins as a result of topographical features, ombro because the source of water for its formation is assumed to be from rainfall and oligo because of its inherent infertility. In general these peats are dark brown in colour, spongy and contain large quantities of woody materials at varying stages of decay. Peat depth ranges from 0.6 to over 15 meters. These lowland peats occurring close to sea level developed during the post Holocene period some 4000 to 5000 years ago. The sea rose to its present level and stabilized about 5000 to 6000 years ago following the last regressional phase which took place after the Wurm glacial period at the Pleistocene-Holocene interface some 11000 years ago (Anderson 1964, 1974). The classification of Malaysian peat differs from state to state. In Peninsula Malaysia the Department of Agriculture (DOA) uses the percentage loss on ignition to separate the different types of organic soil (Table 2.2). Peat areas have also been classified into four phases, Table 2.2, based on peat depth (Ab Jamil et al, 1989).

2.2.2 Chemical Properties

Organic Constituents

Raw material for the formation of peat comprises mainly plant materials such as cellulose, lignin, resins, etc. Mineralisation or decomposition tends to be an on-going process producing new compounds or releasing carbon dioxide, water and energy (Walmsley, 1977).

Ash Content

The mineral constituents are derived from decomposing plant materials as well as from water flowing from mineral soils and wind borne minerals deposited by rain. They are incombustible and ash forming and are quantified as a percentage of oven-dry weight. The usual procedure when ashing, is to fire an oven-dried sample in a muffled furnace at 700°C where the loss in weight is attributed to disintegration of carbonates. Values from less than 1% in undecomposed peat to over 40% in highly decomposed peat are obtained (Walmsley, 1977). Day et al, 1979, ashed the peat at 600°C for 3 hours.

Although the ash content may exceed more than 65%, Malaysian peats frequently have ash contents less than 5% (Ismail, 1984, Jalaludin et al, 1979).

Organic Carbon and Carbon:Nitrogen Ratio

Organic carbon content ranges from 27% to 53% and does not seem to be influenced by peat type. Carbon:nitrogen ratio is expected to be characteristic of peat type as the nitrogen levels differ for different peat types. The ratio for moss peats is about 20:1 while a ratio of 60:1 is common for very acidic organic soils (Walmsley, 1977).

The carbon:nitrogen ratio of Malaysian peat is about 40:1.(Ismail, 1984, Jalaludin et al, 1979).

Total and Available Nutrients

Organic soil contains very little nitrogen in inorganic forms. Organic soils of negligible ash content, with pH below 4, often have a nitrogen content of less than 1%. Phosphorus in peat soil is mainly present in mineral forms as compounds of aluminium, iron and calcium phosphates. Most of the forms of phosphorus are considered immobile. Potassium content tends to be low in organic soils and the presence of other minerals such as calcium, manganese and iron is dependent on the influx of water from surrounding mineral soils (Walmsley, 1977).

Malaysian peat has a total nitrogen content of about 1.5% of its dry weight. Of this less than 1% is in mineral form. Available nitrogen, sulphur and phosphorus are very low as is magnesium, iron, copper, manganese and zinc.(Chew, 1982, Tay, 1980 and Joseph et al, 1974).

Cation Exchange Capacity - CEC

The magnitude of CEC in peat is a function of moisture content, parent material and base content (Puustjarvi et al, 1975). It ranges from 131 to 200 meq per 100 gm for moss peat to 100 to 192 for sedge peat (Walmsley, 1977).

Malaysian peat has CEC of 145 meq per 100 gm. This is mainly due to high H^+ ion contents of between 88 to 170 meq per 100 (Zahari et al, 1982)

Acidity

Organic soils have acidities ranging from pH below 3.0 to 8.0. Acidity may have an overriding influence on the composition of peat because of its effect on vegetation and the rates and product of decomposition. Different methods of measurement may give different pH values. Values obtained using water extract may give higher values than direct insertion of electrodes in peat samples (Walmsley, 1977).

pHs of 3.5 to 3.8 are commonly found in peat in its natural state in Malaysia (Jalaludin et al, 1979). Work by Ismail (1984) using 0.15N $CaCl_2$ however, showed that about 80% of his samples had a pH of between 2 and 3 with higher values of pH more than 3 being confined to soils under cultivation.

2.2.3 Physical Properties

Fibre content

There are generally two alternatives for soil particle size analysis, either dry sieving or wet sieving. In peat the fibre content is also important as this can indicate the degree of decomposition of the peat deposit. The fibre content also affects the bulk density and water holding capacity as well as colour. Under the USDA Soil Taxonomy system, Farnham and Finney (1965) selected 0.1 mm as the minimum fibre size. Deposits with more than two thirds bigger than 0.1 mm of the total mass are classified as fibric, two thirds to one third as hemic and less than one third as sapric. Under the System of Soil Classification for Canada, the minimum fibre size is chosen as 0.15 mm, and it is fibric if the amount exceed 67%, mesic if it is from 33 to 67 % and humic if it is less than 33%. Methods for determining the fibre content are given in detail by Day et al, 1979, but for the Malaysian woody peat the methods may have to be modified to include some of the buried timber in the analysis.

In his study, Ismail (1984), found the rubbed fibre content to be between 10 to 70%, but no method of analysis was given.

Bulk density

Bulk density is obtained by oven drying a known volume of soil at 105°C to a constant weight, usually for 48 hours. The normal volume weight sampling is the cylinder method, taking undisturbed samples using a sharp edged cylinder. For samples with depth a corer would be required with samples for each depth cut from the cored soil sample. A relatively new auger, the gouge auger takes half cylinder sample with depths. Other more involved methods such as the paraffin, and mercury displacement methods are also available. As soil volume changes with water content. the bulk density is calculated on a wet bulk volume. The bulk density of peat may range from 0.06 to 1.2 Mg m^{-3} (gm/cc) (Walmsley, 1977, Ismail, 1984). In peat, higher bulk density values indicate higher mineral content, or/and a higher degree of compaction or decomposition. Results from Badr et al (1978) showed decreases in value of bulk density with depth but also significantly higher values for developed as compared to undeveloped peat deposit.

Studies by Ismail (1984), gives values of bulk density for the top 100 mm to be between 0.1 to 0.35 Mg m^{-3}. The range decreases with depth from 0.06 to 0.2 Mg m^{-3} at 200 to 300 mm below surface to around 0.1 Mg m^{-3} at a depth of about 500 mm. The higher values near the surface are attributed to agricultural activities.

Specific Gravity

The specific gravity of peat has been found by various researchers to range from 1.1 to 2.7. It is generally agreed that specific gravity greater than 2.0 indicates considerable mineral contamination. The standard approach for measurement involves the use of a pycnometer. Care needs to be taken because of the large amounts of entrapped air.

Moisture Characteristics

In many soils field capacity varies between suctions of 1 m (0.1 bar) to 3.3 m (0.33 bar) and is achieved in the field one to two days after irrigating. Wilting point is commonly taken to be at 150 m or 15 bar suction (Marshall et al, 1979, Lucas, 1982). In peat because of the high porosity, the rate of water release at lower suctions is expected to be higher than at higher suction. For well decomposed peat the volumetric moisture content (volume basis) at saturation and 0.1 bar suction have been found to be 85% and 72% respectively while for the more undecomposed sphagnum peat it is 90% and 31% respectively. Crop productivity in peat decreases significantly as the volumetric moisture content drops to below 30%. This occurs at around 5 bar suction (Lucas, 1982). In peat, gravimetric moisture content (dry weight basis) as high as 3,235% has been recorded at saturation (Walmsley. 1977). Because of the changing volume as peat dries, Boelter and Blake, 1964, were of the opinion that moisture content should be expressed on a wet-volume basis together with the state of wetness, such as 0.1 bar suction. Dyal (1960) showed that although moisture content at low suction decreased with increased decomposition, highly decomposed peat retained more moisture at higher suctions. For undecomposed peat at low suction, a small change in suction may release substantial quantities of water and this will result in a significant change in moisture content. Sturges (1968) found that samples of low bulk density contained many large pores which released water easily while samples with high bulk density had smaller pores and retained more water at higher suctions. Badr et al (1978) showed that although water is released at somewhat lower tensions for the undeveloped peat, soil characteristics for the deeper layers are essentially unaffected by agricultural development.

Methods for determining the moisture retention curve differ with the suction range. The porous plate can be use for determining moisture at the lower ranges of suction. The range depends on the type of porous material used. Sand passing the 1.5 mm sieve can take suction up to 1 m while sintered glass up to 10 m (Anon, 1987). The pressure plate can be used for pressure ranges of 1 to 150 m, while the pressure membrane is suitable for pressure ranges of 20 m to 150 m. Dyal (1960) reported that both the pressure plate and pressure membrane procedures as used in mineral soils, satisfactorily measured water retention properties of organic soils. The vapour pressure method is normally used for the higher ranges of suction.

Ismail (1984) showed that at field capacity, the gravimetric (mass per unit bulk volume) moisture content decreases with increase in bulk density. At a bulk density of 0.07 Mg m^{-3} moisture content of as much as 1060% was recorded and at 0.33 Mg m^{-3} a moisture content of 165% was recorded.

Void Ratio, Total Porosity and Drainable Porosity

Void ratio indicates the potential compressibility of the peat deposit. A higher ratio indicates greater potential of compressibility. Void ratio values of 2 to 25 and/or total porosity of between 80% to 98% have been reported by Puustjarvi et al, 1975 and Walmsley, 1977. At saturation the volume of water is assumed to equal the total pore volume. Drainable porosity is normally taken as the difference between the water content of soil at saturation and at field capacity. It is important as it governs the degree to which the water table will rise or fall for a given change in volume of water.

Hydraulic conductivity

The saturated hydraulic conductivity (K) is one of the major parameters determining drain spacing requirements. Both laboratory and field methods are available for the measurement of hydraulic conductivity. Boelter (1965) found that the laboratory methods give significantly higher values than the field methods. This can be attributed to leakage along the interface of the core and cylinder walls. The field methods usually cover a bigger sample area and are more representative of actual field values. The piezometer methods measure the horizontal value while the tube methods measure the vertical value. Boelter also found no significant difference between the two values. The auger hole method measures a larger and deeper sample than the piezometer and gives consistently lower values of K than the piezometer methods (Talsma, 1960). Due to its smaller sample size, the piezometer methods require more measurements for the same amount of accuracy. Better agreement with the auger hole methods may be achieved by lowering the piezometer cavity deeper. K value is a function of peat type and formation. For moderately decomposed woody peat at 350 mm to 450 mm depth Boelter (1965) obtained a K value of around 4.3 m day^{-1}.

Laboratory K values of Malaysian peat using the constant head permeameter method was found to vary from 142 m day^{-1} for the top layer of a secondary jungle to 0.05 m day^{-1} for a layer 150-300 mm depth in a cultivated banana area (Ambak, per comm).

Capillarity

The interstices between the soil particles are known as pore spaces. There are two types of pores, the non-capillary and the capillary pores. The non-capillary pores are relatively large and can be readily emptied. The soil is said to be saturated if all the pore spaces are completely filled with water. For most crops, prolonged saturation or waterlogging, causes an oxygen deficiency as the roots are not able to take in oxygen through the soil water. Under adequate drainage conditions these pores function as channels for the exchange of gases.

The capillary pores are small and important for the storage of water for plant growth. Capillarity arises as a result of attractive forces between molecules. Assuming the contact angle between water and a continuous tube is zero, the column of water, h, held above the water table, can be calculated from (Marshall et al, 1979)

$$h = \frac{2\tau_s}{r_t \rho_w g} \qquad \text{--- 2.1}$$

where

r_t = tube radius
τ_s = the surface tension of water
ρ_w = the density of water
g = gravity

Thus with all other parameters remaining constant, the smaller the radius, the bigger will be the value of h. Two properties commonly measured from this phenomena are the capillary fringe and the rate of capillary rise. The finer the pore sizes, the bigger will be the expected capillary fringe and the rate of capillary rise.

The phreatic surface or the water table is the point in groundwater table where the pressure equals atmospheric pressure. It is the water level of a bore hole which penetrates a saturated soil zone. However, due to capillary action, the mass of water in the soil actually extends above the groundwater table, where the water is held in position at less than atmospheric pressure. This zone of saturation or near saturation above the phreatic water level is called the capillary fringe. The capillary fringe forms the boundary between the K at or near saturation and the unsaturated K which has a much smaller value. Ismail indicated that Malaysian peat has shallow capillary fringes of 100 to 150 mm.

Unlike the capillary fringe, the rate of capillary rise is also influenced by the climate and the depth to the water table. The upward flow rate of water or the rate of capillary rise in peat at water table depth of 1 m is indicated to be near zero but increases to about 1 mm day^{-1} at water table depth of 600 mm. At water table depth of 400 mm and above the rate is indicated to be between 3 to 6 mm day^{-1} (Doorenbos et al, 1984).

Strength, compaction and consolidation

There seems to be a difference of opinion as to whether peat behaviour is frictional or cohesive. Laboratory tests by Hanrahan (1954) led him to postulate that peat strength is entirely cohesive and is derived from surface tension, colloidal and molecular surface forces. The strength of undrained peat is negligible but strength develops as water content is reduced following compression. In his tests Adams, 1965, concluded that peat strength is essentially frictional and in accordance with the principal behaviour of effective stress. A Russian engineer, Korchunov (Maguire et al, 1954) suggested that the shear strength of the peat surface and not its resistance to direct pressure was the important factor influencing the carrying capacity of peat surfaces. The general rule used in Russia then was a maximum carrying capacity of 7.36 kN m^{-2} (0.075 kg cm^{-2}) for undrained peat bogs and 17.17 kN m^{-2} (0.175 kg cm^{-2}) for drained areas.

Bearing capacity in peat varies considerably with moisture content. Other factors, primarily the structure of the top layers are also important. Attempts to improve bearing capacity have led to mechanical compaction in an estate (Singh et al, 1986). This exercise increases the bulk density from a mean of 0.11 Mg m^{-3} to 0.2 Mg m^{-3} . No depth of analysis was given, but compaction was noted to depths of 400-500 mm.

Consolidation of peat under loading is extremely complex because of its highly compressible nature. Large decreases in hydraulic conductivity, K, and coefficient of compressibility, C_v, results with loading. Studies (Adams, 1965 and

Berry et al 1972) showed immediate initial large magnitude of settlement or primary compression followed by an indefinite long term stage of secondary compression in which the rate of settlement was much less but approximately linear with the logarithm of time. The initial void ratio of the peat will also influence the magnitude of the initial compression while the magnitude of settlement is directly related to both the peat thickness and applied load.

Drainage drains the water held within the peat structure. The drained top layers then exert pressure on the lower layers squeezing out the water which is partly drained away and partly evaporated. The effect of drainage and air drying is seen as identical with mechanical loading and is considered as occurrence of primary consolidation by Adams, 1965 and Berry et al 1972. One-dimensional consolidation theories developed by Berry et al (1972) for fibrous peat predicts linear increases in strain with incremental loading for the secondary compression.

The peat subsidence as a result of increase in overburden pressure can be calculated either using the compression index, C_c, from the equation

$$dS = \frac{1}{1+e_i} H_i \; C_c \log (p_i / p_f) \qquad \text{--- 2.2}$$

where

dS = peat subsidence
C_c = compression index
e_i = initial void ratio
H_i = incremental depth of peat deposit
p_i = initial pressure
p_f = final pressure

or using the coefficient of compression, m_v

$$dS = m_v \, p \, dH \qquad \text{--- 2.3}$$

calculated for each incremental depth dH subjected to a pressure of p (Scott, C.R., 1974, Capper et al 1974).

Shrinkage and subsidence

The type of organic material and the bulk density can determine the shrinkage and volume recovery. Results from Badr et al (1978) showed increases in shrinkage value with decreases in bulk density. Gelatinous peat deposits and deposits with low bulk density exhibited greater shrinkage upon drying. The higher the bulk density the greater will be the volume recovery. A shrinkage value of 87% for a gelatinous aquatic peat, volume recoveries of 100% and 45% for deposits with bulk densities of 0.42 Mg m^{-3} and 0.17 Mg m^{-3} respectively are some examples (Lucas, 1982). Records in the Everglades as derived from Stephens, 1969 showed the subsidence rate in the first five years exceeded 150 mm per annum. This is very similar to the maximum value of 148 mm per annum recorded in the Sg Pinggan area of Western Johor, Malaysia (Welch et al, 1989). Although substantial initial loss of volume in peat deposits is due to dewatering, subsequent loss is also a function of water table level, nature of organic material, temperature as well as cultivation practices. As a comparison of the influence of water table depth and climate on subsidence; at average water levels of 300 mm, 600 mm and 900 mm, the annual subsidence was 15 mm, 36 mm and 58 mm respectively in Florida and 3 mm, 15 mm and 30 mm in Indiana. Subsidence can be monitored either by conventional land survey, sinking a permanent post to the stable subsurface or by monitoring movements of plates installed within the deposit or even monitoring movement of soil surface with respect to permanent buildings or bench marks.

In Malaysia shrinkage of between 40.9 to 76% has been recorded by Bachik et al (1986) for peat soils having bulk densities of between 0.37 to 0.17 Mg m^{-3} . The subsidence rate in Malaysia varies from an average 148 mm per year for peat depths exceeding 6 metres to 15 mm per year for depths of 2.4 metres (Welch et al, 1989). No water table data accompanied these figures but the rate does not seem to have stabilised even after nine years and in some cases after 15 years. Another by-product of drainage is irreversible drying. It has been reported by Ismail (1984) to occur in the top soil of cultivated areas and by Caldwell et al (1971) to occur in lenses at depths between 300 mm to 760 mm. In the English Fens, Caldwell et al has related the irreversibility to increases in aluminium and iron content in the soil.

2.3 Crop Production Requirements in Peat

2.3.1 General

Different crops not only have different moisture requirements at the various growth stages but they also require varying farm inputs for optimum production. The type of farming practice, whether heavily mechanised or otherwise will dictate the required minimum allowable bearing capacity that must be achieved in the field. In peat the bearing capacity will dictate the type of machinery that can be used. Water table position governs not only the availability of moisture to crops but also in most circumstances, the allowable working bearing capacity. Thus for optimum crop production, peat drainage and reclamation should be planned and designed together with the choice of crops and other crop production practices.

2.3.2 Agronomic requirements

Water management following reclamation and drainage

The depth of water table has no direct influence on crop growth. Together with the other parameters such as capillary fringe, rate of capillary rise and porosity, it determines the prevailing moisture conditions in the soil. Water table therefore indirectly influences the water supply, aeration conditions and heat properties of the soils. Its correlation with yield has been established by many researchers. Generally the yield increases with increase in water table depth to an optimum depth after which it declines with increases in water table. In fluctuating water tables Sieben (Wesselling 1974) summed up the daily exceedence of water table above 300 mm in winter (SEW_{30}). Large SEW values indicate poor drainage. He found decreasing yield with increasing SEW values.

Lysimeter studies for pineapples (Tay, 1980) found the optimum water table levels to be between 680-860 mm. Tan et al (1989) recorded the highest yields of cassava in lysimeters under water tables held constantly at 150 mm. Optimum water tables for other crops are available from studies outside Malaysia such as 300 mm for cauliflower and between 760-910 mm for lettuce (Snyder et al, 1978). In crops where the water table is well below the root zone arrangements have to be made to prevent mid-day wilting (Leong, 1986).

Crop suitability

Due to the low bearing capacity of the soil, not only is field mechanisation limited but so also is the choice of crops, to those which can be supported by the soft spongy soil. The need to conserve peat, may further limit the crop types to shallow rooted crops such as high value short term vegetables, shrubs and grasses, as is widely practiced in the Netherlands, England and the United States. In Malaysia however pineapples which have fairly deep root zones, are widely grown in peat areas because of their adaptability to acid condition and low soil fertility. Tapioca is also an excellent choice (Tan et al, in print) but a market for its product needs to be created. Oil palm, coconut and coffee are some of the other crops grown in peat. The first two, although perennials have short fibrous roots and can grow well at water tables of 450 to 500 mm depth (Singh, 1986). Existing clones of Hevea or rubber trees planted do not give promising yield. In most of these perennials the choice of clones is limited to those with light canopies or the dwarfed variety so as to minimise any leaning of trees or uprooting.

Soil Amendments

The acidic nature of the peat soils make it necessary for soil amendments to be carried out. Studies on liming requirements have been carried out on various crops. Except for pineapple, liming is necessary for crop cultivation in Malaysian peat. Application of 7.5 t ha^{-1} or more in new peat to raise the pH value to 4.25 is common for vegetable planting. Lime exceeding 16 t ha^{-1} may be required to raise the pH above pH 5 (Leong et al, 1989). In Kalimantan farmers ashed the remains of crops while on oil palm and rubber estates oil palm bunch and rubber branches and twigs can be ashed and used. Traditionally farmers burned the soil to reduce its acidity as well as to liberate nutrients (Kanapathy 1975, Md Sharif et al, 1986). Burning, however will accelerate the rate of peat wastage.

Nutrient Requirements

The inherent infertility of the Malaysian peat deposits requires that it be rectified before cultivation. Trials are continuously being carried out to find the optimum dosage of fertiliser for each particular crop. Various papers have been written (Kanapathy 1975, Md Yusof 1984, Md Shariff et al 1986, Singh et al 1986, Leong et al 1989) outlining additional nutrient requirements of crops such as pineapple, cassava, sweet potatoes, colocasia yams), groundnuts, maize, sorghum, soybean, vegetables, tobacco, mulberry, pastures, legumes, oil palm, coconut, rubber etc.

Disease, pest and weed control

The reduced acidity of the soil with liming increases the level of nematode infection which can kill young seedlings and reduce crop yields. A solution to this problem would probably lie in a well planned crop rotation system. Crickets and cut worms which also affect the seedlings may need insecticide application after transplanting. Weed control measures may also be required to solve problems of alien weeds growing as a result of peat cultivation (Leong et al, 1989).

2.3.3 Mechanisation Techniques

Adequate bearing capacity and shear strength is necessary for farming practices to support the man in the field as well as the machinery used. Mechanisation requires suitable conditions for traction, support and choice of implements. In mineral soil these properties are related to the moisture content. In undrained peat, machines are known to have sunk into the deep peat deposit beyond recovery (Welch, pers comm). In drained peat although the strength is influenced by the moisture content (see 2.2.2) other factors such as peat type and the structure of the top soil are also important. Ease of cultivation in peat is hindered by buried timbers which are substantial in size and quantity. Some machines working on peat in Malaysia, for example the transporter GC602, have a fully loaded ground pressure as high as 36.92 kPa (0.366 kg cm^{-2}) (Ooi and Hamdan, 1986). Andriesse (1988) quoted that the bearing capacity in peat range from 0 to 40 kPa, with most light modern machinery having groundweight of about 50 kPa.

2.4 Engineering requirements in Agriculture

2.4.1 General

In agriculture, the main objective of any artificial movement of water either to or away from the farm is to improve the profitability of farming the land. Irrigation can be defined as the artificial application of water to the soil for the purpose of supplying moisture while drainage is the removal of any excess water.

2.4.2 Infrastructures

Generally the infrastructures in drainage areas consists of

i) the arterial or main system
ii) the field system

The arterial or main system transports excess water collected by the field drains to the sea. This includes trunk drainage lines and rivers, and all the accompanying structures. Excessive drainage can be prevented through the construction of checks, weirs and other drainage controls. In low lying coastal areas requirements for flood alleviation and tidal controls will be necessary. The design discharges of drainage systems are largely dependent on the magnitude of the rainfall as it is almost always the most critical source of water. Groundwater seepage from surrounding areas may however be another source of water. Trunk drainage systems in lowlying areas are normally also required to act as reservoirs in attenuating the flood.

Field drainage systems are necessary to better manage the crop water requirements. It gathers excess water from the land by a network of field drains. Two main types of field systems are

i) surface or shallow drainage system
ii) subsurface drainage system

In surface/shallow drainage systems excess water either ponds on the surface or flows laterally as surface drainage or interflow.

In subsurface field drainage systems excess water infiltrates and percolates through the main rootzone of the soil to the subsoil/substratum and then moves as groundwater flow to the drains.

2.4.3 Subsurface Field Drainage

To control water table below the ground level, subsurface drainage systems are utilised and can be accomplished by means of either open channels or underground buried pipes. A choice of either or a combination of both is influenced by soil type, climatic factors and economic considerations. Closer spaced drains will cost more but will reduce the range of water table fluctuations above the drain depths and reduce the time taken to achieve the same terminal state. The designed drain depths, in principle, governs the depth of the designed midfield water table.

In areas with steady rainfall the design approach is usually to state the allowable minimum water table and its allowable frequency of exceedence. In areas where rainfalls are large and scattered the unsteady state approach would normally be preferred. The unsteady state analysis assumes water tables to fall from the surface to the design level within a given time. The criteria chosen is not only dependent on the climate but also on the type of crops and soil.

2.4.4 Theories of Flow to Drains

Drainage theories have been developed independently by several authors using Darcy's Law and the continuity equations (van Schilfgaarde, 1974, IILRI, 1980, Smedema and Rycroft, 1983). The results can be simplified using Dupuit-Forchheimer assumptions of horizontal streamlines and proportionality of velocities to the slope of the phreatic surface (Kirkham and Powers, 1971). In potential theory the solutions are obtained by solving the Laplace partial differential equation obtained from combining Darcy's Law and the continuity equations. Although the potential theory is more accurate, solutions using Dupuit-Forchheimer assumptions are normally sufficient in most drain designs.

It is not the intention here to review all available drainage theories that have been developed. Suffice to say that the development of drainage equations have been tremendous. Very accurate predictions can be made in the field if accurate soil parameters can be obtained. Of interest in the drain design is the saturated steady and nonsteady state analysis. The saturated steady state analysis is an attempt at predicting the highest level to which the mid-field WT can rise. It assumes continuous steady rainfall which is discharged continuously and steadily by the drain. Although this situation rarely occurs, its use in many cases is justified particularly in areas where rainfall is small and well distributed. In practically every case the situation is a nonsteady state condition involving rising and falling WT. The saturated nonsteady state analysis will predict the rise and fall of the WT in response to a varying rainfall pattern or recharge. The following are some of the equations that will be used in this study:

steady state saturated flow

i) the Hooghout equation

$$q = \frac{8Kdh}{L^2} + \frac{4Kh^2}{L^2} \qquad \text{--- 2.4}$$

unsteady saturated flow

i) the Glover-Dumm equation

$$L^2 = \frac{\pi K dt}{p \ln[1.16(h_o/h_t)]} \qquad \text{--- 2.5}$$

ii) the van de Leur equation (in Wesseling, 1983)

$$q(t) = \frac{2 \pi K d}{L^2} \quad h(t) \qquad \text{--- 2.6}$$

where

q = discharge per unit area
K = saturated hydraulic conductivity
d = Hooghout's depth to the impermeable layer
h = difference in water table and water level in the drain
h_o = initial h
h_t = h at time t
L = drain spacing
p = porosity
D = height of the water level in the drains above the impervious floor

CHAPTER 3 - EXPERIMENTAL APPROACH

3.1 Approach and Alternatives

The objective of agricultural water management in peat as in other soils is to optimise crop production. This study looks into the broad perspective of minimising aeration and moisture stress, peat wastage rate as well as providing adequate bearing capacity for farming activities.

In trying to determine an optimum water management design, research options that are then available are field experiments, laboratory works and computer simulations. The last of these alternatives is only possible if representative and sufficient data are available for all aspects of the design.

As indicated both in the introduction and literature reviews, the hydropedological data of Malaysian peat is essentially not available. As the focus is on Malaysian peat any work which does not include actual analysis of the subject of interest would be superficial. The need for in-situ experimental works in the home country has been proposed and submitted to the university and sponsors from the very beginning.

Any programme would by necessity need to include laboratory works for collection of basic data such as fibre content, bulk density, ash content, moisture retention properties etc. It would be an advantage if sufficiently large samples could be obtained in lysimeters and tested. Field works are necessary to sample the data and test some field values such as hydraulic conductivity, capillary fringe etc and these data are expected to be collected from isolated drainage areas and virgin peat areas.

The nature of the initial proposal, the sponsorship and the time available for the study made any actual field drainage experiment rather unlikely. In the event MARDI's management had already acquired, identified, planned and partially constructed a newly reclaimed area of about 10.9 ha to study various aspects of agronomic studies related to varying water table (WT) depths. The area is located at the Integrated Peat Research Station (IPRS), in Pontian Johore. The Director General of MARDI kindly allowed the drainage experiments for this research to be carried out in this area, and for this the writer is very grateful. Location of the area is shown in Figure 1.3.

3.2. Experimental design

3.2.1 General

The research planning of the study takes into account the various field constraints faced in crop production on peat deposits, namely

i. minimum aeration stress in the wet periods
ii minimum moisture stress during dry periods
iii minimum peat wastage rate
iv adequate bearing capacity for farming activities

Aeration stress and adequate bearing capacity improve with increasing WT depth but moisture stress and peat wastage rate worsen with increases in WT depth. Taking these requirements into account, experiments were planned, designed and carried out for a combination of laboratory works, lysimeter studies and field experiments. Details of these experiments and their instrumentation are given in chapter 4. Drainage and agronomic trials were also planned on the 10.9 ha area. Although optimistic, the design was nevertheless carried out with untested data and new design concepts under Malaysian conditions.

3.2.2 Minimum Aeration Stress in Wet Periods

From Chapter 2, Section 2.4.4, the following are the data required for planning excess water handling to minimise aeration stress

i saturated hydraulic conductivity, K
ii drainable porosity, p
iii WT shape during recession
iv WT reaction time during recession
v design drain discharge or drainage coefficient, q_d

For the estimation of field K, monitoring of the recession curve for midfield WT and corresponding actual drain discharge, q_a, is required. The monitoring can also be used for obtaining items ii to iv. Design drainage coefficient will be estimated from existing DID hydrological procedures.

3.2.3 Minimum Moisture Stress during Dry Periods

Generally the rainfall in the experimental area is well distributed. However, there are frequent long dry periods exceeding more than one week (Table 3.1: return period for 7 dry-days is 2.7 months, for 12 dry-days is 10.9 months). In soils where capillary fringes are high, rates of capillary rise are large and the available water stored substantial, the effect of such lengths of dry periods may not be critical for crops. In other soils, the long dry period may be critical for high value crops, particularly if the soil moisture storage capacity is small. To plan for possible appropriate action the following data is required.

- i appropriate WT depth selection
- ii available water capacity
- iii height of capillary fringe
- iv rate of capillary rise at specific WT depths
- v unsaturated K with varying moisture content
- vi WT shape during irrigation/rain

Appropriate WT depth selection is influenced by the choice of crops to be planted. The optimum WT position of some crops have been determined locally. Other optimum WT data are available for similar local crops from overseas research. Item (ii) involves determining the water retention properties, in particular, the moisture content at field capacity and wilting points. Items (iii) and (vi) are on-field determination while items (iv) and (v) involve studies on undisturbed lysimeter monoliths.

3.2.4 Minimum Peat Wastage Rate

The nature of the peat material is such that any agricultural utilisation will result in lost in volume. The magnitude of the loss rate is due to a combination of physical, chemical and biochemical changes. Cultural practices in agricultural production and high temperature may accelerate the wastage rate. Field settlements can be deduced from measuring and calculating the following items:

i dewatering settlement
ii susceptibility to irreversible drying
iii compression index, C_c
iv oxidation loss

Overall field monitoring of the surface and subsurface elevations will give the actual field subsidence and can counter check the above estimations

3.2.5 Adequate Bearing Capacity

The average peat bulk density of 0.1 Mg m^{-3} in Malaysia indicates poor bearing capacity of the soil. Working in the field requires minimum bearing capacity for crop, man and machine. Farming activities using light modern machinery requires a field bearing capacity of 40 to 50 kPa (Andriesse, 1988). Alternatively, knowing the limit of the bearing capacity that can be achieved, appropriate machines can be designed. Thus the study also includes the data collection for determining the bearing capacity.

The study has a very wide scope as it attempts to collect sufficient minimum data necessary for field water management. Although some of the data may not be statistically sufficient due to time constraints, the need for this type of research is rather critical considering the rapid development into peat areas. The Malayan Agricultural Journal in its editorial in April 1950 states that practically all pineapple fruits were grown on peat which in 1939 covered approximately 2.3% of the 984,500 hectares peat area in the Peninsula (Wee, 1968). Other peat areas were then just beginning to be opened up. The percentage increased to 18% in 1966 and by 1984 it had climbed to 32% of total peat area. (Ab. Jamil et al, 1989). With the completion of the Integrated Agricultural Projects in peat areas of West Johore, North-West Selangor and Sarawak more peat areas will be brought under cultivation in Malaysia by the turn of the century. It is hoped however that this study will generate research in the near future in all the above aspects to give it a deeper scope and understanding.

3.3 Drainage and Agronomic Trials

3.3.1 General

The initial layout by MARDI for the 10.9 ha plot is given in Figure 3.1. The initial WT proposal for water table depths of 450 mm, 600 mm and 900 mm were modified to 300 mm, 600 mm and 900 mm. The choice of 300 mm was felt to give a wider spread of water levels than 450 mm. The modification was also made considering the much shallower root zones of grasses and the necessity to keep as high a WT as possible in order to conserve the peat. Figure 3.1 also shows the completed perimeter drains and the field roads dividing the field into six plots of varying shapes. The roads were constructed with laterite soil to a top width of 4.27 m (14 feet) and a height of 0.9 m (3 feet) above the surface. Due to the porosity and compressibility of the peat, the road at present is almost at the same level as the ground surface. Prior to the construction, a centre wedge of approximately 0.9 m (3 feet) deep and 0.6 m (2 feet) wide was excavated and filled with laterite. It served as a cut off for the flow of water between the plots. The odd shapes of the plots are mainly due to the previous division of land boundary lines as well as existing perimeter drains. Also shown are the initial proposed field drains. However as these were not yet constructed it was possible to redesign and modify their locations. Plot 4 was used as the test plot to gather information for the subsequent design of the project area.

3.3.2 Plot 4 - Test plot

The test plot, as shown in Figure 3.2 is trapezoidal, approximately 120 m wide and with length varying from 127 m to 111 m. The design for the pilot plot was carried out for 900 mm WT, following specifications as initially planned by MARDI. Due to the woody nature of the peat soil and the climate, field ditches were preferred over tube drains. Ditches are simply known as drains locally and will be referred thus, hence forth.

The planning and design was carried out using a 1984 survey plan. For the subsequent overall planning the whole area was later resurveyed. All survey points were tied to the Survey Department permanent bench mark located beside the main road just outside IPRS. Initial surveys of the peat depth of plot 4 were carried out using a gouge auger and were found to be around 2.6 m. The entire peat depth over the whole area was later surveyed using a combination of gouge auger and graduated steel rod which will be discussed in Section 4.1.9.

Various alternative designs were considered. These included a combination of drains and bunds and a design with 6 drains and 2 measuring weirs. Drains with 1.2 m depth and at 20 m spacing were finally constructed. This allowed for the construction of 5 field drains. The 3 middle drains were connected and discharged through a 90° V-notch weir at W4. An automatic water level recorder was installed at W4. The spacing of 20 m was used so that there was an equivalent 20 m wide buffer on each side of the experimental field as well as a length:width ratio of at least 5 for the land between the drains (Dieleman, 1980 and Dieleman and Trafford, 1976). The design also included installation of dip wells or WT observation wells (OW) at 1/8, 1/4 and midfield of the distance between the drains. Four rows of dipwells were installed. One situated upstream of the field drains near the centre road, and the other three at 1/4, 1/2 and 3/4 length of the field. The OW were installed prior to the construction of the drains.

The average natural ground slope is about 1:300 with pockets of depression as deep as 300 to 400 mm. At some locations, particularly in plot 4, the surface gradient is as much as 1:150. Land levelling on a big scale is not yet a practice in Malaysian agriculture and it was not possible to carry it out in this research. When each water management unit is not levelled as is necessary, WT control became difficult and several check structures were needed.

The drain capacities were designed using Manning's equation for a rainstorm of 72 hours and 5 years return period, and Manning's n of 0.025 for unlined canals. The DID HP No 1 by Heiler, 1973 was followed for the estimation of design rainstorms. The drainage rate was taken as 80 mm day^{-1} and estimated from a design rainstorm of 83.8 mm day^{-1} and average evaporation rate of 3.8 mm day^{-1}. The design carried out included that of the whole adjacent perimeter drain, A-M-L (see Figure 3.3). Detailed calculation is given in Appendix A. The drain construction was completed in the first week of October 1986.

With the construction completed the hydropedological data collection commenced. Attempts to collect field hydraulic conductivity, K were not successful as weir W4 was too low in relation to the outfall outside the experimental area. Water either flowed into the gauged area during the rain or there was not sufficient hydraulic head for measurement when the rain stopped.

Available pumps were not of sufficient capacity. K values from auger hole tests were however made.

3.3.3 Project Area

To allow for k field monitoring there must be sufficient head loss between the weirs and the outfall just outside the experimental area. Deepening the main drain outside the area was not within the scope of the study. The increase in head could be achieved if the invert of the weir nearest the outfall was raised. This was done by exchanging the 300 mm and the 900 mm WT plots. The 300 mm WT was moved downstream and the drainage depth in the plot raised using sand bags and wooden structures as checks. The change of WT position was possible as the land has an average slope of 1:300. The exchange was also advantageous for peat conservation, as an overall higher WT just outside of the experimental plot was then possible. Plots 4 and 1 have shallower peat depths of as compared to the upstream plots of 3 and 6. Areas downstream of the experimental area have even shallower peat depths (see Figure 5.66).

The location of the various WT control plots is shown in Figure 3.3. The drainage rate used was 80 mm day^{-1}, the same as for the pilot plot. This is equivalent to 9.3 l/s/ha as compared to 8 l/s/ha used in the cocoa area. The recommended design peak for vegetable farming is a 24 hour storm duration, 1 in 10 years return period. The 24 hour one in 10 years drainage rate would be around 25 l/s/ha. This is rather large and may create extremes in soil moisture regime particularly in peat deposits which do not as yet have WT controls.

Besides the drainage rates, the initial design exercise also looked into allowable fluctuation in WT depths, subirrigation needs, capillary fringe, variation in peat depths and hydraulic conductivity. A fluctuation of ±100 mm for the WT was allowed in the design for each plot. The design drainage base was arrived at by adding the height of the capillary fringe to the maximum allowable WT depth. Details of the parameters used are given in Appendix B.

As the drought season can be rather severe and long (Table 3.1) back flushing from a ponded area downstream of the project area was considered. However the peat is very porous and there is a back grade on the surface of the clay sublayer with respect to the ground surface. Besides seepage losses, an average of 5 mm day^{-1} evaporation loss must be included in sizing the storage pond. Although alternative use for the pond, such as fish rearing could be found, its cost was not within the budget of the project. Pumping artesian water (if any) can be costly and the time consumed was outside the scope of the research. As the dry season is on a regional basis, it was not possible to transport water from another area within the region. The supply of water to maintain WT during the dry periods was therefore not possible.

Drain spacing calculations were made using Hooghout steady state equation as well as the Glover-Dumm falling WT equation. The result of the analysis is given in Appendix B. Considering the k values, and the need for regular drain spacing in the plots, a spacing of 20 m was chosen for plots 1 and 4, 30 m for plots 2 and 5 and 40 m for plots 3 and 6 for a drainage base of 550 mm, 850 mm and 1150 mm respectively.

Figure 3.4 shows the location of all the OW, raingauges, evaporation pan, soil meters, weirs, checks and automatic rainfall recorders. There was no land levelling. Due to the non uniform gradient of the surface and expected peat subsidence, wooden checks and sand bags were preferred over permanent concrete structures to raise the WT. Where possible localised depressions were smoothed out using manual labour. A detailed design of the whole project area is given in Appendix B.

There was interest within MARDI that the area should be planted with a number of crops such as vegetables, fodder, maize, as well as cassava and pineapple to take advantage of the WT control. Considering the status of the study and border effects, etc, the peat task committee of MARDI agreed to plant only cassava and pineapple, two crops which are highly tolerant of the acidic peat soil. Plots 1, 2 and 3 were planted with cassava while plots 4, 5 and 6 with pineapples. This ensures that each crop will be subjected to all three available WT depths.

CHAPTER 4 - EXPERIMENTAL METHODS

4.1 Hydropedological data

4.1.1 General

Most of the experiments were confined to the experimental area at IPRS, Pontian. Where possible and necessary sampling was also carried out in two other areas, namely Parit Sikom and Ulu Air Baloi. The IPRS area was opened up around 1971, and then left under secondary forest. Parit Sikom is an area growing perennials such as rubber, coconut, fruit trees and recently, oil palm and pineapple. It was opened about 40 years ago. Ulu Air Baloi is essentially a virgin peat area, with the main drainage lines having been constructed about 3 years before this research. All the areas are within the Western Johore Integrated Agricultural Development Project (WJIADP).

4.1.2 Moisture content, bulk density, ash content and fibre content

To ensure consistency in the sampling day moisture content, samples were taken at least three days after a rainfall event. A gouge auger was used for taking undisturbed sample with depth. The auger is a semi-circular cylinder with a cutting edge and plate. It has a diameter of 50 mm and length of 500 mm. The soil is sampled by pushing the auger into the peat to the required depth. When the half cylinder is then turned, the cutting edge cuts a semi-circular sample, 500 mm long and 50 mm in diameter which is nested in the auger. Peat samples were augered to depths of 1.05 m. Differences in bulk density measured using this auger and sampling in soil pits were investigated to gauge the variability of the data collected between the two methods. Sampling in soil pits made use of sharp-edged steel moisture rings. These were pressed in to the side of a freshly excavated pit at measured distances from the surface, cut around with a sharp knife and trimmed with scissors and spatula before being sealed in cans for analysis in the laboratory.

Samples with the gouge auger were taken at 150 mm depth increments from the surface. A wooden cutter with sharp cutting edges at 50 mm apart was fabricated to cut each 50 mm length soil sample for bulk density determination.

The samples were then immediately placed in a weighted moisture can and sealed with cellophane tape to minimise moisture loss. The remaining 100 mm length was placed in plastic bags and secured with elastic bands for fibre content analysis. In the laboratory, the samples were oven dried for 48 hours at 105°C for the determination of bulk density and sampling moisture content. The oven dried samples were fired in a furnace at 600°C for 3 hours for ash content determination.

Fibre content for fibres smaller than 0.1 mm in both rubbed and unrubbed samples was estimated using the hypodermic syringe method as outlined by Day et al (1979). For the bigger fibre sizes, the fibre content was obtained by cutting sample blocks approximately 150 x 150 x 150 mm cube and at 150 mm depth intervals from a soil pit. The fibres were then visually separated into the different sizes. Fibres smaller than 0.1 mm were separated using sieves. Fibre contents were quantified on a basis of oven dried weights.

4.1.3 Specific gravity, G_s

Specific gravity (or particle density) determinations were carried out using 25 ml pycnometers as outlined in Blake, 1965. Approximately 10 g of peat, air dried for one day were used in the analysis. Entrapped air was removed from the samples by gentle boiling with frequent agitation in a hot bath. To ensure all the entrapped air was removed the air-dried soil in the pycnometer was left to soak for one day before and after the boiling. The specific gravity was calculated from the following

$$G_s = \frac{\rho_w (W_s - W_a)}{(W_s - W_a) - (W_{sw} - W_w)} \qquad \text{--- 4.1}$$

where

ρ_w	=	density of water
W_s	=	weight of pycnometer plus soil sample corrected to oven-dry condition = $W_{od}+W_a$.
W_{od}	=	$(W_{ws}-W_a)/(m+1)$
W_{ws}	=	weight of pycnometer filled with soil sample
W_a	=	weight of pycnometer filled with air
W_{sw}	=	weight of pycnometer filled with soil and water
W_w	=	weight of pycnometer filled with water
m	=	moisture content of soil sample

4.1.4 Moisture retention properties

The moisture content of the soil was assessed on a weight basis following oven drying for 48 hours. The moisture characteristic curves were determined and estimates made for the field capacity, wilting point and available water.

Sintered glass porous plates were used for estimations of soil moisture content up to suctions of 1 m (0.1 bar) and a pressure plate extractor for suctions up to 150 m (15 bar). To obtain moisture contents at suctions exceeding 150 m the vapour pressure method was used. Measurements were made over 3 depth ranges 0-100 mm, 100-200 mm and 200-300 mm below the surface. For Parit Sikom and Ulu Air Baloi areas only suctions between 1 m and 150 m tests were used. All samples, except for those used for the vapour pressure method, were undisturbed. Samples from Parit Sikom and Ulu Air Baloi were taken in pvc cylinders of 300 mm diameter and 150 mm high and placed in plastic basins and wrapped with two layers of plastic bags for storage in a cool dark area until required.

Porous plate test

This test is carried out only for the IPRS area. Each test required two undisturbed samples taken using preweighed sharp edged moisture cylinders with a diameter of about 76 mm and a height of around 40 mm. One sample was used for initial moisture content determination and the other was trimmed and weighed to fit snugly into the glass funnel. The glass funnel was connected to a burette filled with deaired water. The saturation procedure for the sample was to wet under 10 mm suction for one day, zero suction for the next day and total immersion the third day. The sample was left flooded for a further 72 hours before the test was started. Readings at suctions of approximately 0 mm, 10 mm, 20 mm, 50 mm, 100 mm, 200 mm, 400 mm, 700 mm and 1 m were made. Burette readings to determine water release and the height of water level above a datum were taken after the water has reached equilibrium at each suction. At low suctions equilibrium was reached in less than a day, but the length of time increased to about 5 days at suction near 1 m. To reduce evaporation losses the burette top was covered with foil and taped with cellophane. At the final suction the entire sample was reweighed, oven dried and reweighed for moisture content estimation. Analysis of the data is carried out according to Silsoe College methodology (Anon, 1987). Tests on three samples for each soil layer were carried out and the log of suction plotted against θ_m for each of the sample. The moisture content at the respective suctions were read from the graph for all three samples and the average value calculated.

Pressure plate tests

Undisturbed samples were prepared using 50 mm diameter pvc cylinders cut to 10 mm height and trimmed to give a sharp edge. The samples were then placed on the specific pressure plate and allowed to soaked in about 5 mm depth of water for 72 hours before being subjected to suctions of 1 m (0.1 bar), 3 m (0.3 bar), 50 m (5 bar) and 150 m (15 bar). Moisture content was determined when equilibrium was reached after 5 days. The estimated value for each layer is the average of 12 samples.

Vapour pressure tests

The indirect method used for determining the moisture content-suction relationship in drier soils was that of Schofield, 1935. Soils were equilibrated in atmospheres of known vapour pressure and the equivalent suction determined from the following Schofield formula

$$pF = 6.51 + \log(2 - \log h_r) \qquad \text{--- 4.2}$$

where

h_r = relative humidity

pF = log of suction (suction in cm)

The saturated solutions of potassium sulphate, ammonium sulphate and lithium chloride provided pF values, at 25°C, of 4.63, 5.95 and 6.55, equivalent to suction of 426.6 m, 8912.5 m and 35481.3 m respectively.

About 2 g of soil, air dried for 3 days, were placed in small preweighed glass bottles with covers. The glass bottles were then placed in desiccators containing the appropriate solution at the bottom. The desiccator was vacuum pumped and the sample left to come to equilibrium over a 3 week period, when its moisture content was determined. Two runs of tests each with five samples were carried out so that, the estimated value is an average of 10 samples.

4.1.5 Hydraulic conductivity

Hydraulic conductivity, K, was first defined by Darcy when he discovered that the rate of water movement, q, in a given soil to be proportional to the hydraulic gradient, i, (i=H/L). Darcy's equation is given as follows

$$q = K \frac{H}{L} = K i \qquad \text{--- 4.3}$$

where

q =discharge per unit area per unit time
K =hydraulic conductivity, length per unit time
L =the length of flow path
H =the difference in head.

Saturated K measures the ease with which water flows through a saturated porous media. Measurement of K can be made both in the field and in the laboratory. In peat, changes to soil structure sampled for the laboratory may negate such results. Unless sufficient precautions have been considered and taken, any draining of water while sampling the saturated peat, will result in loss of volume which in turn will reduce porosity. Once dried, recovery to 100% of in situ volume may not be possible. Reduction of volume side-ways will create flow channels between the soil and the cylinder interface. Laboratory methods for undisturbed peat may thus have to contend with substantial leakage on the side walls. Disturbed prepacked samples will also not estimate accurately in situ k values as they have to simulate the actual in situ soil structural arrangement which should include the fibres and buried timbers. Even so, the volume possible for use in laboratory testing will be small and the number of samples required will have to be substantial to give a statistically acceptable estimate. Thus field measurement was preferred because of its in situ properties and bigger sample volumes. Two field methods were used namely,

i) the single auger hole test and
ii) estimations from the installed drainage schemes.

The Single Auger hole tests

The auger hole test was carried out as described by van Beers (1958) using a soil auger, water bailer, a stiff rattan measuring stick, a stand and a stop watch. For the measurement of water table depths, a few methods were tried but the stiff straight rattan cane with 2 fishing net buoys was found to be most suitable. The buoys kept the rattan afloat. The rattan was calibrated accurately at 5 mm spacing. The zero datum was taken at the water level. Due to the nature of the material used this zero point was frequently checked and corrected when necessary. Steel tapes were tested but found not suitable in these area because of the numerous roots jutting out into the hole which hampered the upward movements of the fragile tape. The bailer for the auger hole tests was fabricated from PVC with a caste iron valve (usually used in small pumping operations). The hole augered was 100 mm in diameter. The bailer was approximately 80 mm outside diameter and 1.25 m long. The water in the hole was lowered to the required depth between 200 to 400 mm with just one bailing. This is important as the speed at which water flows back into the hole is very rapid. Multiple bailing would allow excessive draw-down of WT around the hole before measurement could be made.

For the test, a hole was augered to a depth of at least 600 mm below the WT. Water was bailed out several times to reopen the pores smeared during augering. The water in the hole was then allowed to come to equilibrium. With the water level measuring device in place, the bailer was slowly inserted into the hole ensuring at all times that the water inside and outside the bailer was approximately level. Once the bottom of the bailer reached the hole invert it was lifted out quickly, the measuring device swivelled into place and reading commenced immediately.

Estimation from installed drainage systems

For the drainage system tests, WT level and discharge measurements as well as WT control were required. These items were also required in the determination of WT shape, WT monitoring and for the general control of the WT in the area. The description of these structures therefore also applies wherever they are being used in this research unless otherwise stated.

a. water table measurement

To monitor WT positions in the field, observation wells (OW) or dip wells were installed. PVC pipes with external diameter of approximately 63 mm were used. Each pipe was cut to 2.0 m length and drilled with 5 mm diameter holes at about 25 mm distance on four sides of the pipes. The pipe was sealed at the bottom with a pvc cap and then wrapped with nylon netting.

A total of 245 OW were installed. The OW were installed at each quarter of the field length, in the mid drain position and at 1/8 drain spacing as shown in Figure 3.4. In Plot 4, (the pilot plot) the OW were also installed at 1/4 drain spacing from the drains. Augers with 50 mm diameter were used for the installation. For general WT monitoring, WT measurement was carried out initially once a week but later reduced to every two weeks. The rattan measuring stick described earlier for the auger hole tests was used for measuring WT depth.

b. discharge measurements

For discharge measurements a sharp-crested V-notch weir was chosen because of its sensitivity and accuracy to small flow and because of the small available head at the outfall. The weir was installed near the outlet of the centre drain. The design for the V-notch is in accordance with Bos (1978) and is as shown in Figure 4.1. The weir was fabricated from steel plates cut to the required size. It was installed manually with the help of a winch and pulley. During installation the apex of the V-notch was placed about 100 mm above the invert level of the drains.

The coefficients given in Bos (1978) were utilised and calibrations for the flow constant made using a bucket and stop watch.

The discharge through the weir was calculated using

$$Q = C_e \frac{8}{15} (2g)^{0.5} \tan \frac{\theta}{2} h_e^{2.5} \qquad \text{--- 4.4}$$

where

C_e = varies according to h_1/p ratio
g = 9.81 ms^{-2}
θ = 90°
h_e = h_1+0.8 mm
h_1 = height of water above the apex
p = height of crest above approach channel bed

According to Bos, the discharge is valid only for h_1 > 50 mm. When estimating for K, this limitation will have to be considered.

The height of the water level above the V-notch, h_1 was monitored with an automatic water level recorder (AWLR No 1) installed at about 0.8 m upstream of the V-notch plate (W2) (see Figure 4.1 and 4.3).

c. water table control

Two types of check structures were installed. These are

i) sand bags
ii) prefabricated wooden structures/weirs

The sand bags were piled on top of one another. This method is successfully used in private estates around the area. The prefabricated wooden structure has removable planks as gates and is shown in Figure 4.2. Two sizes with centre openings of 0.4 m and 0.6 m respectively were fabricated. The bigger size was used for the perimeter drains while the other, for the field drains. The complete unit was prefabricated in the workshop and installed manually with the help of winch and pulley.

The location of the sand bags and wooden checks are as shown on Figure 4.3. The check structures were also required in the perimeter drain, to maintain minimum WTs at the end of each field, and in the field drains themselves, to compensate for the absence of general land levelling within the field.

Two drainage system measurements were made for the recession curve. Before measurements were made the sand bags along field drains D2/1, D2/2 and D2/3 (Figure 4.3) were removed. During measurement, the WT shape, mid-field WT position and discharge measurement were taken with time as the WT receded. Measurements were made using observation wells and field drains D2/1, D2/2 and D2/3 installed earlier in Plot 2. Automatic water level recorders, AWLR 2 and AWLR 3 were also installed near OW No.235 and No.238 (Figure 4.3)

Prior to the discharge monitoring, the wooden gate checks at the end of all 3 drains were closed. The perimeter drains were then embanked with sand bags, just downstream of the mouth of field drains D2/1, D2/2 and D2/3. To raise the field water levels further, water was pumped from the embanked perimeter drain into the field drains using portable pumps. The pumping commenced in the early morning (about 1 a.m.) approximately 8 hours before the tests were carried out. Beside the 3 automatic water recorders, manual readings of water levels were also taken along the three rows of OWs. Clocks and recorders were synchronised before water was released.

At the start of the test, the sand bag embankments in the perimeter drains were removed to allow free flow readings at the V-notch weirs. Once the water had sufficiently receded in the perimeter drains, the wooden gate structures in the 3 drains were released concurrently at which point readings commenced.

The field K was calculated using both the steady state and the unsteady state formulas. Using Hooghout's steady state equation where

$$q = \frac{8K_1dh}{L^2} + \frac{4K_2h^2}{L^2} \qquad \text{--- 4.5}$$

K_1 is the saturated hydraulic conductivity for the layer below the drain, while K_2 is the saturated hydraulic conductivity for the layer above the drain. If the soil is not significantly layered, no significant difference is expected in the values of hydraulic conductivity of the soil below and above the drainage base, thus,

$$K_1 = K_2$$

In drainage testing, the K values are calculated by plotting q/h versus h. The equation of a straight line

$$y = a + bx$$

is equivalent to the straight line drawn through the points which give the relationship

$$\frac{q}{h} = \frac{8K_1d}{L^2} + \frac{4K_2h}{L^2} \qquad \text{--- 4.6}$$

giving

$$a = \frac{8K_1d}{L^2} \qquad \text{--- 4.7}$$

such that

$$K_1 = \frac{aL^2}{8d} \qquad \text{--- 4.8}$$

The slope, b, is calculated from

$$b = \frac{4K_2}{L^2} \qquad \text{--- 4.9}$$

therefore

$$K_2 = \frac{bL^2}{4} \qquad \text{--- 4.10}$$

Using the unsteady state equation derived by van de Leur (in Wesseling, 1983),

$$q(t) = \frac{2\pi K d}{L^2} \quad h(t) \qquad \text{--- 4.11}$$

In practice K is calculated by plotting q against h, and estimating the gradient of the straight line that passes through the points. The value d is Hoogout d depending on the thickness, D of the aquifer below the drain and the wetted perimeter. Thus K is then calculated from,

$$K = \frac{q \ L^2}{h \ 2\pi \ d} \qquad \text{--- 4.12}$$

where

$d = D/[(8D/\pi L)(\ln(D/u)+1]$ --- 4.13
$D =$ 4.5 m-survey data
$u =$ wetted perimeter $= 0.6$ m
$d = 2.56$
$L = 30.0$ m

The equivalent depth, d, is used, as the drain does not extend to the impermeable layer.

Subsurface clay layer

The values of the in situ hydraulic conductivity of the subsurface clay layer were taken from Redzuan, 1987. Redzuan uses Hvorslev's equations (BS 5930:1981) for estimation of saturated K using variable head tests in boreholes.

Lysimeter Monoliths

Undisturbed soil monoliths were taken using glass reinforced polyester (GRP) cylinders of a diameter of 0.5 m and a height of 1.5 m (Figure 4.4). To minimise soil disturbance, the outside soil was excavated as the cylinder was carefully pushed in. Once it reached the required depth a square steel plate (base plate) measuring 700 x 700 mm was slid in at the bottom and clamped to the GRP cylinder. The undisturbed soil samples were then lifted on to a lorry with a crane and transported to the glass house in the IPRS Station.

At the glass house, the top of the cylinder was clamped with a circular 0.6 m diameter steel plate before being overturned. The base plate was then removed and a 20 mm diameter PVC tubing with 2 mm holes drilled at 10 mm distance was placed in a T-shape in the base to facilitate subsequent drainage (Figure 4.5). The tubes were covered with nylon cloth and then embedded in 100 mm of gravels. About 10 mm of the length of each tube was left jutting out at the side to enable connection to be made to the outside tube system. The bottom of the cylinder was then covered with a GRP cover, sealed and turned over again.

Twenty monoliths were taken and arranged in the glass house as shown in Figure 4.6. Each lysimeter was given a number and the test for each was decided by random numbers. Five monoliths were required for hydraulic conductivity tests and fifteen for determining the rate of capillary rise.

Arrangements for constant head K tests in the five monoliths are as shown in Figure 4.7. Water was supplied to the surface of the sample at a constant rate by overhead piping connected to a storage tank. Plumbers water faucets were used to control the supply to each of the lysimeters. To maintain a constant head, water was allowed to overflow at the top of the sample and the height of the discharge point at the bottom was maintained at a constant level. The discharge at the bottom was collected and K value calculated using Darcy's equation.

Attempts were also made to measure unsaturated K from the monoliths. For the first reading flow from the overhead pipes was reduced until there was no standing water over the sample. Subsequent readings were simply made by reducing the flow. Measurement of discharge was carried out using a measuring cylinder and a stop watch, both at the outlet from the supply pipe and from the sample. However as the water supply pipes were tapped directly from the mains, the water supplied fluctuated with the amount utilised by other users. A flow meter attached to the supply outlet could probably have solved this problem. Water flowing out from the sample was further restricted by the fines which clogged in the nylon cloth wrapped around the drainage tubes. Tensiometers connected to mercury were used as sensors for the change in suction at the various levels. A further problem that developed with the reduced supply of moisture is the shrinkage both lengthwise and sideways of the sample. This resulted in leakage on the sides thus making any measurement inaccurate. Both the flow into and out of the sample have to be solved before any repeated attempts at measurement are to be made. Once the unsaturated test commences the peat begins to dry out and shrink and it may not recover its initial tight fit volume.

4.1.6 Water table shape and insitu field capacity

Water table shape

The two drawdown tests described earlier for the calculation of field K in Section 4.1.5 were also used for the determination of WT shape. It was not possible to carry out tests for the recharge curve within the study period because of constraints in water supply. Readings of WT levels at each and every OW between the drains in Plot 2 at required intervals were taken manually from the moment the wooden gate structures in the 3 drains were concurrently released.

Field capacity

Field capacity was estimated at the same time as the drainage testing. The locations for field capacity determination were identified and the areas covered with plastic sheets before the embanked water was released. The plastic sheet minimised the evaporation losses as well as prevented rewetting of the area by light rainfall. Moisture content at different depths in the profile were taken at 1, 2 and 3 days after releases of water.

4.1.7 Drainable Porosity

Drainable porosity was estimated in two ways, firstly using rainfall and WT changes and secondly using the recession curve of the field drainage system.

Rainfall and water level records.

The changes in mid-field water levels in plots 2 and 5, were determined for specific rainfall events. Rainfall records were taken from gauges installed in the experimental fields. Rainfall events for this estimation were divided into two. One is the instantaneous rainfall event that occurs immediately after a dry period and the other is that occurring at least after three consecutive heavy rainfalls. The first rainfall event can estimate the possible maximum drainable porosity. In the second event, the soil is assumed to be at field capacity. Heavy instantaneous rainstorms (rainstorms which reach its peak almost immediately) were preferred because of the minimal time lag before the field starts to drain. Drainable porosity p is calculated as follows

$$p = \frac{R}{dh} \qquad \text{--- 4.14}$$

where

R = Rain in mm
dh= WT rise in mm

To augment these estimates, water level records from drains (at WP4) were also used. In these cases, the rise of the water levels in the fields is assumed to be directly reflected in the rise of the water levels in the drains. This assumption is acceptable only for soil at field capacity. For a dry soil the initial rain will be absorbed by the soil until it reaches field capacity. Only then will any excess rain, cause a rise in the WT.

Rainfall was recorded using the tipping bucket rainfall sensor connected to a Japanese made recorder. The pan evaporimeter used was the U.S. Class A land pan, a shallow 254 mm depth with a diameter of 1206 mm.

Recession Curve

Using the equation of van de Leur (Wesseling, 1983) the groundwater reservoir coefficient, j, can be calculated from

$$j = \frac{(pL^2)}{(\pi^2 Kd)} \qquad \text{--- 4.15}$$

When log h is plotted against time then

$$\frac{1}{j} = 2.3 \tan\alpha \qquad \text{--- 4.16}$$

where

$$\tan\alpha = \frac{\log h(t_1) - \log h(t_2)}{(t_2 - t_1)} \qquad \text{--- 4.17}$$

or

$$\tan\alpha\_ = \frac{\log q(t_1) - \log q(t_2)}{(t_2 - t_1)} \qquad \text{--- 4.18}$$

Thus, knowing K, drainable porosity, p can then be calculated from

$$p = \frac{(j\pi^2 KD)}{(L^2)} \qquad \text{--- 4.19}$$

4.1.8 Capillarity

Capillary fringe

The capillary fringe, the region of saturation or near saturation just above the WT, is more significant to growing plants than the WT. The height of the capillary fringe can influence drainage design. The depth of the drainage base in subsurface design should include both the root zone and the capillary fringe to ensure that the roots will not be waterlogged.

The height of the capillary fringe in the field was estimated by taking moisture content values at different heights above the WT line. Samples were taken using moisture rings of 50 mm diameter from 100 mm below the water level to the ground surface or 600 mm above the WT whichever is the smaller.

Rate of capillary rise

This rate of rise is not only dependent on the size and distribution of the capillary force but also on the depth of WT as well as the daily rate of evaporation. On hotter days when the rate of evaporation is high, the rate of capillary rise will be bigger. The removal of surface water by evaporation and root uptake will also affect the WT level.

The rate of capillary rise or the amount of water that reaches the surface, was estimated using the soil monoliths. The pipe arrangement shown in Figure 4.5 was used. Reservoir A, were maintained at the respective WT positions. Every day between 7 a.m. and 9 a.m. water was slowly poured in the reservoir until it just flowed from the outflow. The height of water in the observation tube was measured daily from a datum, before and after the water had been replenished. The net volume supplied daily to the monolith was calculated.

Daily open water evaporation at each monolith was estimated by measuring the amount of water evaporated from a petri dish placed on the top of each sample. This was compared to the value measured from a lysimeter which was completely filled with water.

4.1.9 Rainfall and evaporation

Rainfall gauges installed in the experimental area were of the tipping bucket type with charts being changed weekly. Gauges were installed in Plots 2, 4, 5 and 6. An open US class A pan, for estimating daily evaporation was installed in Plot 5. The national network for collection of rainfall, evaporation and other meteorological data is well established. For estimation of design rainstorm, 40 years of rainfall records from the national network was used. A meteorological station maintained by the Meteorological Department is in operation at IPRS.

4.2 Bearing Capacity and Consolidation

4.2.1 General

The conditions and implications of soil heterogeneity is amplified in the peat soil where properties change drastically not only upon drainage but upon drainage with time. In some undrained peat deposits there are instances where there may be minimal bearing capacity (Section 2.3.3). While drainage in peat may have the same identical effect as mechanical loading, the peat strength is also derived from the matrix of fibres and buried timbers. As a result of its genesis, many lowland peat deposit has decreasing dry bulk density with depth. Conventional testing equipment for bearing capacity and consolidation may not be appropriate.

4.2.2 Bearing capacity

penetrometer test

Cone penetrometer tests using a self registering instrument with a 50 mm diameter cone were taken at specific distances from the drains. The recommended constant speed of penetration is 20 mm s^{-1}. The controlled speed at which the instrument penetrated the soil is faster, but this is unavoidable due to the very soft peat soil and the decreasing density with depth. The instrument records automatically and continuously the penetration resistance directly on to graphs in N cm^{-2}.

plate sinkage test

A reasonably large base area is required, to take into account the interlocking fibres and buried timbers. A settlement measuring device, at a height of 500 mm, a bottom circular plate of 300 mm in diameter, and with a square top was fabricated as shown in Figure 4.8. The settlement was measured by two steel rulers placed on either side of the circular plate. The rulers were attached to a 3.6 m bar that was supported at each end, away from the plate. Initial readings on the rulers were taken before any loading. Each load was applied for 15 minutes, and the settlement measured. Loads were increased until either the device tilted over or there was unrestrained sinkage.

Various types of loading were tried. Initially a steel tank was fabricated to slide onto the square top. Loads were increased by pumping water from the perimeter drains into the tank which had a capacity of 2000 litres. The tank tilted however, with increased weight as a result of its size, the movement of the water in the tank and the irregularities of the peat surface. This idea had to be abandoned. Steel weights, each weighing 50 kg, also had to be abandoned. Finally fertiliser bags, each weighing 50 kg were used. A wooden board was fitted on to the square top to support the fertiliser bags.

The settlement readings were plotted against the corresponding pressure. Pressure at each step of the loading were calculated by dividing total load, inclusive of the weight of the steel stand and wooden board, by the area of the circular plate.

The areas chosen for the test were representative of various WT regimes. The moisture content profile with depth was also taken together with cone penetrometer readings of the area around the plate and under the plate after completion of the test.

4.2.3. Consolidation test

Consolidation is the process by which the volume of soil under loading decreases as water flows out. As the standard soil mechanics oedometers available are rather small (50 mm diameter by 20 mm height) and unsuitable for the highly compressible peat soil, a bigger machine, Figure 4.9, was fabricated for a sample size of 250 mm diameter by 70 mm height. The construction of this oedometer follows the BS1377:1975, which specifies the thickness of the sample to be not more than one-third and not less than one-quarter of its diameter.

The sample cell is a fixed ring cell. Undisturbed samples were taken from two depths 0-150 mm and 150-300 mm using a 300 mm diameter pvc ring approximately 150 mm high. The sample was then cut for the test using a cutting ring with 250 mm internal diameter, 70 mm height and trimmed with scissors, knife and spatula before being placed in the cell unit between 2 porous discs. The weight of the soil samples were determined before and after the test.

The study also sought to look into the effect of soil overburden pressures on consolidation of the lower layers. Assuming an average maximum bulk density of 0.5 Mg m^{-3} (or 500 kg m^{-3}), the overburden pressure of a 2 m depth of drained overlying peat is only 9.8 kN m^{-2}. The loading sequence followed was therefore 1, 2, 4, 10, 20, 40, 80 and 160 kN m^{-2}. There are cases where the maximum loading was only 40 kN m^{-2} when the machine reached its maximum deflection. The load was applied using a lever arm with a beam ratio of 10:1. and the settlement measured with a dial gauge of 10 µm accuracy and having a 30 mm range.

Following the consolidation theory of Terzaghi, analysis of the consolidation tests was carried out by plotting the settlement against the square root of time and against the log of time. The void ratio was also plotted against the log of time. The coefficients were calculated using the following formulas (Rosenak, 1968, Capper and Cassie, 1974 and Lambe and Whitman, 1979)

coefficient of consolidation, C_v

a. square root method

$$C_v = \frac{0.848\ H^2}{t_{90}} \qquad \text{--- 4.20}$$

b. log method

$$C_v = \frac{0.197\ H^2}{t_{50}} \qquad \text{--- 4.21}$$

where 2H = thickness of sample

compression index, C_c

$$C_c = \frac{-de}{d(\log p)} \qquad \text{--- 4.22}$$

C_c, is gradient of the straight portion of the void ratio-log pressure curve

coefficient of compressibility, m_v

$$m_v = \frac{-de}{dp(1+e)} \qquad \text{--- 4.23}$$

or

$$m_v = \frac{-1}{h} \times \frac{dh}{dp} \qquad \text{--- } 4.24$$

4.3 Shrinkage, Irreversibility, Peat Depth and Subsidence

4.3.1 General

Peat has a very low wet bulk density and a very high moisture content. As water is drawn out during drainage the peat volume decreases or shrinks and the bulk density increases. This phenomena is dramatically seen in the peat subsidence following drainage. Inevitably upon rewetting most peat deposits do not recover their initial volume. Drainage also results in the inevitable subsidence. The total final subsidence is influenced by the depth of the deposit.

4.3.2 Shrinkage and irreversible drying

Shrinkage and its percentage recovery upon rewetting is another important parameter in determining volume loss on drying. Moisture content and volume relationship can also be used to deduce the volumetric moisture content and suction relationship of the moisture curve. Peat soil loses some of their storage capacity for water on drying. The magnitude of this loss and the cut off point when the drying becomes critical, may be important factors in crop cultivation practices.

To chart the drying process an experiment using 45 samples (in moisture content cylinders measuring 76 mm diameter by 40 mm high) was monitored for daily weight and volume changes. On each of the days when measurements were taken (from zero day sampling), five samples were weighed, their volume measured and then oven dried at 105°C for 48 hours. The average moisture content, volume changes and bulk density against time were then plotted.

From the above test it was noticed that the soil reached its air dry stage of 15 to 25% gravimetric moisture content in about 12 days. The return period of a 12 day dry period is about 11 months (Table 3.1). An air dried sample floating in water for a month remains floating but with increasing percentage volume under water.

Another experiment was necessary to determine the peat rewetting potential of samples with varying initial moisture content and storage time. Three moisture content levels were considered and these were at sampling day moisture content, at 7 days air drying, and after 1 day oven drying at 80°C. The last one is to simulate complete air drying. A total of 85 samples were taken for the three batches. Once treated to the respective drying processes the samples in the cylinders were covered with air tight plastic caps batched and wrapped in two layers of black plastic bags and stored in a cool dark place until required. The sampling day moisture content was also taken for each batch.

Five samples in each batch were tested after each storage period of 0, 1, 2, 4 and 8 weeks. The weight and volume of each sample was determined using the water immersion method. Each sample was then rewetted on a sand bath. The rewetting started with a suction at 10 mm for a day, this was reduced to 0 suction the next day. On the third day the samples were totally immersed for 24 hours before being reweighed and their volume found. The samples were then oven dried at 105°C for 48 hours and their dry bulk density determined. Volume recovery after rewetting was also calculated.

Only the moisture content/suction relationships on samples stored for 2 and 8 weeks and for suctions of up to 1 m were taken, using the porous plate apparatus.

4.3.3 Survey of Peat Depth

The survey of the peat depth in the experimental area, carried out at the same time as the surface land survey, uses a combination of gouge auger and steel rod. A wedge cut (facing upwards) is made in the steel rod at every 50 mm distance. The steel rod was pushed into the peat soil to a known depth. As the steel rod is pulled out each wedge was inspected for any traces of clay. The clay depth was deduced from the depth of the location of traces of clay and the depth of insertion, to the nearest 50 mm. This was checked at random with the gouge auger. Depth of the deposit, from the ground surface to the impermeable substratum, is also required in determining the drain depths and spacing in field drainage design (Section 2.4.4).

4.3.4 Subsidence

The shrinkage value, bulk density and ash content can be used to predict peat subsidence. Actual subsidence can however be measured by direct monitoring of changes in soil surface levels.

Soil meter monitoring

This was fabricated with reference to works by Irwin (1977). However the materials and dimensions were modified to suit local conditions. Aluminium was used because of its light weight and its resistance to corrosion. Figure 4.10 shows the installed instrumentation. Circular plates of 95 mm diameter were attached to 8.5 mm diameter aluminium rods of various lengths for monitoring soil movement at design depths of 0, 50 mm, 100 mm, 200 mm, 500 mm, 1 m, 2 m, and 3 m. The contact pressure of the longest (therefore the heaviest) rod and plate, with the ground is about 1.08 kPa (110 kg m^{-2}), and at a depth of 3 m below the surface. The contact pressure of a fully loaded machine on the surface, presently in use, is between 14.72 to 36.92 kPa (1500 to 3660 kg m^{-2}).

The rods and plates were placed in holes augered to the required depths. The holes were protected by PVC pipes having internal diameter of 127 mm. Due to installation limitations the exact depths were reached within ± 5 mm for the first 4 depths and for the subsequent depths between ± 10 mm. The exception was soil meter No 2 in Plot 2 (SM2 - Figure 3.3) where there were obstructions possibly by buried timbers. The actual depths reached were determined by the length protruding through the horizontal bar. All the rods at each location should protrude by the same amount. Using rod no. 1 as reference on the ground surface, the actual depth of the soil meters, in mm, were deduced as in Table 4.1. Subsequent readings for rod No. 8 of plot 2 had to be abandoned due to outside disturbance on the rod.

A horizontal angle bar holds these rods in place as well as providing a datum for the measurements. The horizontal bar is tied on each side to a 51 mm diameter galvanised iron (GI) pipe sunk deep into the stable subsurface layer. Both ends of the horizontal bar were surveyed to a permanent bench mark (BM) to establish their level. The levels were checked at each survey exercise carried out in the field. Weekly readings of the rods were taken and plotted against time. Daily rainfall was plotted together to determine possible relationship with moisture.

Land survey of experimental area

A detailed land survey of the whole experimental area was carried out in 1984 for the initial detail design by MARDI. Surveys were carried out again in 1986 and 1988 to establish the surface levels. These results together with the depth to the subsurface clay layer were reduced to x, y and z coordinates and analysed using the SAS (1979) computer package in MARDI headquarters.

4.4. Agronomic Trials

4.4.1 General

As attempts were made to control WT at various depths it was appropriate that some crop trials be carried out simultaneously on the land. Pineapple and cassava were chosen for the agronomic trials as both these crops are very tolerant to the acidic condition and have excellent economic potential. The planting, liming, fertiliser application, monitoring, harvesting, yield and quality determination were carried out by the management of IPRS.

4.4.2 Water Table Monitoring

The yield parameters were initially planned to be analysed in relation to the 3 design WTs in plots 4, 5 and 6. The land had a natural average slope of 1 in 300. Due to removal of buried timbers there were pockets of depression exceeding 300 mm. Request for land levelling in each individual plot was not possible. Although a number of check controls were used to raise the WT it was still not possible to have a uniform WT depth in each of the instrumented plots. Thus yield parameters were collected and analysed around individual OW. The middle OW, both between the drains and between the drains and farm roads, were chosen. These middle OW were expected to experience the extremes of WT level both during the wet and dry seasons.

The weekly WTs were monitored for the chosen OW, and measured from the top of the PVC pipes. These were then reduced to levels with respect to the ground surface. When the OW were first installed in early 1987 (September 1986 for Plot 4) most of OW pipes were either at the surface or very near the surface (within 15 mm). By the end of 1988 most of the OW pipes were jutting out at around 100 mm above the ground level (GL). Two survey readings of the top of the OW, $MSL_{OW,}$ pipes were taken in August 1987 and 1988. Interpolated values were used for times in between. The corrected WTs were calculated as such

$$WT(c) = WT(r) - (MSL_{OW} - MSL_{GL}) \quad \text{--- } 4.25$$

where

WT(c)	=	corrected WT below GL (mm)
WT(r)	=	WT reading from the top of OW (mm)
MSL_{OW}	=	Mean Sea Level of the top of OW pipes (mm)
MSL_{GL}	=	Mean Sea Level of the GL around the pipes (mm)

The actual WTs were analysed to determine the minimum, maximum, average and the standard deviation for the whole duration of the planting period and for the stress period of the growing crops.

WTs in the fields, unlike in lysimeter studies, can seldom be kept at a constant level. There is always the expected fluctuation such as the rise in WT levels due to the rainfalls and the lowering of the WTs during the drier periods. During the wetter months the crops might be affected by aeration stress and a summation of excedence above a chosen water level (Sieben in Wesseling, 1974) can provide an indication of the magnitude of water logging above the chosen water levels. It is also possible that the crops may experience moisture stress during the drier months particularly if the soil does not supply sufficient water to the crop to meet its water demand. A measure of this moisture stress also needs to be formulated.

In the Dutch Ysselmeer Polders where Sieben developed his concept of SEW (Sum of Excedence during Winter time) there were high WTs during winter. His SEW_{30} values summed all the daily excedence of water level above the 300 mm. Large SEW values generally indicate poor drainage. In the Pontian area the rainfall is relatively well distributed throughout the year (Figure 1.2).

The average WT over the growth periods as monitored from the individual OW for the six plots (Tables 5.39 to 5.44) is reproduced below in mm

Plot 1	568 to 804 (Designed WT = 300)
Plot 2	605 to 818 (Designed WT = 600)
Plot 3	621 to 952 (Designed WT = 900)

Plot 4	435 to 766 (Designed WT = 300)
Plot 5	573 to 857 (Designed WT = 600)
Plot 6	568 to 848 (Designed WT = 900)

As can be seen there is very little variation in the average values to indicate any effect at all of the different water level controls. A method has to be found to confirm whether there is, if any, an actual difference in the water regime in the 6 instrumented plots. Siebens concept of summation of excedence was used. As this indicates the status of water logging, the summations was calculated over the entire growth period. The middle instrumented depth of 600 mm was chosen. The depth of 600 mm is the depth where many crops can grow well in Malaysia. Sum of the weekly WT values which exceed 600 mm depth from the surface was calculated for the entire growth period (or SEG_{60}-values). An example of the calculation is as given below

$$SEG_{60} = \sum_{i=1}^{n} (60 - x_i) \qquad \text{--- } 4.26$$

where

x_i = weekly WT depths (in cm) below surface during the entire growth period.

Only x_i smaller than 60 cm (600 mm) were taken into account as this is a measure of excedence.

Then to indicate the difference in WT for each plot the average SEG_{60} per week per OW for each plot is calculated as below

$$\text{Average } SEG_{60} = \frac{\Sigma\ SEG_{60}}{\text{no. of OW x no of weekly observations}} \qquad 4.27$$

As a comparison the summation of excedence of all WT above 300 mm, the SEG_{30} were also calculated. The above analysis was also used as an indication of dry condition as a result of the low WT.

4.4.3 Cassava

Cassava is one of the most important food crops in the world and the staple food for an estimated 300 million people. In Malaysia cassava is produced mainly for the extraction of starch in related industries and for animal feed. It also has many other uses and has great economic potential (Chan, 1970, Chew, 1977).

There are about 44 varieties of cassava in Malaysia. The black twig variety that was planted in plots 1, 2 and 3 not only has the highest yielding cultivars but also has a high cyanide content in its tubers. It gives a very good yield on peat of about 41 ton ha^{-1} for harvesting at 12 months.

Planting materials for cassava are cut from matured stems: Comparable cuttings 150 mm long of matured black twigs planted in a horizontal position give the highest yields as compared to slanted and vertical positions. Studies have also shown that a 230 mm length of green twig, planted in a slanting position gives a higher yield than similar material of 80 mm length (Chan, 1970, Chew, 1977). Horizontal planting is applicable to light soils particularly peats.

The black twig variety chosen for the experimental area, was planted in a horizontal position with cuttings of about 200 mm long. The plant was planted in a matrix of 1 m x 1 m which gives an equivalent plant density of 10000 per hectare. Lime and fertiliser were applied at the required times

Samples for yield analysis were taken around each centrally located OW (Figure 3.4). The expected number for each OW is 16 plants but because of growth factors the actual plant varies from 16 to 7 numbers. Measurements for plant height, root weight, stem weight and starch content were taken. Starch yield and harvest index parameters were calculated as below

$$\text{Starch yield} = \frac{\text{Root yield x starch content}}{100} \qquad 4.28$$

$$\text{Harvest index} = \frac{\text{Root weight}}{\text{Total plant weight including roots}} \qquad 4.29$$

The results were then analysed to determine the statistical relationship between root yield, starch yield, harvest index, plant height and WT position.

4.4.4 Pineapple

Pineapple is believed to have been grown as early as in the sixteenth century in Peninsula Malaysia (Wee, 1968). It was initially grown as an intercrop for the perennials in hilly areas. By 1938 pineapple began to be planted on peat. Presently pineapple is grown on approximately 14690 hectares of peat (Ab. Jamil et al, 1989)

The optimum soil pH for pineapple is pH 4.5 to 6.5. It can survive long dry periods (Doorenbos et al, 1979) but water deficits will retard growth, flowering and fruiting. Water deficit at flowering may hasten fruiting and result in uniform ripening. Ample water supply at flowering will lead to vigorous growth and a large core. Frequent irrigation or rain and water logging will affect fruit quality. The roots are generally concentrated between 0.3 to 0.6 m below the surface but can extend up to 1 m in deep soils. Lysimeter studies in Malaysia indicate the optimum water level to be between 0.68 to 0.86 m (Section 2.3.2). The crop coefficient (kc) is 0.4 to 0.5 for the total growth period (Doorenbos et al, 1979).

There are a number of varieties such as Singapore Spanish, Green Selangor, Sarawak and Mauritius. Some of the varieties such as Singapore Spanish are suitable for canning while others are cultivated for table fruit. The variety planted in the experimental area is Mauritius, popular as a table fruit.

The pineapple was planted using suckers, in double rows at a spacing of 0.6 m x 0.6 m. The distance between the double rows was 1.2 m. This matrix allow for easy movement for fertiliser application, weeding and harvesting as well as providing the high planting density of 7000 plants per hectare.

Similar to the cassava, samples were taken around each centrally located OW (Figure 3.4). Measurements were made for fruit size, sugar content and acid content. The fruits were also graded when harvested and the percentage achieved for each grade established. Statistical analysis for the WT and crop yield parameters relationship were also carried out.

CHAPTER 5 - EXPERIMENTAL RESULTS, ANALYSIS AND DISCUSSIONS

5.1 Hydropedological Data

5.1.1 General

Hydropedological data is essential for detailed field drainage design. Where drainage may not be necessary or possible, they can indicate the type of crops suited to the prevailing soil conditions. In peat they also indicate the stage of peat decomposition.

Two comparisons are made with the data collected. One is between a newly drained area (Air Baloi), a 15-year old area (IPRS) and a 40-year old drained area (Parit Sikom). The other is the six monthly monitoring on IPRS itself. Air Baloi, although still under forest when the samples were taken, had the main drains constructed 3 years before. The peat depth here can be more than 6 m deep. The experimental area at IPRS was first cultivated in 1971, and then left under secondary forest with relatively high WT. The depth of the peat deposit varies from 2.3 m to 5.1 m. In Parit Sikom, some of the deposits are less than 1 m thick above the clay surface.

5.1.2 Fibre content, Ash content, Moisture content, Bulk density and Specific gravity

For the above analysis, methods of sampling using the gouge auger and soil pits were first compared for moisture content and bulk density. The relationships of sampling day gravimetric moisture content and dry bulk density between sampling with the gouge auger and the soil pits were established. The results are given in Table 5.1 and plotted in Figures 5.1 and 5.2.

Both methods gave fairly similar results although there is a bigger scatter for the bulk density value as the range considered is small, between 0.06 and 0.29 Mg m^{-3}. The range for the moisture content varies between less than 200% to more than 1300%. Generally the gouge auger sampling estimated about 13 % higher for both the sampling moisture content and dry bulk density. As the gouge auger method is simpler, less time consuming and very much less destructive it was preferred for much of the sampling.

The fibre content (F), ash content (A), sampling-day gravimetric moisture content (θ_m) and dry bulk density (ρ_d) of the experimental area in IPRS, Parit Sikom and Ulu Air Baloi are given in Tables 5.2 to 5.7. Figures 5.3, 5.4 and 5.5 plot the relationship of Tables 5.5 to 5.7. Each value is an arithmetic average of 9 samples. As can be seen from the figures the relationship between ash content, moisture content and bulk density parameters with depth is not linear. An attempt was made to find the best fit curve with respect to depth. Four regression analyses, namely linear, 2-dimensional polynomial, geometric and exponential were tried. Generally the geometric regressions gave the best fit for all three parameters.

Fibre content

The fibre content (F) analysed from samples obtained using soil pit data (Table 5.2) shows extremely high unrubbed fibre percentages.

In this sampling, all fibres within an area measuring approximately 150 mm x 150 mm and for each interval depth (50 mm and 100 mm for the top 2 layers respectively and 150 mm for the subsequent depths) were assessed. The percentages were calculated on an oven dry weight basis. Fibre content decreases from the Air Baloi (73 to 91%) through the IPRS (49 to 67%) to the Parit Sikom (6 to 53%) sites. The higher percentage in the top layer of Air Baloi is due to the much dryer fibres on sampling day, while in Parit Sikom the higher percentage in the top is due to the presence of dried granules (exceeding 106 μm) which have gone through the process of irreversible drying. The very low fibre content in the lower layers at Parit Sikom is because the clay layer has been reached.

The samples from the gouge auger tests (Tables 5.3 and 5.4) were analysed with most of the longer and bigger visible fibres removed to enable the peat to be placed in the syringe. This syringe method is used by the Canadians on their fibrous peats (Day et al, 1979). As can be seen it is not a suitable method for Malaysian peat as substantial amounts of buried timbers and fibres cannot be included. The analysis shows the percentage volume of materials exceeding 106μm. The removal of bigger materials explains the very close fibre content values for the 3 areas below the top 50 mm for both the unrubbed (30 to 53%) and rubbed fibres (13 to 31%). The top 50 mm layer has seemingly a significantly higher fibre percentage in this analysis. This can be attributed to the presence of dried soil granules and other dried materials from the plants.

Ash content

The ash content, A, (Table 5.5 and Figure 5.3) increases from the newly drained area of Air Baloi - (1.92% for the top 50 mm and 1.17% for the 50-150 mm layer) to the old Parit Sikom area - (12.62% for the top 50 mm and 10.48% for the 50-150 mm layer) for the top 150 mm. At IPRS, the ash content of the lower layers does not show any increase over the 12 months monitoring although it is slightly higher than that of Air Baloi. The overall significantly higher values of ash content in Parit Sikom can be attributed to either higher mineralisation as a result of oxidation or the possibility that the depth is in the peat clay interface or both. Except for the ash content of IPRS July 1987 the overall correlations in the geometric regression analyses for ash, A, are quite high, exceeding 80%. The correlation for IPRS July 1987, however, is only 47%.

The higher ash content in the top layer is expected, as this is not only a drained layer but is also subjected to more intense agricultural activity and exposed to aeration and direct heating from the sun. Therefore greater degrees of shrinkage, irreversible drying and oxidation and/or mineralisation occurs here. With drainage, the lower drained layers soon also become aerated and subjected to further increases in the rate of oxidation. Increase in ash content is expected with time. The time frame for any increase will not only depend on drainage but will also depend on cultivation practices which may further increase aeration. The ash contents of the top 150 mm in the IPRS samples are much higher than those of Ulu Air Baloi although their bulk density are similar. This probably reflects the effects of cultivation.

Moisture content and bulk density

From Table 5.12 it can be seen that the field capacity was reached within 3 days after the draining event. As all sampling were carried out more than 3 days after a rain event, the moisture content was assumed to have stabilised with respect to soil depth and WT level.

Generally θ_m (Figure 5.4 and Table 5.6), of the top 150 mm decreases from the newly drained area of Air Baloi - (431% for top 50 mm and 518% for 50-150 mm layer) to the old Parit Sikom area - (165% for top 50 mm and 310% for 50-150 mm layer). Moisture content values for layers below 700 mm are not as clearly affected by the length of drainage time as the top layers. The reduction of θ_m in the top 50 mm in IPRS from January 1988 to July 1988 - (from around 230% to 170%) is substantial. No records of moisture content are available for this layer in IPRS July 1987 but compared with the sampling of Air Baloi, the value of θ_m for IPRS July 1987 could exceed 400%. Although the linear, 2 degree polynomial as well as the geometric relationships for the moisture content all have correlations exceeding 90% the standard error for the geometric relationship is the smallest.

The dry bulk density, ρ_d, for the top 150 mm, (Table 5.7 and Figure 5.5) generally increases from the newly drained area of Air Baloi - (0.129 Mg m^{-3} for top 50 mm and 0.120 Mg m^{-3} for 50-150 mm layer) to the old Parit Sikom area - (0.198 Mg m^{-3} for top 50 mm and 0.185 Mg m^{-3} for 50-150 mm layer). For the IPRS area the ρ_d for the top 50 mm layer (Figure 5.5 and Table 5.7) shows an increase in value from 0.095 Mg m^{-3} in January 1988 to 0.182 Mg m^{-3} in July 1988. The curve fitting analysis for ρ_d showed a higher linear correlation with depth for the newly drained area (exceeding 94% for Air Baloi and IPRS July 1987) but for the longer drained area the curve fits the geometric relation ship better (exceeding 93% for IPRS July 1988 and Parit Sikom). The correlation in all the regression analysis exceeded 73% with standard errors of less than 1.0.

Dry bulk density of the lower layers decreases with depth. However, Figure 5.5 shows that at depths deeper than about 700 mm, the effect of length of drainage time does not seem to have made a significant difference to this parameter. As mentioned previously the moisture content in the layers deeper than 700 mm is not as clearly affected by the length of drainage time as the top layers.

Rainfall in the Pontian area is relatively well distributed throughout the year. Water table records for IPRS area, from Table 5.51 shows the water table depth in the area to fluctuate around an average of 435 mm to 952 mm. Similarly the DID drain constructed in Ulu Air Baloi and Parit Sikom would have similar water table fluctuation as the criteria used for drainage design are similar.

Thus the significant reduction in moisture content, upon drainage and within 6 months (from January 1988 to July 1988), which in turn corresponds with the increase in ρ_d, indicates that the effects of drainage occurs almost immediately. The removal of secondary forest and crop cover which started in September 1986 and completed by May 1987, directly exposed the top soil to atmospheric air drying and heating from the sun. This probably exerted a greater if not equal influence on moisture content and bulk density as indicated by the values of these parameters in the top 50 mm layer.

Specific gravity, G_s

The specific gravity, of the peat in the three areas is given in Table 5.8. The samples from Ulu Air Baloi peat have the biggest values (1.43 to 1.46) though they do not vary very much from those of IPRS and Parit Sikom. The average specific gravity for the peat soil is estimated to be 1.34.

Overall Comparison

Under the USDA soil taxonomy system, peat soil with fibre content exceeding 67% are classified as fibric, 67% to 33% fibre content as hemic and less than 33% fibre content as sapric. Based on fibre content between 73% to 91% the Air Baloi deposit can be classified as fibric, the IPRS experimental area (fibre content between 49% to 67%) as hemic while that of Parit Sikom area (fibre content between 6% to 53%) are generally hemic to sapric.

In soil consolidation, bulk density increases as volume decreases. A point will be reached, when the soil is sufficiently packed such that no further volume decrease can be effected. Consequently the ρ_d would then correspondingly remain constant.

Table 5.9 gathers and tabulates all the available moisture content and corresponding dry bulk density data from varying depths. As peat loses its volume on drying, decreasing peat moisture content can be related to loss in volume and therefore increase in bulk density. Plotting the dry bulk density, ρ_d, against the moisture content, θ_m, for the peat (Figure 5.6), it can be seen that as the peat loses its moisture (decreasing θ_m), the bulk density increases. The relationship can be divided into two parts. The section from θ_m=maximum to around θ_m=400%, projects a linear relationship with a gentler slope where

$$\rho_d = 0.314 - 5.071 \times 10^{-5}\, \theta_m \qquad \text{--- } 5.1$$

For all moisture content below 400%, there is a similar linear relationship but a very rapid increase in ρ_d can be deduced. The plotted line give a relationship of

$$\rho_d = 1.351 - 5.483 \times 10^{-3}\,\theta_m \qquad \text{--- 5.2}$$

The first part of the linear relationship at high moisture is the expected soil consolidation and shrinkage with drainage and drying whereby moisture loss is accompanied by volume loss. At some moisture content below 400%, the peat presumably denatures as the individual soil particles dry out and shrink, enabling the peat to be further tightly packed than otherwise possible. From Figure 5.6, the point where this occurs may be at about the intersection of the two linear curves, where θ_m=226% and ρ_d=0.12 Mg m^{-3}. Figure 5.4 indicates the moisture content of about 400% to occur at about 200 mm below the surface in the old Parit Sikom area and at about 50 mm below the surface in the new Ulu Air Baloi area. The same figure also shows that the moisture content of less than 226% is to be found in the top 50 mm layers of Parit Sikom and the drained IPRS area. The single overall best fit curve for ρ_d against θ_m is however a geometric curve and is given in Figure 5.6 as

$$\rho_d = 3.532\,\theta_m^{-0.554} \qquad 5.3$$

The rapid increase in density at very low moisture content is quite different in the behaviour of mineral soils

The specific gravity, G_s, the dry bulk density ρ_d and the density of water, ρ_w, is related to the void ratio, e, in the following equation.

$$\rho_d = \frac{G_s\,\rho_w}{1+e} \qquad \text{--- 5.4}$$

Therefore

$$1+e = \frac{G_S\,\rho_w}{\rho_d} \qquad \text{--- 5.5}$$

Assuming the volume of solid to be unity, and the void ratio to be e, the total volume can then be estimated as (1+ e). Table 5.10 shows the decreasing total volume, (1+ e) values, with drying as compared to the unit volume of the solids.

These results are estimated from the range of ρ_d in Figure 5.6. The value of specific gravity, G_s, is taken as 1.34.

From Table 5.10 it can be seen that as the ρ_d increases the net volume reduces. Even at a net volume of 34% of its initial volume, there is still room for compaction as the porosity of the soil is still very high, at 86%.

From Figure 5.4, moisture content of 250% or less in the Parit Sikom and IPRS July 1988 samples are found to occur at depths of around 50 mm and less. At this corresponding depth, the ash content and ρ_d analysis in Figures 5.3 and 5.5 exhibit comparatively higher values than the lower layers, indicating the material within this layer as having properties different from the layers below.

Below the surface layer the parameters, particularly θ_m and ρ_d, from the different drainage areas overlap, and hence do not reflect the age of the drainage of each particular area.

5.1.3 Moisture Retention Properties

The gravimetric moisture contents, θ_m, obtained from the three methods, namely the porous plate and the pressure plate apparatus and the vapour pressure method at the respective suctions are given in Table 5.11 and plotted on a semi-log graph in Figure 5.7. As can be seen, moisture is released as suction increases. Initially the graph has a steep slope up to about 0.3 bar for the 0-100 mm and 100-200 mm layers and 0.1 bar for the 200-300 mm layer. Moisture release up to 0.3 bar for the top three layers is 106%, 134% and 231% respectively. Moisture release up to 0.1 bar for the 200-300 mm layer is 123%. At lower moisture contents the graph has a gentler slope but starts getting steeper again at about a suction of 1 bar. Moisture release between 0.3 bar and 5 bar for the three layers is 148%, 204% and 189% respectively. Moisture release between 0.1 bar and 5 bar for the three layers is 175%, 235% and 297% respectively. Between 5 to 15 bar the graph is almost vertical, indicating minimal moisture release within this suction range. The moisture content here is between 210 to 260%. However, as the suction increases above 15 bar suction, the rate of moisture release increases again. The moisture content at a suction of 316 bar, around 26%, is similar to that of θ_m for air dried peat soil.

In other soils the lower limit of available water, the permanent wilting point (PWP) is generally taken at 15 bar. The moisture characteristic curve in Figure 5.7 indicates that for peat in its natural state, at suctions between 5 and 15 bar almost no moisture can be extracted. Poor contact between soil and apparatus cannot be the reason as moisture release between suction of 15 to 316 bar (using vapour pressure method) is quite high at around 200%. Figure 5.7 also shows that beyond the suction of 15 bar further moisture can be extracted from the peat. Moisture content at 5 to 15 bar, from this figure, is between 215% to 250% very close to the θ_m value of 226% at the intersection of the two linear curves in Figure 5.6. The moisture extracted below 15 bar is the moisture held between the soil particles whilst the moisture extracted above 15 bar can be assumed to be absorbed water, held tightly in the organic matter. The extraction of moisture results in the peat sample shrinking as is shown in Figure 5.54. While the volume decrease per unit mcisture, increases with decreasing moisture content, Figure 5.54 shows a more rapid decrease in volume per unit moisture, again at θ_m of about 200%. From Figure 5.4 it can be seen that θ_m less than 200 % occurs at a depth between the surface to 50 mm depth. At this depth, Figure 5.3 shows the peat having very high ash content which also coincides with comparatively high dry bulk density in Figure 5.5. Presumably this is the thresh-hold limit not only between the two types of moisture held in the soil but also the thresh-hold whereby the peat denatures resulting in higher ash content and bulk density.

From the above it can be concluded that moisture in the peat soil above the 5 bar suction is not available for plant growth ie the PWP for peat can be taken to be at 5 bar suction. Assuming the peat soil is denatured as it dries to below 250%, the turning point of irreversible drying probably occurs around this moisture content and between 5 to 15 bar suction.

The moisture curves in Figure 5.7 show that although more moisture is available in the lower or deeper soil layers, the moisture content of all the layers converge to around 26 % at the suction of 316 bar. For the two lower layers the curves almost coincide from the suction of about 0.3 bar or from about $\theta_m = 450\%$. All three curves have similar shapes indicating similar moisture release characteristics. The figure also shows that about half the total soil moisture in the peat soil is easily available at suctions below 1 bar ie 214%, 271% and 348% respectively for the three layers. Moisture release from 1 to 5 bar is 40%, 67% and

72% giving the total moisture release below 5 bar suction as 254%, 338% and 420% respectively.

It is evident from Section 5.1.2, that the moisture content, θ_m, increases with depth. This increase is not only because of the approaching water table (WT) but also because of the changing properties of peat soil with depth. It is expected, therefore that the field capacity value, the upper limit of available water will be specific to the soil type and therefore the soil depth.

The available water capacity (AWC) for crop growth can be estimated from the difference of the moisture content at permanent wilting point (PWP) and at field capacity (FC). For all practical purposes, moisture content at wilting point for peat can be taken to be similar to that at 5 bar. The value of actual FC was monitored during the drainage system testing (Section 4.1.5) in the field. The monitored moisture content, θ_m, following the release of the flooded water is given in Table 5.12. This table shows that moisture content, θ_m, at FC is extremely low for the top 50 mm layer, (at less than 200%). It increases from about 400% at the 50-100 mm layer to about 700% at the 200-300 mm layer. Between 300 mm to 500 mm depth the θ_m value at FC is 1000% or less. The θ_m value between 500 mm to 800 mm averages around 1100%. The area sampled was covered (see Section 4.1.6) before the embanked water was released, and only uncovered for daily sampling. Thus any moisture loss through evaporation is minimal. From Section 5.1.2 and Table 5.12 it can be deduced that the material below 300 mm depth is quite similar. As the WT is at 700 mm depth from the surface and the moisture content from below the WT and up to 500 mm depth is around 1100%, the capillary fringe can then be deduced to be within 200 mm above the WT.

Comparing the θ_m value in Table 5.11 and the moisture release curve in Figure 5.7, it can be seen that for the 0-100 mm curve (sampling taken with the top granule level removed) the suction for a moisture content of 400 % is 0.1 bar. From Figure 5.7, θ_m at 0.1 bar for the lower layers of 100-200 and 200-300 mm depth are 484% and 555% respectively. This is less than the recorded 500% to 750% from Table 5.12. As the WT is at 700 mm and the capillary fringe reaches up to 500 mm depth, the influence of capillary rise probably accounts for the higher moisture content. Thus it can be concluded that, because of changing soil properties, the value of moisture content at FC (taken at a suction of 0.1 bar) is expected to increase with depth.

The available water capacity (AWC) can be estimated from known moisture content values at PWP and FC. The θ_m value at FC increases with depth while the θ_m at PWP (5 bar) is about 250% for the 3 layers monitored above 300 mm depth. Based on this trend, the same values for θ_m at PWP can be assumed for the lower layers as the peat condition is similar. Thus the gravimetric AWC will increase with depth. However gravimetric percentages are based on the percentage of the mass of dry solids. Dry bulk density of the peat decreases with depth and if this bulk density is known then the volume of AWC at various depths can be estimated and compared.

Moisture content at FC below 300 mm depth is about 900%. Assuming the moisture content at 5 bar to be around 250%, the available water will be 650% of the dry mass. Table 5.13 shows the estimated volumetric moisture content, θ_v, at the different dry bulk densities and the corresponding AWC in mm per 50 mm depth.

A comparison of the volume at field capacity for the three instrumented areas is made in Table 5.14 using values of θ_m and ρ_d taken from Figures 5.4 and 5.5. Assuming θ_m at PWP to be 250% for all three instrumented areas and θ_m at FC to be not exceeding 900% (those values exceeding 900% are assume to be in excess of FC), the respective AWC are calculated and presented in Table 5.15.

Table 5.15 shows that in contrast to the old Parit Sikom area and the well drained area of IPRS Pontian, there is AW for plant growth from the top 50 mm of the newly open peat soil in Ulu Air Baloi. Between 50 mm depth to 450 mm depth, where the soil is expected to be affected by drainage there is a decrease in available water with time upon drainage. There is no significant difference in AW below the 450 mm layer as the WT is taken to be at 700 mm and the saturated condition to be from 500 mm depth.

As can be seen in Tables 5.13 and 5.15, although the increase in gravimetric percentages of available water with depth is very high, the corresponding volumetric percentage increase is at a slower rate due to the decrease in dry bulk density. For similar AW of 650%, gravimetric basis, the actual available volume will be smaller with lower dry bulk density values. The available water, exceeding 50% volumetric basis for peat, is very high when compared to that of other soils in Malaysia which are generally below θ_v=25% and can be as low as θ_v=3.3% (Soong, 1979). As can be seen from Tables 5.14 and 5.15, for the top 50 mm layer, although there is a substantial volumetric moisture content exceeding 30%, this however, is not available for plant growth since the water is held at suctions near 15 bar.

Although the moisture characteristic curves of Ulu Air Baloi, IPRS and Parit Sikom for the range up to 15 bar suction are available and are presented together in Figures 5.8 and 5.9 they are not used in the estimation of available water in Table 5.15 due to insufficient data depthwise. Only values for the respective layers of 0-150 and 150-300 mm are available.

Nevertheless the moisture release pattern for the three areas can be compared. From Figures 5.8 and 5.9 it can be seen that the curve for Ulu Air Baloi releases more than half of the total moisture below 1 bar suction. There is minimal moisture release between 1 and 15 bar suction (θ_m between 280 to 330%) for peat from this area. The IPRS curves shows the peat as having less moisture content per unit soil mass. About one third of water is released below 1 bar suction. More water is released between 1 to 15 bar suction for the IPRS curves as compared to that of Ulu Air Baloi. The Parit Sikom curves indicate gravimetric moisture content as being the least of the three. For this area minimal release of moisture is indicated to be between 0.3 to 5 bar (θ_m between 210 to 170%) with a distinct increase in moisture release above the 5 bar suction.

The results indicate that the length of time following the initial drainage not only influences the magnitude of the total moisture content but also affects its moisture release pattern. The longer the peat is drained the less will be the total gravimetric moisture content. The accompanying increase in the dry bulk density, ρ_d, will influence the volumetric moisture content, θ_v, as $\theta_v = \rho_d\theta_m$. If the increase in ρ_d is small while the decrease in θ_m is rapid, the actual value for θ_v will decrease with drainage.

The details on the mechanics of soil water release patterns and the potentials responsible for holding the water are available in many books on soil physics. Suffice to say that the moisture release pattern indicates how soil water is available, easily or otherwise, to the crops and is important for the design of field water management systems. Figure 5.7 gives the moisture release curve (drying curve) based on gravimetric analysis. As the peat soil dries the bulk density increases. Using increasing ρ_d values on drying from Table 5.10, θ_v values from

Table 5.11 and the equation $\theta_v = \theta_m \times \rho_d$, Table 5.16 gives the corresponding volumetric moisture content at the various suctions for soils from IPRS Pontian.

5.1.4 Hydraulic Conductivity, K

Saturated K measures the ease with which water flows through a saturated porous media. It is required in determining drain spacing and subirrigation requirements. As the spacing determines the density of the drainage lines, it will consequently influence project costing.

Auger Hole Tests

Hydraulic conductivity results from the auger hole tests for the three areas are given in Tables 5.17, 5.18 and 5.20. The frequency of occurrence, f, of K values for IPRS (Tables 5.17 and 5.18) are then plotted against the value K in Figures 5.10 and 5.11. For comparison with results from drainage testings, auger hole tests from Plot 2 only are extracted and tabulated in Table 5.19.

Figure 5.10, plotted for a frequency counted at each 1 m day^{-1} interval, indicates that the K value has several peaks with two peaks of equal occurrence, K between 4 to 5 m day^{-1} and K between 5 to 6 m day^{-1}. The highest peak is for K between 7 to 8 m day^{-1}. When the frequency interval was increased to 2 m day^{-1}, as in Figure 5.11, the peak frequency was more clearly defined and occurs between 4 to 6 m day^{-1}. This constitutes 22.2% of the total 72 readings taken (Table 5.18). However, 30 numbers or 41.7% have values of between 4 to 8 m day^{-1}. A total of 65.3% or 47 readings have values of between 2 to 10 m day^{-1}. Results from Plot 2 only, Table 5.19, shows the peak value for plot 2 (35.7% or 5 out of 14 readings) to be between 5 to 6 m day^{-1}.

The K values for Ulu Air Baloi range from 2.4 to 48 m day^{-1} whilst those at IPRS Pontian range from 3.8 to 69 m day^{-1}. The 3 values from Parit Sikom are within the range of values obtained for both IPRS and Ulu Air Baloi. The peat soil of Parit Sikom, where sampling was carried out, has been reduced generally to about 1 m depth. The WT at these locations were generally at 0.6 m or lower.

Table 5.20 indicates K for Ulu Air Baloi to be generally higher while that of Parit Sikom to be generally lower. The Ulu Air Baloi area is newly drained while that of IPRS has been drained for about 15 years. Once the initial drainage of Ulu

Air Baloi is completed it is expected not to differ much from that of IPRS at least for the layer above the water table.

The results of these auger hole tests indicate a reasonable overall working hydraulic conductivity value for IPRS (Figure 5.11 and Table 5.19) as well as Ulu Air Baloi, to be 5.5 m day^{-1}.

Subsurface Clay Layer

The K values for the subsurface layer were extracted from Redzuan, 1987, and reproduced in Table 5.21. The hydraulic conductivity of this layer is less than 0.01 m day^{-1}. As this is less than a tenth of the K value estimated for peat from the auger hole tests, the clay subsoil can be considered to be relatively impermeable.

Drainage Testings

The records of the water levels at the V-notch weir as well as at two mid-field positions were monitored using automatic recorders. These records were then converted into discharge at the V-notch and to height above MSL for the midfield positions (Appendix C). The discharge and hydraulic head from two field tests carried out for the WT recession curves on 13th September 1988 and 27th September are plotted in Figure 5.12. and 5.14. Both figures show the water in mid-field receding at a very fast rate. Figure 5.12 shows the water table reaching within 60 mm of the drain drainage base (midfield WT=0) within 3 to 4 days. Thus this is essentially a non-steady state situation.

The K values, given in Table 5.22, are estimated using van de Leur's equation (section 4.1.5) where

$$K = \frac{q\ L^2\ 1}{h\ 2\pi\ d} \qquad \text{--- 5.6}$$

for L=30 m and where q/h is estimated from Figures 5.13 and 5.15. and

$$d = \frac{D}{(8D/\pi L)(\ln(D/u)+1)} \qquad \text{--- 5.7}$$

For the test on 13th September, Figure 5.20 shows that the best parallel point between lines plotting log h and log q is at just about before the 20th hour to the 25th hour. At this point both h_5 and h_8 exceed 50 mm. For the test on the 27th of September Figure 5.21 shows that the best parallel point between lines plotting log h and log q to be at the end of the reading, at just before the 60th hour. This stage is more defined in Figure 5.21 as compared to Figure 5.20. The value q/h is the slope of the line passing through the points discussed above and the origin in figures 5.13 and 5.15.

d is in turn influenced by the value of the wetted perimeter, u and the depth to the impermeable surface D. From Figure 5.13 and 5.15 the height of water in the ditch is less than 200 mm and as q is only valid for h>50mm then for a width of ditch, b=0.6m, u ranges from 0.7 m to 1.0 m. From Figure 5.66 the value D is estimated to be 4.5 m. Table 5.22 presents the values of k for varying d values and for two drawdowns. However the drawdown on the 27th of September is preferred to that of 13th September as the discharge at the weir is free flowing. Comparison of the K values from the auger hole tests will be made with this drawdown which ranges from 5.5 to 5.0 m day^{-1}. The hydraulic conductivity of 5.0 m day^{-1} is when the water in the ditch is 150 mm deep. From Figure 5.16 and 5.17 (which monitors drawdown for more than 70 hours) the water table in the ditch stabilised to around 60 mm giving the value of u=0.72m. Thus the K value from this drawdown is taken as 5.5 m day^{-1}.

General Discussion

The hydraulic conductivity estimated using the auger hole method shows a very wide range of values for each location. These big differences in K values are due to the variability of the peat soil itself. If the holes were augered directly into the cavities located beside buried tree trunks or logs, water would be gushing into the hole after each bailing. These can give tremendously high estimates of K values. The magnitude of K will be dependent on the size of the cavity in the vicinity of the augered hole. Some of the buried timbers in the Malaysian peat can be very big and the peat density decreases with depth. The cavities created can thus be very large. It is possible to have estimates of K values from auger hole tests exceeding 10 or even 100 times the actual value. Estimates of the hydraulic conductivity from the drainage tests considers the whole field as its sample size.

The sample size for an auger hole test is just around the hole augered which is approximately 0.5 m^3.

Any reduction of the K value following drainage will depend on the decrease in porosity. There is the expected consolidation of the peat soil as it changes from a saturated condition to an unsaturated condition as evident from past experiences. However Figure 5.5 shows that where the deposit remains saturated there is only a slight increase in dry bulk density, indicating minimal consolidation.

The hydraulic conductivity values for the three areas lie between 2 to more than 48 m day^{-1}. Whilst Figure 5.11 shows the peak frequency to occur for K between 4 to 6 m day^{-1}, 41.7% of the readings lies for K between 4 to 8 m day^{-1}. Peat in Parit Sikom area has subsided considerably. In some parts of Parit Sikom the clay layer has been exposed. Figure 5.3 shows the peat in Parit Sikom to have significantly higher ash content. Figure 5.5 also shows the peat in this area to have a significantly higher bulk density. The lower K value for Parit Sikom can therefore be due to differing peat material. All three values from Parit Sikom is less than 8 m day^{-1} while 8 out of 12 readings (or 67%) from Ulu Air Baloi has values more than 8 m day^{-1}. Thus although minimal K data were collected, generally the results indicate that the hydraulic conductivity, K, of saturated soil will increase with drainage.

The estimation of K from installed drainage systems uses a much bigger sample area and is generally expected to give a more accurate estimation. The K value estimated from the drawdown is taken as 5.5 day^{-1} and compares favourably with that of the auger hole values for Plot 2 of IPRS. Since Plot 2 is part of IPRS project area and of the same characteristic, its K values should not generally differ significantly from the rest of the project area.

A working K value of 5.5 m day^{-1} is therefore recommended for design purposes in similar types of peat. If bigger K value than necessary is use, the area may suffer from excessive drainage. Usage of smaller K value may result in increase length of inundation period of the area. With drainage and time the K value may decrease slightly, resulting in a system which will drain less readily. As the expected decrease is relatively small, the system should still be able to function well with appropriate adjustment to the operation and maintenance procedures.

5.1.5 Water Table (WT) Shape

Figures 5.16 to 5.19 shows the WT shape in recession during the two drainage tests in Plot 2. The water table readings are given in Appendix C. Row 3 is the mid-field position while Row 4 is the 1/4 distance from the perimeter drain of Plot 2. The figures were drawn with the vertical scale exaggerated at 100 times the horizontal scale. Monitoring was carried out from just before the water was released. Figure 5.16 and 5.17 record the WT shape across the field for up to 3 days of drawdown. Rain fell on the fourth day. Figure 5.18 and 5.19 is a one day monitoring of the recession curves at closer intervals starting with an interval of approximately 15 minutes and ending at about an hour interval.

In all the four figures the water level in the drain receded to almost midway between the embanked level and drain invert within half an hour after the checks were removed. The reaction of the mid field WT was much slower but within one day, the WT had receded by about 300 mm. There is a further recession of about 100 mm in the next 48 hours, as shown in Figures 5.16 and 5.17. At this point it was only about 60 mm above the drain invert. Both figures show a lowering of about 150 mm in the mid field WT within 7.5 hours after the checks were removed or a drawdown of about 20 mm/hr. Figures 5.16 and 5.17 indicate that this rate continued for the first 24 hours but reduced there after.

The difference between midfield WT (15 m from the drain) and the WT at about 1/8 distance from the drains (3.75 m from the drain) changes with time. About 15 minutes after water was released this difference was about 50 mm in Figure 5.16 for OW238. It increased to about 100 mm after 1 hour. On the second day the difference was reduced to about 50 mm and by the third day there was about 30 mm difference between midfield WT and the 1/8 distance.

For the second drawdown on the 27th of September 1988, the drains were cleared of debris and slightly deepened by 50 mm. Drawdown for the centre drain, D2/2, for both tests was somewhat, restricted by the V-notch weir as is indicated by both Figures 5.17 and 5.19.

In Figure 5.18, after the first half hour, the drop in water level at mid-field was almost constant, at about 15.4 mm per hour. Similar to the drawdown on the 13th of September, the difference between the mid field water level and the water level at 1/8 distance became increasingly pronounced with time until at about 7.5

hours after the release the difference was approximately 75 mm between D2/1 and D2/2 and about 125 mm between D2/2 and D2/3.

Monitoring of the recharge WT shape was not possible as water supply for the recharge exercise was difficult and limited. The recharge WT should rise as rapidly as it recedes, with the areas near the water supply (near the drains) being rewetted earlier than at mid field. Consequently a trough or a concave shape is expected for the recharge curve as compared to the convex shape for the recession curve. The midfield position is therefore the critical position. It is the point that is drained the last and will also be the last area to receive water from subsurface irrigation.

The recession curves indicate that unless there is an obstruction in the flow discharge, WT can drop to at least 300 mm in one day for a location of 15 m from the drain. Any obstruction to the flow, such as the V-notch weir, will restrict WT drawdown as shown by the mid-field position between drains D1 and D2. Conversely an area located at 15 m from the drain is expected to receive subsurface irrigation water up to 300 mm deep within a day. Soil moisture supply for crop growth can be replenished from the subsurface water level through capillary rise. The water level is however receding very fast. If the soil moisture storage within the root zone is inadequate, steps have to be considered to ensure that the root zones are within reach of the WT level.

5.1.6 Drainable Porosity

The drainable porosity was calculated from both the rainfall and rise in WT as well as from the drainage tests.

Rainfall and rise in water table

Table 5.23 gives the values of p calculated from instantaneous rainfall, Ri and rise in WT dh, for the various locations of the IPRS experimental area. The average porosity, p, is estimated to be 0.38.

Drainage testings

Graphs of log of discharge, q, and midfield water tables, h_5 and h_8, are plotted in Figures 5.20 and 5.21. The best tangent to the curves were drawn in as explained in section 5.1.4. The value of tan α was then estimated, with the x-axis converted from time in hours to time in days. The drainable porosity, p, was then calculated as outlined in Section 4.1.7 where

$$p = \frac{\pi^2 k d j}{L^2} \qquad \text{--- 5.8}$$

where

$$\frac{1}{j} = 2.3 \tan\alpha \qquad \text{(unit in days)} \qquad \text{--- 5.9}$$

Table 5.24 shows the calculated p values using the tan α values from Figures 5.20 and 5.21 as well as q/h values from Figures 5.13 and 5.15. As explained previously the monitoring from the drawdown on the 27th of September is preferred. The average p value obtained from this drawdown is 0.38 which is similar to the overall average porosity obtained from calculation using rainfall and rise in water table levels as shown in Table 5.23.

5.1.7 Capillarity

Table 5.10 indicates the void ratio, e, decreasing from about 20 to 6 or total pore spaces decreasing from 95.2% to 86.0% of the soil volume on drying. This indicates the possibility of the pore sizes being relatively large. If this is so, then the percentage of capillary pores will be small, similar to that of sand. Smaller percentages of capillary pores will result in a smaller capillary fringe and lower rates of capillary rise.

Capillary Fringe

The capillary fringe is the region of saturation or near saturation just above the WT. It is more significant to growing plants than the phreatic WT. The capillary fringe also forms the boundary between the hydraulic conductivity at or near saturation and the unsaturated k which has a very much smaller value.

Moisture profiles above known water tables are presented in Figure 5.22. Each graph is an average of 3 results. Saturated conditions are assumed at the water table level. Usually, within the capillary fringe the soil should be almost fully saturated. Figure 5.22 however, does not show any graphs dipping into the WT at right angle. It is possible therefore that there were minimal or almost no capillary fringes in the sample collected. A more reasonable explanation, in view of the high degree of porosity and moisture content is the loss in moisture during sampling. However using moisture contents (θ_m) of 90% and 95% of saturated moisture content (θ_{ms}), as the minimum cutoff for the capillary fringe, Table 5.25 deduced the capillary fringes from the graphs plotted in Figure 5.22. It can be seen that the capillary fringes, for θ_m > 90%, can vary from 110 to 250 mm from the phreatic WT with an average of about 185 mm. If the moisture content of the capillary fringe is taken to be 95% of saturated moisture content then the capillary fringe will be reduced further to between 160 and 75 mm with an average of 119 mm. Section 5.1.3 and Table 5.12 presents sampling data of field moisture contents in days after drainage (water table drawdown of section 5.1.4). Water table in the field is at 700 mm below surface. Referring to the field capacity deduced, moisture content from 700 mm to 500 mm depth below the surface is 1100%. Thus the capillary fringe had been deduced, to be within 200 mm above the WT. Table 5.12 also shows increases in moisture content for the 500 mm to 700 mm depth on the 3rd day as compared to the 2nd day. On the 4th day this increase has crept up to the 300 mm layer. In both cases the moisture content of the top layer has continued to decrease. As the surface area is covered with plastic sheeting during these samplings, the increase in moisture content must be due to capillary rise. Thus accounting for losses of moisture during sampling the capillary fringe can be assumed to be within 200 mm above the water table.

Rate of Capillary Rise

The rate of capillary rise is a source of water supply for crop growth during the dry periods. Lysimeter monoliths as shown in Figures 4.5 and 4.6 were used to estimate the rate of capillary rise at the various water tables. As listed in Figure 4.6 and Appendix D the lysimeters were treated to varying WT treatments. The rates of capillary rise were analysed based on water table levels, kept constant in the lysimeter ,together with the as well as rate of evaporation of water from an open petri dish (E_d).

Table 5.26 gives the average of the results of the respective lysimeters irrespective of the relative rate of E_d. E_c is the rate of loss in water level in the external water column and actually records the actual WT drawdown in the lysimeters. E_s is the rate of water loss from the top of the soil in the lysimeters.

As can be seen generally the rate of capillary rise, E_s, decreases with the lowering of the water table depth. However in the average for lysimeters 4, 6 and 14, the E_s is more for the WT depth of 500 and 600 mm as compared to that of 400 mm. This corresponds with a higher rate of E_d. Table 5.27 shows the average E_s for various WT and relative to the E_d values.

From Table 5.27 it can be seen that at the same E_d, E_s generally decreases with increase in WT depth. E_s also generally increases with increasing E_d for the same WT depth. Although, in some specific lysimeters (L4 and L6 at WT=500 mm) there are indications that the maximum E_s occurs at E_d=3-4 mm day^{-1}. the E_d values are not sufficiently distributed to confirm such a situation. However it is reasonable to expect E_s value to decrease with E_d values after it has reached a certain optimum. This can be due to the discontinued moisture supply from soil layers below the surface.

Using values of rate of capillary rise from lysimeters 2, 8 and 18 (the whole range from 0 mm to 900 mm is available for these lysimeters), Figure 5.22b is drawn. This figure shows a decrease in the rate of capillary rise, E_s, with increasing water table depth and increasing E_s with increase in open water evaporation in the petri dish, E_d. From this figure, Figure 5.22b, the rate of capillary rise at the various water table depths and varying E_d is deduced and produced in Table 5.28. Bearing in mind that the daily evaporation rate in the area averages around 3 to 4 mm per day it would appear that the rate of capillary rise ranges from 4.0 mm day^{-1} when the water table is at the surface and reduces to 1.0 mm day^{-1} when the water table is at 900 mm below the ground.

5.1.8 Rainfall and Evaporation

As stated in Section 4.1.9, for the estimation of design rainstorms, the data from the established hydrological national network is utilised. At Pontian Besar, the monthly rainfall values over 35 years vary from 9.7 mm in January 1965 to 478 mm in November of 1982 (Rainfall Records Station No 1534104, DID Hydrology Branch). The mean monthly rainfall distribution however varies from a January low of 163.2 mm to a November high of 284.4 mm, as is given in Figure 1.2. Figure 5.23 is an extract from Nieuwolt, 1982 showing the Agricultural Rainfall Index (ARI) of the same station. The ARI indicates the expected monthly rainfall in percent of E_0 (the monthly potential evaporation) for the same period and station. Compared to other areas analysed by Nieuwolt, Pontian generally has a well distributed rainfall throughout the year. The ARI at the rainfall probability level of 80% exceeds 100 for most part of the year except for a one month period in mid January to mid February and a short period in July. Even within these two periods the ARI for the same rainfall probability is above 90. Table 3.1 presents the return period of various lengths of dry-days for the same station. As an example, the table shows that a dry period which lasts for 7 days is expected once in less than 3 months.

5.2 Bearing Capacity and Consolidation

5.2.1 General

A general minimum bearing capacity is required to enable the soil to support farming activities. While peat strength is substantially derived from the matrix of fibres and buried timbers, consolidation will increase the bulk density of the soil and consequently its bearing capacity. Consolidation coefficients indicate the compressibility of the soil and the possible settlement of structures after construction.

5.2.2 Bearing Capacity

A total of 11 tests were made using the plate sinkage equipment which was fabricated as described in Section 4.2.2. The sinkage at the end of 15 minutes after the load was applied was taken. All the loadings were tested to failure. Failure was taken as the point at which the plate tilted and fell over or sunk continuously. Graphs of cumulative sinkage against the pressure applied are presented in Figure 5.24.

As can be seen, when all the curves are considered together (Figure 5.24), there seems to be no distinct relationship between the water table (WT) depth and maximum bearing pressure. This could be due to the nature of the peat soil with its substantial fibre matrixes and buried timbers at varying depths, and the contribution of these fibres and timbers to the bearing capacity.

On regrouping, two pressure/sinkage relationships, however, emerge. This regrouping was based on the type of failure, whether by tilting (Figure 5.25) or through unrestrained sinkage (Figure 5.26). Figure 5.25 shows the sinkage increasing, first at a lower rate and then at pressures between 15 to 25 kNm^{-2} (kPa), the rate of sinkage increases considerably. The tests in this group had to be abandoned at the respective maximum pressures, because the equipment tilted and fell over as a result of unequal sinkage/settlement. The recorded cumulative sinkage at maximum pressure varies from 120 to 300 mm. The displacement of each graph from the y-axis and the value of the maximum recorded sinkage, do not indicate any pattern that can be connected to WT depth.

In Figure 5.26 the slopes changed at cumulative sinkage values of between 30 to 100 mm and showed sudden unrestrained sinkage thereafter. The final cumulative sinkage value could have been a little higher but the test was stopped/restrained manually because of the limitation of the equipment. In this figure the pressure versus settlement relationship at various WT depths is very distinct, and as expected, the bearing pressure increases with deeper water tables and drier soil conditions.

Results of penetrometer tests (Table 5.29) for the areas failing through unrestrained sinkage (WT levels 900 mm, 550 mm and 200 mm), confirm the absence of any distinct buried timbers at all the three locations. Penetrometer results in the area with the WT at 300 mm depth also clearly indicate the absence of buried timber, but this test had to be stopped when the equipment tilted, due probably to poor placement of the load increment during loading.

Only 3 results could be clearly isolated. Although inadequate, since data is not available and because this relationship is known to be a gentle shape, the relation is presented in Figure 5.27 as a gentle curve. The equation for the curve is rewritten below as

$$y = 5.246 + 0.056\,x - 1.102(10^{-5})\,x^2 \qquad \text{--- } 5.10$$

However the straight line relationship is also given and is reproduced below

$$y = 7.68 + 0.0436\,x \qquad \text{--- } 5.11$$

where

y = bearing capacity in kN m^{-2} (kPa)
x = WT in mm

The limiting bearing capacity in Figure 5.26 is taken as the pressure at the turning point (point of maximum curvature). The bearing capacity at zero WT depth ($x = 0$), is likely to be about 5.3 kPa when using the curve relationship and 7.7 kPa when using the straight line relationship. One actual reading tested with the WT at the surface, Figure 5.24 indicates that the bearing capacity value at this WT position can exceed 35 kPa. This can be largely attributed to the influence of fibre matrix and buried timbers as indicated by the penetrometer results in Table 5.29. The influence of buoyancy should be minimal as water under pressure can be dissipated around the area of the sinkage plate.

Thus, considered with the tilting results the relationship in Figure 5.27, most probably represents the minimum bearing capacity of this peat at a given water table depth.

5.2.3 Consolidation

Basic soil data for the consolidation test samples taken from the three areas of IPRS, Parit Sikom and Ulu Air Baloi are given in Table 5.30. For comparison, results of similar tests on a Malacca marine clay (LAI, 1987) are also included. Samples marked with an asterisk (*) were subjected to continuous loading beyond 24 hours, at each loading, until the ratio of deflection:time is less than $1\text{x}10^{-2}$ mm per 24 hours.

Only samples from the top 300 mm layer were taken for these tests as this layer was easily accessible as well as having less large fibres. The bottom layers are less decomposed and have greater percentages of the bigger sized fibres and timbers (Section 5.1.2). In virgin areas peat soils are usually completely saturated with WT rising to the surface. The dry bulk density decreases with depth (Figure 5.5) and can be somewhat soupy and colloidal at the lowest layer giving rise to difficulty in sampling. The process of sampling and preparation for the consolidation test, will allow natural initial drainage to occur. The extent of this initial drainage will depend on physical properties such as porosity and the size of the pores as well as methods of sampling. As the top layers are generally much denser than the lower layers, the consolidation coefficients of the lower layers will be expected to show greater compressibility than the top layers.

As can be seen from the basic data in Table 5.30, both the wet and dry bulk densities of the peat soil are very much less than that of the Malacca clay. The void ratio as expected, is much higher than that of the clay. The magnitude of these three values indicate a potentially high compressibility for the peat soil itself. The coefficients derived from the tests using the classical theory proposed by Terzaghi, and presented in Table 5.31 confirmed the high degree of compressibility of the peat. The results for each of the tests are presented in Figures 5.28 to 5.38. A sample calculation for a single test analysis, IPRS(Sep), is given in Appendix E.

The coefficients derived using the classical theory of Terzaghi were based on a number of assumptions, which include soil homogeneity and the incompressibility of water and soil grains. The decrease in soil depth (deflection of the dial gauge) during the consolidation tests can generally be divided into three parts. The first is the substantial sudden initial decrease with applied load., the elastic deformation The second is the steep straight line section which follows on from this initial volume loss while the third is gently curved. The first part of the deflection, the elastic deformation, indicates the initial compression which results from the sudden increase in loading. Although there is no clear demarcation of primary and secondary consolidation, the second part is generally assigned to be due to primary compression while the third portion indicates the significance of the secondary compression. Primary compression is attributed to the plastic deformation on drainage of pore water while the secondary compression is attributed to the compression of the soil skeleton under imposed load. It is actually only the primary compression portion that is described by Terzaghi's classical theory.

Homogeneity is assumed in most soil theories although many soils do not approximate to it. The heterogeneity of the Malaysian woody peat is very much in evidence with varying sizes of buried timbers in the deposits. Even in samples of 0.25 m diameter, soil homogeneity is difficult to achieve.

The assumption of incompressibility of the soil grains is not at all acceptable in peat as the organic skeleton of the deposit can easily be compressed as is evident from insitu inspection as well as laboratory soil analysis. However in these tests it is assumed that the compression of the soil skeleton only takes place after the pore water has been drained out.

The three parts of the consolidation curves as described earlier is evident in the deflection versus square root of time graphs, an example of which is given in Figure 5.39, (further details are given in Appendix E). In most clay soils the third part or the secondary compression would be relatively small, generally a fraction of the primary compression. The compression curve will also tend to be asymptotic to the x-axis with time. In peat the deflection beyond the primary compression, ie the secondary compression, is substantial. In the tests that were carried out, on samples subjected to 24 hours loading at each stage, the deflection in the secondary compression, in most cases, follows a straight line although at a much gentler slope than primary compression. The magnitude of the secondary compression within the 24 hour period is generally equal to if not more than the primary compression.

For the three samples which were subjected to more than 24 hours at each stage of the loading - *IPRS(Sep), *IPRS(Nov) and *IPRS(Dec)- there is indication of a decreasing slope at the end of the loading period in some of the readings as shown in Figure 5.39. This decreasing slope is also indicated in some of the results on the secondary compression of the older drained peat area of Parit Sikom as shown in Figure 5.43. In the Ulu Air Baloi deposit the straight line nature of the curve at the tail end (after 24 hours consolidation) is clearly defined in Figure 5.45. While the deflection versus $\log_{10}$ time curve of most clay soils is asymptotic to the x-axis at the end of the 24 hour period, that of the peat soil continues its steep gradient as shown in Figure 5.40, 5.42, 5.44 and 5.46. The value of this tail end gradient is c_t, the secondary compression index and is given in Table 5.31. The coefficient of secondary consolidation, C_α can then be calculated using

$$C_\alpha = \frac{C_t}{1 + e_o} \qquad \text{--- 5.12}$$

The above equation is from Peck et al 1973, and C_t is presented in Table 5.31. With known initial void ratio, e_o, the coefficient of secondary consolidation, C_α, can be estimated.

Because of the shape of the deflection log time curve, the t_{50} value cannot be deduced and hence c_v was calculated using only the square root method (Section 4.2.3)

The void ratio versus $\log_{10}$ pressure curve of the peat samples tested (Figures 5.28 to 5.38) is very similar to that of the preloaded clay soils where a distinct straight line can be found at the tail end of the loading. However the magnitude of the void ratio is very much higher in peat and occurs at a very much lower pressure.

The consolidation coefficients, c_v, from column 2, Table 5.31, were obtained from the graphs of deflection plotted against the root of time in minutes. The coefficient of compression, m_v, is calculated from each incremental deflection/strain, specimen thickness and pressure at each stage of the loading. Sample calculation of both c_v and m_v are given in Figures 5.39 and 5.40. The preconsolidated pressure, P_p, the preconsolidated void ratio, e_p, and the compression index, C_c, in columns 4, 5 and 6 are obtained from the graphs of void ratio plotted against log of pressure (kN m^{-2}) in Figures 5.28 to 5.38. The values for the secondary compression index, C_t, in column 7, are calculated from the straight portion at the end of the deflection log time graphs as shown in Figures 5.43 to 5.46.

The results confirm that the peat soil is highly compressible. Its consolidation coefficient, c_v, coefficient of compression, m_v, and compression index, C_c, are all very much higher than those of clay soils. The preconsolidation pressure of between 31 to 8 kPa (kN m^{-2}) in this surface layer could probably be due to the overburden pressure from the vegetation previously cleared.

The peat settlement as a result of increases in overburden pressure can be calculated using either the compression index, C_c, from equation 2.1 or using the coefficient of compression, m_v, as shown in equation 2.2 of Chapter 2. Both equations have their limitations. From the results in Figures 5.28 to 5.38 it can be seen that compression index, C_c although well defined, is calculated from the straight line portion of the void ratio, e, versus log p curve. This straight line portion is true only for log of pressure exceeding 20 kN m^{-2}. Estimation using C_c for the range of overburden pressure less than 20 kN m^{-2} will overestimate the value of subsidence due to consolidation.

The value of m_v is estimated from the primary compression part of the consolidation. As the secondary compression is substantial and ongoing this method will underestimate the subsidence due to consolidation.

Table 5.31 summarises all estimated values from the consolidation experiments. Values of consolidation coefficient, c_v, (column 2) are obtained using t_{90} values from deflection versus root time curve. The t_{90} values are determined from inspection of the curve and because of the nature of the peat soil can be rather subjective. The results give very high consolidation coefficient values for the peat soil as compared to the Malacca marine clay. However there is insufficient data to differentiate this value between the three sites of IPRS, Parit Sikom and Ulu Air Baloi.

This trend is repeated for all the other values of coefficient of compression, m_v, preconsolidated void ratio, e_p and the compression index, C_c. The preconsolidated pressure, P_p, of the three areas are much lower than that of the marine clay.

5.3 Shrinkage, Irreversibility, Peat Depth and Subsidence

5.3.1 General

The extent of irreversible changes to soil properties, shrinkage and subsidence are well documented in many countries. In Malaysia such changes have been noted and a few have been documented (TAY et al, 1987, WELCH, 1989). The knowledge of the extent of such changes are not only of great help in the design and planning of the engineering infrastructures but are also useful for the choice of suitable agricultural crops, cropping practices and mechanisation operations. Peat depth will be affected by shrinkage and subsidence. Thus the initial and existing peat depth status also needs to be established in order to predict the effect of these phenomena on the net peat depth and consequently on crop practices.

5.3.2 Shrinkage and Irreversibility

The results of the irreversible drying experiment carried out on undisturbed samples in moisture cylinders measuring 76 mm diameter x 40 mm high are given in Table 5.32. Figure 5.47 shows the actual average volumes of five samples, as a percentage of the initial volume on air drying. The oven dry volume of the samples from the top 100 mm layer is higher, at about 41% of its fresh volume. The next two 100 mm lower layers have oven dry volumes of about 31% and 30% of their respective fresh weight.

Moisture contents (gravimetric, θ_m and volumetric, θ_v) fell drastically on air drying (Figures 5.48 and 5.49). However the difference in θ_m between the top 100 mm layer and the next two layers is more marked than that for θ_v. In both figures the minimum values are approximately the same for all the three layers, at about 25% and 7% respectively. Both figures show the tendency for the moisture content to stabilised within 20 days. From FIGURE 5.48 it can be seen that the moisture content, θ_m, of 250 % was reached within 7, 9 and 10 days respectively for the top to the third layer. From Table 3.1 the return period for 7, 9 and 12 dry days is once every 2.7, 4.7 and 10.9 months. Figures 5.50 and 5.51 compare the volume change with θ_m and θ_v respectively. As can be seen the moisture content falls almost linearly as the volume reduces particularly for θ_v. The relationships for the two deeper layers seem similar, indicating the similarity of the peat soil in the deeper layers.

The result of the second experiment, the "rewetting" experiment (described in Section 4.3.2) is given in Table 5.33. Three batches of samples were stored for 0, 7, 14, 28 and 56 days. Batch A is stored from fresh samples, batch B from samples having been air dried for 7 days and batch C, after having been oven dried. Table 5.33 records the changes to the properties at each particular moisture content and for each length of storage period. Each sample was subjected to 3 days rewetting as outline in Section 4.3.1. In this analysis, the "volume" is the volume of the sample at the particular moisture content after a given storage time. Where the fresh sample volume has been used it will be specifically mentioned. Suffixes "b" and "a" are used for the before and after situations respectively. ρ_{od} is the oven dry bulk density using the oven dry volume while ρ_{dry} is the dry density using the fresh volume.

As can be seen, the length of storage hardly affected the rewetting potential. This is evident in the increases in θ_m, θ_v, V_a and V_a/V_b in all the three samples. However the rewetting potential was clearly affected by the initial moisture content of the samples before storage. In Table 5.33, batch A, which is stored from fresh samples, have θ_m values before rewetting varying from 460 to 525%, to 509 to 562 % after rewetting. Batch B, (stored after 7 days air drying), θ_m were between 156% to 172% and 287% to 386% before and after rewetting, respectively. θ_m for the batch, C, (stored after oven drying) increases from 13-30% to 83-109% after being rewetted. Similarly there are similar changes with other values such as θ_v, wet and dry bulk densities.

Referring to Table 5.33 the volume of all the samples increases as a result of rewetting. Although the drier samples have a slightly bigger incremental increase than the fresh samples, they are far from attaining their original fresh volume. The oven dry volume of all the three categories is around 33 to 37 % of the fresh volume. The wet bulk densities at the different initial moisture contents ranged from around 0.94 Mg m^{-3} to around 0.56 Mg m^{-3}. After rewetting, the wet bulk density for samples in batch A and B was similar, between 1.26 to 0.96 Mg m^{-3}. However the wet bulk density for samples in batch C is only between 0.83 to 0.91 Mg m^{-3}. The value of ρ_{od} increased slightly from samples in batch A (0.44 Mg m^{-3}) to samples in batch B (0.51 Mg m^{-3}) and C (0.57 Mg m^{-3}).

As the rewetting potential seemed to be affected by the initial moisture content rather than storage time, 3 (three) additional samples were dried to a moisture content of approximately 400%, 90% and 20% and similar readings taken and presented in Table 5.34 (2, 10 and 14 days air-dried samples). This table also retabulates all other the results from Table 5.33 for zero storage time (batches A, B and C). It confirms the effect of moisture content on the rewetting potential. The oven dry volume of the sample is between 35% to 33% of its fresh volume with ρ_{od}, ranging from 0.43 to 0.49 Mg m^{-3}. There is no trend towards an increase in ρ_{od} with decrease in initial moisture content. There is a full volume recovery for samples with initial θ_m at about 395% or more. The volume recovery reduces however with reductions in the initial moisture content below 395% or above. Similarly the wet bulk density decreases from 0.94 Mg m^{-3} for the fresh volume to 0.42 Mg m^{-3} for the sample with average θ_m=19.9%. The graphs of volume before (V_b) and after (V_a) rewetting is plotted against θ_m in Figure 5.54. V_b and V_a are calculated as a percentage of the fresh sample volume. This graph indicates the possibility of a full volume recovery (ie V_a = 100%) if θ_m is not reduced beyond around 400% and a substantial volume recovery of more than 80% of initial volume if θ_m is not reduced beyond 200%. Figure 5.54 illustrates the possibility of full volume recovery up to a certain moisture content, after which the rewetting becomes increasingly difficult.

To check the moisture release pattern of the partially dried samples, two sets of the above samples stored at 2 weeks and 8 weeks were rewetted and subjected to moisture extraction from 0 to 0.1 bar, using the porous plate described in Section 5.1.3 above.

The results presented in Figures 5.55 and 5.56 indicate almost identical moisture release patterns for both the storage periods. This confirms the important influence of initial moisture content rather than the storage time on the ability of the peat to rewet.

From Table 5.34 the initial moisture content of samples dried for 14 days and oven dried are nearly the same (19.9% and 16.2% respectively). They also have quite similar before and after volumes (before - 39% and 36%; after - 44% and 43%). However the capacity to absorb water by the 14 day air-dried sample is significantly greater than that of the oven dried sample. θ_m of the rewetted air dried sample of Table 5.34 is about 11 times its dry value while that of the oven dried sample is only 5 times its dry value. The rewetted θ_v for the samples is 9.5 times and 5.4 times of their dry value respectively. Thus both moisture content and temperature can affect the rewetting potential of the peat soil.

Figure 5.54 indicates the possibility of a thresh-hold moisture content (at about 400%) above which the sample will recover almost all its volume. This figure also indicates that if the peat is dried considerably, volume recovery will be very small. As compared to the oven dried sample the air dried samples have a better rewetting potential (Table 5.34, θ_{va} values) although both volume recoveries of the samples are similar.

5.3.3 Peat Depth

The result of the survey of peat depth in the experimental area at IPRS, Pontian, is given in Figure 5.66. As can be seen, within the experimental area itself, the peat depth increases with the distance from the sea from 2.3 m to around 5.0 m.

5.3.4 Subsidence

The single most distinct feature in peat drainage is the resultant subsidence. The quantum is expected to be higher at the beginning of drainage and decreases with time. Subsidence may stop if the remainder of the peat deposit is under total submergence. Two tests, the soil meter monitoring and conventional annual land survey (described in Section 4.3.4), were carried out. While both methods monitor changes of the soil surface elevation, the first method also monitors changes at varying peat depths. Both confirm that there is a net annual surface subsidence on drained peat.

5.3.4.1 Soil meter

Results of the soil meter monitoring are presented in Figures 5.57 to 5.65. Figure 5.57 shows the settlements/subsidence at various peat depth of SM1 (Soil Metre 1) in Plot 1. As can be seen the subsidence is more pronounced for the layers nearer the surface. This is repeated at the other 5 locations, one in each plot. At SM1, the WT fluctuates at around 300 mm. For plates placed deeper then this depth there seems to be minimal or no subsidence, instead a net expansion at 370 days was recorded as follows (+ve for expansion and -ve for subsidence)

Rod	depth, mm	record at 370 days, mm	record at 399 days, mm
5	500	+0.15	-0.65
6	1000	+0.25	-0.30
7	2000	+0.55	+0.40
8	3000	+0.45	-0.25

The surface subsided again after the next few dry days. The occurrence was similar for the deeper peat soil under permanent WT at the other five locations, as can be seen in Figure 5.65.

The results of all the 6 soil meters were rearranged and presented together for each of the different depths in Figures 5.58 to 5.65.

Figure 5.58 is the subsidence record of all the surface plates and indicates the sensitivity of the peat layers to moisture condition. Although there is an annual net subsidence, the peat layers subside during the dry periods (end of December 1987, February 1988, May 1988 and in July and October 1988) but swell again when the rain rewets them in January, March, June/July, and at the end of August 1988. Depending on the location and weather, drainage lowers the WT in the fields to between 0.23 to 1.07 m (Table 5.42 and 5.41 respectively). On dry days the WT is lowered further and rises when rain falls. The rain also replenishes soil moisture in the soil above the WT.

After the initial dry and wet period from, December to February 1988, the figures show the slope of the subsidence line plotted against time to be almost similar for each specific layer of soil regardless of the site location. Layers associated with deeper WT however have a slightly steeper slope.

The surface layer measured by rod no. 1 has the steepest rate of subsidence with a net subsidence of between 18 to 35 mm during the year from December 1987 to December 1988. The highest values are obtained from SM6, in plot 6 (Table 5.35). The water tables on this plot were largely below 0.6 m (Table 5.44). Plot 6 is also at the deeper end of the deposit. From Figures 5.58 to 5.65, it can be seen that, SM6 also recorded the highest subsidence rate at all the other layers except for the 50 mm, 2 m and 3 m depth in which the highest subsidence is recorded by plot 4. This is not surprising as SM4 is only about 20 m from W4 on the perimeter drain (Figure 3.3). Check structure, W4, controlled upstream WT at between 0.2 m to 0.3 m most of the time. But its downstream water level is about 1.4 m below ground level. The peat soil subsidence at SM4 is also affected by the drawdown curve of the WT at this point.

The net subsidence decreases with deeper layers until at depths below the water table (1, 2 and 3 m below the surface - rods 6, 7 and 8 respectively), the net subsidence recorded is almost nil and in some cases even swelling/expansion. This swelling may also be due to a buoyancy effect.

The linear relationship of $y = a + bx$ for subsidence at the ground surface with time, was analysed for records from March to December 1988 where the time subsidence relationship seemed to be more stable. The subsidence from this analysis is given in Table 5.35 for

$$y = a + bx \qquad \text{--- 5.13}$$

where

y =subsidence in mm
x =time in day
a =intercept at y axis, mm
b =rate of subsidence in mm day^{-1}

The average rate of subsidence for the surface layer is about 8.044×10^{-2} mm day^{-1} or 29.4 mm per annum. The maximum rate of subsidence is from SM6

@ 9.6325 x 10^{-2} mm day^{-1} or 35.2 mm per annum. SM2 recorded the lowest subsidence @ $6.2337x10^{-2}$ mm day^{-1} or 22.8 mm per annum. The summary for the minimum, maximum and average rate of subsidence per annum in mm for each layer is as given in Table 5.36. This table gives the actual net subsidence from the soil meters, from Dec 1987 to Dec 1988.

The actual surface subsidence of 27.1 mm per annum (Table 5.36) compares favourably with the straight line graph result of 29.4 mm from Table 5.35. At 1.0 m (1000 mm) depth and below, most of the soil meters (they are situated in the lowest corner of each field) will be continually under water. Water at SM4, because of its vicinity to the outfall to the main drain, may still be draining out at 1.4 m.

5.3.4.2 Land survey

The land survey of 1986 is presented in Figure 5.67. Using the peat depth survey shown in Figure 5.66 and the surface survey of 1986, the subsurface levels were deduced as in the contours of Figure 5.66. The survey results of the clay subsurface, the 3 surveys of 1984, 1986 and 1988 were reduced to three dimensional coordinates of *x*, *y* and *z* for analysis of subsidence. Distance *x* is the distance along the length of the field while distance *y* is along the breadth of the field. The origin is taken downstream as shown in Figure 5.66 and 5.67. The height *z* is the MSL. All distances are in metres. These coordinates were analysed to determine the best fit curve using the Statistical Analysis System (SAS) of the SAS Institute, Cary, North Carolina, United States. Pictorial analyses of the analysis are given in Figures 5.68, 5.69 and 5.70.

During the design stage it was planned not to vary the WT with increasing *x*, ie plots with WT=300 mm were to be at the downstream end and plots with WT=900 mm at the upstream side. Changes in water level along the *y*-axis (width) were not expected. As a result, the effect of differences in WT on subsidence along the width was expected to be minimal. The two dimensional *x-z* relationship is given in Table 5.37.

To obtain the average peat depth along the length, *x*, of the field and compare the differences in depth over the 3 surveys, the vertical *z*, was estimated relative to the values of *x* as given Table 5.38. The *z*-values were estimated for *x* distances of 250, 375 and 505 m. The distance 250 m is at the upstream end of plots 1 and 4, 375 m, the upstream end of plots 2 and 5 and 505 m, the upstream end of plots 3 and 6 (Figure 5.66 and 5.67).

The correlation coefficient for data in the pineapple area is very good (Table 5.37) and it also has a high confidence limit. In contrast, on the other half of the field where cassava is planted, only the 1988 survey shows a corelation exceeding 90%. The 1984 and 1986 surveys have a correlation of less than 50%.

The curve fitting in the cassava area for the 1984/86 results shows a substantial subsidence for plot 1, minimal subsidence for plot 2 and swelling in plot 3. This can perhaps be explain by the fact that the perimeter drain was not yet build before the survey of 1984. The upstream end of plot 3 received water from the substantial catchment upstream of the area and was generally wet most of the time. Even after its construction, while the perimeter drain at other points may dry out during the dry period, the perimeter drain adjacent to plot 3 is seldom below 0.6 m from the surface (top level of the weir - kept at 0.6 m because of the grade of the land). Drainage water from upstream agricultural areas discharges through this point and 2 wooden check structures across the drain, ensure that the water level is maintained at 0.6 m.

In contrast the perimeter drain adjacent to the pineapple area is an existing drain which discharges directly into the secondary drain of the DID. The high 1984/1986 subsidence for the downstream end is to be expected as the perimeter drain was deeper on the downstream side, then. The 900 mm WT control was finally chosen for the upstream plot 6, while the downstream plot 4 was controlled at watertable level of 300 mm.

Field leveling on a major scale is not currently widely practiced in Malaysia. This has not previously posed a problem as the emphasis was on regional drainage. In tree crop areas (rubber, oilpalm, etc) as compared to field crops (cassava, pineapple, etc) the micro relief may also not be very critical. In an effort to optimise crop production and therefore yield, water management at field level has become increasingly important. For effective water management micro relief in the field is important as water table is a function of both the water level and the ground surface level. In Malaysian peat the surface micro relief is further aggravated due to removal of buried timber. A difference of 300 mm in micro relief in the peat surfaces is quite normal and depressions (due to removal of tree stumps) as deep as 500 mm are common.

As it was not possible to carry out leveling of each field, variation of watertables in the field is not only due to the water table shape but more importantly due to micro reliefs which could have been eliminated. Variation due to general relief as a result of changes in slope were minimised using wooden weirs and sandbags (Figure 3.3). These differences are reflected in the water table levels monitored. Statistical analysis of these water table levels are given in Tables 5.39 to 5.44. Table 5.51 highlighted the difficulty in maintaining the water level at the respective design level of 300 mm, 600 mm and 900 mm. Although there are locations monitored which read the design WT, the overall average of Plot 1 is 706 mm and that of Plot 4 is 630 mm instead of 300 mm. Overall average for plots 2 and 5 are 715 mm and 703 mm respectively instead of 600 mm while that of plots 3 and 6 are 758 mm and 757 mm respectively instead of 900 mm.

Error in the survey is possible but quite unlikely as the survey team were experienced surveyors of the DID. The ground surface micro-relief, however varied tremendously. Soil meter results show plot 3 to have a subsidence value comparable to plots 1 and 2 for depths lower than 100 mm. However, its surface layer has a high net subsidence of 35 mm from December 1987 to December 1988.

The 1986/88 rate of subsidence of 22 to 38 mm for plots 1, 2, 3 and 4 (Table 5.38) is quite close to the subsidence at the monitored surface value of the soil meters (Table 5.35). Plots 6 and part of plot 5 accidently caught fire in 1986, before the survey. Plot 6 was again under fire in September 1987, before planting. The rate of subsidence from the soil meters were averaged from March to December 1988, and this probably explained the lower values. The secondary forest on the land were cleared for the construction of farm roads between 1984 to 1986. Burning is quite common during clearance and plots 1, and 4 are nearest to the existing MARDI farms and existing drainage lines. This may also explain the rather high subsidence rate in the 84/86 period for these two plots.

Comparing the subsidence in the cassava area (plots 1, 2 and 3) for the year 1988, in Table 5.38 and the water table in Table 5.51 it looks as though subsidence decreases with increase in water table depth. The perimeter drain G-F-E-D (Figure 3.3) is an existing drain which also caters for discharge from the upstream catchment areas. The water flows downstream through the perimeter drain from G to D and then to A. The water level in the perimeter drain adjacent to plot 3 is always about 650 mm from the surface. The plots on this side of the field are generally kept wet from upstream discharges.

In contrast the perimeter drain J-K-L-M-A (Figure 3.3) starts at J and does not received any direct upstream discharges. During the drier months the water level in this perimeter drain frequently reached the lowest depth of about 1200 mm. The downstream reaches of K-L and L-M are maintained at higher levels with the help of wooden weirs. Comparing the subsidence rate of plots 4, 5 and 6 in Table 5.38 and the average water table levels in Table 5.51 it can be seen that here subsidence increases with deeper water table depth. Comparing these two tables again, it can be seen that the subsidence rate of plot 6 is 31.2 mm more than that of plot 5. The subsidence rate of plot 5 is only 14.1 mm more than that of plot 4. However the difference in WT between plots 5 and 6 is only 54 mm as compared to 73 mm between plots 4 and 5. Such a high rate of subsidence is due to burning, as explained earlier. The higher rate for plot 6 is because it had been twice affected by burning. The burning however did not touched the location near the soil meters.

Table 5.35 is the record of surface subsidence at point locations. The subsidence rate at soil meters in plots 1 and 4 are higher than those in plots 2 and 5. This can be explained by the fact that the soil meters are located adjacent to the perimeter drains and at the corner of each plots (Figure 3.3). Depth of water level after point C and M are no longer controlled. Looking at the other 4 points, the subsidence rate shows an increase with deeper water table depth. There is an increase subsidence of about 0.7 mm to 1.1 per annum with each increase of about 10 mm water table depth.

5.4. Agronomic Trials

The WT results for each monitored OW (observation wells) were first analysed and then comparison made with the respective yield parameters of both cassava and pineapple.

Although the water table levels in the drains were controlled to the required levels, the water table levels in the field, largely due to micro relief and slope of the land, could not be controlled as required. Thus it was decided that the analysis of yield and water table parameter be limited to crops harvested in the vicinity of the monitored OW for both cassava and pineapple. When carrying out the statistical analysis for SEG60 values (for both the cassava and pineapple areas) data with SEG60=0 are not included as SEG60=0 is also a cutoff value for all water table levels deeper than 600 mm.

5.4.1 Water Tables

The design water levels will depend on the criteria chosen and the constraints to which the system design and construction is subjected to. The design of the project area was based on a storm drainage of 1 in 5 years which should be drained away within 72 hours to the drainage base. The drainage bases in the various instrumented areas were the designed water levels of 300, 600 and 900 mm as shown in Figure 3.3. Wooden check structures were used in an attempt to maintain water level at the drainage base.

The actual detailed water table (WT) results of each monitored OW in all the plots were taken. Tables 5.39 to 5.44 present a statistical analysis of the water table levels collected. The results clearly indicate the significant effect of sloping and undulating land. For reference the first number of each OW identifies the plot, the second number identifies the row and other subsequent numbers, the individual OW. Row 4 is nearest the perimeter drain, and all downstream corners start with the smallest number. As an example the most downstream of the OW in plot 1 are OW 122, 132 and 143 with 143 nearest the perimeter drain (see Figure 3.4). From the tables it can be seen that these 3 OW generally record the highest WT in plots 1, while those of 1213, 1313 and 1413 the deepest. Because of the in-field pockets of depression it is not surprising that OW 1412 has lower daily WTs than OW 1413.

Although the wooden check control at the most downstream end of plot 1 managed to control the water level at 200 to 300 mm below GL most of the time, this is not reflected in any of the OW because of the average slope of 1:300. The most downstream of the OW in row 4, OW143 (about 30 m from the control check) had WTs fluctuating from the highest of 415 mm (21st April 1988) to the lowest of 873 mm (2nd September 1987) giving a very significant range of 458 mm. The average weekly WT results for the OW over the growing period are given in Tables 5.39 to 5.44.

The sum of the WT values (monitored every fortnight) which exceed 300 mm, 600 mm and 900 mm WT depth from the surface were estimated for the entire growth period (SEG30, SEG60 and SEG90 respectively - see section 4.4.2) and are given in Tables 5.45 to 5.50. As can be seen hardly any WT levels exceed the SEG30 except for OW242 (Table 5.46) and OW422 (Table 5.48). OW422 is near the road beside Plot 1. This again reflects the significant difference in the micro relief of the peat surface as this location is on comparatively elevated ground. With WT finding its own level, WT @ OW422 is expected to be deeper with reference to ground surface than WT @ OW432 and OW442.

Tables 5.51 and 5.52 summarised the average water table levels and SEG values for all plots. Table 5.51 gives the average of the mean water table levels. While the upstream plots all have deeper water table levels than the plots down stream, the range is only from 758 mm to 630 mm and not the designed 900 mm to 300 mm. The SEG values from Table 5.52 show the upstream plots having smaller average SEG values per OW, indicating that the upstream plots are drier than the downstream plots.

5.4.2 Cassava

Yield parameters for cassava as measured for each OW are given in Table 5.53. The average WT and the SEG60 values are given in Table 5.54. The statistical analysis between the SEG60 and average WT values and the yield parameters are given in Tables 5.55 and 5.56 respectively.

Tables 5.55 and 5.56 show very weak correlation between yield parameters and the water table parameters. Generally Table 5.55 indicate positive correlation between high summation of excedence and yield. The best correlation is for starch content which has a correlation 0.527 using the third degree polynomial regression analysis. This can be interpret to indicate higher starch content with frequent WT exceeding above the 600 mm water table levels or higher starch content with frequent wetter condition.

Lysimeter studies by Tan and Ambak, 1989, for WTs of 150 mm, 300 mm 450 mm, 600 mm and 750 mm indicate higher fresh weight of "tops" per plant and harvest index with increasing high water table. The highest is for WT of 150 mm. The range of average WT in the field is between 547 mm and 944mm (Table 5.51). Table 5.56 however indicate positive correlation, although very weak,, between deeper average WT levels and yield. The highest correlation, less than 0.5, is still for starch content ie 0.377 using the third degree polynomial regression analysis.

Tables 5.51 and 5.52 indicate that the downstream plots are generally wetter than the upstream plots. Comparing the water table parameters with the average yield parameters (Table 5.61) show that cassava plant height and stem weight increases with wetter condition and higher water table levels. Starch content however seems to be higher with drier condition.

5.4.3 Pineapple

Similar to the cassava, the pineapple yield parameters were also analysed for each monitored OW. Yield parameters at each monitored OW are given in Table 5.57. The average weekly WT and the SEG60 values are given in Table 5.58. The statistical analysis between the SEG60 and average WT values and the yield parameters are given in Tables 5.59 and 5.60 respectively.

Tables 5.59 generally indicate positive correlation between yield and increase summation of excedence of water table levels. The best correlation, 0.554, is for sugar content from Table 5.59. This is from using the third degree polynomial regression and can be interpret to indicate that sugar content increases with increase in SEG60 values or wetter condition.

The range of recorded average WT is between 435 mm and 857 mm. The optimum water table level for pineapple is between 680 mm to 860 mm (Section 4.4.4). Thus the field water table level was controlled at optimum level. Yet, although the correlation is very weak, the statistical analysis using average WT, Table 5.60, indicate positive correlation between deeper average WT levels and yield. The highest correlation, 0.395 , is less than 0.5. This is for sugar content using the third degree polynomial regression analysis.

Comparing average water table parameters (Tables 5.51 and 5.52) with the average value for yield parameters (Table 5.61) it can be seen that fruit length, diameter, sugar and acid content are higher for the wetter plots. The fruit weight, however is higher for the intermediate plot.

To gauge the percentage of marketable fruits from the WT treatment a section of each plot was demarcated in which all fruits regardless of the stage of growth were harvested. The areas chosen were between the centre drains (Figure 3.4) and for this purpose a total of 2277, 4003 and 2240 fruits were harvested from plots 4, 5 and 6 respectively. The fruits were graded on the basis of length and fruit quality into grades A, B and C. Grade A are fruits exceeding 200 mm long, grade B between 165 to 200 mm and grade C less than 165 mm. Any fruits that suffer defects such as broken pedestal etc but are otherwise marketable, are automatically grouped into group C. The result (Table 5.62) shows Plot 5 (with intermediate WT level) having more than 60% grade A fruits. Plot 4, with the shallowest WT level, gave the lowest percentage of grade A fruits.

5.4.5 Overview

The statistical analysis show very weak correlation, generally around 0.3 or less. The summation for SEG and average WT values were carried out for WT monitored once every two weeks. The difference in maximum and minimum WT for each individual OW is between 400 to 300 mm in the cassava plots (Tables 5.39 to 5.44). From drainage testing, the water level is known to have receded to the drainage base very quickly, within 3 to 5 days. Evapotranspiration and the overall low water level in the area in the dry period may have further depressed the daily WT levels, which may explain the weak correlation obtained the WT parameters and the yield parameters. It may be possible that better correlations could be obtained with the SEG values if the summation were calculated on a daily excedence instead of the two weekly excedence. Similarly an improved correlation may be possible for the average WT if it is calculated from daily WT data.

Possibly the poor correlation between average WT and yield is due to the large range of fluctuation in the field. The average WT value may not actually reflect the soil moisture condition prevailing most of the time.

Another factor may be that the critical WT is not for the entire growth period but only for certain growth period such as after hormone application for the pineapple. In such instances the critical growth period need to be identified and moisture stress situation avoided during this period.

Beside the problems of significant differences in micro relief and non levelling of sloping surfaces and taking into consideration the properties of the peat soil, it is possible that better designed cutoffs or bigger buffer zones between plots may be required to ensure designed water table is achieved.

CHAPTER 6 - MODELLING WATER-TABLE MOVEMENT IN BENUT

6.1 General

The ability to model watertable levels in mid-field with known geometrical configurations and using meteorological and hydropedological data will be necessary not only to design the field system but also to properly managed any proposed water management of the area. This requirement is similar to the use of hydraulic models in designing the main arterial system.

A number of watertable models have been developed using land drainage theories and known meteorological and hydropedological data. Some of these models have been made available to Malaysia through the ICID network. The model developed by Youngs et al had been tested in flat lowlying peat wet land of Somerset Levels where the simulated watertable levels were found to agree with available dipwell observations. This area in Somerset is drained by open ditches. An added advantage of this model is its simplicity.

Within the Western Johore Integrated Agricultural Development Project (WJIADP) subsidence monitoring has been carried out since 1974 in the Benut Area (Figure 6.1). Twenty four (24) subsidence posts were installed into the ground using 7 m and 3.5 m (20 ft and 10 ft) galvanised iron pipes (92 mm or 4 in diameter) painted with 3 layers of anti corrosive paint. These posts were driven "to set" into the ground using 113.5 kg (250 lb) weights dropped vertically at a distance of 0.9 m (3 ft) until 20 blows to the inch (25.4 mm) were required for further penetration. The top of the posts were then surveyed to MSL datum and checked at interval. Records of subsidence were made with reference to the top of the posts. Reports on the subsidence rate (Welch and Adnan, 1989) shows values varying from 148 mm to 15 mm per annum. Although records of initial peat depth at each station are available, no records of watertable were however made.

The possibility of relating subsidence rate to watertable levels, influenced the choice of the testing site for the Youngs et al water table model in this area. The initial expectation, once the model can be validated, was to back predict the watertable of the area using available rainfall and evaporation records and relate the subsidence rate to watertable levels. This peat area is contiguous with that of the Integrated Peat Research Station, IPRS (and also Ulu Air Baloi and Parit

Sikom). The area was also initially opened at about the same time as that of the IPRS. Thus the peat soil state is assumed to be similar to that of the experimental area in IPRS. Hydropedological data obtained from the experimental area were used in modeling watertable levels for the Benut area.

6.2 Youngs et al Mathematical Model

Youngs et al, 1989, using land-drainage theory, modelled the unsteady water-table movement caused by intermittent rainfall and varying evaporation in the flat low-lying peat wet lands of the Somerset Levels in England. The unsteady water tables are assumed to behave as a continuous succession of steady states with the flux through the water table given by the sum of components due to rainfall and evaporation through the soil surface and due to water released or taken up by the unsaturated soil above the water table. Using a steady-state drainage equation for the relationship between water-table height and flux, an equation is derived which forms the basis of a numerical procedure for modelling changing water-table height in lands intersected by a network of ditches containing water standing at a known height and subjected to intermittent rainfall and varying evaporation. This equation is reproduced below

$$\Delta H = \left\{ \frac{(K_1 - K_0)}{A_m p D^2} \left[n (H_0 - b)^2 - j (H_m - b)^2 \right] + \frac{K_0}{A_m p D^\alpha} \left[H_0^\alpha - i(i H_m)^\alpha \right] - \frac{V}{p} \right\} \Delta t \qquad \text{--- 6.1}$$

where

Δt	=	time interval considered
ΔH	=	change in the water-table height during the time increment t
H_0	=	average height of ditch water level during the time increment t
H_m	=	average mid-field water level above ditch base during the time increment t
D	=	the drain half spacing
p	=	porosity or specific yield
A_m	=	shape factor for the centre of a rectangular field
K_0	=	hydraulic conductivity of the subsoil
K_1	=	hydraulic conductivity of the topsoil
b	=	height above the ditch base to the interface between the subsoil and the topsoil
i	=	1 if $(H_o/D)^\alpha > V/k$
i	=	-1 if $(H_o/D)^\alpha < V/k$
V	=	the vertical flux, measured positive upwards through the water table

K = hydraulic conductivity of the saturated soil
j = 1 when $H_m > b$
j = 0 when $H_m < b$
n = 1 when $H_0 > b$
n = 0 when $H_0 < b$
α = $2 (d/D)^{d/D}$ for $0 < d/D < 0.35$
α = 1.36 for $0.35 < d/D < \infty$
d = depth below the drain to the impermeable layer

6.3 Testing of Youngs et al Model in Benut

Detail monitoring of peat subsidence in Benut has been carried out from the time that it was initially being drained, over 15 years ago. The rate of subsidence ranges from 15 mm year^{-1} for a deposit with initial depth of 2.4 m to 148 mm year^{-1} for a deposit of more than 6.1 m deep (Welch et al, 1989). However no water table records are available over those 15 years.

6.3.1 Data collection

A location plan of the monitored area and the rainfall station is given in Figure 6.1. Peat Depth Station No 18 (PD 18) was chosen because of its location between ditches D8/13 and D8/14. These two ditches drained freely into the Benut River. The geometric configuration of the area was measured and presented in Figure 6.2. Daily water-table monitoring were carried out from 1st May 1989 to 17th July 1989 for SG1 (stage record of D8/13), SG2 (stage record of D8/14), P1 (water-table reading beside PD18) and P2 (mid-field water-table).

Daily rainfall and evaporation records from Rainfall Station No 1632201, about 10 km distance were used in the analysis. To check the tidal influence, a 12 hour record (from 7.00 am to 7.00 pm on the 19th of July 1989) of the water level at SG5 were carried out. This tide curve is presented in Figure 6.3.

From Chapter 5, the estimated hydraulic conductivity, K_0 and K_1, of 5.5 m day^{-1} and specific yield or porosity p of 0.38 for the peat soil in the IPRS experimental area were assumed to be applicable also for the peat soil in Benut area as these two areas are contiguous as well as having a similar peat type. The topsoil and subsoil K values are assumed to be the same, as the soil in the range of the fluctuation of water levels was assume to have the same K value. Other available parameters, are ditch spacing, the peat depth to impermeable layer, geometrical factor for ditch system, initial water table depth and depth from surface to ditch bottom. The soil boundary depth was assumed to be at 0.10 m and the unsaturated K exponent assumed at 6.4. These basic values are presented in Table 6.1. Unless otherwise stated the values in Table 6.1 are used in all the simulation exercises.

Using the above values, water-table levels across D8/13, PD18 and D8/14, were simulated using rainfall and evaporation records from Station No 1632201 (Table 6.2). Various hydraulic conductivity and porosity values were also used in the simulation exercises. These simulated water table levels were then compared to the actual monitored water-table levels given in Table 6.3.

6.3.2 Simulating water table levels

Tidal and non-tidal

Figure 6.4 compares the simulated mid-field water table levels with and without tidal influence to actual mid-field water-table and ditch levels. Whilst there is some similarity between the actual mid-field water-table and ditch water-table patterns there does not seem to be much similarity between the simulated and the actual midfield water-table patterns.

Different unsaturated hydraulic conductivity exponent

The simulation exercises were also carried out for different unsaturated hydraulic conductivity exponent ranging from 12.4 to 0.4 but made no significant difference on the simulated water-table levels.

With certain critical rain days removed

The simulated water-table levels however, were closely influenced by the rainfall pattern. Any substantial rain causes almost immediate substantial rise in the modelled water table. The rainfall records used were collected from a station about 10 km from the monitored area. As localised rainfall are very common, this probably accounts for the difference between the simulated and actual water-table patterns. Evaporation is almost constant throughout the year and should not unduly affect the simulated water-table levels.

Figures 6.5a and 6.5b compares three simulated water table levels with the actual mid-field water-table levels when certain critical rain days were removed. The rain on day 24 and day 70 may not have fallen in the area as the actual mid-field water-table level is hardly affected despite the substantial value. With these two rainfalls removed the results appear to be better correlated. Other permutations such as simulation excluding rainfall input on the 70 day only and simulating by removing all rainfall input from day 55 to day 73 were carried out. Each of these simulations indicate corelations of some parts of the simulated mid-field water-table levels to that of the actual levels.

Varying saturated hydraulic conductivity

Using rainfall records with data for day 24 and day 70 removed (Table 6.4), further simulations were carried out. Figure 6.6 are water table levels simulated using varying saturated hydraulic conductivity values with all other values constant. It shows, that if all other values assumed are correct then the estimated saturated hydraulic conductivity of 5.5 m day^{-1} is reasonable as the simulated water level using saturated hydraulic conductivity of 5.5 m day^{-1} coincides best with the actual water-table levels. A saturated hydraulic conductivity value of 20 m day^{-1}would be excessive, as the simulated water-table level is much lower then the actual water-table levels.

Varying specific yield

Figure 6.7 simulates the mid-field water-table levels for varying specific yield or porosity. The simulated water table shows more sensitivity with lower specific yield. Again the figure also indicates that the estimated drainable porosity (specific yield) of 0.38 is reasonable. The difference between the simulated water table levels using p of 0.38 and 0.6 is much less than the difference between the simulated levels using p of 0.38 and 0.2. The peat in the area has an initial void ratio ranging from 13.9 (Figure 5.28) to 4.69 (Figure 5.30) thus giving the actual initial total porosity of the peat to range from 93% to 82%. The estimated drainable porosity of 0.38 is for the IPRS experimental area for drained peat depths ie from the surface to about 1 m depth. The actual recorded mid-field water-table levels in this Benut area fluctuate from 2.54 to 2.87 m above the ditch invert. With such a high value of initial total porosity and deeper drainage depth involved, it is reasonable to expect the possibility of the drainable porosity to be higher than 0.38 in Benut. With drainage there is loss in buoyancy of the top soil which now acts as an overburden pressure on the bottom soil layer (section 6.2.1) and compresses and consolidates it with the resultant release in water. The peat also shrinks on drying and with drainage (section 5.3.2). This will further release more water.

6.4 Applicability of Youngs et al Model in Benut

The major shortfall to validating the model in this area presently, is the non-availability of rainfall records within the area during the time the watertable readings were taken. Rainfall which is a major component of the vertical flux V, in equation 6.1, greatly influenced the predicted watertable levels. As the saturated K value in the area is large, the effect of the rainfall will be almost immediate. Localised rainfalls are common and these explain the difference between the actual midfield and ditch watertable level patterns recorded, particularly between day 30 to day 40 (Figure 6.4). "Apparent" high rainfall falling on day 24 and 70 hardly affect the actual watertable levels (Figure 6.4). With the removal of this rainfall, there seems to be better agreement between the actual and predicted watertable levels (bottom figure compared to top figure, Figure 6.5a). Similarly there could be rainfall falling in the area which was not picked up by the rainfall recorder (situated about 10 km away) as can be seen in the substantial midfield watertable rise on day 7 and day 43.

Based however on the bottom figure of Figure 6.5a (with day 24 and day 70 rainfall removed) the model show some promise for use in the area. Subsequently an attempt to model past midfield watertable levels using rainfall and evaporation recorded from the same station were made and described below.

Rainfall and evaporation records are available from Station No 1632201 since January 1982. No record of actual ditch water level is available. From the reported subsidence in the area (Welch et al, 1989) the initial datum of the surface of the soil in 1982 should be higher. The ditch water level, H_o, was measured from the base of the ditches. The present difference between midfield surface level and the ditch base is about 3.0 m. The recorded subsidence at PD18 from February 1982 to June 1986 is 0.17 m or 38.5 mm per annum (unpublished). For this analysis the depth from the surface to the ditch bottom was assumed to be 3.17 m. Assuming the subsidence rate to be constant, there is an additional subsidence of about 0.12 m from June 1986 to June 1989 or a total subsidence of 0.29 m from January 1982 to June 1989. Thus the difference in depth between the ditch base and midfield surface in January 1982 could be 3.29 m.

Using average monthly rainfall and evaporation records from January 1982 to June 1987 (Table 6.5) various simulated water-table levels are presented in Figure 6.8. Figure 6.8 also assumed the ditch water-levels in D8/13 and D8/14, H_o, to be constant at 0.5 m. The initial mid-field water table level, H_m, was assumed to vary from 0.7 m to 2.5 m from the surface. Table 6.6 gives the simulated mid-field WT levels, H_m, for an assumed initial H_m of 0.7 m.

The simulated water table levels in Figure 6.8 show a nett increase in mid-field water levels. Changing the value of average ditch water level, H_o, from 0.5 m give very insignificant influence on the simulated mid-field WT levels. Figure 6.8 also shows that using shallower initial Hm value, 0.7 m, gives a gentler increase in the rise of H_m.

The attempt to model past watertable levels of the area, Figure 6.8, using average daily rainfall and evaporation for each month, results in an increasingly high predicted watertable level. While actual daily evaporation figures generally have smaller ranges (2 to 6 mm) this is not so with daily rainfall. As this area is in the Pontian District, rainfall for Pontian Besar used in the estimate of runoff in Chapter 3 is a good comparison. Average monthly rainfall records of Pontian Besar over 25 years shows variation from 9.7 mm to 478.0 mm. Not all this rainfall infiltrate into the ground. The amount of rainfall infiltrating into the ground depend on the antecedent conditions. Once the infiltration capacity have been reached, rainfall that exceed this infiltration capacity will flow as overland flow and may not contribute to the rise in midfield watertable levels as analysed in the model. Analysis of the length of its dry days (Table 3.1) indicates the occurrence of 3-day dry days to be twice in each month and 7-day dry days to be every 2.7 months. Rainfall records of the Benut area from 1st May to 17th July 1979 (Table 6.2) shows a number of occurrence of dry days together. The maximum length is 8 days which occurs twice (14th to 21st May and 25th May to 1st June 1989). Fifty five (55) out of the 78 days in Table 6.2, have a daily net evaporation.

Using average daily values results in a net rainfall input for most of the months (Table 6.5 - only 16 out of 84 months have net evaporation over rainfall). A net increase in the predicted watertable levels is therefore to be expected providing no surface runoff occur. Because of the influence of antecedent conditions on infiltration capacity, daily actual values should have been used. The wide ditch spacing of 800 m may also create difficulty in controlling moisture input, thus resulting in watertable rise with time.

Additional tests with adequate instrumentation need to be further carried out to properly validate Youngs et al model before it can be applied in Benut or similar areas. Modification to this model should also be looked into with considerations given to local factors such as component of rainfall that infiltrates into the ground as well as the component for surface flow with respect to antecedent condition. The exponential factor c, for evaporation in the limiting case, should be obtained for local condition. The influence of any tidal effect locally have to be included in any analysis.

6.5 Application of the simulation model

6.5.1 Improved agricultural production

In Malaysia, design for drainage of agriculture areas is based more on required discharge of excess regional drainage water. Field water management considerations, when considered, are more from past experiences and rule of thumb. Minimum drain spacings presently constructed by the DID are generally placed at about 800 m apart. As the country gears itself towards a developed agricultural sector it must also update its agricultural drainage procedures and water management needs. The ability to predict mid-field water-table levels with known rainfall and evaporation records, will allow the design of field water management system to be fine tuned to specific requirements of the crop and soil type of the area. With knowledge of the capillary fringe and rate of capillary rise, the required mid-field water-table levels can be estimated. The ditch spacing and depth can then be designed together with the required control measures for proper water management.

Proper water management should also include the ability to vary the field WT levels to suit cropping activities such as tillage, harvesting and fallow period. This become more critical as cropping practices are increasingly mechanised.

6.5.2 Conservation

With rapid development, increasing hectarage of new land are being opened. These include problem soil areas such as peat swamp deposits. Requirements to conserve some of these areas adjacent to drained areas can be carried out using similar principles as for agricultural field water management. In such cases water table may have to be permanently maintained at specified levels. Similar principles can also be used to reclaim drained and abandoned wetland areas.

6.5.3 Estimation of subsidence

Table 7.5 in Chapter 7 gives varying rate of subsidence for three different WT levels. Although there are no records of WT levels, records of subsidence are available in Benut. If the model can be validated for use in Benut, then past WT levels can be simulated.

Looking at the records from Benut, Table 6.3 shows the mid-field water-table over the 3 months to range from 2.54 m to 2.87 m from the ditch base. Depth of the ditch base from the surface is 3.0 m. Thus the mid-field WT levels fluctuate between 0.46 m (460 mm) and 0.13 m (130 mm) from ground surface. Although Figure 1.2 indicate the months of May to July to be among the driest month in the area, the difference between the wettest and dry months are relatively small when compared to the other areas in Malaysia. Therefore it is reasonable to assume the mid-field water-table levels to fluctuate around the levels monitored (460 mm to 130 mm) over the years. At this water-table level the expected subsidence rate at PD18 following Table 7.5 would be less than 42 mm yr^{-1}. Subsidence at IPRS for WT fluctuating between 417 mm to 1049 mm is 27.1 mm yr^{-1} for 1988. Initial peat depth at PD18 is 4.7 m. Record of subsidence at PD18 (unpublished) from 1974 to 1986 is 0.317 m or 26 mm yr^{-1}. This is within the predicted value. Rate of subsidence at other peat depth (PD) stations in the area such as PD21, PD22, and PD24 (Figure 6.1) are 126 mm yr^{-1}, 135 mm yr^{-1} and 94 mm yr^{-1}.respectively. Initial peat depths for PD 21 and 22 were more than 6 m, while that for PD 24 was about 5.5 m (Welch et al, 1989). Thus if the model can be used to simulate the WT levels, rate of subsidence in at these stations can then be related to WT levels. The subsidence rate with respect to specific WT levels can be used in the prediction of subsidence for newly open areas.

CHAPTER 7 - DISCUSSION

7.1 General

The results have to be analysed together, to give an overall understanding of field water management requirements for agriculture and the implications of drainage and deep watertable drawdown in peat soil.

7.2 Field Water Management Requirements

Watertable level, although indicating the depth of aerated soil is by itself not the single factor that affects the soil moisture status, bearing capacity and the subsidence rate. It is however an easily measured indicator which can and has been related to the soil moisture status, the degree of compaction and consolidation of peat soil as well as its subsidence rate. As such watertable (WT) drawdown in peat areas has been related to significant differences in soil bearing capacity, irreversible drying and peat subsidence, all of which influence crop production practices. The ability to predict midfield watertable levels with known field geometrical configurations, moisture inputs and outputs will allow the water management of an area to be fine tuned to suit requirements of both design, operation and maintenance of the system.

7.2.1 Bearing Capacity

A minimum bearing capacity is required not only for crop establishment and production, but also for man and machinery to clear the peat swamp jungle and construct the required engineering infrastructure. Although the surface bearing capacity is dependant on the matrix of fibres and buried wood and timbers, the bulk density and moisture status also have a significant effect, particularly once the wood and timbers have decomposed. Higher bulk density indicate more compact soil and therefore better bearing capacity. Overburden pressure over, once undrained peat, will be greater with deeper drainage depth. Thus deeper drains will induced greater compaction. Generally the deeper the watertable level the drier will be the soil near the surface. The drier the soil the better will be the bearing capacity.

Problems of poor bearing capacity in undrained Malaysian peat soil is further compounded by the decrease in bulk density with depth of the peat soil (Figure 5.5). From experience (and also Figures 5.3 and 5.5) it seems that once the surface crust is literally punched through the soil effectively losses its bearing capacity.

Consolidation results from Figures 5.28 to 5.38 indicate decreasing void ratio with increasing pressure. The curves, as the pressure is released (Figures 5.28 to 5.38), show that the final void ratio is very much lower than the initial void ratio. Assuming the average wet bulk density of newly drained peat above the watertable is 0.9 Mg m^{-3}, the resulting overburden pressure of this drained peat at watertable level of 2 m deep is 17.66 kN m^{-2}. Figure 5.28 indicates, at this pressure, a decrease in void ratio from 13.9 to 11.0 or an increase in dry bulk density from 0.09 Mg m^{-3} to 0.11 Mg m^{-3}.

Watertable/bearing-pressure relations for the experimental area in IPRS is given in Figure 5.27. This area has been drained for more than 15 years. From Table 5.7, for IPRS July 1988, the average dry bulk density of the top 50 mm and 50-150 mm layers are 0.18 Mg m^{-3} and 0.10 Mg m^{-3} respectively. The average dry bulk density 900-1050 mm is less than 0.07 Mg m^{-3}. The watertable/bearing-pressure relationship is rewritten below

$$y = 5.246 + 0.056x - 1.102(10^{-5})x^2 \qquad 7.1$$

where

y = bearing capacity in kN m^{-2}
x = water table in mm

Using the above equation, at zero WT (x = 0 m), the bearing capacity is 5.3 kN m^{-2}. At a WT depth of 1 m the bearing pressure that can be supported is about 50.2 kN m^{-2}. If a Factor Of Safety (FOS) of 1.5 is required, the allowable bearing pressure at this watertable should only be about 33.5 kN m^{-2}.

When selecting vehicles and ground equipment for work on peat, the above equation is an essential guide since this is the limiting case. Some machines working on peat in Malaysia have a fully loaded ground pressure as high as 35.905 kN m^{-2} (0.366 kg cm^{-2} - GC602). Although the WT requirement for this machine is about 647 mm, using a FOS of 1.5, a WT drawdown of 1.06 m is more appropriate. Machines must be designed for a fully loaded ground contact pressure less than the critical value. Machines with ground contact pressure exceeding the critical value run the risk of being sluggish in operation or even disappearing into the peat mass at weak spots.

For a man weighing approximately 80 kg, and assuming a ground contact area of 200 x 200 mm, the ground contact pressure is 19.6 kN m^{-2}. Ignoring the FOS, the required WT level is around 270 mm or approximately 0.3 m.

Thus farming practices have to be planned with the required bearing capacity in mind. The water management system must be designed to achieve this required bearing capacity value. Although a higher WT may mean lower rates of peat wastage, the bearing capacity achieved must allow economic farming practices to be supported. This becomes more important and critical in mechanised agricultural production practices.

The results of soil meter monitoring (Figures 5.57 to 5.65) showed that although there is a net subsidence, the ground surface regains some volume during wet rainy periods. Figure 5.54 indicates that drained peat soil can recover its initial volume if θ_m is not reduced to below 400%. Taking advantage of this property, the WT then should be kept at the highest possible level for each specific crop production stage and lowered only sufficiently for each mechanisation need. It should then be subsequently raised again after the mechanisation works have been completed. To enable this practice to be carried out, the appropriate duration required for the soil to reach specific bearing capacity after each WT lowering will be required. This is at present not available, although FIGURE 5.16 indicate that the WT at 15 m from the drain stabilised to about 100 mm above the drainage base within 3 days after draining. Further reduction of subsidence rate can be achieved if the field is kept water logged during fallow periods. The above requirement will have to be considered during the design of the field system. Storage areas for water drained temporarily for mechanisation needs, have to be identified. Water will also be required for flooding of the area during fallow period so as to reduce subsidence, as well as for irrigation during the dry period. This source of water must be identified. The economic feasibility of this alternative will have to be considered.

Alternatively, where mechanisation is envisaged, suitable machines and implements need to be designed for the expected bearing capacity. Whether manual or mechanised farming is practiced, a minimum bearing capacity needs to be achieved not only to support the farm hands but also the crop to be planted. Obviously the maximum achievable bearing capacity and shear strength in peat will govern any new machinery on peat in the future.

7.2.2 Crop Production

Beside hydrology and hydraulics, knowledge of the soil properties, such as the soil moisture release curve, moisture content at field capacity (FC) and permanent wilting point (PWP), hydraulic conductivity (K), capillary fringe (CF) and rate of capillary rise (RCR), are also required to design an efficient water management system for crop production. Information on the moisture needs at each stage of growth of the crop to be planted, is also crucial for efficient water management system design.

From Figure 5.7 for the 100-200 mm layer, θ_m at 0.1 bar is about 480% while θ_m at 0.3 bar is about 450%. For the 200-300 mm layer, θ_m at 0.1 bar is about 550% while θ_m at 0.3 bar is also about 450%. Table 5.12 shows θ_m for the 100-200 mm layer, in the field 4 days after rain, to be between 512% to 612%, while that for the 200-300 mm layer to be between 620% to 687%. Change in moisture content from 5 to 15 bar is minimal (Figure 5.7). Thus the FC and PWP of the peat of the IPRS Pontian area were considered to be effectively at suctions of 0.1 and 5 bar respectively. Assuming PWP to be at 5 bar suction, Figure 5.7 indicates that for the peat soil at IPRS experimental area, around two-thirds of the soil water, about 430%, (difference between moisture content at 0.001 bar and at 5 bar) for the 200-300 mm soil layer is easily available water (EAW) for plant growth. About 130% (moisture content between 0.001 bar and 0.1 bar) is lost by gravity before reaching FC, thus leaving an AWC of about θ_m = 430-130 = 300%. Figure 5.8 shows moisture characteristic curves taken from three (3) areas subjected to different lengths of drainage time. As stated earlier the Parit Sikom area has been drained for about 40 years. The values for IPRS Pontian are taken about 17 years after it had been initially drained while the Ulu Air Baloi area had been opened about 3 years earlier. The record of gravimetric moisture content at various suctions with time after drainage are reproduced in Table 7.7. As can be seen, θ_m at the various suctions decreases from Ulu Air Baloi to the Parit Sikom area. As the peat properties, other than moisture content of this contiguous area are similar, it can be conclude that moisture content of drained peat decreases with time.

The volumetric available water capacity (AWC) for IPRS Pontian, at various depths, is estimated in Table 5.15. From this table the AWC for the following rooting depths (RT) in IPRS Pontian are as estimated below

RT = 0 to 300mm, AWC = 0.17x100+0.36x150 = 71.0 mm
RT = 0 to 600mm, AWC = 71+0.50x150+0.49x150 = 219.5 mm
RT = 0 to 900mm, AWC = 219.5+0.46x150+0.42x150 = 351.5 mm

In Table 5.25, the capillary fringe, at θ_m exceeding 90% of saturated moisture, was estimated to range from 110 to 250 mm. If the capillary fringe is assumed at a depth with θ_m exceeding 95% of saturated moisture, then the capillary fringe ranges from 75 to 160 mm. The rate of capillary rise (RCR) for dish evaporation, E_d, between 3 to 4 mm is reproduced below (from Figure 5.22b and Table 5.28)

For WT = 0, RCR = 4.0 mm day^{-1}
For WT = 300 mm, RCR = 2.4 mm day^{-1}
For WT = 600 mm, RCR = 1.6 mm day^{-1}
For WT = 900 mm, RCR = 1.0 mm day^{-1}

ET_{crop} is calculated using the Pan Evaporation Method (Doorenbos and Pruitt, 1977) where

$$ET_{crop} = kc \times ET_o \qquad 7.2$$

$$ET_o = kp \times E_{pan} \qquad 7.3$$

where

ET_{crop} = crop evapotranspiration
= crop water requirement (mm day^{-1})
ET_o = reference crop evapotranspiration
= 3.85 mm day^{-1} (DID WR 5, 1976, average for Stn No 1820115, Pontian Kecil)
ET_{pan} = pan evaporation (mm day^{-1})
kc = crop coefficient (Doorenbos and Pruitt, 1977)
= 1.1 (average peak requirement, > 70% Relative Humidity)

kp = pan coefficient (Doorenbos and Pruitt, 1977)
= 0.85 (light wind < 175 km day^{-1})

Therefore

$$ET_c = ET_{crop}$$
$$= kc \times kp \times E_{pan} \quad \text{--- 7.4}$$
$$= 1.1 \times 0.85 \times 3.85$$
$$= 3.6 \text{ mm day}^{-1}$$

Table 7.8 shows sample calculations of crop water requirement for a 15-day period for crops with 3 different rooting depths, all planted in one area, having a 0.9 metre deep WT and assuming RCR=1.0 mm day^{-1}. For comparison with deeper WT of 2 m depth, it is assumed RCR=0 ie no contribution from ground water. For comparison also, sample calculations are made for other soil types (Assume RCR=1 mm day^{-1} for clay and medium textured soil at WT=0.9 m deep and RCR=0 for sand at WT=0.9 m. For all soil types at WT=2 m deep, RCR=0).

From Table 3.1 the return period for 15 and 21 dry days in Pontian are 2 and 6.67 years respectively. At ETcrop=3.6 mm day^{-1}, and assuming that the peak water requirement is required during this period of dry days, the total crop water requirement for 15 dry days is 54 mm and for 21 dry days is 75.6 mm.

As can be seen in Table 7.8, in peat areas in Pontian, there is possible water shortage for crops with rooting depths less than 300 mm if the WT is 900 mm below the surface. There should not however be a water shortage for crops on peat with rooting depths exceeding 600 mm, even if the WT is 2 m deep. Thus for crops with rooting depth between 0 to 300 mm (eg. vegetables), there is a need for irrigation if the WT is below 900 mm. Table 7.9 indicates that if the WT is controlled at about 300 to 600 mm depth, the need for surface irrigation will be alleviated.

Table 7.8 indicates that the allowable dry days in similar peat areas for crops with rooting depth of 900 mm will be 53 days and 49 days if the water table drawdown is 0.9 and 2.0 m respectively. Thus the deeper the water table drawdown the less will be the number of allowable dry days. In areas where the dry period can exceed this estimated allowable dry days, water shortage is likely to be experienced. In the north-east of the Malaysian Peninsula, where the climate is monsoonal a dry period of around 3 months is common. In such an area irrigation will be necessary.

The available water capacity (AWC) values for peat in Table 7.8 are derived from Table 5.13. From Taylor et al, 1978, the values of AWC for Malaysian clays are generally less than 180 mm per m depth of soil. The same reference also uses similar assumptions for AWC for loamy soils and sand. Thus estimations from Table 7.8 show that Malaysian peat has a better volumetric water holding capacity than the non peat soils. It indicates that the non peat areas will be more affected (in so far as moisture supply is concern) by the lowering of water table depths upon drainage. Under similar climatic conditions, while crops on peat may just be able to sustain themselves, crops on "good soils" may suffer from water stress related problems.

7.2.3 Excessive and Irreversible Drying

It has been observed in the field that the top soil on drying denatures, becomes granule-like and is very difficult to rewet. Section 5.1.2 and Figure 5.6 indicates that the point where this occurs is approximately at $\theta_m = 226\%$. Laboratory tests (Figure 5.48), shows that the moisture content for samples from the top 300 mm layer stabilised to $\theta_m = 25\%$ within 20 days of drying, while θ_m of 220% is reached within 7 to 10 days. Figure 5.4 and Table 5.6 however showed that in the field $\theta_m < 220\%$ is confined to the top 50 mm layer only. This is probably due to the insulation of the deeper layer by the top 50 mm layer from the sun as well as continuous moisture supply, through capillary rise, from the deeper layers (WT fluctuates from an average of about 400 mm to 800 mm). It is however well known that the top peat soil (about 30 mm), which has been exposed to the sun is generally granule-like substance and cannot be rewet. With tillage and continued exposure there is a possibility for the depth of this granule-like substance to increase.

From Section 5.3.2, the rewetting potential is seen to be affected by the initial moisture content before rewetting. Figure 5.54 illustrates the possibility of full volume recovery on drying up to a certain moisture content, after which the rewetting becomes increasingly difficult. It indicates the possibility of a full volume recovery (ie $V_a = 100\%$) if the initial θ_m is not reduced to below 400%, and a substantial volume recovery of more than 80% of initial volume, if the initial θ_m is not reduced to below 200%.

Figure 5.48 shows, the samples in the laboratory for the top 300 mm of peat soil reaching θ_m = 400% between 3 to 7 days. The return period for 3 and 7 dry-days is 0.5 and 2.7 months respectively (Table 3.1). The moisture contents are from monitored samples in the laboratory (samples with no continuous contact to WT, through capillary rise). However the very short drying period required and the frequent occurrence of continuous dry-days in nature, clearly indicates the significant effect of climate on peat soil irreversible drying.

Figure 5.4 and Table 5.6 and 5.12, however, showed that θ_m below 200 mm depth for all 3 areas, Ulu Air Baloi, IPRS and Parit Sikom generally exceeds 400%. Thus it is apparent that only the top 200 mm is affected by this near total irreversibility indicating that this phenomena is caused more by the effect of heat than WT drawdown. This is confirmed by Tables 5.33 and 5.34. An oven dried sample with θ_m = 29.6%, increases its θ_m to 109% on rewetting. An air dried sample with θ_m = 19.9%, increases on rewetting to θ_m = 217.9%.

From the above discussion it can be seen that in order to minimise irreversible drying, it is important that the gravimetric soil moisture content be maintained above 400%. In the field this occurrence of less than 400% occurs only in the top 200 mm layer. Thus farming practices must be designed to try to alleviate this drying. This can be done by minimising the drying of the top soil either by planting cover crops, maintaining high WT level and/or ensuring minimal rotovation.

Frequent ploughing of peat soil (as land preparation for crop establishment) will dry the soil faster. A perennial crop, which would generally require less land preparation and therefore less rotovation than an annual crop, would be preferred to minimise irreversible drying.

If annuals or vegetables should be planted, a crop should be chosen which has a root system that can penetrate deeper than 200 mm. Such crops will then be less affected by the lack of moisture in the top layer.

7.2.4 Subsidence

From section 1.2.1, subsidence in drained peat areas is attributed to 3 processes namely:

i. dewatering - resulting in soil settlement and shrinkage

ii. compaction and consolidation - due to farming practices and increase in overburden pressure

iii. peat wastage - due to oxidation/mineralisation of the organic material

Results showed that drained soil samples, lost up to 60% of their initial volume after being left to air-dry for 19 days (Figure 5.47). This, will result in subsidence due to dewatering. An indicator of this loss in volume due to dewatering process is the increase in the dry bulk density value. From Figure 5.5, whilst the dry bulk density of the top 50 mm layer can be between 0.1 to 0.2 Mg m^{-3}, the dry bulk density at 1 m depth below the surface can be as low as 0.04 Mg m^{-3}. Watertables in these areas of Pontian, generally fluctuate between 0.3 m to 1.2 m below the surface.

Figure 5.50 shows reducing volume in peat soil on drying. If the gravimetric moisture content, θ_m, is not reduced to below 400%, peat can recover its full volume on rewetting (Figure 5.54). In the field (Figure 5.4) θ_m of less than 400% only occurs in the top 200 mm layer. Table 5.6 shows the sampling day θ_m for the newly drained Ulu Air Baloi to exceed 400 % even in the top 50 mm layer. In the IPRS area only the top 50 mm layer has $\theta_m < 400\%$. However in the 40-year old drained area of Parit Sikom a more substantial depth, the top 150 mm layer, has $\theta_m < 400\%$. As there would be a constant moisture supply from the water table to the top layer (due to capillarity) it is expected that subsidence as a result of shrinkage on drying is minimal below the 200 mm layer. Subsidence below this layer will be due more to settlement as a result of dewatering and compaction and consolidation from farming practices and increase in overburden pressure.

Suppose drainage allows the top 100 mm soil to dry from a θ_m of around 800% to 200%. Figure 5.50 indicates a possible loss in volume of about 30% or 30 mm height of a 100 mm depth soil in the field. As a result of tillage and compaction from farming practices, assume then that the average dry bulk density,

ρ_{dry}, within this 100 mm increases from 0.08 Mg m^{-3} to 0.10 Mg m^{-3} (Figure 5.5). The decrease in depth in the field is 20 % of the remaining 70 mm depth or 14 mm, giving a total loss of 44 mm or 44%. If the ρ_{dry} increases from 0.08 Mg m^{-3} to 0.20 Mg m^{-3} (Figure 5.5) the decrease in volume is 60 % or 42 mm. This will give a resultant loss of 72 mm depth or a 72% lost in volume. Figure 5.53 shows the increase in ρ_{dry} on drying of an intact sample from the top 300 mm layer. The volume used in the estimation of ρ_{dry} in this figure is the actual volume of the intact specimen, which has not been broken or remoulded. Values in the field may be different because of effects such as capillary rise and rainfall, but the figure nevertheless indicates the possible range of dry bulk density increase from 0.11 to 0.32 Mg m^{-3} in an undisturbed peat mass subjected to air drying.

Loss of buoyancy for a drained area will result in an increase of overburden pressure which will further consolidate the peat soil. The contributory weight of the overburden pressure can be calculated from the resultant wet bulk density with drainage.

Assume the initial water table in a peat deposit of 3 m depth (eg IPRS) is at 0.1 m from the ground level. Assume also that the average wet bulk density above the water table is 0.9 Mg m^{-3} (900 kg m^{-3}) and the bulk density of the deposit under water to be equal to the density of water (Table 5.33 and Figure 5.52). The initial overburden pressure, p_i, on the lower deposit is then

$$p_i = 900 \times 0.1 \times 9.81/(1000) = 0.88 \text{ kN m}^{-2}$$

Assume the water table is then lowered below the ground level and assume the peat deposit above the water table maintains a wet bulk density of 0.9 Mg m^{-3}. From Table 5.31 the compression index, C_c varies from 12.12 to 2.40 for the IPRS area (average C_c= about 4). Using values from Figure 5.37 the settlement of the deposit as a result of increases in overburden pressure is estimated in Tables 7.1 to 7.2 using equations 2.2 and 2.3 from Chapter 2.

With known initial void ratio, e_i, and estimating for unit area, then

$$e_i = \frac{V_{vi}}{V_s} = \frac{h_{vi}A}{h_s A} \qquad \text{--- 7.5}$$

hence

$$e_i = \frac{h_{vi}}{h_s} \qquad \text{--- 7.6}$$

where

V_{vi} = initial volume of voids
V_s = volume of solids
h_{vi} = initial height of voids
h_s = height of solids
A = unit area

as

$$h_{vi} = h_i - h_s \qquad \text{--- 7.7}$$

then

$$h_s = \frac{h_i}{1+e_i} \qquad \text{--- 7.8}$$

Using the coefficient of compression, m_v, (Figure 5.37 and Table 7.1) and analysing only for the peat mass under water, then the porosity and void ratio of the peat soil below the water table is as given in Table 7.3. Only the weight of the soil mass above the water table is considered in this analysis.

Using the compression index, C_c, of 4.01 and initial void ratio, e_i, of 8.48 (Figure 5.37 and Table 7.2) and analysing only for the peat mass under water, then the porosity and void ratio of the peat soil below the water table is as given in Table 7.4.

The calculation using the coefficient of compression, m_v, only covers the primary consolidation. As the secondary compression is substantial and an ongoing process, this will underestimate the subsidence. The time taken to reach 90% of the primary consolidation stage is estimated to be 15.5 days (Table 7.1).

On the other hand the compression index, C_c, is estimated from the graph of void ratio versus pressure. These are readings at the end of each loading and take into consideration the secondary consolidation component and hence can be expected to give a better estimate of the subsidence as a result of consolidation.

Comparison of results from Table 7.1 and 7.2 shows that estimations of subsidence using the coefficient of compression, m_v, is very much smaller than the estimation using compression index, C_c. Using m_v, the changes to porosity and void ratio with increasing overburden on water table drawdown is higher (TABLE 5.5 and FIGURE 5.3, Ulu Air Baloi a newly drained - top soil ash content), then there will be a correspondingly lower subsidence is minimal (Table 7.3). Although there is greater significant reduction in void ratio with increase overburden when using C_c, the porosity of the consolidate soil remains in excess of 78% (Table 7.4).

The increase in dry bulk density of the top layer is as a result of both drying and oxidation. FIGURE 5.3 shows the ash content of the top 50 mm layer of the newly drained Ulu Air Baloi area to be about 4.5 times that of the ash content at 1 m depth (1.92% to 0.43%). For simplification, and with reference to the sharp increase of ash content in the top layer (FIGURE 5.3), assume the initial ash content to be an average of 0.43% and constant with depth. Then the ash content of 1.92% of the top 50 mm layer, has been contributed from the top initial/virgin depth, h_{ti}, where

$$h_{ti} = \frac{1.92\%}{0.43\%} \; 50 \text{ mm} = 223 \text{ mm} \qquad \text{--- 7.9}$$

As a result of oxidation this 223 mm has been reduced to 50 mm resulting in a subsidence of 173 mm.

Similarly, in the IPRS area, there is an increase in ash content from about 0.4% at 1 m depth to 4.6% at the top 50 mm surface. Using the same assumption as for Ulu Air Baloi, there appears to be a subsidence of 525 mm for the top 50 mm in IPRS area. If the initial ash content of an undrained peat area is higher then there will be a correspondingly lower subsidence.

TABLE 7.5 summaries the total estimated subsidence. In row 3, 4 and 5, the subsidence rate is calculated using the compression index, C_c which is preferred for reasons already discussed previously. The actual subsidence rate of similar depths of peat area (3 m deep) over 4 years is 115.4 mm $year^{-1}$. Looking at the estimated value, the subsidence rate over 17 years varies from 85.1 mm $year^{-1}$ to 124 mm $year^{-1}$, depending on the water table drawdown. From water table records (Table 5.51) the average water level for Plot 6 varies between a minimum of 417 mm and a maximum of 1049 mm. Thus the estimated subsidence over 17 years can be between 85 mm $year^{-1}$ to 124 mm $year^{-1}$. This seems to agree with the actual overall recorded subsidence over 4 years of 115.4 mm year^{-1} (Table 7.5). Table 7.5, row 6 and 7, also shows the actual rate of subsidence decreasing with years after drainage. While the overall rate of subsidence from 1984 to 1988 is 115.4 mm year^{-1}, it is only 38.4 mm year^{-1} from 1986 to 1988 and 27.1 mm year^{-1} for the year 1988. Therefore the actual subsidence rate over the last 17 years (from the time it was open) for this area could exceed 115.4 mm year^{-1}. An indication is the subsidence rate for 1984/86 of 192.4 mm year^{-1} (Table 5.38). Thus Table 7.5, row 5, probably under estimates the subsidence rate over the last 17 years of the area, although the estimated value is already substantial.

The subsidence due to dewatering and oxidation is inter-related. The subsidence over the first few years after drainage is expected to be largely due to dewatering, consolidation and shrinkage. Subsidence due to shrinkage and oxidation is expected to be higher near the surface ground level and for soils above the WT. Although the primary consolidation can be completed within a few days to a few months, the secondary consolidation is an on going process as long as there is an overburden pressure. (See Figures 5.39 to 5.46)

Some areas in Sungai Pinggan, Pontian (peat depth exceeding 6 m) have maintain a subsidence rate of 148 mm per annum since first opened up about 10 years ago (Welch et al, 1989). From visual inspection and drainage design the water table in the area has generally been dropped to between 1 to 2 m depth.

From Table 7.5, row 7, the stabilised annual subsidence rate for a drained area with an average water table fluctuating from about 400 to 1050 mm is 27.1 mm year^{-1}.

From row 5 of Table 7.5, and using the conservative figures from an estimation using the coefficient of compression, m_v, there is an increase of about 13 mm year^{-1} of subsidence for every increase of water table depth of 500 mm. Assuming the rate of subsidence for WT @ 500 mm to be 27 mm year^{-1}, then the average subsidence rate of a drained peat deposit with a 1000 mm and 1500 mm average water table depth will be 40 mm year^{-1} and 53 mm year^{-1} respectively. TABLE 7.6 estimates the probable IPRS ground levels in 50 years from 1988 to 2038 using these assumptions. There is a probable increase in subsidence of 0.65 m for every increase of 500 mm water table depth over the calculated 50-year period.

7.3 Water Management System Requirement - the Ideal Case

The preceding discussions show implications of watertable levels on

i consolidation
ii bearing capacity
iii crop growth
iv irreversible drying
v subsidence

While consolidation on lowering of watertable levels results in subsidence, this is not a process where matter is loss, but a process of soil compaction which is beneficial for plant support as well as crop production activities. Figure 7.1 shows that subsidence from consolidation increases with watertable depth in a geometrical relationship where

$$S_c = f(z)$$

where

S_c = subsidence due to consolidation
z = watertable depth from the surface

Consolidation as a result of lowering the water table immediately on drainage can result in higher dry bulk density, therefore an increase in bearing capacity (Section 7.2.1). Thus to induce overall higher dry bulk density the watertable levels should be dropped to 2-3 m depth initially, before raising the watertable levels again to cater for crop growth and to reduce oxidation rate. The big drainage capacity as a result of deep drain depths can be utilised for its flood mitigation function.

The relationship of bearing capacity to watertable levels on a 15-year old drained area is given by equation 7.1. In this relationship the value of bearing capacity at 0 m watertable level is 5.3 kPa (kN m^{-2}). As light modern machinery has a ground pressure of about 50 kPa (Andriesse, 1988) it is therefore important to lower the watertable levels to specific ground pressure requirements before each crop production or mechanisation practices. The presence of the matrix of fibres in the surface layer can usually allow a higher bearing capacity (35 kPa @ 0 m watertable level - Figure 5.24).

Drained peat can attain full volume recovery if moisture content in the soil is not reduced to below 400% (Figure 5.54). Figure 5.6 indicates a rapid increase in dry bulk density as peat dries to less than 250%. At this moisture content of about 250%, generally, water in the soil is not available for crop growth (Figure 5.7). Figure 5.4 indicates gravimetric moisture content in the field (3 days after a rainfall event) at 250% or less to be in the top 60 mm while that at 400% or less to be in the top 150 mm. Thus for an area with WT fluctuating around 700 mm, irreversible drying occurs only within this depth. As the capillary fringe is about 150 mm depth above the watertable level, to avoid irreversible drying watertable levels should be kept at 150 mm depth or less.

Watertable levels for optimum crop growth will depend on the depth of the root zone of each specific crop. While most crops are adaptable to changes in WT depth (which influence the soil moisture status), the design of water management systems must consider root depth of crops. Root depth of a crop varies as it grows from seedlings to harvesting. For pineapple the root depth varies from 0 mm to 680 mm. (For most vegetables the maximum root depth is around 300-450 mm at harvesting.) The ideal situation, for pineapple, is to drop the watertable levels gradually from 0 mm during the fallow period to 680 mm, just before hormoning and thereafter till harvesting. At anytime when watertable level is less than 650 mm depth, the level will have to be dropped to this level for mechanised activities at least 3 days (time taken for mid-field water table level to fall to about 100 mm above the drainage base, Figure 5.16) before the planned work. To ensure that watertable levels are kept at the required level, not only must there be adequate control but sources of watersupply for subsurface irrigation must also be available during the dry period.

7.3.1 Field System

The present drainage criteria used in Malaysia are based on the removal of design storm discharges within specific time periods. Reference is usually made to Khoo et al 1976, "Hydrological Design of Agricultural Drainage Systems, Hydrological Procedure No 18". This procedure recommends for different crops, the appropriate design rainstorms and the length of allowable inundation periods. For most tree crops the recommended length of inundation period is 72 hours duration, occuring once in 5 years. During the actual designing of projects drainage controls are built in to limit excessive drainage.

Using a design of 1 in 5 years return period, protects the area from a 1 in 5 years design rainstorm as the drains are designed to have capacities to discharge design storm of once in five years. At other times these drains will actually be oversize. Recognising the effect of overdrainage, in the WJIADP Phase 2, the drainage criteria have been reviewed to optimise the costs and benefits, specific to the area. This results in drainage modules of 5 l/s/ ha for oil palm and 8 l/s/ha for rubber or 43.2 mm day^{-1} and 69.1 mm day^{-1} respectively. Thus although Malaysia has only between 2.5 to 3 times the annual rainfall of Western Europe, the drainage rate in the agricultural fields is still about 6 times that used in Western Europe (7 to 12 mm day^{-1}. The present criteria used in the WJIADP Phase 2, generally, allows for maximum ponding of 9 days to 5 days in 20 years or about 6 days and 3 days respectively, in 5 years.

The above consideration is for drainage of excess surface water only. Whilst the drain depths (less than 250 to 300 mm for farm drains and less than 400 to 500 mm in tertiary or feeder drains) are mentioned, design procedures relating to maintaining water levels at appropriate depths for varying soil physical parameters are yet to be incorporated. Economic costs of the effect of overdrainage or moisture stress on crop production in Malaysia are scarce. However Chuah et al, 1989, has written a paper on the significant effect of excessive drainage on oil palm yield. A yield reduction of as much as 4 tons per hectare from average yield has been estimated as a result of overdrainage. With adequate moisture, the average yield of palms in a particular area have been recorded to exceed normal averages by as much as 9 tons per hectare.

As has been discussed in Chapters 2 and 6, the development of field drainage equations allow the possibility of accurate predictions of water table in the field, if soil and climatological parameters are available. In areas where rainfall is small and well distributed the saturated steady state analysis can be use to predict the average mid-field WT level. It assumes continuous steady rainfall which is discharge continuously and steadily by the drains. While the magnitude of design discharges remain as the primary criteria for the steady state situation, the criteria should also include provision for holding water tables at a level within reach of the plant roots, ie just about 150 mm below the root zone.

In practice, the situation in Malaysia is a nonsteady state condition involving rising and falling water tables. The saturated nonsteady state analysis predicts the rise and fall of the water table in response to rainfall, irrigation, evapotranspiration and seepage. In such an analysis the criteria should include the allowable number of times a specific water table can be allowed to exceed a design level and the duration of the allowable time at each exceedence.

To incorporate the above criteria, hydropedological parameters such as hydraulic conductivity, drainable porosity, rate of capillary rise and capillary fringe are required.

Section 5.1.4 concluded that the reasonable overall working hydraulic conductivity, K, value in this area is 5.5 m day^{-1}. This indicates that water collecting within the drainable pores of the soil is being drained away very rapidly. As can be seen from the daily rainfall recorders in plots 2 and 5 in IPRS, the mid-field WT rises almost immediately with recharge from rain. Records from the automatic water table recorders also show that corresponding mid-field water levels fall to about 100 mm above the drainage base within 3 days (Figure 5.16). Exceptions arise when there are restrictions and/or obstructions to the flow from the peat area. Such rapid movement of water away from the area also indicate that the soil moisture will be depleted equally rapidly. This will affect water supply to crops which are dependent on moisture stored in the soil and can become critical particularly during long dry periods.

The substantial drainable porosity of around 0.38 indicates the substantial storage capacity of the peat soil. This mean that peat soil can absorb substantial rain water before the excess rain flows away as overland drainage flow. It also means that part of the peat swamp can be utilised as a storage reservoir without the necessity to clear its natural vegetation.

Mathematical models have been developed to predict water table movement in the field using land drainage theories. These models require data of initial conditions and geometrical configuration of the flow region, rainfall, evaporation, and soil hydraulic properties. The applicability of a model developed by Youngs et al, 1989, was discussed in detail in Chapter 6.

The importance of appropriate water management in the field is paramount to achieving optimum yield particularly if all other agricultural inputs have been exploited. Adequate moisture content can be maintain with appropriate water table control. The requirement for field water management, will subsequently, dictate the requirement for the whole system design of drainage areas, including the design of the required control structures.

7.3.2 Arterial System

The drains in drainage areas in Malaysia, were designed primarily to cater for the flood mitigation function which is crucial during the wet season. This flood mitigation function can best be achieved by providing a drainage system which ideally can drain all excess water immediately. Yet for optimum crop production the drains have also to function as water management infrastructures. This requires that these drains be appropriately controlled and operated to ensure the crops are supplied with essential moisture during critical dry periods. At the moment this function is not incorporated in the general design of an agricultural drainage area.

In practice, the capacity of the arterial channel is design for a certain design rainstorm. Control should be judiciously carried out to minimise moisture stress to crops. The extend of the severity of this stress is dependent on the climate, crop type as well as inherent soil properties. Whilst climatic input is being looked into by the Department of Irrigation and Drainage, the required constraints for crop and soil types have to be supplied by other agencies. Consideration for design criteria should start at field level, before considering other criteria and limitations at the arterial level. Although arterial drains are essentially transport structures and cater more for the flood mitigation function, their design must give due consideration to criteria decided for water management at field level.

7.3.3 Structures

The substantially lower bearing capacity and the subsidence in peat areas, requires a rethinking of the control structures. Permanent structures such as concrete may proved to be more expensive in peat areas because of the need to ensure that the foundations are adequately anchored to the subsoil. The design criteria and considerations utilised for the design of these permanent structures may be obsolete within a few years due to subsidence. The problem may be further aggravated if the rate of subsidence is very high.

Structures using materials that are cheap and easily replacable should be preferred. Such structures should take into account the rate of subsidence and the number of replacements required during the life time of the project. The number and cost of replacements should be incorporated into the total costing of the project. The present practice of initial dewatering of the area before construction of any infrastructures should be refined in terms of adequate timing with respect to particular drain depth, drain spacing and the required working bearing capacity.

7.4 Environmental Requirement

Undrained virgin peat areas are complete ecosystems in themselves. Draining them, be it for agriculture, industry or for any other purposes, changes this ecosystem. Generally the changes are irreversible and can have various physical, economic, social and ecological implications. The continuing process of decomposition to the limit arises through chemical reaction of oxygen with the peat material and biochemical action of bacteria and other animals on the peat substrate. The deposit will only stop decomposing if it is returned to its initial condition of complete saturation or if the entire organic content has been fully oxidised or utilised.

Technically it is possible either to drain the peatlands and turn them into productive agricultural land or, if need be, to utilised the same technology to maintain wetland status of the area or pockets of the area.

The reclamation of the peat area for agriculture, changes the surface cover and effects on climate can be expected particularly if the area is extensive and the new cover crop is significantly different from the swamp rain forest jungles that it replaces. From an environmental point of view, watertable need to be held as close to the surface as possible for as long a period as possible.

7.5 Other Management Requirements

For peat areas with severe dry seasons, irrigation supply from another area within or outside of the region or backflushing from a ponded area should be considered. The very porous nature of the peat and possible back grade on the surface of the clay sublayer with respect to the ground surface have to be considered. Beside seepage losses, an average of 4 to 5 mm day^{-1} evaporation loss must be included in sizing the storage pond. Alternative use for the pond, such as fish rearing can be included. Pumping artesian water is another alternative for water supply.

Mulches to protect the soil from the scorching heat and therefore unnecessary drying will have to be incorporated extensively in farming practices in order to conserve as much top soil available water (AW) as possible. Mulching can also minimise problems of irreversible drying and possibly reduce the rate of subsidence.

7.6 Proposed Model Water Management For Pineapple in Peat

Two widely grown crops on peat in Malaysia are pineapple and oil palm. Pineapple is a field crop while oil palm is a perennial crop. With induced fruiting, pineapple requires less than 12 months from planting to harvesting of the first crop. For economic production, two ratoon crops are also harvested. The time period from initial planting to harvesting of the second ratoon crop is about 26 months. The hardy nature of the pineapple crop, and its shorter period for harvesting and therefore faster return on investment makes this crop popular among the smallholders, but peat subsidence and fire risk during the dry period must be considered.

7.6.1 Agronomic Requirements

From section 2.2.2, the peat soil natural pH is indicated to be between 3.5 to 3.8. As the optimum soil pH for pineapple is between pH 4.5 to 6.5 (section 4.4.4), liming will still be required for optimum growth. Section 4.4.4 also state that the roots are generally concentrated between 0.3 to 0.6 m with optimum water table level between 0.68 to 0.86 m. This indicates a capillary fringe of less than the range between 260 mm to 380 mm and compares well with the estimated 200 mm in section 5.1.7. It can survive long dry periods (Doorenbos and Kassam, 1986) but severe water deficits can retard growth, flowering and fruiting. Appropriate amount of water deficit at flowering may hasten fruiting and result in uniform ripening. Excessive water supply at flowering will not only lead to vigorous growth but also a large core. Excess water supply during the growth period (excessive irrigation or rain and water logging) will also reduce the fruit quality. Thus it is apparent that proper water management is required for the production of optimum yield and quality fruits.

Pineapples which are allowed to flower naturally will produce a harvest which will ripen over a period of two to three months. Chemicals such as alphanaphthaleneacetic acid or calcium carbide can be applied to the plant to induce flowering. When used correctly and with correct overall planting methods and management, the harvesting in an area can be concentrated over a period of a week. To get even sized fruits, healthy plants of sufficient and equal size only (with about 35 leaves) should be induced. This is at about eight months from planting, or even earlier if larger plants are established. The fruit can be harvested about 4 months there after.

Pineapple is a hardy crop, similar to oil palm, thus following Khoo et al, 1976, this crop should be able to withstand 72 hours inundation of surface water. Present practice in oil palm areas in Western Johore Integrated Project indicate that oil palm can withstand inundation of up to 10 days. Similar records are not yet available for pineapples. Although it is possible that the pineapple is equally hardy, it has to be remembered that pineapples are very much shorter in height and a lower depth of flood can totally immerse it while only partially immersing the oil palm.

7.6.2 Engineering Requirements

The engineering design for the IPRS area is given in section 3.3.3 with details given in Appendix B. As can be seen above, the root depth is 0.6 m. The recorded optimum water level for pineapple is between 0.68 m to 0.86 m. In peat agriculture the need to minimise wastage and subsidence is paramount for long term sustainability. Thus the highest possible water table level of 0.68 m (instead of the lowest which is 0.86m) should be chosen. From Table 5.25 the average capillary fringe (at 95% of saturated moisture content) is 119 mm or about 0.12 m. Thus the mid-field water table should be designed for a minimum depth of 0.72 m.

Referring to Figure 5.17, for a spacing of 30 m the mid field water table stabilised to about 0.1 m above the drainage base within 3 days. Thus there is no necessity to design field drains for a closer spacing than 30 m. A wider spacing will definitely be more economical particularly if it can be shown that the drawdown time of water level at mid-field is within the allowable time.

Figure 5.17 also shows that the water-table curve dropped sharply to the ditch water level from a distance of about 1/8th of the ditch spacing. Thus the land within 1/8th distance of the ditch on each side, should generally be able to provide similar moisture supply to the crop.

The drainage rate of 80 mm day^{-1} in Section 3.3.2 was calculated from a design rainstorm of 83.8 mm day^{-1} and average evaporation rate of 3.8 mm. From Figure 5.22b and for open water evaporation of 3 to 4 mm day^{-1}, the rate of capillary rise for water table level at 0.72 m, is 1.5 mm. Using the above data and with a K value of 5.5 m day^{-1} the required depth and size of the field ditches can be designed. The present ditch size is the minimum size in accordance with construction requirement. Both peat and crop requirements must be considered together. As the mid field water table stabilised to about 0.1 m above the drainage or ditch base within 3 days the depth to the ditch base should be designed for 0.82 m or 0.8 m. Gated structures, operating procedures and in some areas irrigation supplement have to be planned and followed to ensure adequate water in the field for optimum yield production.

7.6.3 Crop Scheduling of Pineapple

Using all the information gathered in this study crop scheduling for pineapples can be proposed. Rainfall in Pontian, Figure 1.2, is generally uniform with 2 drier periods around January and from May to September. The main crop requires about 7 to 8 months before it is ready to be treated with hormone after which it takes another 4 months before the fruits are ready to be harvested. Thus the most appropriate planting time should be in October. The crop should be ready to be hormoned around May/June and be ready for harvesting of the main crop in August/September. May is the beginning of a generally drier period of about 5 months so that any water deficit can be taken advantage of in hastening fruiting and inducing uniform ripening. Although there are advantages of reduced moisture during this period, growth will be excessively retarded if there is serious water deficit.

The first ratoon crop will be ready for hormone treatment in January of the second year and the fruits ready for harvesting in April. The second ratoon crop can be hormoned in July of the second year and the fruits harvested around November.

Although the main crop can be hormoned and harvested during generally drier period thus inducing better quality fruits, the first and second ratoon crop, will be fruiting during generally wetter months. For these crops it is important to ensure that there is no water deficit before the hormone period and no water excess during the fruiting period to achieve timeliness and quality fruit.

7.6.4 Field Operation and Maintenance Procedure

Operation and maintenance procedures in the field should ensure all moisture requirements are considered and all moisture stress situations are alleviated. While an appropriate crop scheduling is necessary for economic production there are times when there will be an excess of water and times when there will be severe water deficit. Appropriate operation and maintenance procedures in the field should be developed to minimise such stresses and estimations of crop water requirements made for the duration of the growing period. Irrigation facilities should be made available if the dry period in the area is expected to be severe.

As the drain is designed for a specific design rainstorm, it will be oversized for rain events smaller than the design storm. In order to operate and manage the water in the field, gated structures will be required as the lands are generally gently sloping. Gated structures should be manipulated to ensure water tables are kept on the higher side (of the 0.68 and 0.86 m range) during the period before hormone treatment. During fruiting the water table can be allowed to be on the lower side. Excessive low water table should be avoided.

In sloping areas, for example, one with 1/250 slope and a field length of 100 m length, the difference in surface level of the downstream area will be 400 mm lower than the upstream area. If only one gated structure is used and manipulated for the down stream area, this will result in water level in the upstream area being deeper by 400 mm from the designed water table level. Thus land levelling, especially in the area served by the same ditch, must be considered to ensure that the design water table can be provided.

Another inherent feature of peat farming areas, is localised deep depressions due to destumping of trees and removal of hidden and buried wood and logs. These depressions can at times be as deep as 500 mm. In such instances smoothing of the surface level will be necessary. If smoothing is not carried out, care must be taken not to plant crops in the specific area so as not to subject the crop to excessive moisture. Smoothing will also ensure faster and easier working by the farm hands.

CHAPTER 8 - FINDINGS AND RECOMMENDATIONS

8.1 General

Almost any man made project that utilises natural resources has an impact on the ecological system. Because of the irreversible effect of drainage on peat, reclaiming it for agriculture presents various challenges, particularly for a sustainable agriculture. The word sustainable has to be further defined. Is it relative or absolute? At a subsidence rate of 30 mm yr^{-1}, 900 mm or 0.9 m deep peat deposit will be depleted within 30 years (generally, the assumed project life) unless subsidence rates can be reduced through improved peat and water management. This is not inclusive of the initial subsidence which has been indicated to be quite substantial. If a perennial crop requires at least 500 mm deep peat deposit to sustain its growth, then for a project life of 30 years only deposits of at least 1.4 m deep can support this activity till full term if no management changes are made.

8.2 Research Findings

The primary objective of the study was to develop a field water management system for agriculture in peat soils in Malaysia, with an overall approach of integrating the engineering and agronomic aspects associated with crop production in deep peat areas. Thus aspects and parameters associated with both requirements were looked into. The following are the findings of this research

1) The design procedures for drainage of agriculture land in Malaysia were found to be biased towards discharging surface water, primarily because of the heavy rainfall. Efforts to maintain adequate moisture within the drained soil are made through the placement of drainage control structures at specific intervals. Criteria for placement of these structures are base on topography of the land and experience.

2) Some physical properties in Pontian peat, essential for field drainage design were determined. These properties, presented in Chapter 5, include hydraulic conductivity, drainable porosity, water table drawdown and shape, capillary fringe,

rate of capillary rise, moisture characteristic curve, peat rewetting potential, bearing capacity, consolidation constants and rate of subsidence.

3) Comparison of basic data such as ash content, moisture content and dry bulk density between old, intermediate and newly reclaimed land show significant differences only in the upper drained area. This indicates that the lower and saturated section of the peat deposit generally remains unchanged following drainage of the surface layers.

4) Bearing capacity can be related to WT depths using the equation in Section 7.2.1. The bearing capacity on peat is generally poor and can be as low as 5.3 kPa for WT at or near the surface. The deeper the WT levels the higher will be the bearing capacity achieved.

5) The moisture characteristic curves determined, indicates minimal moisture differences between 5 and 15 bar. Therefore, for practical purposes, the wilting point of local peat can effectively be taken at a suction of 5 bar.

6) Within the same region, local peat has a better water holding capacity than the non peat soils. WT levels in the peat areas can however drop very rapidly as a result of its relatively high hydraulic conductivity of around 5.5 m day^{-1}. The drainable porosity of around 0.38 indicates however the substantial storage capacity of the peat soil above field capacity.

7) Due to peat soil physical properties of low available water, minimal capillary fringe and small rate of capillary rise, crops with rooting depths of less than 300 mm will require irrigation if WT levels are not kept immediately below the root zone. Crops with such rooting depths include high value crops such as vegetables and flowers.

8) Moisture content of drained peat areas decreases with time. Rewetting potential is influenced by the initial moisture content before rewetting. Results indicate that as long as gravimetric moisture content, θ_m , is maintained in excess of 400%, irreversible drying may be avoided. In the field this occurrence of θ_m, less than 400% occurs only in the top 200 mm layer. Laboratory tests show samples reaching θ_m, of 400% between 3 to 7 days. The return period for 3 and 7 dry days in Pontian is 0.5 and 2.7 months respectively.

9) Subsidence rate can be very high. The land survey and surface monitoring results indicate that the rate of subsidence increases with deeper WT levels although decreasing with time. Estimates of subsidence using shrinkage values, increase in ash content and consolidation constants shows similarity with the monitored values for overall average rates of subsidence. These estimates confirmed existing records of Welch et al 1989 for areas drained over 15 years, the rates of which varied from 15 mm yr^{-1} to 148 mm yr^{-1}.

10) The agronomic component of the study indicates the sensitivity of yield to moisture condition. Any water management system must take into consideration implications of WT levels not only on crop growth, but also on consolidation, bearing capacity, irreversible drying and subsidence. A water management model for pineapple has been proposed in Chapter 7.

8.3 Recommendations

Some recommendations have already been made by the author previously (Salmah and Adnan, 1989 and Salmah, 1990). These recommendations were

i) Review current drainage design procedures and assess their applicability and suitability to peatland drainage.
ii) Develop procedures, suitable to the Malaysian conditions, to determine peat soil parameters related to drainage such as soil bearing capacity, hydraulic conductivity, water table positions, depth to impermeable layer, etc and monitoring their changing values with time.
iii) Study the dynamics of water table fluctuations and the resulting subsurface flow characteristics in peat.
iv) Develop an Operation & Maintenance model to meet both the requirements for flood mitigation and water management requirements in peat.
v) Develop innovative new design concepts and materials for structures in peat areas so as to take into account the continuous subsidence.
vi) Identify economic design, construction and maintenance procedures for farmroads on peat soils.
vii) Cultivate awareness among managers and farmers of their role regarding water management and therefore conservation of peat.
viii) Develop suitable equipment and machinery that can be effectively deployed in peat areas for construction, transportation and farming activities.

ix) Set aside suitable pockets of peat land in its virgin state as a bench mark and a natural library/museum for future references.

The following are some additional and detail recommendations.

1) Recommended measuring techniques and corresponding instrumentation, specific to woody peat soil need to be developed. These include instrumentations for soil sampling (without lost of moisture, particularly for the deeper layers), fibre content analysis, bearing capacity estimation and consolidation tests.

2) The ability to predict water-levels with known moisture inpu'ts and outputs will allow the water management of an area to be fine tuned to suit requirements. Many models have been developed and are being developed. A mathematical model developed by Youngs et al, 1989, and tested in the Benut area shows some promise. Further studies need to be carried out to gauge its applicability (also that of other models).

3) All possibilities and alternatives to improve field water management systems should be considered. The proposed system should as far as possible be accommodated within the existing drainage system. With increasing data now becoming available, the design criteria for allowable number of days ponding should be reviewed. The criteria should also specify the required allowable depth of ponding, specific to each crop type. The possibility of maintaining the deposit in saturated or even ponded condition during fallow periods should be explored. The drainage criteria should include not only the requirements for excess drainage but also the acceptable range of water table levels for optimum crop production. The allowable frequency exceeding these maximum WT levels should be identified for each crop. Moisture stress may have negative effects or even be beneficial at certain stages of crop growth and such situations should be taken advantage of, wherever possible. Economic costings of the effect of overdrainage or moisture stress on crop production in Malaysia are scarce. Nevertheless it can be critical to economic viability of agricultural projects and efforts must be made to identify this cost and incorporate them in all project analysis.

4) As moisture content also influences the strength of peat, relations between strength and water table depth as well as time required to achieve the required strength must be determined. These can then be incorporated into the field water management plans. During crop growth, WTs should be kept at the highest possible level that will not create aeration stress. The field can be flooded in between cropping seasons or during fallow periods. Water should be drained from the area at the appropriate time and to the appropriate water table depth in preparation for mechanised harvesting.

5) Machines and farm implements suitable for use on peats need to be designed for the expected bearing capacity.

6) The requirement for field water management will subsequently, dictate the requirement for the whole system design of drainage areas including the design and operation of the required control structures. Therefore any review of design procedures for a drainage system, including any flood mitigation requirements, must be sensitive to the field water management requirements.

7) Appropriate choice of crops must be made at the planning stage. This will affect not only the economics of the chosen crops (because of the soil inherent infertility), but will also dictate the type of farming practices and the drainage intensities. Heavily mechanised farming will require a minimum allowable bearing capacity that must be achieved in the field. Water table position governs not only the availability of moisture to crops but also, the allowable working bearing capacity.

8) The agronomic trials carried out in this research underline the importance of refining related agronomic practices in tune with any advancement in field drainage design. Land levelling in the field is required as removal of buried timber from the peat deposit may cause as much as 300 to 500 mm variation within a short distance. In peat areas because of high hydraulic conductivity values, the mid-field water-table levels will stabilised to the drainage base within a couple of days.

9) The depth where peat soil is affected by irreversibility is identified to be within the top 100 to 200 mm. This has to be confirmed and consideration given to suitable agronomic practices. Mulches could be used to prevent excess drying of the soil. Crops grown should have substantial root zones exceeding this 200 mm depth from the surface. Crops which give maximum ground cover should be preferred.

10) Subsidence can be very high and can be critical for the economic viability of a project. Estimation of project life should include an estimate of the life of the deposit with respect to WT levels required for the crop as well as the WT levels that can be maintained. Subsidence due to burning can be very substantial. Burning has always been part of the cropping practices in peat areas to release essential soil nutrient. The tropical climate of Malaysia makes accidental burning a common occurrence during the dry period. Extension works as well as legislative alternatives should be considered to minimise accidental burning.

11) A master plan for peatland utilisation at national level is required to ensure a reasonable portion of the peat ecosystem be kept in pristine condition. This masterplan should include areas for conservation, siviculture, ecotourism and agriculture. It should also include future plans for present peat areas which will be depleted of the deposit in future.

8.4 Conclusion

1) The agricultural sector must fully utilise its assets and optimise its production practices. Agronomic, socio-economic, financing and marketing needs have been looked into. It is time that appropriate and adequate water management in crop production be given due attention not only because of the environmental implication but also because it has been shown that its financial viability is very promising.

2) The implications of peat wastage rates on the economic viability of an agricultural project in peat areas must be analysed for the economic duration of the project (say 30 years). Most of the existing cropped peat areas are in shallow and medium peat with depths less than 1 and 2 m respectively. If the subsidence rate in

this area is 30 mm per annum, in 30 years, 900 mm of the soil would be lost. If the depth becomes too shallow, the assumption made in the agricultural development plan at project commencement is no longer valid and the project economic viability may be affected. The problem will further be aggravated if the underlain soil is not suitable for agriculture, such as acid sulphate or sand. New uses, having different economic, social and political implications, may emerge.

3) Undrained virgin peat areas are complete ecosystems in themselves. Draining them, be it for agriculture, industrial purposes or for any others, changes this ecosystem and not necessarily for the better. Generally the changes are irreversible and can have various physical, economic, social and ecological implications. For any new peatland areas to be developed, this must be borne in mind as well as the peat inherent infertility. If and when further reclamation of peatland becomes necessary it should be considered in terms of the total perspective of water and land management, environmental implications as well as the created social implications at the end of the life span of the peat deposit.

4) Technically it is possible either to drain the peatlands and turn them into productive agricultural land or, if need be, to utilised the same technology to maintain wetland status of the area or pockets of the area. If there are other land areas better suited, these peat ecosystems should be left untouched, preserved as a natural living library for scientific research as well as to help stabilised any climatic changes.

5) The total destruction of 2.4 million hectares of peat ecosystem in Malaysia, if drained, is very real. This will have distinct and irreparable consequences on local as well as global climatic factors. The short term economic benefit expected from the drained area must be compared to the long term economic advantages that can be obtained from the area in its existing condition. Such comparisons must include consideration of the environmental and socio-economic problems that can arise and other tangible and intangible benefits from peat swamps in their initial condition. An integrated body comprising of scientists, agronomists, foresters, conservationists, engineers and others must be set up to study and recommend a National Policy and Masterplan for peatland utilisation in the country.

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WATER MANAGEMENT IN DEEP PEAT SOILS IN MALAYSIA

VOLUME 2 - TABLES AND FIGURES

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March 1992

This thesis is submitted in full fulfilment of the requirements for the degree of Doctor of Philosophy.

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TABLE 2.1 General Peat Classification

i. Base on broad outline of ecology

	Nutrition		
Source of water	eutrophic	oligotrophic	source of water and shape of deposit
rock or soil precipitation	fen(a) -	bog or fen(b) bog(c)	topogeneous ombrogeneous

Other equivalent names		
(a)	(b)	(c)
rich fen	poor bog valley bog	moss raised bog or blanket bog

(Kivinen 1977, Anderson 1979 and Clymo 1983)

ii Based on material characteristics

1.Botanical composition			
moss peat	herbaceous peat	woody peat	mixed peat
>75% moss <10% wood	>75 % herbaceous plant <10% wood	<35% wood	any other type/ combination

2.Decomposition		
little	medium	highly
3.Nutritional state		
oligotrophic (infertile)	mesotrophic (intermediate)	eutrophic (fertile)

TABLE 2.2 Peat Classification in Peninsula Malaysia

a. Classification base on loss on ignition

	loss on ignition
organic clay muck peat	20-35% 35-65% >65%

b. Classification base on peat depth

shallow	moderate	deep	very deep
<1.0 m (<3 ft)	1.0-1.5 m (3-5 ft)	1.5-3.0 m (5-10 ft)	>3.0 m (>10 ft)

TABLE 3.1 Return Period of No-rain Days, 1946-1985 (40 years)

Duration of Dry days	Total Number of Occurrence	Occurrence (per Year)	Return Period (months)
3	974	24.35	0.5
5	411	10.28	1.2
7	181	4.53	2.7
9	102	2.55	4.7
12	44	1.10	10.9
15	20	0.5	24.0
18	9	0.23	53.3
21	6	0.15	80.0
24	2	0.05	240.0

Station No 1534104, JKR, Pontian Besar, Analysed by DID, Hydrology, 1989

TABLE 4.1 Depth of Soil Meters

Rod	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
	Depth (mm)					
1	0	0	0	0	0	0
2	50±5	50±5	50±5	50±5	50±5	50±5
3	100±5	100±5	100±5	100±5	100±5	100±5
4	200±5	200±5	200±5	200±5	200±5	200±5
5	500±10	500±10	500±10	500±10	500±10	500±10
6	1000±10	760	1000±10	1000±10	1000±10	1000±10
7	2000±10	1875	2000±10	2000±10	2000±10	2000±10
8	3000±10	2775	3000±10	3000±10	3000±10	3000±10

TABLE 5.1 Gouge auger, soil pit sampling comparison

Gravimetric moisture content %		Dry bulk density Mg m^{-3}	
pit	auger	pit	auger
400.34	199.53	0.17	0.29
584.82	545.95	0.13	0.08
415.27	687.75	0.14	0.07
749.78	1024.36	0.10	0.06
772.05	1181.79	0.11	0.07
945.69	1216.10	0.10	0.08
1063.71	1085.59	0.09	0.09
1073.42	1154.27	0.09	0.07
255.79	244.61	0.22	0.22
369.44	426.09	0.17	0.11
507.40	600.70	0.15	0.11
610.91	544.60	0.12	0.14
769.21	764.55	0.10	0.09
585.18	759.48	0.13	0.10
923.78	961.58	0.10	0.11
954.13	966.52	0.10	0.09
415.28	205.00	0.17	0.21
501.04	451.58	0.14	0.11
683.89	636.03	0.10	0.11
770.80	732.29	0.09	0.11
877.00	851.63	0.09	0.07
1031.65	701.55	0.08	0.10
1002.91	1328.57	0.09	0.07
1071.14	1249.32	0.09	0.06

TABLE 5.2 **Fibre Content, soil pit sample (% of OD weight) - (unrubbed)**

Depth (mm)	Ulu Air Baloi	IPRS	Parit Sikom
0-50	91	49	53
50-150	84	53	30
150-300	91	58	37
300-450	82	66	49
450-600	73	57	48
600-750	73	68	51
750-900	79	67	11
900-1050	80	64	6

TABLE 5.3 **Unrubbed fibre Content, gouge auger, (% vol)**

Depth (mm)	Ulu Air Baloi	IPRS	Parit Sikom
0-50	42	73	60
50-150	44	37	30
150-300	44	35	41
300-450	43	36	53
450-600	44	40	52
600-750	48	42	52
750-900	47	40	49
900-1050	50	44	48

TABLE 5.4 **Rubbed fibre Content, gouge auger, (% volume)**

Depth (mm)	Ulu Air Baloi	IPRS	Parit Sikom
0-50	16	47	33
50-150	17	17	12
150-300	20	13	15
300-450	19	16	24
450-600	21	21	20
600-750	26	20	23
750-900	28	20	20
900-1050	31	22	21

TABLE 5.5 Ash content, *A* (%)

Depth	U Air Baloi	IPRS			Parit Sikom
(mm)	Jul 87	Jul 87	Jan 88	Jul 88	Jul 87
0-50	1.92	-	4.53	4.48	12.62
50-150	1.17	*1.05	1.46	1.65	10.48
150-300	0.70	1.16	1.07	1.57	3.99
300-450	0.62	0.99	0.86	0.98	5.53
450-600	0.92	0.55	1.10	0.89	8.71
600-750	0.49	0.67	0.51	0.59	7.11
750-900	0.49	1.06	0.53	0.57	4.97
900-1050	0.43	0.78	0.40	0.47	4.01

* value for 0-150mm

TABLE 5.6 Sampling day moisture content, θ_m (%)

Depth	UA Baloi	IPRS			P Sikom
(mm)	Jul 87	Jul 87	Jan 88	Jul 88	Jul 87
0-50	431.4	-	231.8	170.2	165.0
50-150	517.9	*558.5	494.2	493.3	310.5
150-300	685.8	751.5	636.3	613.7	688.1
300-450	713.3	852.3	742.7	744.9	993.2
450-600	868.2	955.3	936.0	1106.2	896.4
600-750	1329.0	1222.1	1241.71	1222.2	927.2
750-900	1271.9	1466.0	1268.50	1180.8	1066.1
900-1050	1285.3	1489.7	1302.27	1384.7	1001.9

* value for 0-150mm

TABLE 5.7 Dry bulk density, ρ_d (Mg m^{-3})

Depth	UA Baloi	IPRS			P Sikom
(mm)	Jul 87	Jul 87	Jan 88	Jul 88	Jul 87
0-50	0.129	-	0.095	0.182	0.198
50-150	0.120	*0.099	0.081	0.100	0.185
150-300	0.112	0.097	0.094	0.095	0.086
300-450	0.107	0.095	0.084	0.087	0.082
450-600	0.074	0.083	0.060	0.065	0.083
600-750	0.062	0.066	0.069	0.073	0.080
750-900	0.068	0.058	0.071	0.077	0.074
900-1050	0.065	0.059	0.069	0.064	0.072

* value for 0-150mm

TABLE 5.8 **Specific Gravity/Particle density**

Sample	1	2	3	Average
Plot 1*	1.23	1.25	1.27	1.27
Plot 2	1.37	1.40	1.25	1.34
Plot 3	1.29	1.27	1.28	1.28
Plot 4	1.23	1.30	1.39	1.31
Plot 5	1.39	1.37	1.40	1.39
Plot 6*	1.32	1.29	1.31	1.31
P. Sikom*	1.35	1.36	1.36	1.36
U. A. Baloi*	1.46	1.43	1.44	1.44
Average				1.34

*tests were for 10gm oven-dry soil in 100mls pyctometer.

TABLE 5.9 **Moisture content dry bulk density comparison**

Moist. cont. %	bulk density $Mg\ m^{-3}$	Moist. cont. %	bulk density $Mg\ m^{-3}$	Moist. cont. %	bulk density $Mg\ m^{-3}$
199.53	0.29	244.61	0.22	205.00	0.21
545.95	0.08	426.09	0.11	451.58	0.11
687.75	0.07	600.70	0.11	636.03	0.11
1024.36	0.06	544.60	0.14	732.29	0.11
1181.79	0.07	764.55	0.09	851.63	0.07
1216.10	0.08	759.48	0.10	701.55	0.10
1085.59	0.09	961.58	0.11	1328.57	0.07
1154.27	0.07	966.52	0.09	1249.32	0.06
431.4	0.129	170.2	0.182	165.0	0.198
517.9	0.120	493.3	0.100	310.5	0.185
685.8	0.112	613.7	0.095	688.1	0.086
713.3	0.107	744.9	0.087	993.2	0.082
868.2	0.074	1106.2	0.065	896.4	0.083
1329.0	0.062	1222.2	0.073	927.2	0.080
1271.9	0.068	1180.8	0.077	1066.1	0.074
1285.3	0.065	1384.7	0.064	1001.9	0.072
231.8	0.095	1241.71	0.069	852.3	0.095
494.2	0.081	1268.50	0.071	955.3	0.083
636.3	0.094	1302.27	0.069	1222.1	0.066
742.7	0.084	558.5	0.099	1466.0	0.058
936.0	0.060	751.5	0.097	1489.7	0.059

From Tables 5.1, 5.6 and 5.7

TABLE 5.10 Expected Decrease in Total Volume with drying.

moisture content θ_m (%)	dry bulk density ρ_d (Mg m^{-3})	total volume $V_t = 1+e$	nett volume %	porosity 100 % e/(1+e)
1400	0.064	20.94	100	95.2
1200	0.070	19.14	91.4	94.8
1000	0.077	17.40	83.1	94.3
800	0.087	15.40	73.5	93.5
600	0.102	13.14	62.8	92.4
400	0.128	10.47	50.0	90.4
200	0.188	7.13	34.0	86.0

(the values are estimated from the geometric relationship. Volume of solid = 1 unit volume for G_s=1.34)

TABLE 5.11 Moisture Content, θ_m, at various suctions (IPRS Pontian).

Suction	Average θ_m %			Methods
bar	0-100mm	100-200mm	200-300mm	
0.001	480	587	678	porous
0.002	478	584	671	-do-
0.004	476	577	659	-do-
0.006	474	568	651	-do-
0.008	472	559	644	-do-
0.010	470	551	638	-do-
0.020	451	530	616	-do-
0.040	428	512	594	-do-
0.060	418	501	580	-do-
0.080	409	492	568	-do-
0.1	401	484	555	-do-
0.3	374	453	447	pressure
1.0	266	316	330	-do-
5	226	249	258	-do-
15	214	245	251	-do-
43	153	203	217	vapour
316	26	27	28	-do-
3020	16	15	15	-do-

Note: porous plate -average of 3 estimates
pressure plate -average of 12 estimates
vapour pressure -average of 10 estimates

TABLE 5.12 **Moisture content, θ_m (%), in the field at various days after drainage. (Average of 3 samples, WT=700 mm)**

Depths(mm)	Day 2	Day 3	Day 4	average	*Field Capacity
0-50	193	196	173	187	200
50-100	405	411	367	394	400
100-150	546	514	512	524	500
150-200	651	590	612	665	650
200-250	736	755	620	703	700
250-300	823	773	687	761	750
300-350	850	871	893	870	850
350-400	940	851	1026	939	900
400-450	995	820	1155	990	1000
450-500	895	890	1272	1019	1000
500-550	940	1033	1264	1079	1100
550-600	932	1162	1341	1145	1100
600-650	976	1053	1169	1066	1100
650-700	1036	1057	1203	1099	1100
700-750	**941**	**984**	**1346**	**1090**	**1100**
750-800	**1142**	**1053**	**1459**	**1218**	**1200**

* deduced FC value; figures in bold below water table

TABLE 5.13 **Estimated AWC for IPRS Pontian, at various depth**

Depth (mm)	$\theta_{mAWC} = \theta_{mFC} - \theta_{mPWP}$ (%)	ρ_d (Mg m^{-3})	$\theta_v = \rho_d \theta_{mAWC}$ %	AWC (mm/50mm)
0-50	-	-	-	-
50-100	150	0.1	15.0	7.5
100-150	250	0.09	22.5	11.3
150-200	350	0.08	28.0	14.0
200-250	450	0.07	31.5	15.8
250-300	550	0.06	33.0	16.5
below 300	650	0.08	52.0	26.0
-do-	650	0.06	39.0	19.5
-do-	650	0.04	26.0	13.0

FC as deduced in TABLE 5.12; PWP=250%

TABLE 5.14 Volumetric moisture content at field capacity at various locations

Location	U.A. Baloi			IPRS Pontian			Parit Sikom		
Depth	θ_m %	ρ_d Mg/m^3	θ_v %	θ_m %	ρ_d Mg/m^3	θ_v %	θ_m %	ρ_d Mg/m^3	θ_v %
0-50	400	.13	52	180	.18	32	150	.21	32
50-150	550	.12	66	390	.12	47	330	.145	48
150-300	740	.095	70	630	.095	60	530	.11	58
300-450	900	.085	77	840	.085	71	730	.09	66
450-600	1020	.075	77	1010	.075	76	870	.08	70
600-750	1120	.07	78	1160	.07	81	1000	.075	75
750-900	1200	.065	78	1300	.065	85	1130	.07	79
900-1050	1300	.06	78	1430	.06	86	1250	.065	81

from Figures 5.4 and 5.5

TABLE 5.15 Available water capacity, AWC, at various locations.

Location	U.A. Baloi			IPRS Pontian			Parit Sikom		
Depth	FC -PWP %	ρ_d Mg/m^3	awc θ_v %	FC -PWP %	ρ_d Mg/m^3	awc θ_v %	FC -PWP %	ρ_d Mg/m^3	awc θ_v %
0-50	150	.13	20	-	.18	-	-	.21	-
50-150	300	.12	36	140	.12	17	80	.145	12
150-300	490	.095	47	380	.095	36	280	.11	31
300-450	650	.085	55	590	.085	50	480	.09	43
450-600	650	.075	49	650	.075	49	620	.08	50
600-750	650	.07	46	650	.07	46	650	.075	49
750-900	650	.065	42	650	.065	42	650	.07	46
900-1050	650	.06	39	650	.06	39	650	.065	42

FC from θ_m in TABLE 5.14; PWP=250%

TABLE 5.16 **Moisture Content, θ_v, at the various suctions (IPRS Pontian).**

Suction	Average θ_v					
bar	0-100mm		100-200mm		200-300mm	
	ρ_d	θ_v	ρ_d	θ_v	ρ_d	θ_v
	Mg m^{-3}	%	Mg m^{-3}	%	Mg m^{-3}	%
0.001	0.118	56.6	0.104	61.0	0.096	65.1
0.002	0.118	56.4	0.104	60.7	0.097	65.1
0.004	0.118	56.3	0.105	60.6	0.098	64.6
0.006	0.118	56.2	0.106	60.2	0.098	63.8
0.008	0.119	56.1	0.107	59.8	0.099	63.8
0.010	0.119	55.9	0.108	59.5	0.099	63.2
0.020	0.121	54.6	0.111	58.8	0.101	62.2
0.040	0.124	53.1	0.113	57.9	0.103	61.2
0.060	0.126	52.7	0.115	57.6	0.105	60.9
0.080	0.127	51.9	0.116	57.1	0.106	60.2
0.1	**0.128**	**51.3**	**0.117**	**56.6**	**0.108**	**59.9**
0.3	0.136	50.9	0.121	54.8	0.122	54.5
1.0	0.168	44.7	0.153	48.3	0.149	49.2
5	0.180	**40.7**	**0.173**	**43.1**	**0.171**	**44.1**
15	0.184	**39.4**	**0.175**	**42.9**	**0.173**	**43.4**
43	0.216	33.0	0.187	38.0	0.183	39.7
316	0.316	8.2	0.314	8.5	0.312	8.7
3020	0.347	5.6	0.350	5.3	0.350	5.3
AWC=FC-θ_{v5bar}		10.6		13.5		15.8
AWC=FC-θ_{v15bar}		10.9		13.7		16.5

Note: porous plate, average of 3 estimates
pressure plate, average of 12 estimates
vapour pressure, average of 10 estimates
FC=0.1 bar; PWP=5bar; AWC=FC-PWP

TABLE 5.17 **Frequency f for all K values from IPRS, Pontian, at a value interval of 1 m day^{-1}**

K m day^{-1}	f	K m day^{-1}	f	K m day^{-1}	f
0- 1	0	11-12	2	22-23	0
1- 2	0	12-13	3	23-24	1
2- 3	5	13-14	3	24-25	0
3- 4	3	14-15	2	25-26	1
4- 5	8	15-16	0	26-27	0
5- 6	8	16-17	4	27-28	0
6- 7	4	17-18	0	28-29	0
7- 8	10	18-19	0	29-30	0
8- 9	6	19-20	3	30-31	0
9-10	3	20-21	1	31-32	0
10-11	3	21-22	0	32-33	1

TABLE 5.18 **Frequency f for all K values from IPRS, Pontian, at a value interval of 2 m day^{-1} (rearranging data in TABLE 5.17)**

K m day^{-1}	f	K m day^{-1}	f
0- 2	0	18-20	3
2- 4	8	20-22	1
4- 6	16	22-24	1
6- 8	14	24-26	1
8-10	9	26-28	0
10-12	6	28-30	0
12-14	6	30-32	0
14-16	2	32-34	1
16-18	4		

TABLE 5.19 **Frequency f for K values, Plot 2, IPRS, Pontian**

K m day^{-1}	f	K m day^{-1}	f
0- 1	0	11-12	0
1- 2	0	12-13	0
2- 3	0	13-14	1
3- 4	1	14-15	0
4- 5	1	15-16	1
5- 6	5	16-17	1
6- 7	1	17-18	0
7- 8	0	18-19	0
8- 9	1	19-20	1
9-10	0	>20	1

TABLE 5.20 **Hydraulic conductivity, k, values using auger hole tests for Ulu Air Baloi (UAB) and Parit Sikom (PS).**

K m day^{-1}	location	K m day^{-1}	location
5.4	UAB	2.9	UAB
5.6	UAB	12.8	UAB
2.4	UAB	16.0	UAB
9.6	UAB	9.6	UAB
20.0	UAB	2.3	PS
15.4	UAB	7.0	PS
48.0	UAB	3.7	PS
30.0	UAB		

TABLE 5.21 **Hydraulic conductivity, K, values for clay subsurface (Redzuan, 1987)**

location	K m day^{-1}	depth of casing (m)	comments, soil type
P1	0.0008	6	clay
P2	0.0099	6	clay
P3	0.0010	10	clay
P4	0.0033	6	clay
P5	0.0033	6	clay
P6	0.0023	8	clay
P7	0.0060	5	clay

TABLE 5.22 **Estimates of K (m day^{-1}) using Van der Leur's equation**

	slope q/h	u=0.7 d=2.63	u=0.8 d=2.71	u=0.9 d=2.79	u=1.0 d=2.86
13th Sept 1988					
h_5	0.0752	4.1	4.0	3.9	3.8
h_8	0.0644	3.5	3.4	3.3	3.2
average	0.0698	3.8	3.7	3.6	3.5
27th Sept 1988					
h_5	0.0867	4.7	4.6	4.5	4.3
h_8	0.1149	6.3	6.1	5.9	5.8
average	0.1008	5.5	5.3	5.2	5.0

TABLE 5.23 Drainable Porosity from rainfall and rise in water table levels

Date	rain mm	dh mm	p %
Plot 2			
25.9.88	37.5	86.0	0.44
1.10.88	41.0	137.1	0.30
22.10.88	19.0	62.0	0.31
29.10.88	16.0	47.7	0.34
1.10.88	41.0	149.0	0.28
22.10.88	19.0	52.0	0.37
29.10.88	16.0	76.0	0.49
average for Plot 2			0.36
Plot 4			
1.7.87	32.0	90.0	0.36
21.7.87	28.5	80.0	0.36
8.9.87	35.5	120.0	0.30
26.9.88	55.5	120.0	0.46
26.10.88	39.5	93.0	0.43
27.11.87	93.0	195.0	0.48
9.2.88	21.0	50.0	0.42
12.2.88	34.5	95.0	0.36
12.4.88	29.0	80.0	0.36
18.4.88	67.5	140.0	0.48
9.5.88	21.0	65.0	0.32
4.6.88	34.0	75.0	0.45
27.6.88	39.0	125.0	0.31
28.7.88	40.0	100.0	0.40
19.8.88	32.0	70.0	0.46
average for Plot 4			0.40
Plot 5			
11.11.87	21.5	59.6	0.36
19.11.87	13.0	37.5	0.35
23.11.87	17.0	42.0	0.40
27.11.87	93.0	231.8	0.40
2.3.88	19.5	55.2	0.35
3.3.88	12.5	33.1	0.38
30.4.88	15.0	44.2	0.36
11.7.88	18.0	44.2	0.41
average for Plot 5			0.38
Summary for p value,			
average for Plot 2			0.36
average for Plot 4			0.40
average for Plot 5			0.38
Overall average porosity			0.38

TABLE 5.24 Porosity, p, calculated from drainage tests

	q/h	Kd	tan α	p
13th September 1988				
h_5	0.0752	10.78	0.2937	0.17
h_8	0.0644	9.23	0.2937	0.15
average	0.0698	9.99	0.2937	0.16
27th September 1988				
h_5	0.0867	12.41	0.1808	0.32
h_8	0.1149	16.46	0.1808	0.43
average	0.1008	14.43	0.1808	0.38

TABLE 5.25 Estimated Capillary Fringes

No	WT Depth mm	Sat. $Ø_{ms}$ (@ WT) %	90% of θ_{ms} %	CF @90%θ_{ms} mm	95% of θ_{ms} %	CF @95%θ_{ms} mm
1	600	850	765	230	807	140
2	525	1190	1071	110	1131	75
3	640	1280	1152	250	1216	160
4	760	1340	1206	170	1273	120
5	675	1370	1233	165	1302	100
average				185		119

TABLE 5.26 Average Evaporation from petri dishes, external column and rate of capillary rise

WT depth (approx)	average evaporation for (mm per day) lysimeters No 4, 6 and 14		
mm	E_d	E_c	E_s
0	3.0	42.0	3.0
100	2.6	28.4	2.3
200	2.4	20.2	2.1
300	2.6	19.1	2.1
400	1.8	14.1	1.2
500	2.2	17.2	1.7
600	2.2	16.7	1.4
	lysimeters No 3, 5, 9, 17 and 19		
300	2.8	22.4	3.1
	lysimeters No 7, 10 and 12		
0	3.1	38.8	2.7
300	2.3	24.8	2.0
600	2.2	17.7	1.4
	lysimeters No 2, 8 and 18		
0	3.5	44.3	3.8
300	2.7	19.1	2.1
600	2.6	15.8	1.4
900	2.3	9.5	0.8

TABLE 5.27 **Rate of capillary rise, E_s, with respect to water table as well as relative open water evaporation**

WT depth (approx)	E_s for varying E_d (both in mm per day) lysimeters No 4, 6 and 14				
mm	E_d=1-2	E_d=2-3	E_d=3-4	E_d=4-5	E_d=5-6
0	2.12*	3.93	2.59*	2.36*	3.29*
100	1.97	2.12	2.88	3.30**	-
200	1.81	2.10	2.42	-	-
300	2.65	2.04	2.39*	-	-
400	1.19	1.35	1.34*	-	-
500	1.37	1.95	3.19*	1.99*	2.40*
600	1.24	1.71	-	-	-
	lysimeters No 3, 5, 9, 17 and 19				
300	2.64	3.02	3.22	3.46	3.69*
	lysimeters No 7,10 and 12				
0	1.83	2.74	3.15*	3.04*	4.07**
300	1.69	2.18	2.86*	2.91**	-
600	1.39	1.64	1.61	2.62**	-
	lysimeters No 2, 8 and 18				
0	3.21	2.71*	3.97*	3.96	3.61
300	1.77	2.14	2.41	3.11**	-
600	1.33	1.52	1.61	1.76**	-
900	0.91	0.90	0.73	0.73	-

TABLE 5.28 **Average Rate of Capillary Rise, E_s for varying E_d, both in mm/day (deduced from Figure 5.22b)**

Water Table mm	E_d=1-2	E_d=2-3	E_d=3-4	E_d=4-5
0	3.2	3.6	4.0	4.4
300	1.8	2.1	2.4	2.7
600	1.2	1.4	1.6	1.8
900	0.8	0.9	1.0	1.1

TABLE 5.29 Penetration resistance from cone penetrometer test (N cm^{-2})

Water Table	Penetration Resistance (N cm^{-2}) Maximum		100 mm and below	
mm	before	after	before	after
0	21.0	1.0	17.0	1.0
200(*)	4.9	0.3	4.9	0.3
300	9.5	3.0	9.3	3.0
400	10.0	7.0	10.0	7.0
550(*)	16.2	5.0	16.2	5.0
600	24.0	12.9	24.0	12.9
700(1)	14.0	1.8	14.0	1.8
700(2)	19.5	7.2	15.0	7.2
750	12.5	5.5	12.5	5.5
850	15.3	5.2	15.3	5.2
900(*)	7.3	3.3	7.3	3.3

NB. (*) shows sudden unrestrained sinkage in sinkage plate test.

TABLE 5.30 Consolidation Tests, Basic Soil Data (Specific gravity = 1.34)

Sample Location	Depth mm	ρ_w Mg m^{-3}	ρ_d Mg m^{-3}	θ_m %	Deg. Satn %	Init. Void Ratio	$\theta_v = \rho_d\theta_m$ %
IPRS(Jan)	150	0.85	0.09	853	83	13.9	76.8
IPRS(Feb)	300	0.83	0.13	533	78	9.1	69.3
IPRS(Mar)	150	0.85	0.24	262	75	4.7	62.9
IPRS(Apr)	150	0.91	0.22	305	82	5.0	67.1
IPRS(Sep)	150	0.88	0.17	408	82	6.7	69.4
IPRS(Nov)	150	0.79	0.14	451	72	8.5	63.1
IPRS(Dec)	150	0.79	0.13	495	73	9.1	64.4
PS(May)	150	0.96	0.23	314	89	4.7	72.2
PS(Jun)	300	0.82	0.13	547	76	9.6	71.1
UB(Jul)	150	0.84	0.14	507	78	8.7	71.0
UB(Aug)	300	0.80	0.15	418	73	7.7	62.7
Malacca marine clay	2m to 17m	2.0 to 1.5	1.7 to 0.7	107 to 20	148 to 80	3.1 to 0.5	74.9 34.0

TABLE 5.31 Results of Consolidation Tests

1	2	3	4	5	6	7
Sample Location (depth) (mm)	**Consol Coef. C_v m^2yr^{-1}**	**Coef of Compr m_v $m^2\ MN^{-1}$**	**2ndary Compn Index C_t mm lg min**	**Precon Press P_p kN m^{-2}**	**Precon Void e_p**	**Compn Index C_c**
IPRS(Jan) (0-150)	163.62 to 9.17	19.31 to 5.19	0.14 to 2.10	13.0	12.8	12.12
IPRS(Feb) (150-300)	2531 to 1.54	9.10 to 2.58	0.28 to 2.90	16.0	8.5	4.19
IPRS(Mar) (0-150)	1133 to 1.43	7.89 to 3.07	0.16 to 3.20	18.0	4.3	2.40
IPRS(Apr) (150-300)	815.4 to 1.62	7.35 to 2.44	0.011 to 3.6	24.0	4.35	3.24
PS(May) (0-150)	1735 to 2.04	1.55 to 7.34	0.20 to 1.50	31.0	4.3	1.62
PS(Jun) (150-300)	202.7 to 2.76	12.82 to 2.96	0.13 to 0.27	8.0	9.0	3.42
UB(Jul) (0-150)	131.72 to 1.3	7.57 to 1.87	0.08 to 3.00	28.0	7.8	3.66
UB(Aug) (150-300)	380.79 to 10.70	9.66 to 2.61	0.09 to 2.00	16	7.25	3.55
*IPRS(Sep) (0-150)	307.5 to 36.8	19.8 to 8.3	0.05 to 1.40	22.0	6.15	3.48
*IPRS(Nov) (0-150)	139.70 to 7.31	9.67 to 4.35	0.14 to 1.50	15.0	7.75	4.01
*IPRS(Dec) (0-150)	49.7 to 3.2	11.2 to 3.6	0.13 to 1.80	14.0	8.6	4.40
Range of Pontian peat	**2531 to 1.3**	**19.8 to 1.8**	**3.6 to 0.01**	**31.0 to 8.0**	**12.8 to 4.3**	**12.1 to 1.6**
Malacca marine clay	**35.6 to 0.3**	**2.3 to 0.1**	**-**	**115 to 29**	**2.9 to 0.5**	**1.3 to 0.1**

TABLE 5.32 **Changing Peat Properties on air Drying**

time days	vol ml	vol %	θ_m %	θ_v %	ρ_w Mg m^{-3}	ρ_d Mg m^{-3}
0 to 100 mm depth ρ_{od} = 0.42 Mg m^{-3}						
0	187.0	100.0	508.3	71.3	0.90	0.18
3	168.2	89.0	409.5	66.1	0.82	0.16
8	140.7	75.2	197.7	42.5	0.64	0.21
10	139.0	74.3	179.1	29.7	0.53	0.22
12	129.7	69.4	91.2	22.9	0.50	0.27
15	106.0	56.7	45.3	12.8	0.41	0.28
19	103.2	55.2	24.1	7.6	0.39	0.32
od	76.7	41.0	0	0	-	-
100 to 200 mm depth ρ_{od}=0.38 Mg m^{-3}						
0	186.2	100.0	700.7	75.8	0.87	0.11
3	163.5	87.8	517.1	67.0	0.80	0.13
8	130.7	70.2	284.8	45.3	0.60	0.16
10	128.3	68.9	227.6	38.7	0.56	0.17
12	109.5	58.8	163.0	31.7	0.51	0.19
15	80.7	43.3	56.3	15.1	0.42	0.27
19	80.2	43.1	26.6	7.3	0.35	0.28
od	57.5	30.9	0	0	-	-
200 to 300 mm depth ρ_{od}=0.37 Mg m^{-3}						
0	187.7	100.0	755.1	78.5	0.90	0.12
3	165.2	88.0	594.6	66.2	0.77	0.11
8	125.7	67.0	315.5	50.2	0.66	0.16
10	123.7	65.9	221.8	37.1	0.54	0.17
12	123.3	65.7	191.7	35.3	0.54	0.19
15	81.3	43.3	64.1	14.8	0.38	0.23
19	72.3	38.5	25.3	7.2	0.36	0.28
od	55.9	29.8	0	0	-	-

TABLE 5.33 **Rewetting Potential for Peat Samples at Different Initial Moisture Content and at Different Storage Time**

	Storage days	θ_{mb} %	θ_{ma} %	θ_{vb} %	θ_{va} %	V_b %	V_a %	V_a/V_b %	V_{od} %	ρ_{wb} Mg m^{-3}	ρ_{wa} Mg m^{-3}	ρ_{od} Mg m^{-3}
Batch A	0	524.6	562.4	78.5	82.4	100	102	102	34	0.94	0.97	0.44
	7	475.4	518.8	76.9	80.8	100	103	103	37	0.92	0.96	0.44
fresh	14	460.0	509.3	76.2	83.8	100	101	101	36	0.92	1.00	0.47
samples	28	480.0	526.8	76.2	82.9	100	101	101	37	0.92	0.99	0.44
	56	515.3	562.8	77.3	83.8	100	101	101	35	0.93	0.98	0.43
Batch B	0	160.9	386.0	40.6	78.2	67	84	125	35	0.66	0.99	0.49
	7	159.5	324.2	42.8	75.8	69	80	115	37	0.70	0.99	0.51
air dried	14	172.0	337.5	42.0	79.3	71	75	105	34	0.67	1.03	0.52
for 7 days	28	166.8	320.2	41.0	76.6	70	71	103	34	0.66	1.26	0.51
	56	156.6	287.8	41.0	73.3	73	74	104	37	0.68	0.99	0.52
Batch C	0	16.2	87.4	7.3	39.3	36	43	115	33	0.60	0.85	0.58
	7	17.5	83.1	8.2	37.5	35	38	108	39	0.57	0.83	0.60
oven dried	14	23.5	91.3	1.0	40.5	37	40	108	32	0.61	0.86	0.58
	28	13.6	109.2	6.6	41.3	40	41	105	36	0.56	0.89	0.55
	56	29.6	109.0	2.9	47.1	40	41	102	34	0.58	0.91	0.54

NB: **b- before; a- after**

TABLE 5.34 **Rewetting Potential for Peat Samples at Different Initial Moisture Content only (air dried at 0, 2, 7, 10, 14 days and oven dried at 80°C for 24 hours - storage time=0)**

dried days	θ_{mb} %	θ_{ma} %	θ_{vb} %	θ_{va} %	V_b %	V_a %	V_a/V_b %	V_{od} %	ρ_{wb} Mg m^{-3}	ρ_{wa} Mg m^{-3}	ρ_{od} Mg m^{-3}
0	524.6	562.4	78.5	82.4	100	102	102	34	0.94	0.97	0.44
2	395.2	600.4	70.1	83.3	80	102	128	33	0.88	0.97	0.43
7	160.9	386.0	40.6	78.2	67	84	125	35	0.66	0.99	0.49
10	91.4	345.9	26.2	79.0	52	65	126	34	0.55	1.02	0.44
14	19.9	217.9	7.4	70.1	39	44	114	33	0.42	1.03	0.41
OD	16.2	87.4	7.3	39.3	36	43	115	33	0.60	0.85	0.58

TABLE 5.35 Subsidence results of the soil meter at ground surface

Location	approx WT mm	a mm	b x 10^{-2} mm day^{-1}	corr. coef.	stand. error	subsidence mm yr^{-1}
Plot 1	540	-0.1321	8.3424	0.9365	0.3248	30.4
Plot 2	580	0.0322	6.2337	0.8727	0.3311	22.8
Plot 3	670	0.5240	8.8616	0.9682	0.5874	32.3
Plot 4	470	-0.0413	8.6914	0.9127	0.3700	31.7
Plot 5	620	-0.2137	6.5029	0.9549	0.2910	23.7
Plot 6	780	0.0412	9.6325	0.9694	0.2343	35.2
average			8.044			29.4

Note: assume gradient of land @ 1/300 to estimate WT @ SM. Average water table levels from Tables 5.39 to 5.44

Location	soil meter	monitored OW	averagep WT of mon. OW	location of SM	dist.from mon.OW m	approx WT at SM mm
Plot 1	SM1	OW132	603	C	10	570
Plot 2	SM2	OW242	634	E	15	584
Plot 3	SM3	OW342	739	F	20	672
Plot 4	SM4	OW442	506	M	10	473
Plot 5	SM5	OW542	666	L	15	616
Plot 6	SM6	OW642	848	K	20	781

TABLE 5.36 Subsidence results, over 370 days, from all 6 soil metres

Depth mm/yr	minimum mm/yr	maximum mm/yr	average mm/yr
0	-19.5	-35.0	-27.1
50	-12.0	-27.0	-19.8
100	-11.0	-27.0	-16.9
200	- 8.5	-24.5	-14.8
500	+ 2.0	- 6.5	- 3.5
1000	+ 6.0	- 6.0	- 0.6
2000	+ 5.5	- 5.0	- 0.6
3000	+ 4.5	- 5.0	- 0.5

NB: -ve denote subsidence; +ve denote expansion

TABLE 5.37 Results of land survey of surface level and survey of subsurface area

survey	best fit relationships, z, (MSL-metre)	r^2 %	F	significant at %
subsurface	$3.6168 - 0.0012\,x$	23	7.75	0.9
cassava area, plots 1, 2 and 3				
1984	$6.2452 + 0.0024\,x$	36	21	0.01
1986	$4.6416 + 0.0086\,x - 0.0000053\,x^2$	42	68	0.01
1988	$4.5212 + 0.0088\,x - 0.0000054\,x^2$	93	325	0.01
pineapple area, plots 4, 5 and 6				
1984	$5.5181 + 0.0043\,x$	85	614	0.01
1986	$5.3122 + 0.0043\,x + 0.0000004\,x^2$	94	1993	0.01
1988	$5.2130 + 0.0047\,x + 0.0000006\,x^2$	94	274	0.01

TABLE 5.38 MSL (in metres) of the IPRS plots from 1984 to 1988

	plot	x metre	z MSL-metre	sub-sidence metre	sub-sidence mm/annum
cassava					
1984	1	250	+6.8452	-	-
	2	375	+7.1452	-	-
	3	505	+7.4572	-	-
				1984/1986	**1984/1986**
1986	1	250	+6.4604	0.3848	192.4
	2	375	+7.1213	0.0239	12.0
	3	505	+7.6330	+0.1758	expansion
				1986/1988	**1986/1988**
1988	1	250	+6.3837	0.0767	38.4
	2	375	+7.0618	0.0595	29.8
	3	505	+7.5881	0.0449	22.5
pineapple					
1984	4	250	+6.5931	-	-
	5	375	+7.1306	-	-
	6	505	+7.6896	-	-
				1984/1986	**1984/1986**
1986	4	250	+6.4122	0.1809	90.5
	5	375	+6.9810	0.1496	74.8
	6	505	+7.5857	0.1039	52.0
				1986/1988	**1986/1988**
1988	4	250	+6.3505	0.0617	30.9
	5	375	+6.8911	0.0899	45.0
	6	505	+7.4333	0.1524	76.2

TABLE 5.39 Water Table Reading (cm) @ Plot 1

	Observation Well Number					
	122	123	126	129	1212	1213
Minimum	40.8	52.7	41.3	56.2	56.1	59.3
Maximum	84.9	91.6	85.5	99.2	94.9	99.5
Mean	63.3	72.2	66.0	81.2	79.4	79.6
Standard Deviation	10.6	9.37	11.0	11.5	10.2	10.1
Variance	110.2	86.1	117.9	128.8	101.7	99.8
Skewness	0.129	0.002	0.698	0.929	1.160	0.007
Kurtosis	0.832	0.787	0.820	0.847	0.845	0.839

	Observation Well Number					
	132	133	136	139	1312	1313
Minimum	42.7	50.4	40.5	47.7	43.1	51.0
Maximum	85.8	93.7	80.3	93.9	87.5	87.9
Mean	60.3	68.6	61.9	76.7	70.7	70.6
Standard Deviation	13.4	10.3	9.0	9.8	10.7	9.4
Variance	176.2	103.3	79.3	93.7	112.9	86.4
Skewness	-0.889	-1.012	0.486	1.807	1.515	0.393
Kurtosis	0.861	0.824	0.782	0.780	0.856	0.834

	Observation Well Number				
	143	146	149	1412	1413
Minimum	41.5	40.8	48.4	49.0	48.2
Maximum	87.3	82.6	96.6	97.0	91.3
Mean	56.8	59.9	80.4	79.5	72.6
Standard Deviation	12.2	11.6	9.7	11.21	9.5
Variance	146.1	131.6	91.4	123.1	88.2
Skewness	-1.870	-0.452	2.466	1.725	0.891
Kurtosis	0.801	0.815	0.734	0.850	0.831

TABLE 5.40 Water Table Reading (cm) @ Plot 2

	Observation Well Number					
	222	225	228	2211	232	235
Minimum	53.1	47.4	63.3	41.7	61.8	58.3
Maximum	90.4	88.2	100.2	91.7	100.3	94.1
Mean	70.6	67.8	81.8	60.5	80.2	76.5
Standard Deviation	9.2	11.1	10.8	11.7	10.4	10.2
Variance	82.7	121.3	113.8	133.7	106.3	101.3
Skewness	-0.373	0.001	0.002	-1.593	-0.225	0.007
Kurtosis	0.834	0.847	0.854	0.819	0.845	0.851

	Observation Well Number					
	238	2311	242	245	248	2411
Minimum	58.2	40.8	35.4	60.4	53.9	51.1
Maximum	95.7	85.9	90.0	100.3	91.8	90.7
Mean	75.4	61.2	63.4	80.7	71.8	67.5
Standard Deviation	11.0	10.4	12.2	12.3	12.2	11.2
Variance	119.4	106.3	146.0	147.1	145.9	122.8
Skewness	-0.418	-0.614	0.171	0.008	-0.261	-0.901
Kurtosis	0.855	0.825	0.829	0.839	0.878	0.870

TABLE 5.41 **Water Table Reading (cm) @ Plot 3**

	Observation Well Number				
	322	325	328	332	335
Minimum	58.9	72.1	59.0	53.6	75.9
Maximum	95.7	100.7	86.7	86.3	107.3
Mean	77.0	86.6	72.2	70.1	95.20
Standard Deviation	8.34	6.5	7.9	8.0	6.6
Variance	68.2	41.5	61.0	62.1	42.9
Skewness	-0.119	0.008	-0.253	0.005	1.644
Kurtosis	0.819	0.825	0.879	0.810	0.779

	Observation Well Number			
	338	342	345	348
Minimum	44.6	59.8	61.2	56.4
Maximum	93.1	91.9	84.7	94.6
Mean	62.1	73.9	72.0	73.2
Standard Deviation	9.2	7.6	5.6	9.4
Variance	83.1	57.0	30.8	87.3
Skewness	-2.235	-0.761	-0.498	-0.724
Kurtosis	0.795	0.810	0.826	0.834

TABLE 5.42 Water Table Reading (cm) @ Plot 4

	Observation Well Number					
	422	424	429	4214	4219	4221
Minimum	23.0	47.5	63.6	60.2	53.5	49.4
Maximum	64.1	81.7	84.8	91.2	88.2	81.2
Mean	43.5	66.1	73.2	76.6	71.8	66.0
Standard Deviation	10.3	7.3	5.7	7.7	8.7	8.5
Variance	104.1	51.6	31.5	58.6	75.0	70.6
Skewness	-1.725	0.600	-0.524	0.342	0.318	0.238
Kurtosis	0.833	0.808	0.817	0.815	0.807	0.802

	Observation Well Number					
	432	434	439	4314	4319	4321
Minimum	41.7	50.3	42.8	57.9	47.4	51.5
Maximum	78.5	76.0	73.8	85.3	78.1	80.5
Mean	59.2	61.5	60.5	71.6	61.6	68.3
Standard Deviation	10.0	6.8	6.7	7.2	7.8	7.4
Variance	98.4	45.9	44.6	50.4	59.3	54.2
Skewness	-0.249	-0.734	0.987	0.001	-0.453	0.936
Kurtosis	0.848	0.816	0.782	0.828	0.820	0.786

	Observation Well Number					
	442	444	449	4414	4419	4421
Minimum	35.1	38.0	46.9	55.3	46.2	48.8
Maximum	70.7	70.1	75.7	83.4	70.2	77.2
Mean	50.6	51.7	57.3	70.1	59.0	64.6
Standard Deviation	8.7	7.5	6.9	6.9	6.6	7.1
Variance	75.0	54.5	47.1	47.2	43.3	50.1
Skewness	-0.817	-0.954	-1.718	0.303	0.379	0.668
Kurtosis	0.833	0.809	0.834	0.822	0.800	0.816

TABLE 5.43 Water Table Reading (cm) @ Plot 5

	Observation Well Number					
	522	525	528	5211	532	535
Minimum	41.1	54.6	51.7	58.2	55.4	49.7
Maximum	77.5	92.9	94.2	96.0	91.9	88.9
Mean	57.3	72.1	71.6	74.0	71.9	66.3
Standard Deviation	10.3	11.6	12.6	9.6	10.1	11.5
Variance	103.2	132.9	154.9	89.9	99.1	129.1
Skewness	-0.587	-0.433	-0.331	-0.963	-0.512	-0.781
Kurtosis	0.862	0.862	0.843	0.829	0.839	0.839

	Observation Well Number					
	538	5311	542	545	548	5411
Minimum	46.1	57.5	49.7	50.4	69.1	58.6
Maximum	90.9	96.2	84.7	85.9	108.6	97.9
Mean	64.9	73.7	66.6	65.2	85.7	74.6
Standard Deviation	11.4	11.0	9.3	9.7	11.6	11.0
Variance	127.8	118.8	85.4	91.4	131.0	117.6
Skewness	-0.931	-0.866	-0.192	-0.920	-0.804	-1.006
Kurtosis	0.849	0.832	0.854	0.834	0.859	0.845

TABLE 5.44 Water Table Reading (cm) @ Plot 6

	Observation Well Number				
	622	625	628	632	635
Minimum	41.7	66.0	55.1	65.0	62.2
Maximum	76.0	89.1	76.1	95.7	88.8
Mean	56.8	77.5	66.5	78.7	72.9
Standard Deviation	8.9	5.6	5.0	8.4	5.8
Variance	78.2	30.4	24.6	69.6	32.6
Skewness	-0.692	-0.002	0.566	-0.592	-1.349
Kurtosis	0.832	0.826	0.820	0.833	0.800

	Observation Well Number			
	638	642	645	648
Minimum	70.1	66.9	69.8	72.0
Maximum	91.3	104.9	94.1	95.6
Mean	80.9	84.8	79.4	83.7
Standard Deviation	5.6	8.6	5.2	6.9
Variance	30.9	72.6	26.7	46.7
Skewness	0.100	-0.374	-1.472	-0.004
Kurtosis	0.839	0.811	0.785	0.845

TABLE 5.45 SEG values estimated from Weekly WT reading for Plot 1 (mm)

Plot 1

Obs Well	No of occur	SEG30 (mm)	No of occur	SEG60 (mm)	No of occur	SEG90 (mm)
122	0	0	19	1392	42	11801
123	0	0	6	292	41	7966
126	0	0	14	1078	42	10503
129	0	0	4	85	30	4437
1212	0	0	3	81	39	5097
1213	0	0	1	7	39	5153
132	0	0	31	2613	42	13334
133	0	0	7	376	41	9688
136	0	0	18	1308	42	12183
139	0	0	4	223	40	6094
1312	0	0	9	490	42	8672
1313	0	0	5	293	42	8782
143	0	0	32	3323	42	14809
146	0	0	29	2280	42	13179
149	0	0	3	188	40	4615
1412	0	0	2	123	33	5102
1413	0	0	3	203	41	7930
Ave/OW	0	0	11.2	84.4	40.0	878.5

TABLE 5.46 SEG values estimated from Weekly WT reading for Plot 2

Plot2

Obs Well	No of occur	SEG30 (mm)	No of occur	SEG60 (mm)	No of occur	SEG90 (mm)
222	0	0	5	208	41	8600
225	0	0	12	747	42	10062
228	0	0	0	0	32	4550
2211	0	0	26	2198	41	13283
232	0	0	0	0	34	4951
235	0	0	3	34	40	6243
238	0	0	2	34	39	6832
2311	0	0	22	1786	42	12956
242	1	14	22	1664	41	12104
245	0	0.0	0	0	33	5203
248	0	0.0	7	226	41	8619
2411	0	0.0	12	526	42	10298
Ave/OW	0	0	9.3	61.9	39.0	864.2

TABLE 5.47 SEG values estimated from Weekly WT reading for Plot 3

Plot3

Obs Well	No of occur	SEG30 (mm)	No of occur	SEG60 (mm)	No of occur	SEG90 (mm)
322	0	0	1	11	40	5987
325	0	0	0	0	29	2191
328	0	0	3	17	42	7997
332	0	0	7	272	42	8807
335	0	0	0	0	8	465
338	0	0	20	1347	42	12419
342	0	0	2	3	42	7287
345	0	0	0	0	42	7908
348	0	0	3	64	41	7830
Ave/OW	0	0	4.0	19.0	36.4	676.6

TABLE 5.48 SEG values estimated from Weekly WT reading for Plot 4

Plot 4

Obs Well	No of occur	SEG30 (mm)	No of occur	SEG60 (mm)	No of occur	SEG90 (mm)
422	5	186	48	8311	50	23249
424	0	0	9	424	50	11956
429	0	0	0	0	50	8391
4214	0	0	0	0	48	6734
4219	0	0	7	236	50	9116
4221	0	0	11	688	50	12020
432	0	0	27	2331	50	15383
434	0	0	20	1057	50	14260
439	0	0	22	1204	50	14740
4314	0	0	3	44	50	9198
4319	0	0	19	1248	50	14197
4321	0	0	9	305	50	10840
442	0	0	44	5057	50	19722
444	0	0	42	4454	50	19153
449	0	0	32	2187	50	16326
4414	0	0	3	97	50	9969
4419	0	0	24	1552	50	15480
4421	0	0	14	660	50	12702
Ave/OW	0	0	18.6	165.9	49.9	1352.4

TABLE 5.49 SEG values estimated from Weekly WT reading for Plot 5

Plot 5

Obs Well	No of occur	SEG30 (mm)	No of occur	SEG60 (mm)	No of occur	SEG90 (mm)
522	0	0	29	2884	49	16019
525	0	0	8	265	46	8841
528	0	0	9	477	45	9121
5211	0	0	3	35	46	7925
532	0	0	7	234	47	8875
535	0	0	18	923	49	11612
538	0	0	20	1119	48	12293
5311	0	0	5	74	43	8177
542	0	0	13	679	49	11481
545	0	0	18	802	49	12149
548	0	0	0	0	33	3775
5411	0	0	1	14	44	7762
Ave/OW	0	0	10.9	62.6	45.7	983.6

TABLE 5.50 SEG values estimated from Weekly WT reading for Plot 6

Plot 6

Obs Well	No of occur	SEG30 (mm)	No of occur	SEG60 (mm)	No of occur	SEG90 (mm)
622	0	0	30	2735	49	16279
625	0	0	0	0	49	6105
628	0	0	7	112	49	11495
632	0	0	0	0	44	5731
635	0	0	0	0	49	8372
638	0	0	0	0	46	4496
642	0	0	0	0	35	3266
645	0	0	0	0	48	5258
648	0	0	0	0	35	3418
Ave/OW	0	0	4.1	31.6	44.9	715.8

TABLE 5.51 **Summary of Water Table Readings from TABLES 5.39 to 5.44**

location	minimum mm	maximum mm	range of mean mm	average of mean mm	design WT mm
Plot 1	408	992	633 to 812	706	300
Plot 2	354	1003	605 to 818	715	600
Plot 3	446	1073	621 to 952	758	900
Plot 4	230	912	435 to 766	630	300
Plot 5	411	1086	573 to 857	703	600
Plot 6	417	1049	568 to 848	757	900

TABLE 5.52 **Summary of average SEG values from TABLES 5.45 to 5.50**

location	SEG30 total no occur	SEG60 no occur per OW	Average per OW mm	SEG90 no occur per OW	Average per OW mm
Plot 1	0	11.2	84.4	40.0	878.5
Plot 2	1	9.3	61.9	39.0	864.2
Plot 3	0	4.0	19.0	36.4	676.6
Plot 4	5	18.6	165.9	49.9	1352.4
Plot 5	0	10.9	62.6	45.7	983.6
Plot 6	0	4.1	31.6	44.9	715.8

TABLE 5.53 Cassava Yield Parameters

OW	Plant Number	Plant Height (metre)	Root Weight (kg)	Stem Weight (kg)	Starch Content (%)
122	14	2.41	3.32	2.27	30.1
123	16	1.90	2.92	1.33	29.9
126	12	2.52	4.01	2.70	32.6
129	16	2.37	3.53	2.19	30.1
1212	16	2.53	4.44	2.20	28.5
1213	13	2.04	2.53	1.19	28.0
132	14	1.86	3.34	1.69	27.0
133	14	1.94	3.34	1.35	28.3
136	13	2.26	4.51	2.22	29.9
139	14	1.91	3.54	1.77	31.1
1312	14	2.70	4.35	2.53	29.1
1313	8	2.03	3.11	1.73	29.1
143	14	2.22	3.68	1.89	24.1
146	15	2.24	4.10	1.72	26.3
149	14	2.28	4.24	1.99	27.0
1412	15	2.23	3.67	1.64	30.8
1413	15	1.75	2.65	1.37	25.0
222	11	2.22	3.45	1.56	32.7
225	11	1.66	2.69	1.04	31.5
228	11	2.06	3.47	1.70	30.5
2211	13	1.80	2.75	0.96	32.6
232	15	2.06	3.42	1.50	25.4
235	12	1.74	2.27	0.83	27.3
238	12	2.02	3.22	1.42	27.1
2311	14	2.15	3.63	1.40	27.5
242	14	1.83	2.97	1.11	32.5
245	15	2.32	3.86	2.00	33.0
248	13	1.91	3.12	1.39	31.5
2411	12	2.10	1.47	1.47	32.5
322	10	2.03	3.69	1.51	33.5
325	7	1.63	2.88	0.88	31.0
328	11	1.74	2.98	1.11	29.6
332	14	1.71	3.69	1.33	31.4
335	7	1.48	2.18	1.06	29.5
338	10	1.54	3.75	1.54	29.5
342	14	2.61	5.43	2.34	30.2
345	10	1.61	2.23	1.03	28.8
348	7	1.10	1.92	0.82	28.7
min -	-	1.1	1.47	0.82	24.1
max -	-	2.7	5.43	2.70	33.5
mean -	-	2.01	3.322	1.573	29.55
std dev -	-	0.34	0.785	0.486	2.36

TABLE 5.54 **Cassava Yield and Water Table Parameters.**

	OW	Freq.of Occur.	SEG60 (cm week)	Average WT (mm)	Harvest Index	Starch Yield kg
	122	19	1392	633	0.59	1.00
	123	6	292	722	0.69	0.87
	126	14	1078	660	0.60	1.31
	129	4	85	812	0.62	1.06
	1212	3	81	794	0.67	1.27
	1213	1	07	796	0.68	0.71
	132	34	2613	603	0.66	0.90
	133	7	376	686	0.71	0.95
	136	20	1308	619	0.67	1.35
	139	4	223	767	0.67	1.10
	1312	8	490	707	0.63	1.26
	1313	5	293	706	0.64	0.91
	143	34	3323	568	0.66	0.89
	146	31	2280	599	0.70	1.08
	149	3	188	804	0.68	1.15
	1412	2	123	795	0.69	1.13
	1413	3	203	726	0.66	0.66
	222	5	208	706	0.69	1.13
	225	11	747	678	0.72	0.85
	228	0	0	818	0.67	1.06
	2211	27	2198	605	0.74	0.90
	232	0	0	802	0.69	0.87
	235	3	34	765	0.73	0.62
	238	2	34	754	0.69	0.87
	2311	23	1786	612	0.72	1.00
	242	22	1664	634	0.73	0.96
	245	0	0	807	0.66	1.27
	248	7	226	718	0.69	0.98
	2411	13	526	675	0.50	0.48
	322	1	11	770	0.71	1.24
	325	0	0	866	0.77	0.89
	328	3	17	722	0.73	0.88
	332	7	272	701	0.74	1.16
	335	0	0	952	0.67	0.64
	338	21	1347	621	0.71	1.11
	342	2	3	739	0.70	1.64
	345	0	0	720	0.68	0.64
	348	3	64	732	0.70	0.55
min	-	-	0	547	0.5	0.48
max	-	-	3323	944	0.77	1.64
mean	-	-	618.2	706.8	0.681	0.982
std dev	-	-	864.9	86.2	0.049	0.245

TABLE 5.55 Cassava Yield and SEG60 Statistical Relations

	Plant Height	Root Weight	Stem Weight	Starch Content	Harvest Index	Starch Yield
Linear regression						
r	0.040	0.099	0.090	-0.252	-0.010	-0.010
e	2.091	3.465	1.674	30.585	0.692	1.048
Two Degree Polynomial regression						
r	0.040	0.099	0.126	0.526	0.105	0.147
e	0.351	0.820	0.503	2.079	0.052	0.251
Third Degree Polynomial regression						
r	0.131	0.102	0.294	0.527	0.422	0.149
e	0.355	0.834	0.493	2.114	0.048	0.256
Geometric regression						
r	0.012	0.030	0.138	0.074	0.173	0.008
e	0.182	0.262	0.312	0.083	0.080	0.269
Exponential regression						
r	0.062	0.130	0.103	0.272	0.010	0.045
e	0.182	0.260	0.313	0.080	0.081	0.270

TABLE 5.56 Cassava Yield and Average WT Statistical Relations

	Plant Height	Root Weight	Stem Weight	Starch Content	Harvest Index	Starch Yield
Linear regression						
r	-0.096	-0.132	-0.138	0.093	0.073	-0.081
e	2.351	4.339	2.230	28.143	0.660	1.194
Two Degree Polynomial regression						
r	0.170	0.146	0.156	0.195	0.081	0.155
e	0.346	0.799	0.494	2.380	0.050	0.249
Third Degree Polynomial regression						
r	0.326	0.338	0.230	0.377	0.151	0.239
e	0.337	0.771	0.493	2.279	0.050	0.248
Geometric regression						
r	0.099	0.132	0.147	0.119	0.077	0.094
e	0.181	0.257	0.315	0.082	0.077	0.268
Exponential regression						
r	0.107	0.134	0.151	0.105	0.081	0.100
e	0.181	0.257	0.315	0.082	0.077	0.268

TABLE 5.57 **Pineapple Yield Parameters**

OW	Plant Number	Weight (kg)	Length (mm)	Diam (mm)	Sugar Content °Brix	Citric Acid (%)
422	16	1.28	191	114	14.0	0.53
424	11	1.30	192	118	13.9	0.55
429	11	1.19	187	113	15.0	0.61
4214	12	1.54	211	121	12.3	0.58
4219	10	1.22	189	115	12.3	0.53
4221	13	1.17	177	111	13.5	0.57
432	11	1.36	203	117	13.3	0.51
434	12	1.41	201	119	13.2	0.53
439	10	1.44	203	120	12.7	0.50
4314	11	1.33	196	114	13.1	0.52
4319	12	1.48	205	121	14.0	0.54
4321	10	1.54	206	122	13.5	0.55
442	15	1.32	197	117	14.9	0.61
444	15	1.30	191	119	14.5	0.64
449	11	1.43	204	120	14.0	0.45
4414	13	1.48	206	119	13.0	0.52
4419	14	1.39	200	117	14.2	0.60
4421	13	1.43	201	115	13.8	0.60
522	16	1.53	207	121	13.0	0.46
525	16	1.53	202	120	13.1	0.46
528	17	1.41	198	117	13.3	0.47
5211	12	1.36	189	115	13.5	0.53
532	14	1.37	198	116	14.2	0.57
535	15	1.39	198	116	13.7	0.48
538	12	1.37	187	115	13.0	0.48
5311	15	1.36	193	115	13.7	0.57
542	13	1.46	201	118	13.4	0.46
545	13	1.44	193	119	12.6	0.45
548	11	1.38	194	116	13.7	0.48
5411	11	1.40	192	117	13.6	0.54
622	16	1.48	197	119	13.4	0.49
625	13	1.40	196	117	12.4	0.43
628	13	1.11	174	111	13.8	0.60
632	15	1.31	181	113	13.7	0.47
635	16	1.37	193	116	12.3	0.47
638	16	1.30	186	115	13.6	0.53
642	15	1.43	194	118	12.9	0.46
645	16	1.53	202	120	13.4	0.48
648	17	1.27	181	118	13.4	0.52
min -	-	1.11	174	111	12.3	0.43
max -	-	1.54	211	122	15.0	0.64
mean -	-	1.380	195.3	117.0	13.46	0.522
std dev -	-	0.103	8.5	2.7	0.65	0.054

TABLE 5.58 **Pineapple Yield and Water Table Parameters.**

	OW	Freq.of Occur.	SEG60 (mm week)	Average Wt (mm)
	422	48	8311	435
	424	9	424	661
	429	0	0	732
	4214	0	0	766
	4219	7	236	718
	4221	11	688	660
	432	27	2331	592
	434	20	1057	615
	439	22	1204	605
	4314	3	44	716
	4319	19	1248	616
	4321	9	305	683
	442	44	5057	506
	444	42	4454	517
	449	32	2187	573
	4414	3	97	701
	4419	24	1552	590
	4421	14	660	646
	522	29	2884	573
	525	8	265	721
	528	9	477	716
	5211	3	35	740
	532	7	234	719
	535	18	923	663
	538	20	1119	649
	5311	5	74	737
	542	13	679	666
	545	18	802	652
	548	0	0	857
	5411	1	14	746
	622	30	2735	568
	625	0	0	775
	628	7	112	665
	632	0	0	787
	635	0	0	729
	638	0	0	809
	642	0	0	848
	645	0	0	794
	648	0	0	837
min	-	-	0	435
max	-	-	8311	857
mean	-	-	1031.0	679.1
std dev	-	-	1704.5	93.3

TABLE 5.59 Pineapple Yield and SEG60 Statistical Relations

	Weight	Length	Diam	Sugar Content	Citric Acid
Linear regression					
r	-0.109	0.035	0.053	0.434	0.137
e	1.419	199.663	119.134	13.585	0.534
Two Degree Polynomial regression					
r	0.304	0.326	0.450	0.440	0.159
e	0.101	7.927	2.583	0.536	0.054
Third Degree Polynomial regression					
r	0.378	0.383	0.460	0.554	0.514
e	0.100	7.899	2.618	0.507	0.048
Geometric regression					
r	0.092	0.233	0.283	0.267	0.070
e	0.078	0.042	0.023	0.042	0.101
Exponential regression					
r	0.099	0.040	0.054	0.425	0.125
e	0.078	0.043	0.024	0.039	0.101

TABLE 5.60 Pineapple Yield and Average WT Statistical Relations

	Weight	Length	Diam	Sugar Content	Citric Acid
Linear regression					
r	0.013	-0.221	-0.130	-0.334	-0.263
e	1.392	211.385	121.125	15.201	0.633
Two Degree Polynomial regression					
r	0.129	0.277	0.136	0.392	0.264
e	0.105	8.350	2.778	0.614	0.054
Third Degree Polynomial regression					
r	0.212	0.311	0.354	0.395	0.283
e	0.105	8.376	2.659	0.621	0.054
Geometric regression					
r	0.026	0.202	0.123	0.348	0.252
e	0.078	0.044	0.023	0.046	0.101
Exponential regression					
r	0.013	0.221	0.130	0.331	0.255
e	0.078	0.043	0.023	0.046	0.101

TABLE 5.61 Summary of average yield per plant (from Tables 5.53, 5.54 and 5.57

Cassava Yield

	Plant Height (m)	Root Weight (kg)	Stem Weight (kg)	Starch Content (%)	Harvest Index	Starch Yield (kg)
Plot 1	2.188	3.605	1.869	28.641	0.660	1.035
Plot 2	1.989	3.027	1.365	30.342	0.686	0.916
Plot 3	1.717	3.194	1.291	30.244	0.712	0.972

Pineapple Yield

	Weight (kg)	Length (mm)	Diam Content (mm)	Sugar Acid (°Brix)	Citric (%)
Plot 4	1.367	197.8	117.3	13.62	0.552
Plot 5	1.417	196.0	117.1	13.40	0.496
Plot 6	1.356	189.3	116.3	13.21	0.494

TABLE 5.62 Results of Pineapple Gradings

	Plot 4 (300 mm)		Plot 5 (600 mm)		Plot 6 (900 mm)	
Grade	No of Fruits	% of Total	No of Fruits	% of Total	No of Fruits	% of Total
A	626	27.49	2419	60.42	880	39.28
B	1036	45.49	1127	28.15	715	31.91
C	615	27.00	457	11.41	645	28.79
Total	2277		4003		2240	

TABLE 6.1 **Basic Data for Young's Water-Table Modelling**

WATER TABLE MODEL FOR FLAT DITCH DRAINED LAND

DITCH SPACING (m)	800.0
DEPTH TO IMPERMEABLE LAYER (m)	4.30
GEOMETRICAL FACTOR FOR DITCH SYSTEM	1.00
INITIAL WATER TABLE DEPTH (m)	0.34
HYDRAULIC CONDUCTIVITY OF THE TOPSOIL (m/d)	5.50
HYDRAULIC CONDUCTIVITY OF THE SUBSOIL (m/d)	5.50
SOIL BOUNDARY DEPTH (m)	0.10
SPECIFIC YIELD (m/m)	0.38
UNSATURATED HYDRAULIC CONDUCTIVITY EXPONENT	6.40
DEPTH FROM SURFACE TO DITCH SPACING (m)	3.00
SET DITCH WATER LEVELS? (YES/NO)	N
IS THERE IRRIGATION? (YES/NO)	N
TIDAL DITCH LEVELS? (YES/NO)	N

TABLE 6.2 **Actual Rainfall, Evaporation and Ditch water levels (Stn.No. 1632201; from 1.5.89 to 17.7.89; Ditch WT measured from ditch bottom)**

D	R (mm)	E (mm)	.WT (m)	D	R (mm)	E (mm)	.WT (m)
1	0.0	3.5	0.4404	40	16.0	3.5	0.3185
2	15.5	5.0	0.5776	41	0.0	5.0	0.3490
3	17.0	5.0	0.5319	42	0.0	4.5	0.3642
4	0.0	2.0	0.5776	43	0.0	4.0	0.3490
5	0.0	2.0	0.6233	44	0.0	4.5	0.3490
6	0.0	1.5	0.5623	45	27.0	6.0	0.3490
7	0.0	5.0	0.5014	46	0.0	3.0	0.3794
8	0.0	4.0	0.5318	47	0.0	5.0	0.3794
9	0.0	3.5	0.5014	48	0.0	5.0	0.3794
10	0.0	4.0	0.5319	49	0.0	5.0	0.3794
11	0.0	3.0	0.4710	50	6.0	3.0	0.3794
12	27.5	8.5	0.4557	51	0.0	3.5	0.3794
13	2.5	2.5	0.7300	52	25.5	5.5	0.3794
14	0.0	3.0	0.7757	53	0.0	6.0	0.3794
15	6.0	6.0	0.8367	54	35.8	6.0	0.3794
16	0.0	2.0	0.8062	55	0.0	3.0	0.4862
17	0.0	4.0	0.6233	56	0.0	4.0	0.4404
18	6.0	3.0	0.5471	57	0.0	3.0	0.4709
19	0.0	4.0	0.5319	58	3.5	5.5	0.4557
20	0.0	1.5	0.5624	59	5.5	2.5	0.3947
21	0.0	4.0	0.5471	60	0.0	5.5	0.4100
22	53.50	3.0	0.5319	61	0.0	5.0	0.4100
23	0.0	5.0	0.5624	62	0.0	3.5	0.3947
24	34.0	8.0	0.5624	63	0.0	5.0	0.3947
25	0.0	2.0	0.6233	64	0.0	3.0	0.3947
26	0.0	3.0	0.5472	65	8.8	5.0	0.3947
27	0.0	4.5	0.4862	66	9.0	2.5	0.3947
28	0.0	4.0	0.4709	67	10.0	3.0	0.3947
29	0.0	4.0	0.4252	68	0.0	5.0	0.3947
30	0.0	3.0	0.4100	69	0.0	3.0	0.3847
31	0.0	3.0	0.4100	70	52.0	3.0	0.3947
32	0.0	4.0	0.5319	71	0.0	1.5	0.4252
33	6.0	4.0	0.5471	72	0.0	4.0	0.4100
34	0.0	4.5	0.6386	73	0.0	4.0	0.4100
35	0.0	3.5	0.3795	74	15.5	3.5	0.4100
36	0.0	4.0	0.3642	75	0.0	2.0	0.5624
37	0.0	5.5	0.3642	76	8.4	4.5	0.5319
38	0.0	3.0	0.3490	77	0.0	4.5	0.5014
39	4.8	5.0	0.3185	78	2.0	2.0	0.3947

TABLE 6.3 **Actual mid-field water-table levels (measured from ditch base from 1.5.89 to 17.7.89; Day 1 = 1.5.89)**

D	WT (m)	D	WT (m)
1	2.6609	40	2.6243
2	2.6670	41	2.5969
3	2.7371	42	2.5969
4	2.7249	43	2.8499
5	2.7005	44	2.8378
6	2.7005	45	2.8255
7	2.7920	46	2.7249
8	2.7493	47	2.7127
9	2.7005	48	2.7005
10	2.7249	49	2.6853
11	2.7249	50	2.6731
12	2.7249	51	2.6609
13	2.8773	52	2.6609
14	2.8133	53	2.6487
15	2.7889	54	2.6609
16	2.7737	55	2.7767
17	2.7615	56	2.7615
18	2.7371	57	2.7493
19	2.7249	58	2.7249
20	2.7249	59	2.6853
21	2.7371	60	2.6609
22	2.7249	61	2.6609
23	2.7249	62	2.6609
24	2.7249	63	2.6609
25	2.7493	64	2.6487
26	2.7005	65	2.6365
27	2.7005	66	2.6365
28	2.6853	67	2.6243
29	2.6731	68	2.6091
30	2.6365	69	2.6548
31	2.6365	70	2.6487
32	2.6243	71	2.6670
33	2.6121	72	2.6365
34	2.5451	73	2.6487
35	2.6731	74	2.6365
36	2.6609	75	2.7615
37	2.6487	76	2.6822
38	2.6487	77	2.7005
39	2.6365	78	2.6304

TABLE 6.4 **Simulated Rainfall, Evaporation Values and Ditch water levels (from 1.5.89 to 17.7.89, ie Day 1 = 1.5.89)**

D	R (mm)	E (mm)	.WT (m)	D	R (mm)	E (mm)	.WT (m)
1	0.0	3.5	0.4404	40	16.0	3.5	0.3185
2	15.5	5.0	0.5776	41	0.0	5.0	0.3490
3	17.0	5.0	0.5319	42	0.0	4.5	0.3642
4	0.0	2.0	0.5776	43	0.0	4.0	0.3490
5	0.0	2.0	0.6233	44	0.0	4.5	0.3490
6	0.0	1.5	0.5623	45	27.0	6.0	0.3490
7	0.0	5.0	0.5014	46	0.0	3.0	0.3794
8	0.0	4.0	0.5318	47	0.0	5.0	0.3794
9	0.0	3.5	0.5014	48	0.0	5.0	0.3794
10	0.0	4.0	0.5319	49	0.0	5.0	0.3794
11	0.0	3.0	0.4710	50	6.0	3.0	0.3794
12	27.5	8.5	0.4557	51	0.0	3.5	0.3794
13	2.5	2.5	0.7300	52	25.5	5.5	0.3794
14	0.0	3.0	0.7757	53	0.0	6.0	0.3794
15	6.0	6.0	0.8367	54	35.8	6.0	0.3794
16	0.0	2.0	0.8062	55	0.0	3.0	0.4862
17	0.0	4.0	0.6233	56	0.0	4.0	0.4404
18	6.0	3.0	0.5471	57	0.0	3.0	0.4709
19	0.0	4.0	0.5319	58	3.5	5.5	0.4557
20	0.0	1.5	0.5624	59	5.5	2.5	0.3947
21	0.0	4.0	0.5471	60	0.0	5.5	0.4100
22	53.50	3.0	0.5319	61	0.0	5.0	0.4100
23	0.0	5.0	0.5624	62	0.0	3.5	0.3947
24	0.0	8.0	0.5624	63	0.0	5.0	0.3947
25	0.0	2.0	0.6233	64	0.0	3.0	0.3947
26	0.0	3.0	0.5472	65	8.8	5.0	0.3947
27	0.0	4.5	0.4862	66	9.0	2.5	0.3947
28	0.0	4.0	0.4709	67	10.0	3.0	0.3947
29	0.0	4.0	0.4252	68	0.0	5.0	0.3947
30	0.0	3.0	0.4100	69	0.0	3.0	0.3847
31	0.0	3.0	0.4100	70	0.0	3.0	0.3947
32	0.0	4.0	0.5319	71	0.0	1.5	0.4252
33	6.0	4.0	0.5471	72	0.0	4.0	0.4100
34	0.0	4.5	0.6386	73	0.0	4.0	0.4100
35	0.0	3.5	0.3795	74	15.5	3.5	0.4100
36	0.0	4.0	0.3642	75	0.0	2.0	0.5624
37	0.0	5.5	0.3642	76	8.4	4.5	0.5319
38	0.0	3.0	0.3490	77	0.0	4.5	0.5014
39	4.8	5.0	0.3185	78	2.0	2.0	0.3947

TABLE 6.5 Average Daily Rainfall and Evaporation from January 1982 to December 1988 (Stn. No. 1632201)

Month	R (mm)	E (mm)	Assumed H_{O},(m)	Month	R (mm)	E (mm)	Assumed H_{O},(m)
1	1.44	3.79	0.5	43	6.70	3.99	0.5
2	3.84	4.42	0.5	44	2.92	4.06	0.5
3	6.38	4.06	0.5	45	11.11	3.90	0.5
4	10.78	3.68	0.5	46	7.72	3.83	0.5
5	7.01	4.00	0.5	47	11.85	3.81	0.5
6	0.72	3.84	0.5	48	9.98	4.15	0.5
7	7.15	5.06	0.5	49	9.48	3.58	0.5
8	5.21	4.37	0.5	50	1.57	4.11	0.5
9	4.91	4.32	0.5	51	18.74	4.15	0.5
10	9.08	4.12	0.5	52	11.98	4.50	0.5
11	10.72	4.07	0.5	53	5.64	4.50	0.5
12	8.85	3.64	0.5	54	5.44	3.93	0.5
13	7.87	3.67	0.5	55	4.00	4.59	0.5
14	1.00	4.50	0.5	56	3.48	4.51	0.5
15	1.80	5.32	0.5	57	11.20	4.43	0.5
16	2.34	4.65	0.5	58	12.20	3.45	0.5
17	3.85	4.26	0.5	59	9.08	3.88	0.5
18	2.38	3.46	0.5	60	6.28	4.17	0.5
19	11.52	3.81	0.5	61	13.41	3.73	0.5
20	5.85	3.99	0.5	62	0.20	4.17	0.5
21	6.10	3.61	0.5	63	3.57	4.27	0.5
22	4.20	4.19	0.5	64	11.92	4.89	0.5
23	4.39	3.73	0.5	65	4.57	4.30	0.5
24	5.21	3.33	0.5	66	7.33	4.15	0.5
25	12.18	3.42	0.5	67	5.46	3.98	0.5
26	11.18	3.82	0.5	68	3.92	3.53	0.5
27	16.20	4.39	0.5	69	8.13	4.21	0.5
28	11.43	3.67	0.5	70	6.08	4.06	0.5
29	3.44	3.83	0.5	71	7.46	4.15	0.5
30	9.80	3.79	0.5	72	5.23	3.77	0.5
31	2.28	4.32	0.5	73	4.84	3.73	0.5
32	8.08	4.38	0.5	74	9.51	4.06	0.5
33	11.02	3.92	0.5	75	11.70	4.43	0.5
34	5.26	4.63	0.5	76	12.34	4.16	0.5
35	7.30	3.48	0.5	77	6.74	4.43	0.5
36	7.41	3.65	0.5	78	4.13	3.58	0.5
37	6.57	4.77	0.5	79	6.38	3.92	0.5
38	9.25	3.69	0.5	80	6.93	3.60	0.5
39	6.84	4.06	0.5	81	8.21	3.56	0.5
40	5.98	3.85	0.5	82	5.56	4.36	0.5
41	4.51	4.14	0.5	83	10.72	3.58	0.5
42	2.74	4.33	0.5	84	4.52	4.07	0.5

TABLE 6.6 **Simulated Rainfall, Evaporation and Ditch Water Levels for January 1982 to December 1988**

Day	Hm (m)	R (mm)	ECUR (mm)	Day	Hm (m)	R (mm)	ECUR (mm)
1	2.46	-1.44	3.79	43	2.72	-6.70	3.99
2	2.46	-3.84	4.42	44	2.72	-2.92	4.06
3	2.47	-6.38	4.06	45	2.73	-11.11	3.90
4	2.48	-10.78	3.68	46	2.74	-7.72	3.83
5	2.49	-7.01	4.00	47	2.76	-77.85	3.81
6	2.48	-0.72	3.84	48	2.78	-9.98	4.15
7	2.49	-7.15	5.06	49	2.79	-9.48	3.58
8	2.49	-5.21	4.37	50	2.79	-1.57	4.11
9	2.49	-4.91	4.32	51	2.82	-18.74	4.15
10	2.50	-9.08	4.12	52	2.84	-11.98	4.50
11	2.52	-10.72	4.07	53	2.84	-5.64	4.50
12	2.53	-8.85	3.64	54	2.85	-5.44	3.93
13	2.54	-7.87	3.67	55	2.85	-4.00	4.59
14	2.53	-1.00	4.50	56	2.84	-3.48	4.51
15	2.52	-1.80	5.32	57	2.86	-11.20	4.43
16	2.52	-2.34	4.65	58	2.88	-12.20	3.45
17	2.51	-3.85	4.26	59	2.89	-9.08	3.88
18	2.51	-2.38	3.46	60	2.90	-6.28	4.17
19	2.53	-11.52	3.81	61	2.92	-13.41	3.73
20	2.53	-5.85	3.99	62	2.91	-0.20	4.71
21	2.54	-6.10	3.61	63	2.91	-3.57	4.27
22	2.54	-4.20	4.19	64	2.93	-11.92	4.89
23	2.54	-4.39	3.73	65	2.93	-4.57	4.30
24	2.55	-5.21	3.33	66	2.93	-7.33	4.15
25	2.57	-12.18	3.42	67	2.94	-5.46	3.98
26	2.59	-11.18	3.82	68	2.94	-3.92	3.53
27	2.62	-16.20	4.39	69	2.95	-8.13	4.21
28	2.64	-11.43	3.67	70	2.95	-6.08	4.06
29	2.63	-3.44	3.83	71	2.96	-7.46	4.15
30	2.65	-9.80	3.79	72	2.96	-5.23	3.77
31	2.64	-2.28	4.32	73	2.96	-4.84	3.73
32	2.65	-8.08	4.38	74	2.98	-9.51	4.06
33	2.67	-11.02	3.92	75	2.99	-11.70	4.43
34	2.67	-5.26	4.63	76	3.01	-12.34	4.16
35	2.68	-7.30	3.48	77	3.02	-6.74	4.43
36	2.69	-7.41	3.65	78	3.02	-4.13	3.58
37	2.69	-6.57	4.77	79	3.03	-6.38	3.92
38	2.71	-9.25	3.69	80	3.03	-6.93	3.60
39	2.71	-6.84	4.06	81	3.04	-8.21	3.56
40	2.72	-5.98	3.85	82	3.05	-5.56	4.36
41	2.72	-4.51	4.14	83	3.06	-10.72	3.58
42	2.71	-2.74	4.33	84	3.06	-4.52	4.07

TABLE 7.1- **Estimation of subsidence as a result of increase in overburden pressure due to drainage using coefficient of compression, m_v - from FIGURE 5.37 ($dS = m_v p dH$)**

Drop in WT (m)	Depth of deposit (m)	Thickns of layer H_i (m)	Press. p ($KN\ m^{-2}$)	coef of comp, m_v ($m^2\ 10^3$ KN)	subsid. layer ds (m)	Cumm. sub. (m)
	0-0.1	0.1	-	-	-	
	0.1-0.2	0.1	0.88	5.46	0.000	0.000
0.5	0.2-0.3	0.1	1.77	5.46	0.001	0.001
	0.3-0.4	0.1	2.65	5.10	0.001	0.002
	0.4-0.5	0.1	3.53	4.62	0.002	0.004
(under water)	0.5-3.0	2.5	4.42	4.62	0.051	0.055
Sub total of cummulative subsidence due to 0.5 m WT drawdown						**0.055**
	0.5-0.6	0.1	4.42	4.62	0.002	0.006
	0.6-0.7	0.1	5.30	5.19	0.003	0.009
1.0	0.7-0.8	0.1	6.18	5.75	0.004	0.013
	0.8-0.9	0.1	7.06	6.32	0.004	0.017
	0.9-1.0	0.1	7.95	6.89	0.005	0.022
(under water)	1.0-3.0	2	8.83	7.46	0.132	0.154
Sub total of cummulative subsidence due to 1.0 m WT drawdown						**0.154**
	1.0-1.1	0.1	8.83	7.46	0.007	0.029
	1.1-1.2	0.1	9.71	8.02	0.008	0.037
1.5	1.2-1.3	0.1	10.60	8.30	0.009	0.046
	1.3-1.4	0.1	11.48	8.43	0.010	0.056
	1.4-1.5	0.1	12.36	8.55	0.011	0.067
(under water)	1.5-3.0	1.5	13.25	8.68	0.173	0.240
Sub total of cummulative subsidence due to 1.5 m WT drawdown						**0.240**

for $C_v = 88.34\ m^2\ yr^{-1}$, $H = 2$ m

$$t_{90} = \frac{0.94\ H^2}{C_v}$$

$= 4.3 \times 10^2$ yrs

$= 15.5$ days

TABLE 7.2 - Estimation of subsidence as a result of increase in overburden pressure due to drainage for p_i=0.88 KN m^{-2}, C_c=4.01 and e_i=8.46 - from FIGURE 5.37

$$dS = \frac{1}{1+e_i} H_i C_c \log (p_f/p_i)$$

Drop in WT m	Depth of deposit (m)	Thick-ness of layer H_i (m)	Final Pres-sure p_f(KN m^{-2})	subsi-dence of layer ds (m)	Cum. subsi-dence (m)
0.5	0-0.1	0.1	-	-	-
	0.1-0.2	0.1	0.88	0	0
	0.2-0.3	0.1	1.77	0.013	0.013
	0.3-0.4	0.1	2.65	0.020	0.033
	0.4-0.5	0.1	3.53	0.025	0.058
(under water)	0.5-3.0	2.5	4.42	0.739	0.797
Sub total of cummulative subsidence due to 0.5 m WT drawdown					0.797
1.0	0.5-0.6	0.1	4.42	0.030	0.088
	0.6-0.7	0.1	5.30	0.033	0.121
	0.7-0.8	0.1	6.18	0.036	0.157
	0.8-0.9	0.1	7.06	0.038	0.195
	0.9-1.0	0.1	7.95	0.040	0.235
(under water)	1.0-3.0	2.0	8.83	0.846	1.081
Sub total of cummulative subsidence due to 0.5 m WT drawdown					1.081
1.5	1.0-1.1	0.1	8.83	0.042	0.277
	1.1-1.2	0.1	9.71	0.044	0.321
	1.2-1.3	0.1	10.60	0.046	0.367
	1.3-1.4	0.1	11.48	0.047	0.414
	1.4-1.5	0.1	12.36	0.048	0.462
(under water)	1.5-3.0	1.5	13.25	0.746	1.208
Sub total of cummulative subsidence due to 0.5 m WT drawdown					1.208

TABLE 7.3 **Estimation of changes in porosity and void ratio with water table drawdown (results from Table 7.1 - using coefficient of compression, m_v)**

1	2	3	4	5	6	7
WT drawdown (thickness) H_i m	height of solids h_s $\frac{H_i}{1+e_i}$ m	subsidence from Tab. 7.1 ds m	resultant peat depth h, H_i-ds m	height of voids, h_v h-h_s	porosity, n h_v/h m	void ratio, e h_v/h_s %
0 (3.0)	0.32	0	3.0	2.68	89.3	8.4
0.5 (2.5)	0.26	0.05	2.45	2.19	89.4	8.4
1.0 (2.0)	0.21	0.13	1.87	1.66	88.8	7.9
1.5 (1.5)	0.16	0.17	1.33	1.17	88.0	7.3

TABLE 7.4 **Estimation of changes in porosity and void ratio with water table drawdown (results from Table 7.2 - using compression index, C_c)**

1	2	3	4	5	6	7
WT drawdown (thickness) H_i m	height of solids h_s $\frac{H_i}{1+e_i}$ m	subsidence from Tab. 7.2 ds m	resultant peat depth h, H_i-ds m	height of voids, h_v h-h_s	porosity, n h_v/h m	void ratio, e h_v/h_s %
0 (3.0)	0.32	0	3.0	2.68	89.3	8.4
0.5 (2.5)	0.26	0.74	1.76	1.50	85.2	5.8
1.0 (2.0)	0.21	0.85	1.15	0.94	81.2	4.5
1.5 (1.5)	0.16	0.75	0.75	0.59	78.7	3.7

TABLE 7.5 **Estimate of subsidence rate for exp. field IPRS, Pontian (17 years - 1971-1988)**

No	Cause of subsidence	subsidence(mm) @ various WT		
	Water table depth (mm)	**500**	**1000**	**1500**
1	**dewatering**: for soil above the respective water table, θ_m reduce from 800% to 400% vol lost 25%, (Figure 5.39 and Figure 5.40 for samples @ 200-300 mm depth)	125	250	375
2	**Oxidation**: increase.in ash content of the top 50 mm layer from 0.4% to 4.6%	525	525	525
	sub total of subsidence due to dewatering and oxidation in 17 years	650	775	900
3	**Consolidation**: cumulative subsidence from, Using C_C, TABLE 7.1 Using m_V, TABLE 7.2	 797 55	 1081 154	 1208 240
4	**Total subsidence**: including all subsidence above, 1+2+3 Using C_C, TABLE 7.1 Using m_V, TABLE 7.2	 1447 705	 1856 929	 2108 1140
5	**estimated average subsidence per year** over 17 yrs, 1971-1988 Using C_C, TABLE 7.1 Using m_V, TABLE 7.2	 85.1 41.5	 109.2 54.6	 124.0 67.1
6	**actual subsidence rate** of IPRS from 1984 to 1988, from **land survey data** for peat deposit of 3 m depth in the cassava field @ x=250m (Table 5.38).	overall subsidence - **115.4 mm yr^{-1}** {(384.8+76.7)/4} for 1986-88 only **38.4 mm yr^{-1}**		
7	**actual average rate** of subsidence, IPRS 1988 from **soil meter monitoring**, (Table 5.36). Average water table generally varies between 417 mm and 1049 mm	**27.1** mm yr^{-1}		

TABLE 7.6 - Projection of ground elevation in IPRS in 50 years, 1988 to 2038 - section 7.2.1

1	Water table level (m)	0.5	1.0	1.5
2	Rate of subsidence (mm per annum)	27	40	53
3	Amount of subsidence by 2038 (m)	1.35	2.00	2.65
4	Surface level by 2038 (m)	+5.00	+4.35	+3.70
5	Depth of remaining deposit, (take subsurface at +3.0 m, therefore present depth of deposit is 3.35 m)	2.00	1.35	0.70

1988 soil surface taken to be +6.35 (all levels in m unless otherwise stated). Subsurface clay level is between +3.0 to +3.6.

TABLE 7.7 Changing θ_m (%) with drainage and time, - 50-150 mm layer (from Figure 5.8)

Suction (bar)	Ulu Air Baloi	IPRS 1988	Parit Sikom
0.001	700	420	320
0.1	470	380	230
5.0	280	230	170
EAW	230	40	90
AWC	190	150	60
TAW	420	190	150
% of TAW	60.0	45.2	46.9

EAW=Easily Available Water
AWC=Available Water Capacity
TAW=Total Available Water

TABLE 7.8 Total available water for 15 days, at various soil depths, and for different type of soils, ET_C=3.6 mm/day.

Water Table @ 900 mm					
c1	c2	c3	c4	c5	c6
Root Depth (mm)	AWC) (mm)	1/2 AWC) (mm)	RCR x 15 WT=1.0 (mm)	Total AW (c3+c4) (mm)	allowable dry days (c5/ETc)
Peat					
300	71	36	15	51	14
600	219.5	110	15	125	35
900	351.5	176	15	191	53
Clay					
300	60	30	15	45	12
600	120	60	15	75	20
900	180	90	15	105	29
loam					
300	42	21	15	36	10
600	84	42	15	57	15
900	126	63	15	78	21
sand					
300	18	9	0	9	3
600	36	18	0	18	5
900	54	27	0	27	8
Water Table = 2000 mm					
Peat					
300	71	36	0	36	10
600	219.5	110	0	110	31
900	351.5	176	0	176	49
Clay					
300	60	30	0	30	8
600	120	60	0	60	17
900	180	90	0	90	25
loam					
300	42	21	0	21	6
600	84	42	0	42	12
900	126	63	0	63	18

NB:The following assumptions are made
For peat @ WT = 0.9 m, RCR=1.0 mm/day
For clay @ WT = 0.9 m, RCR=1.0 mm/day
For loam @ WT = 0.9 m, RCR=1.0 mm/day
For sand @ WT = 0.9 m, RCR=0.0 mm/day
For peat, clay, loam and sand @ WT=2 m, RCR=0.0 mm/day

TABLE 7.9 Total available water for IPRS peat, for 15 days. WT at varying depths, ET_c=3.6 mm/day.

c1	c2	c3	c4	c5	c6
WT Depth (m)	AWC) (mm)	1/2 AWC) (mm)	RCR x 15 WT=1.0 (mm)	Total AW. (c3+c4)	allow. dry days (c5/ETc)
rooting depth = 300 mm					
0.3	71	36	36	72	20
0.6	71	36	24	60	16
0.9	71	36	15	51	14
rooting depth = 600 mm					
0.6	219.5	110	24	134	37
0.9	219.5	110	15	125	34
rooting depth = 900 mm					
0.9	351.5	176	15	191	53

WT @ 0.3 m, RCR=2.4 mm/day
WT @ 0.6 m, RCR=1.6 mm/day
WT @ 0.9 m, RCR=1.0 mm/day

TABLE 7.10 Water Table Requirements

Depth of root zone (mm)	**300**	**600**	**900**
WT depth for min. subsidence requirement (mm), assuming capillary fringe @ 150 mm	15	15	15
WT depth for adequate bearing capacity	(man)	(machine)	(machine)
-No FOS (mm)	270	647	647
-With FOS=1.5 (mm)	475	1060	1060
WT depth for minimum irreversible drying(mm)	15	15	15
WT depth for adequate aeration = RZ+CF (mm) (for CF=200mm)	500	800	1100
Required WT (mm)			
- No FOS	**500**	**800**	**1100**
- with FOS	**500**	**1060**	**1100**

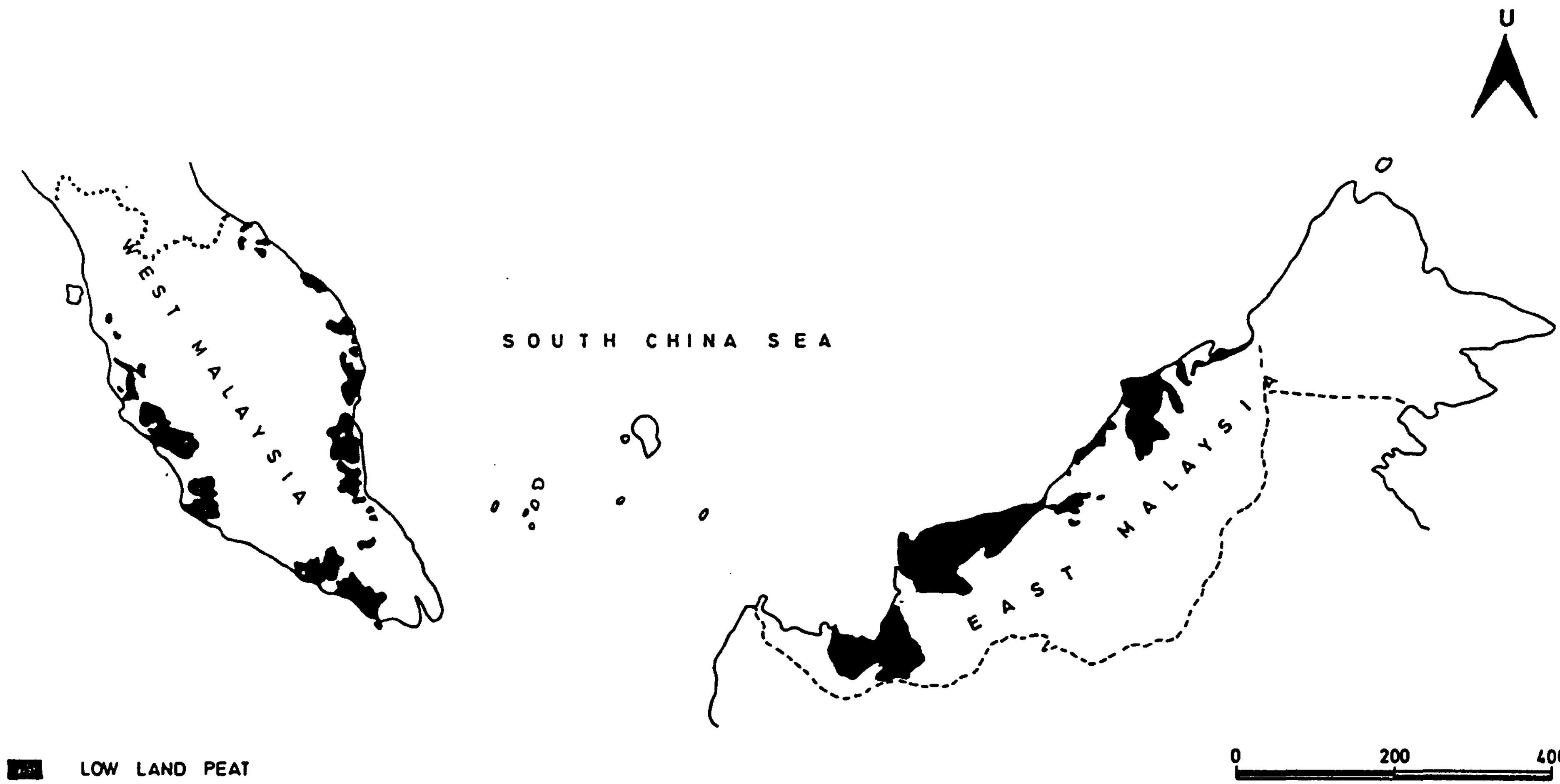


FIGURE 1.1: DISTRIBUTION OF PEAT SOILS IN MALAYSIA
(ANDRIESSE 1974)

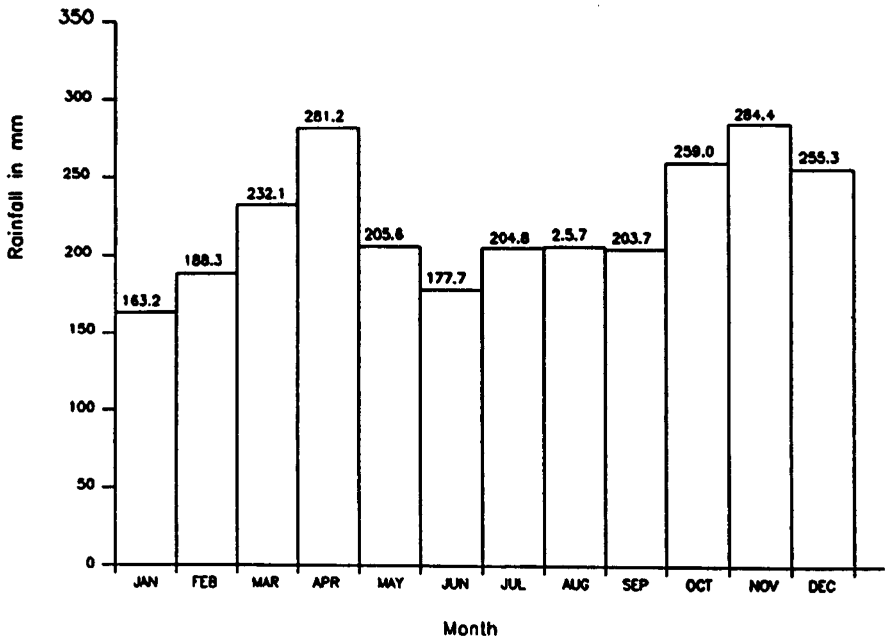


FIGURE 1.2 – Average Rainfall Distribution for Pontian Besar, Station No 1534104, 1951 to 1985

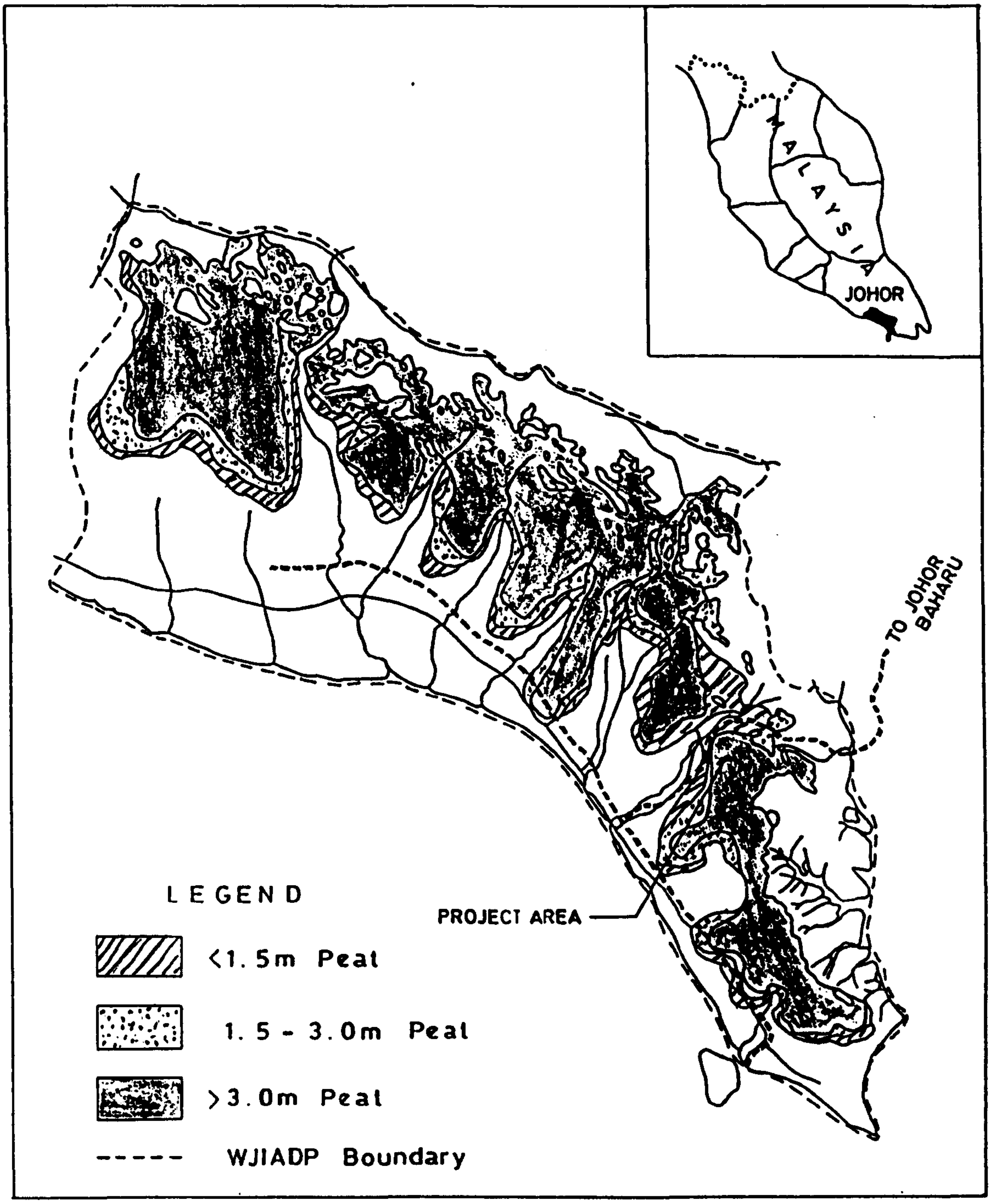


FIGURE 1.3: LOCATION OF THE PROJECT AREA

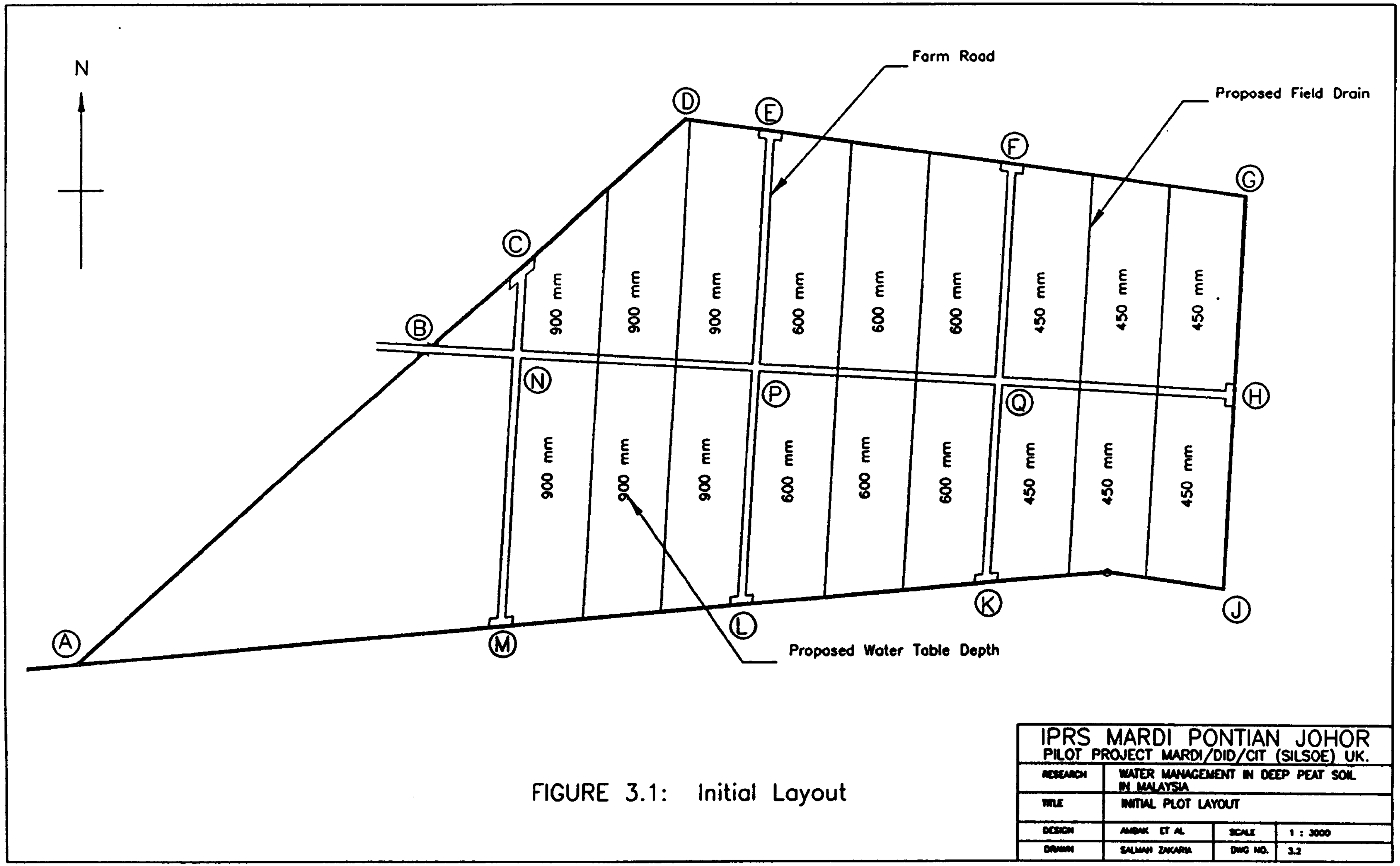


FIGURE 3.1: Initial Layout

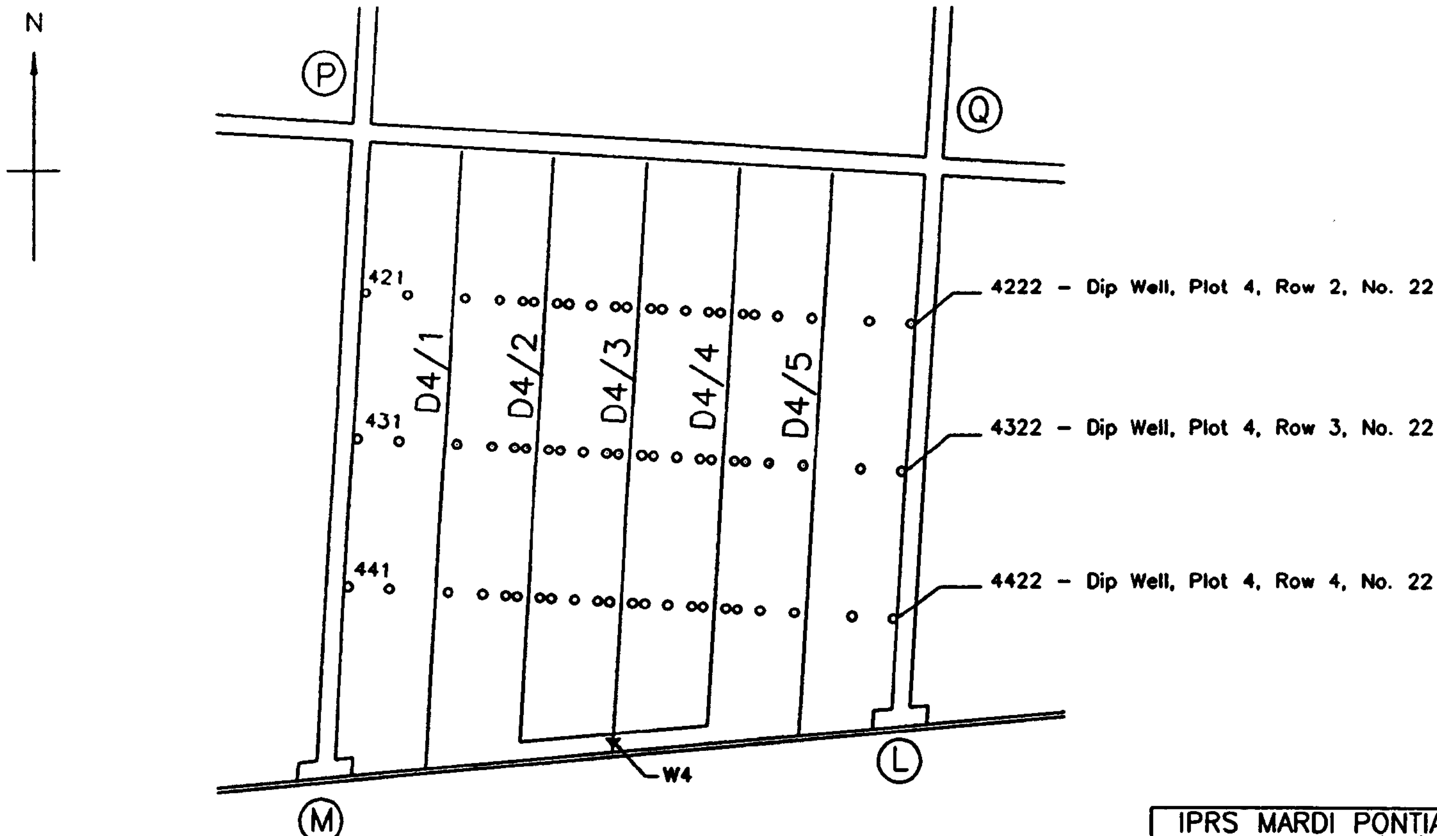


FIGURE 3.2: Plot 4 – Test Plot

IPRS MARDI PONTIAN JOHOR PILOT PROJECT MARDI/DID/CIT (SILSOE) UK.			
RESEARCH	WATER MANAGEMENT IN DEEP PEAT SOIL IN MALAYSIA		
TITLE	PLOT 4 - PILOT PLOT		
DESIGN	SALMAN ZAKARIA	SCALE	1 : 1500
DRAWN	SALMAN ZAKARIA	DWG NO.	3.3

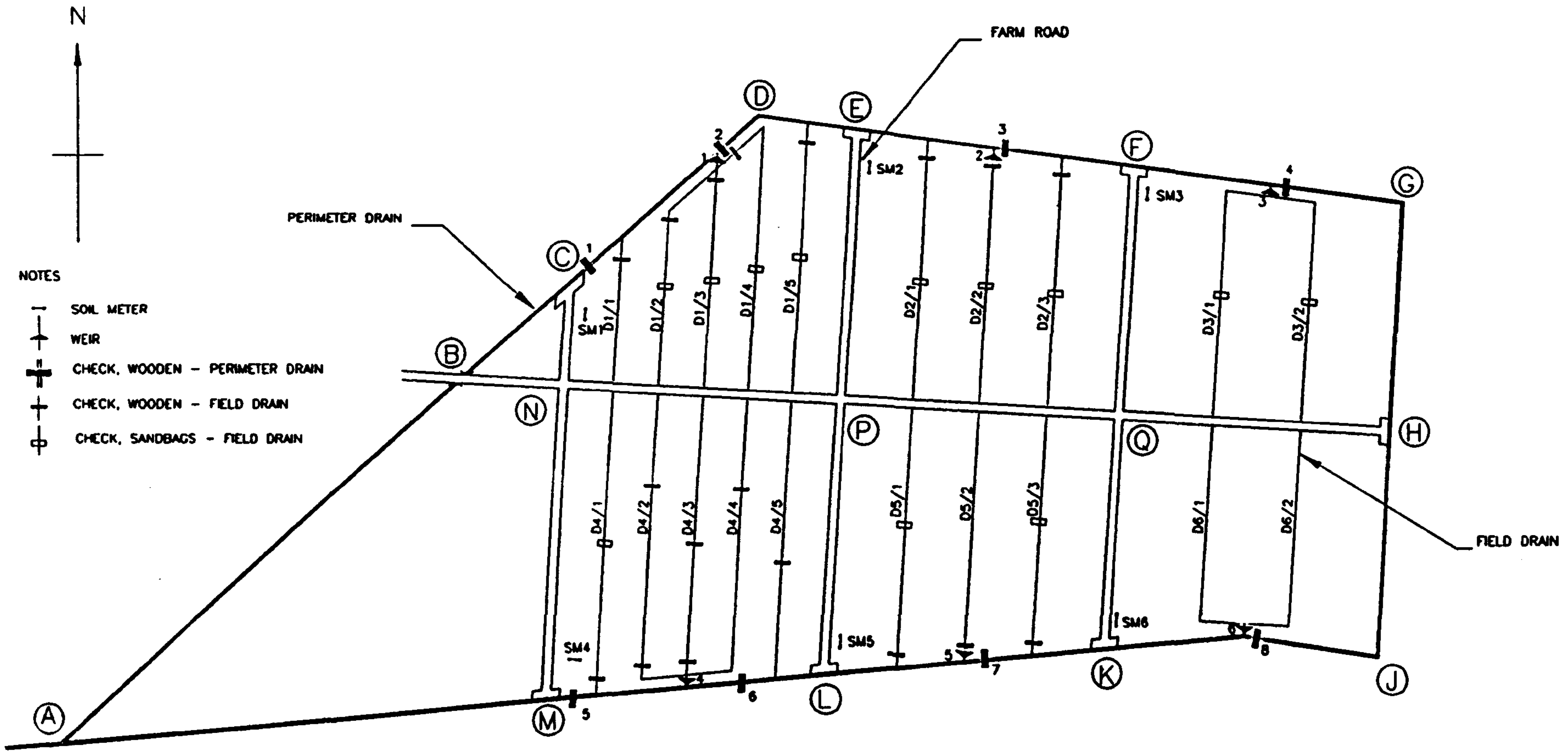


FIGURE 3.3: Final Layout

IPRS MARDI PONTIAN JOHOR PILOT PROJECT MARDI/DID/CIT (SILSOE) UK.			
RESEARCH	WATER MANAGEMENT IN DEEP PEAT SOIL IN MALAYSIA		
TITLE	EXPERIMENTAL PLOT LAYOUT		
DESIGN	SALMAH ZAKARIA	SCALE	1 : 3000
DRAWN	SALMAH ZAKARIA	DWG NO.	3.4

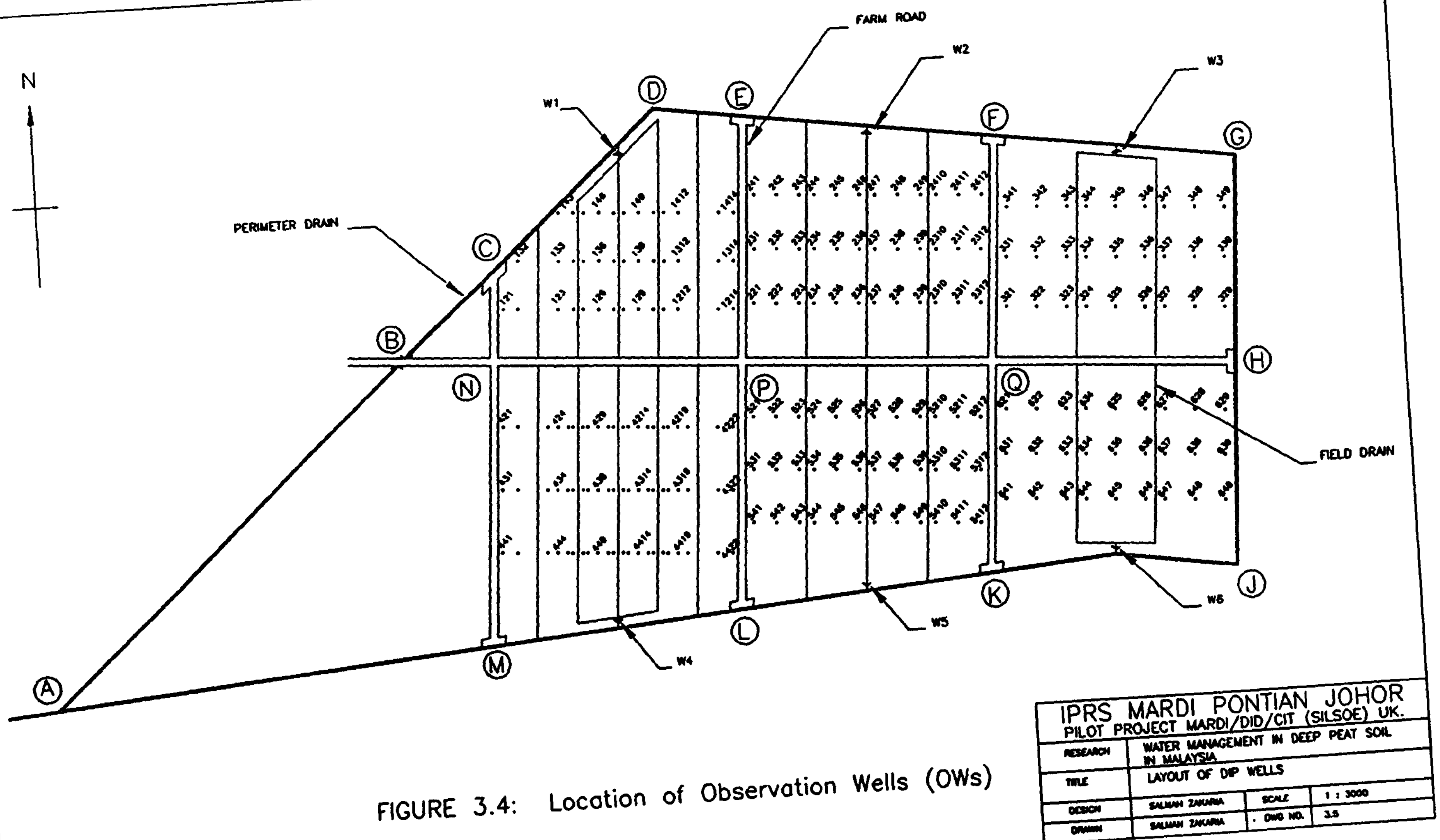


FIGURE 3.4: Location of Observation Wells (OWs)

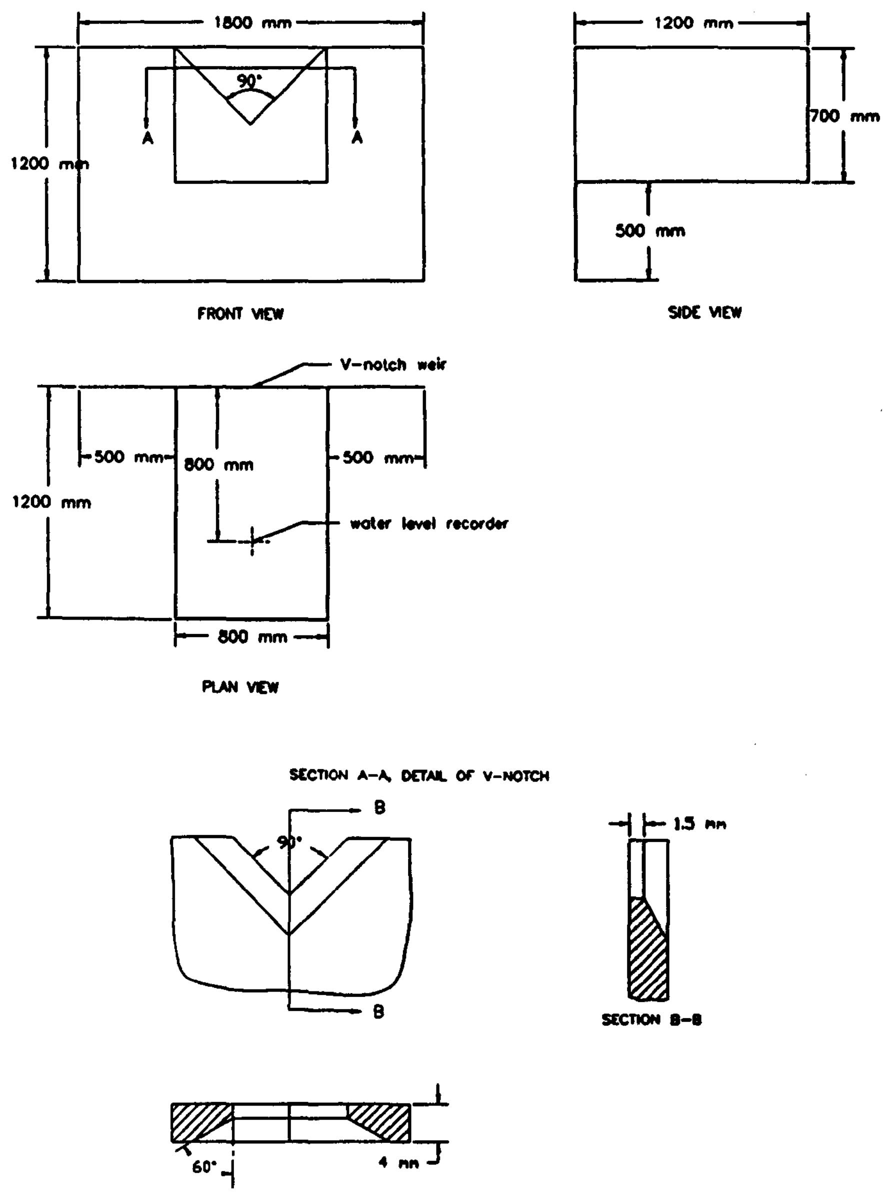
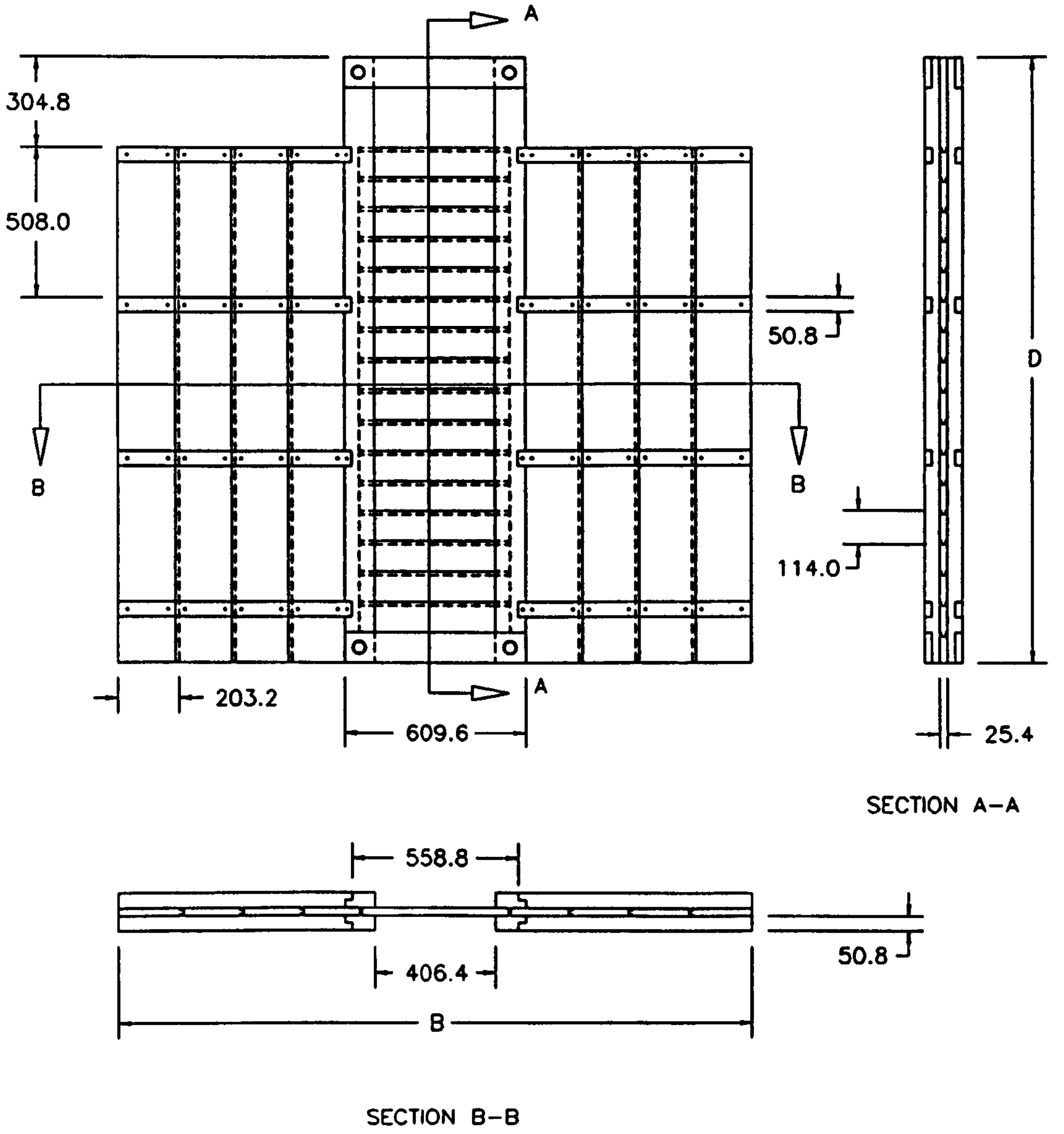


FIGURE 4.1: DETAIL DRAWING OF V-NOTCH WEIR



NOTE:
PERIMETER CHECK STRUCTURE – D=2006.6mm, B=2082.8mm
FIELD CHECK STRUCTURE – D=1562.0mm, B=1701.8mm
ALL DIMENSION IN MILLIMETRE

FIGURE 4.2 – Wooden Check Detailed Drawing

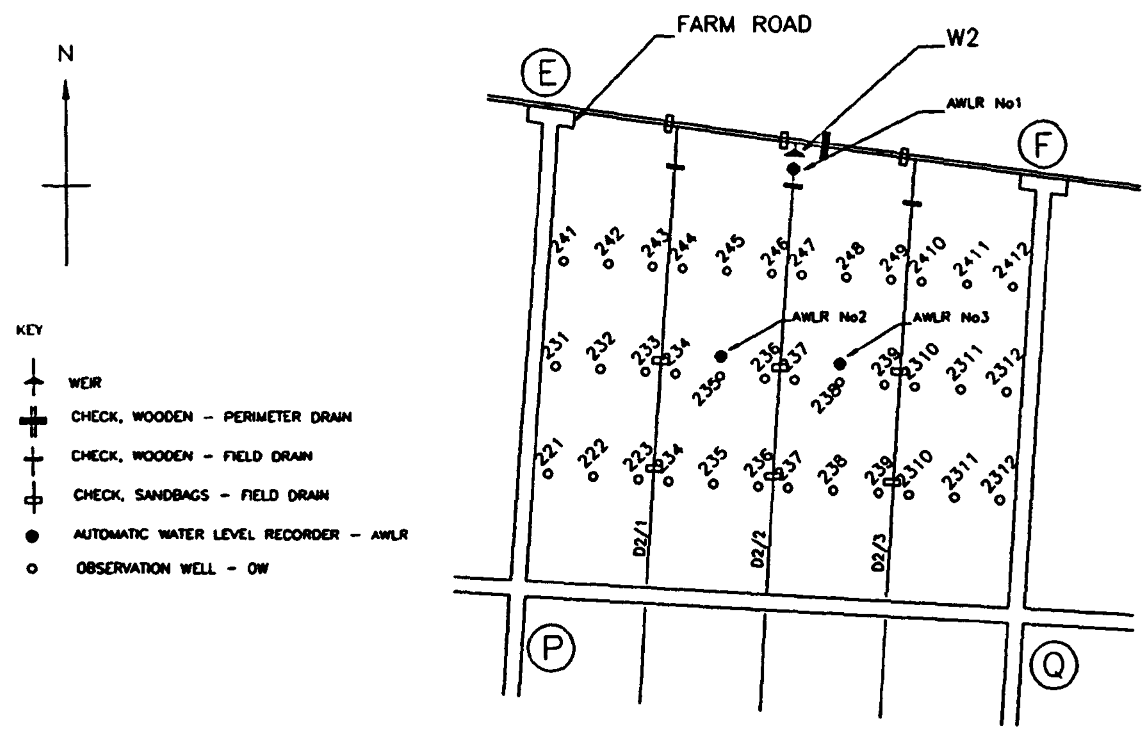


FIGURE 4.3: Layout of Plot 2 for Field Hydraulic Conductivity Estimates

IPRS MARDI PONTIAN JOHOR PILOT PROJECT MARDI/DID/CIT (SILSOE) UK.			
RESEARCH	WATER MANAGEMENT IN DEEP PEAT SOIL IN MALAYSIA		
TITLE	LAYOUT PLOT 2 - RECESSION EXERCISE		
DESIGN BY	SALMAH	SCALE	
DRAWN BY		DWG NO.	3.5

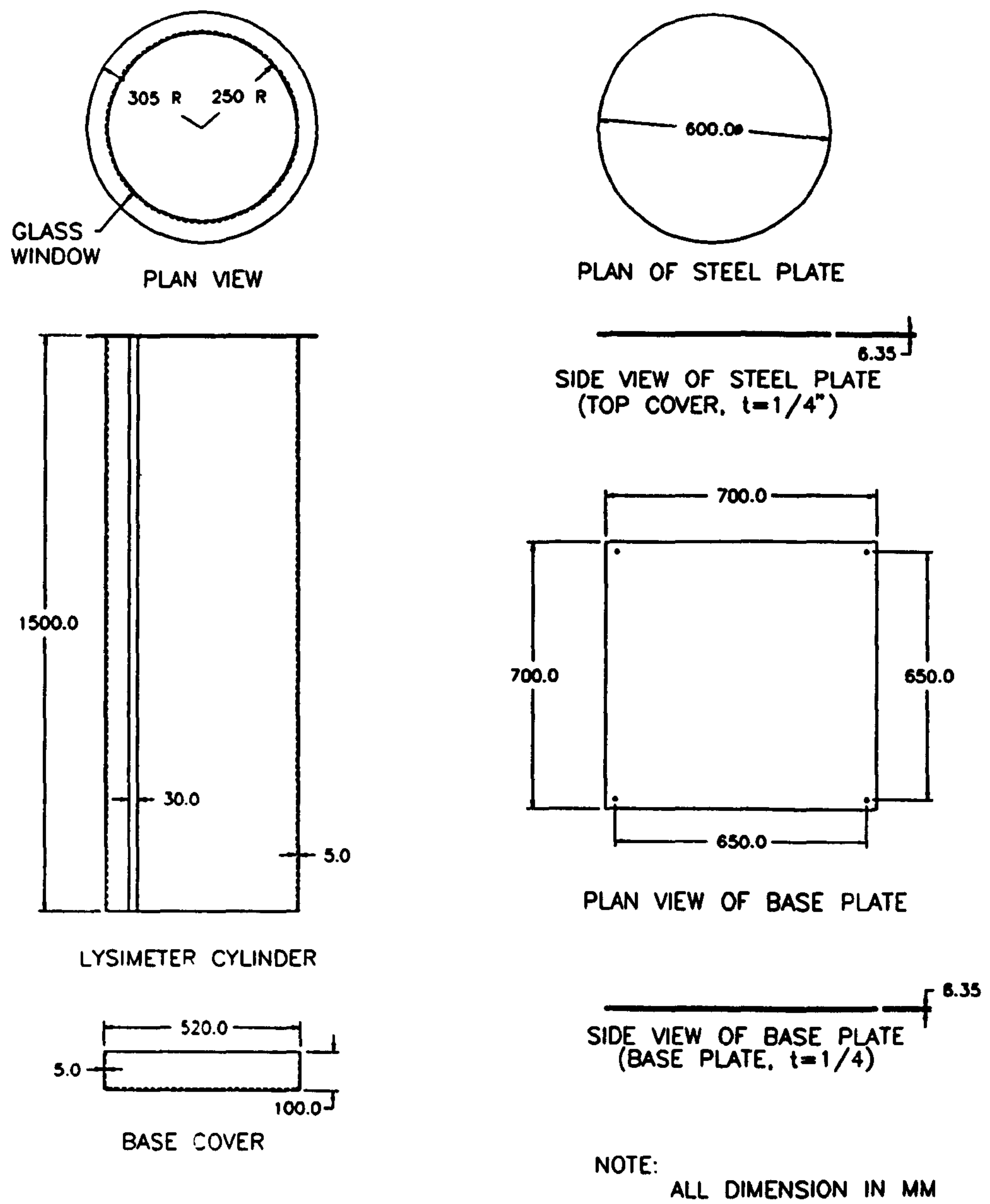
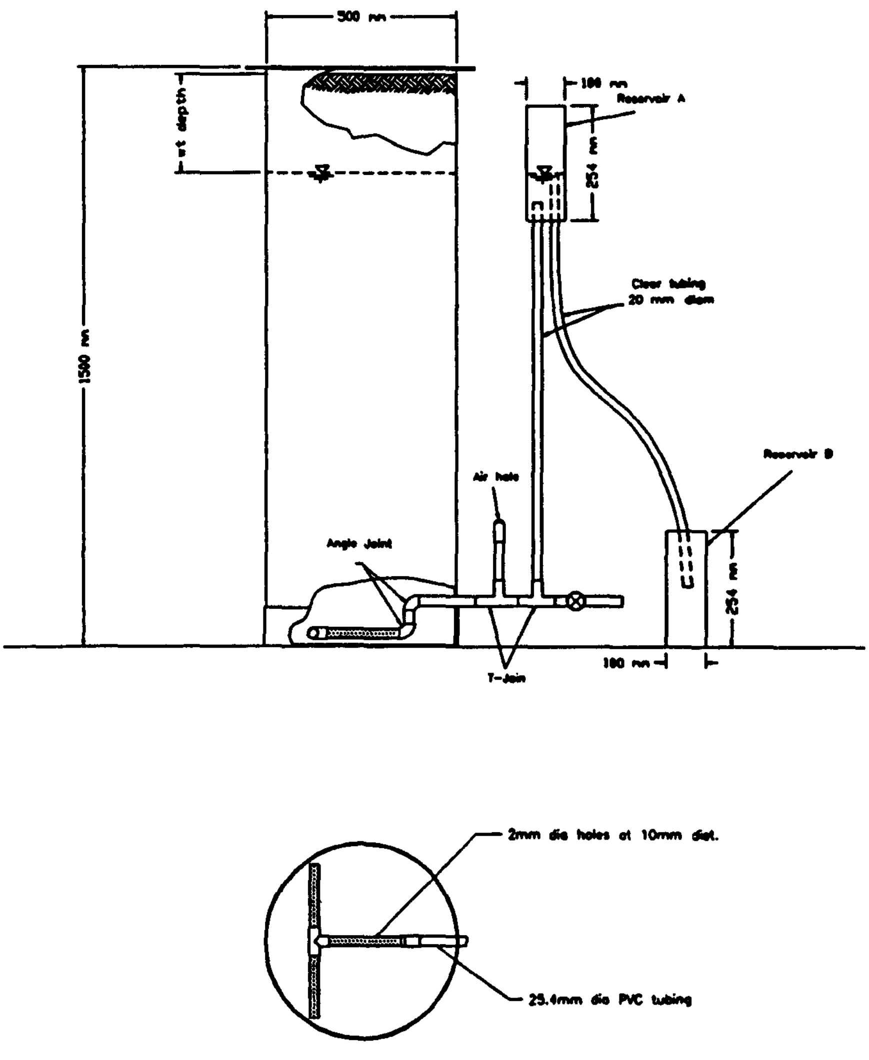
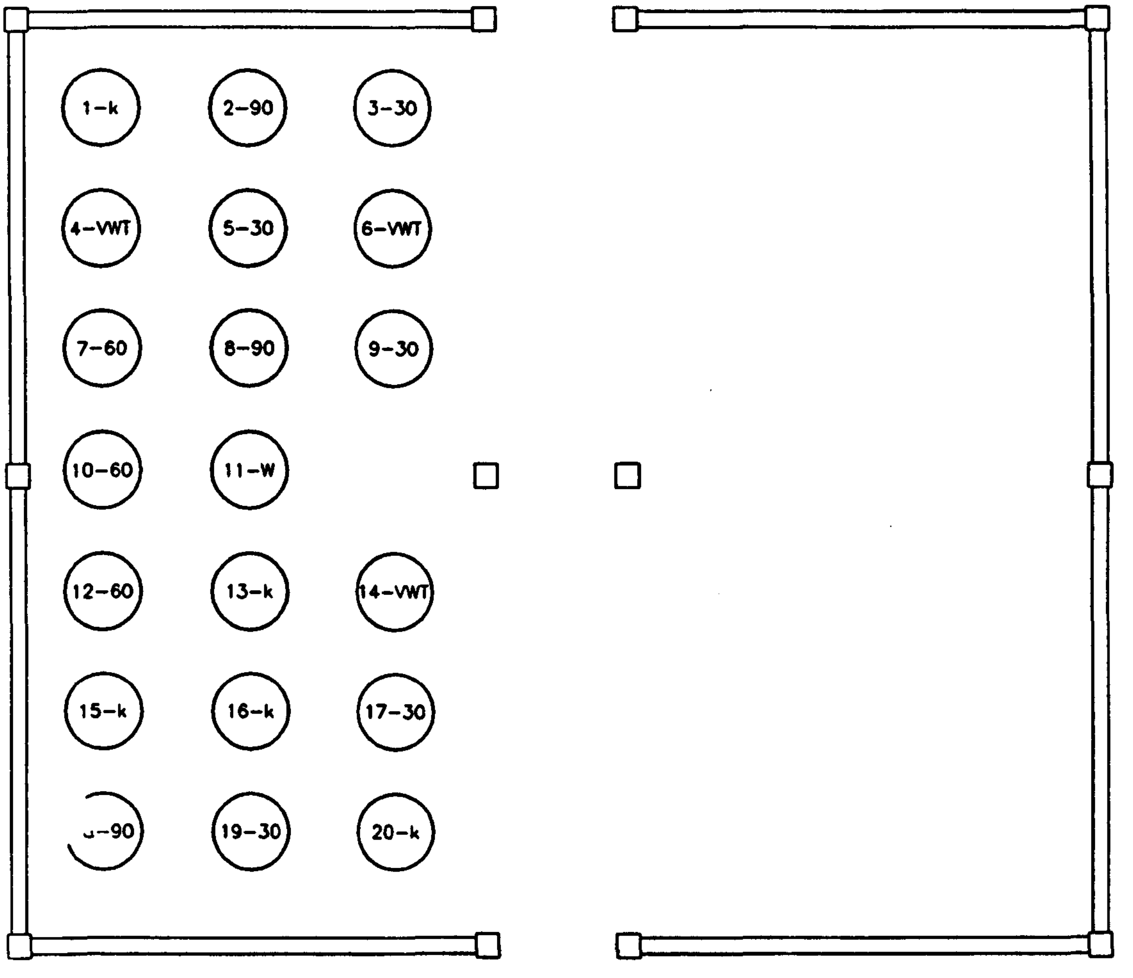


FIGURE 4.4 – Lysimeter Casing



DETAIL OF DRAINAGE TUBES

FIGURE 4.5 – Lysimeter Monolith for measuring Rate of Capillary Rise



Note:

1. Lysimeters were numbered 1 to 20
2. Postions were determined by random numbers
3. The first 5 members were assigned to saturated hydraulic conduntivity test. eg. (1-k)
4. The next 3 members were assigned to rate of capillary rise experiment (ROCRE) with a constant WT = 300mm. eg. (3-30)
5. The next 3 members were assigned to ROCRE with a constant WT = 600mm. eg. (7-60)
6. The next 3 members were assigned to ROCRE with a constant WT = 900mm. eg. (2-90)
7. The next 3 members were assigned to ROCRE with WT lowered to 600 mm after every 2 weeks until 900 mm. eg. (4-VWT)
8. The last Lysimeter is filled with water. eg. (11-W)
9. For all the ROCRE experiment test started with WT = 0mm from the surface before the WT were lowered to the required level.

FIGURE 4.6 – Arrangement of Lysimeter Monoliths

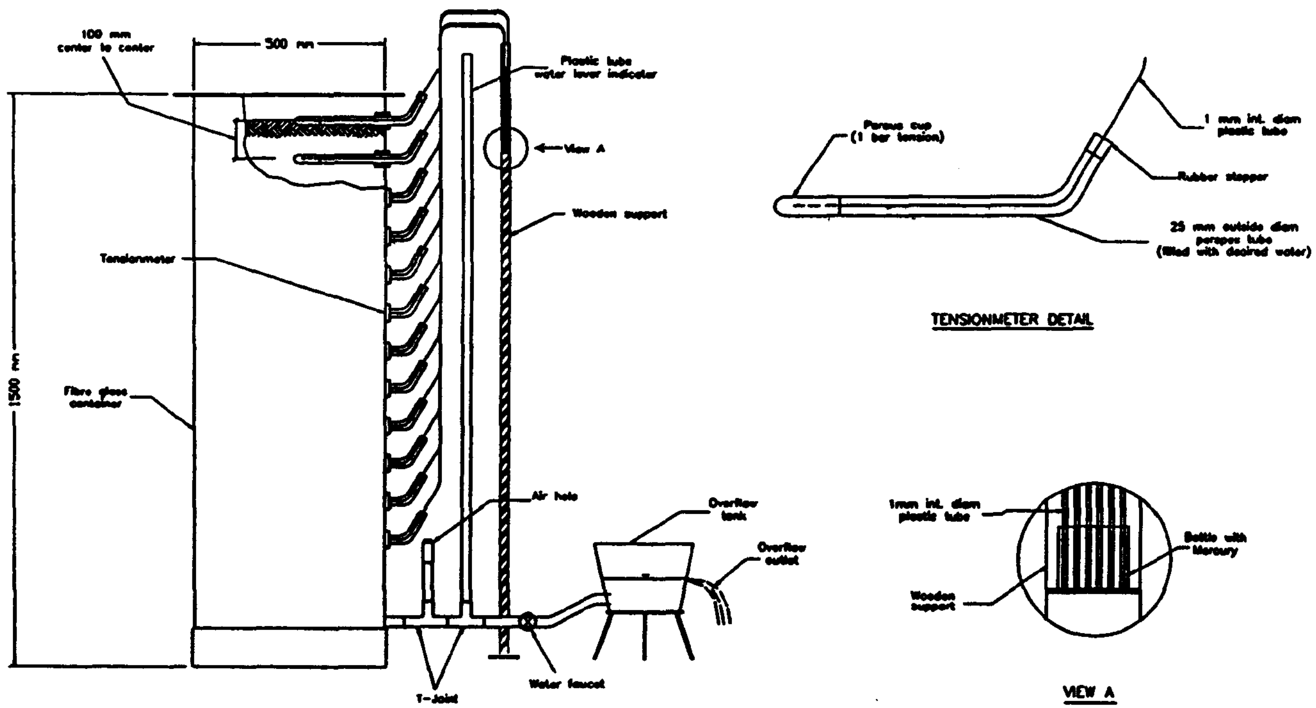


FIGURE 4.7 – Lysimeter Monolith for Measuring Hydraulic Conductivity

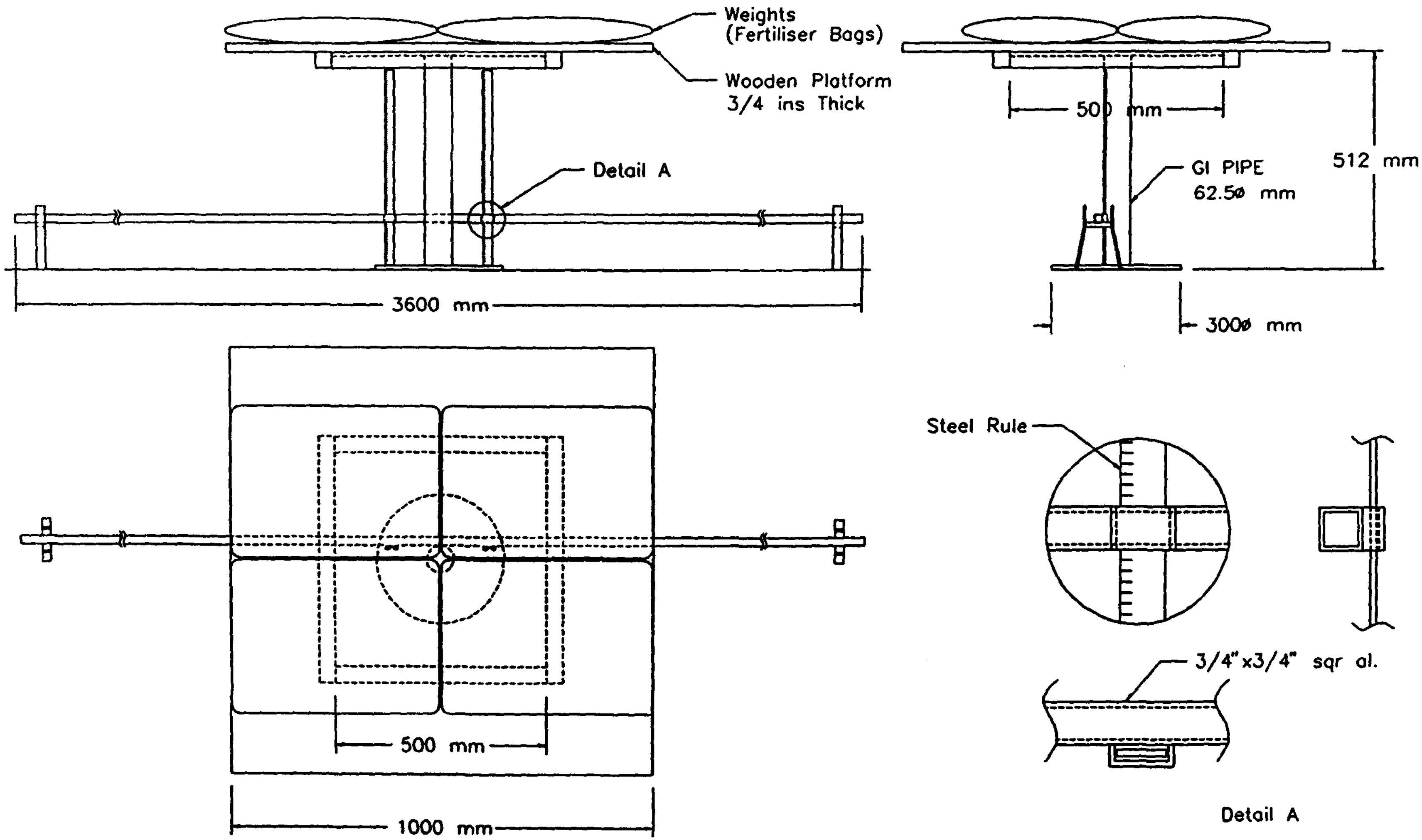
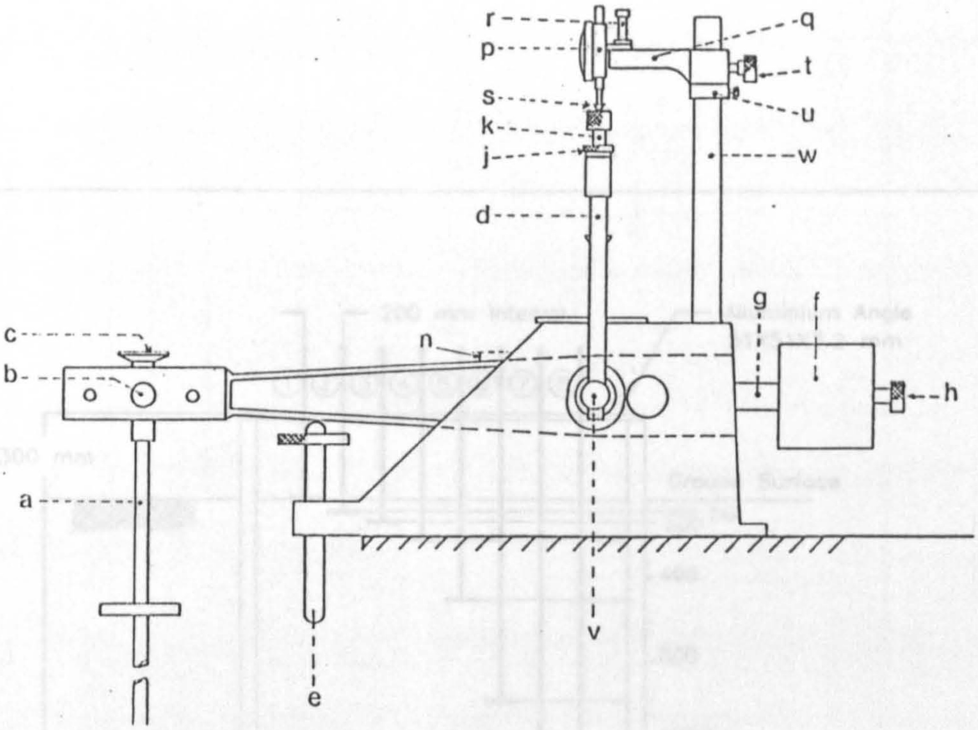
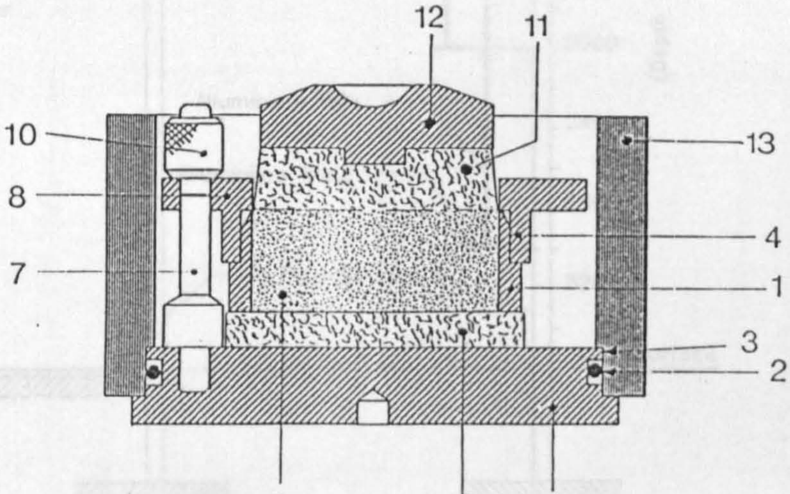


FIGURE 4.8 – Plate Sinkage Test Apparatus



Loading Apparatus



Fixed Ring Cell

[Figures 1 and 4 from Operating instructions for Consolidation Apparatus, EL28-205, Engineering Laboratory Equipment Limited]

FIGURE 4.9 Consolidation Test Apparatus

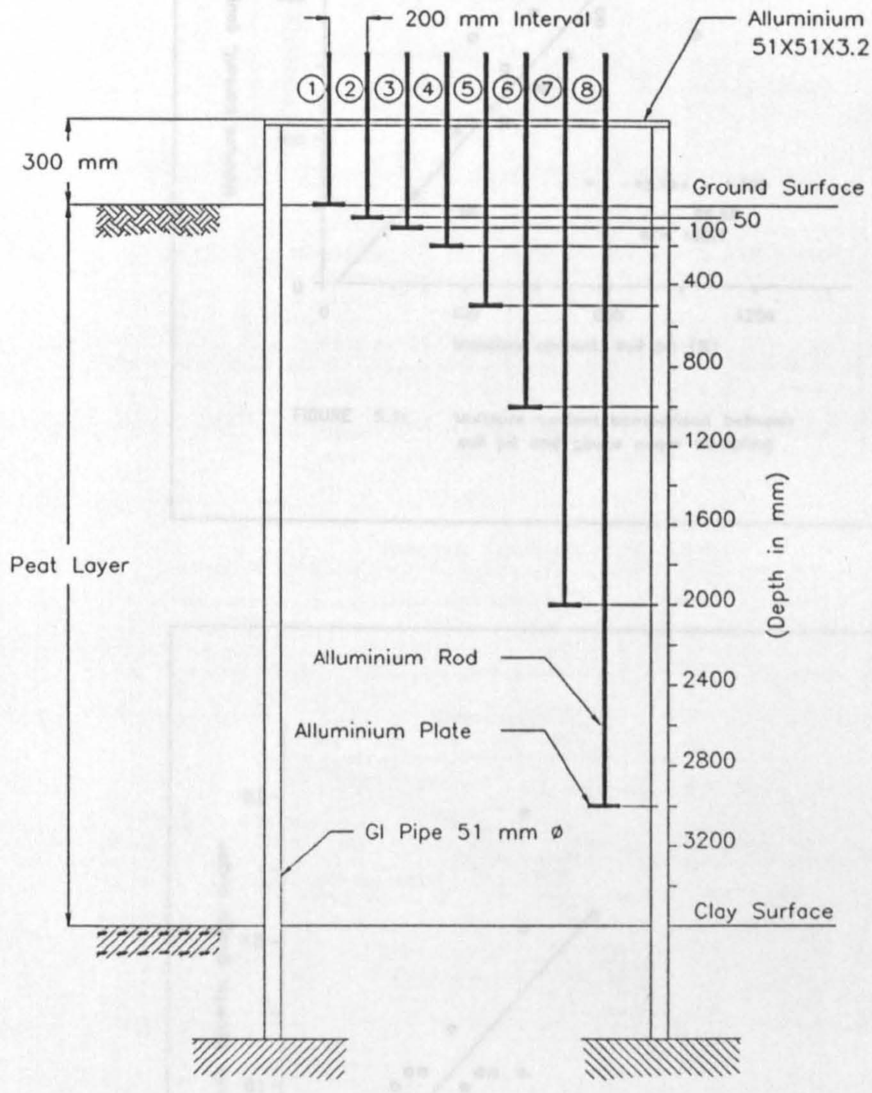


FIGURE 4.10: Soil Subsidence Monitoring Apparatus

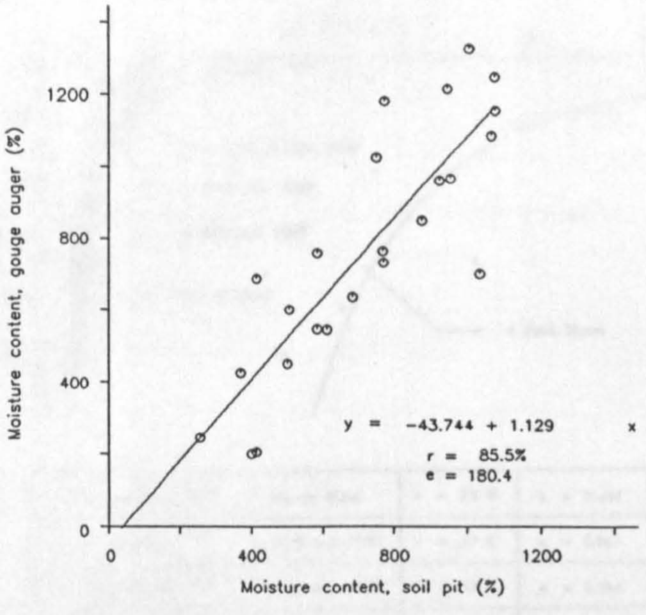


FIGURE 5.1: Moisture content comparison between soil pit and gouge auger sampling

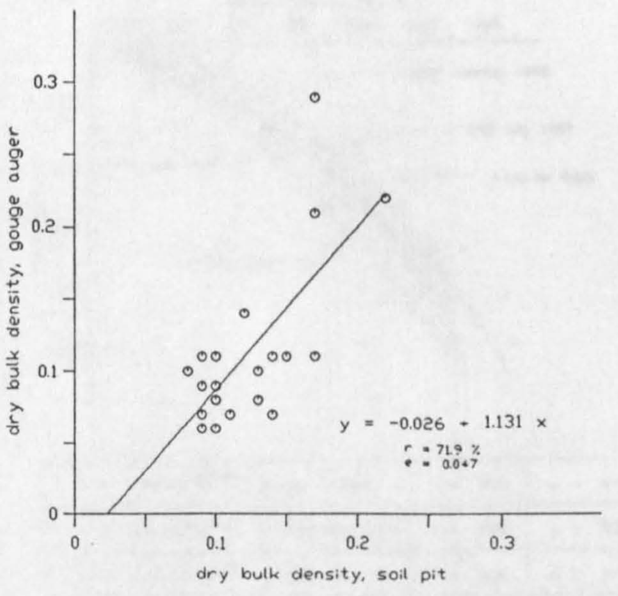
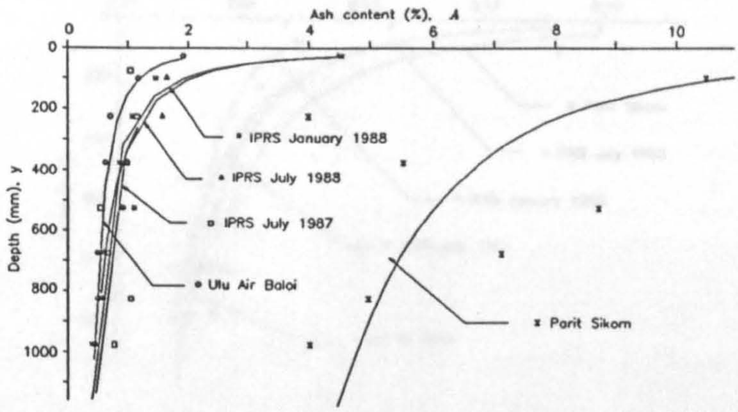
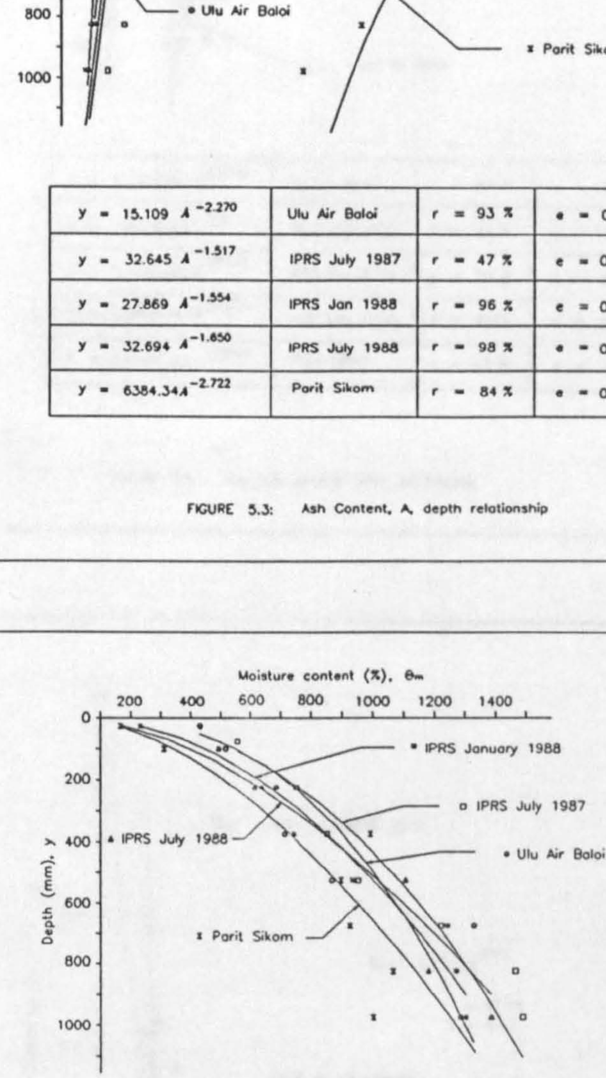


FIGURE 5.2: Comparison of dry bulk density between soil pit and gouge auger sampling



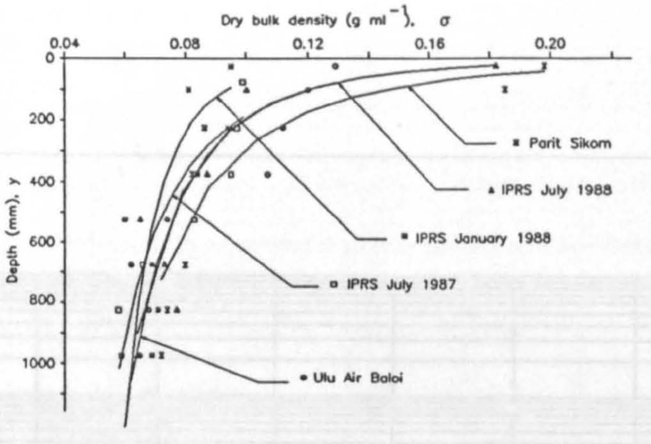
$y = 15.109\ A^{-2.270}$	Ulu Air Baloi	r = 93 %	e = 0.491
$y = 32.645\ A^{-1.517}$	IPRS July 1987	r = 47 %	e = 0.864
$y = 27.869\ A^{-1.554}$	IPRS Jan 1988	r = 96 %	e = 0.384
$y = 32.694\ A^{-1.650}$	IPRS July 1988	r = 98 %	e = 0.261
$y = 6384.34 A^{-2.722}$	Parit Sikom	r = 84 %	e = 0.789

FIGURE 5.3: Ash Content, A, depth relationship



$y = 4.19E-07\ \theta_m^{2.69}$	Ulu Air Baloi	r = 93%	e = 0.49
$y = 3.34E-06\ \theta_m^{2.37}$	IPRS July 1987	r = 96%	e = 0.27
$y = 3.00E-05\ \theta_m^{2.08}$	IPRS Jan 1988	r = 99%	e = 0.18
$y = 2.48E-04\ \theta_m^{1.77}$	IPRS July 1988	r = 99%	e = 0.21
$y = 3.21E-04\ \theta_m^{1.77}$	Parit Sikom	r = 98%	e = 0.34

FIGURE 5.4: Gravimetric Moisture Content, θm, depth relationship



$y = 5.232\,E{-}03\,\sigma^{-3.565}$	Ulu Air Baloi	r = 87 %	e = 0.664
$y = 1.320\,E{-}02\,\sigma^{-3.143}$	IPRS July 1987	r = 84 %	e = 0.536
$y = 1.527\,E{-}05\,\sigma^{-5.647}$	IPRS Jan 1988	r = 74 %	e = 0.907
$y = 5.665\,E{-}03\,\sigma^{-3.520}$	IPRS July 1988	r = 95 %	e = 0.415
$y = 4.365\,E{-}02\,\sigma^{-2.819}$	Parit Sikom	r = 93 %	e = 0.491

FIGURE 5.5: Dry bulk density depth relationship

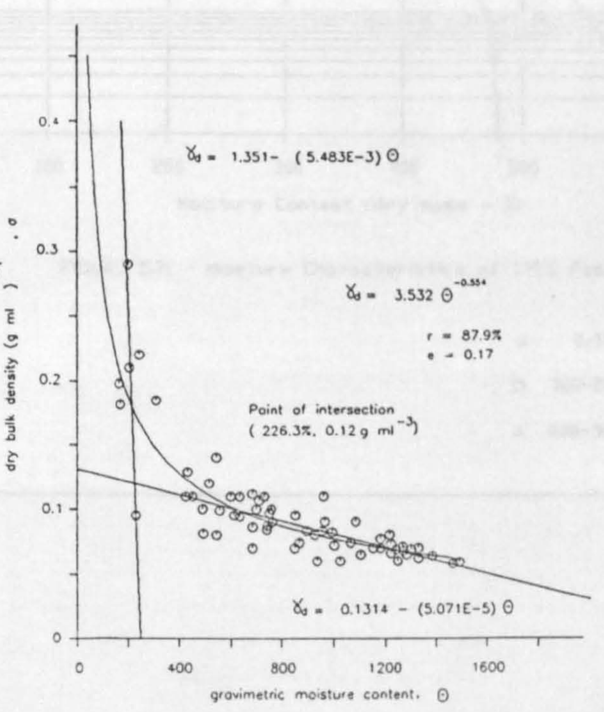


FIGURE 5.6: Gravimetric Moisture Content Bulk Density Relationship

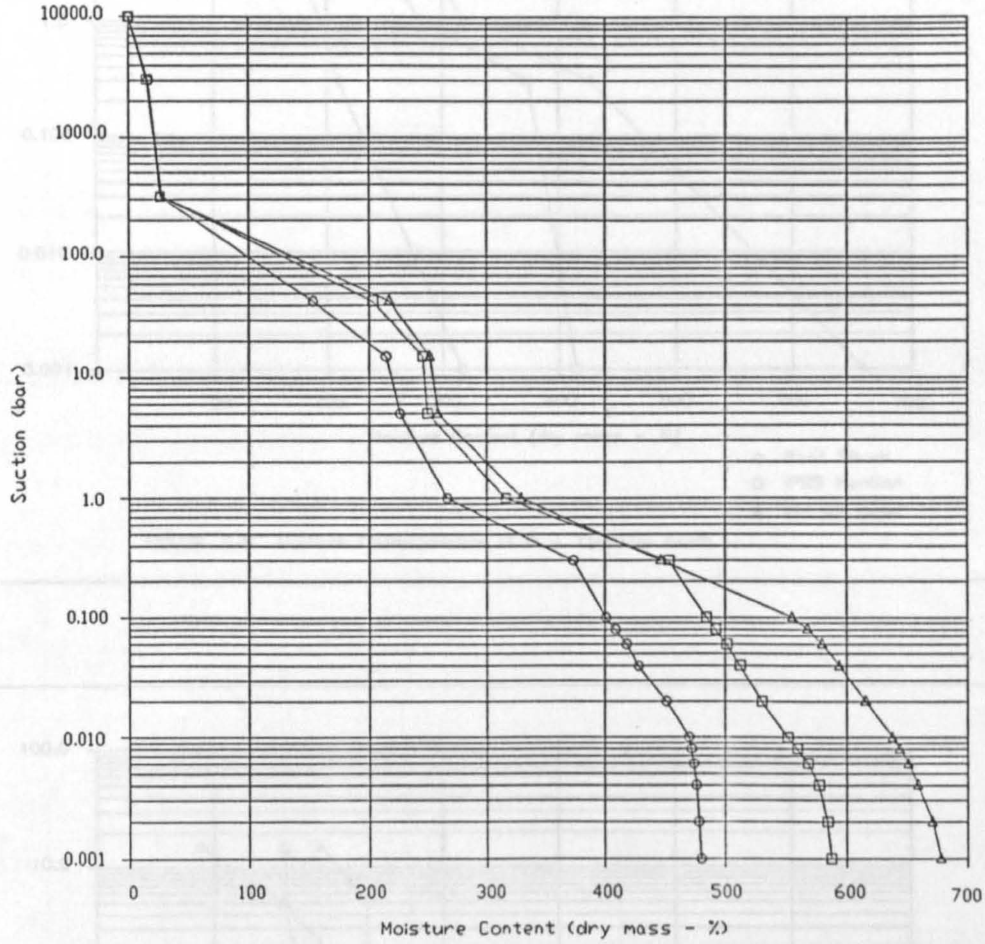


FIGURE 5.7: Moisture Characteristics of IPRS Peat

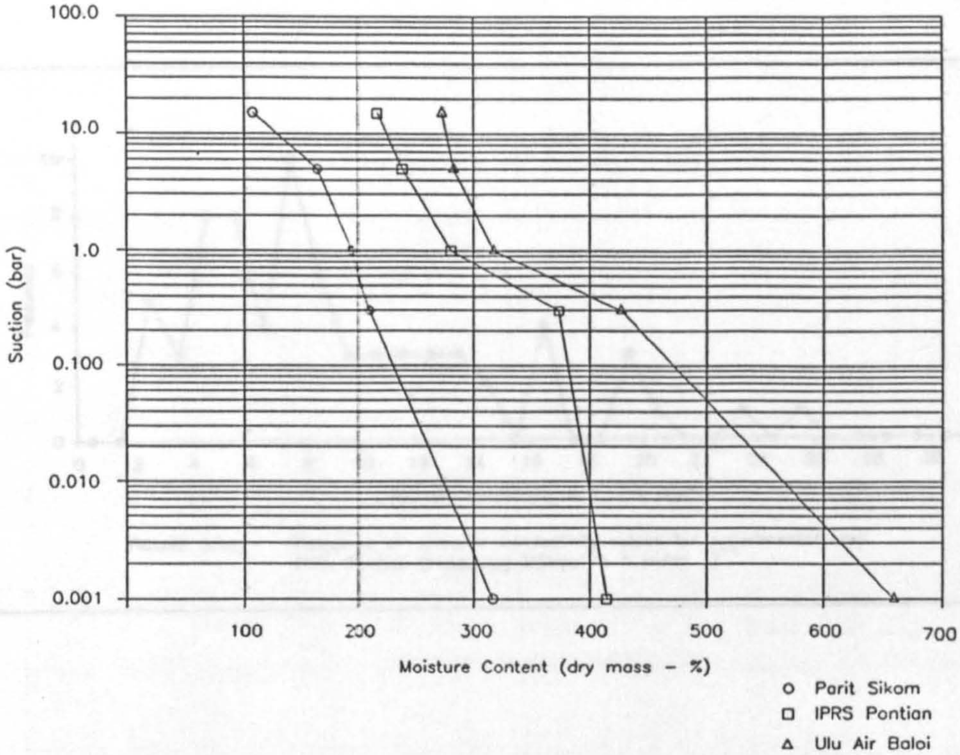


FIGURE 5.8: Moisture Characteristics of 0 – 150 mm depth

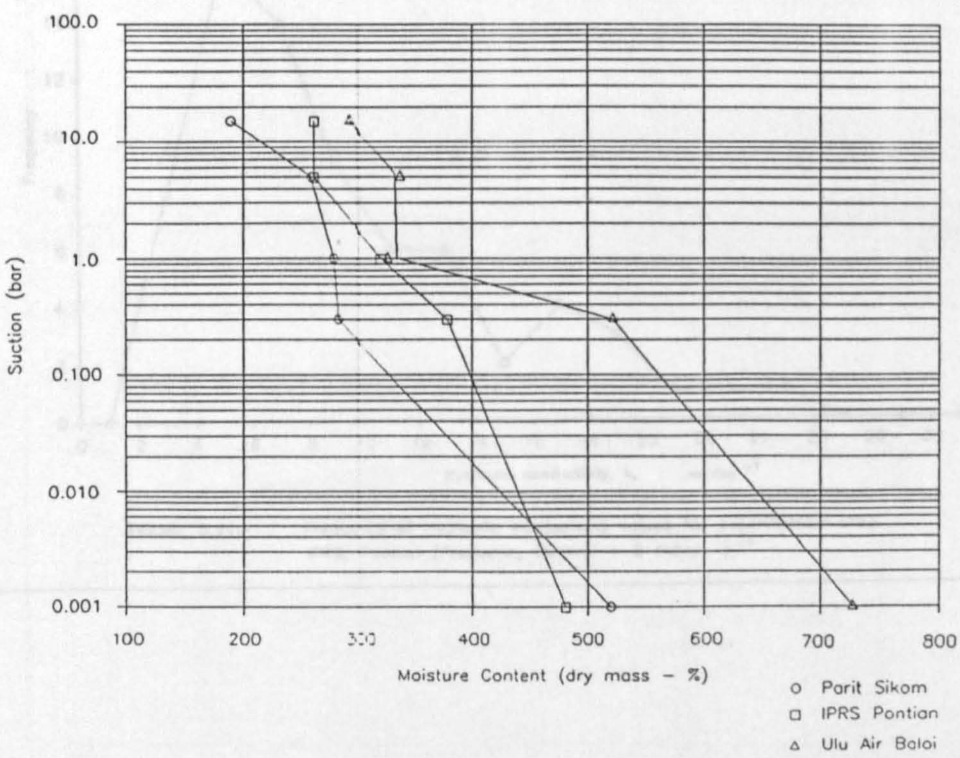


FIGURE 5.9: Moisture Characteristics of 150–300 mm depth

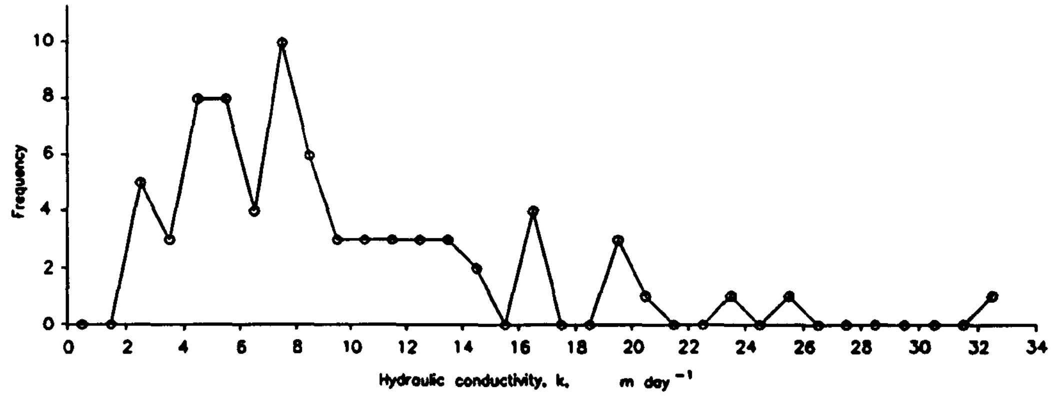


FIGURE 5.10: Frequency of hydraulic conductivity values for experimental area IPRS, Pontian (Frequency interval = 1 mday^{-1})

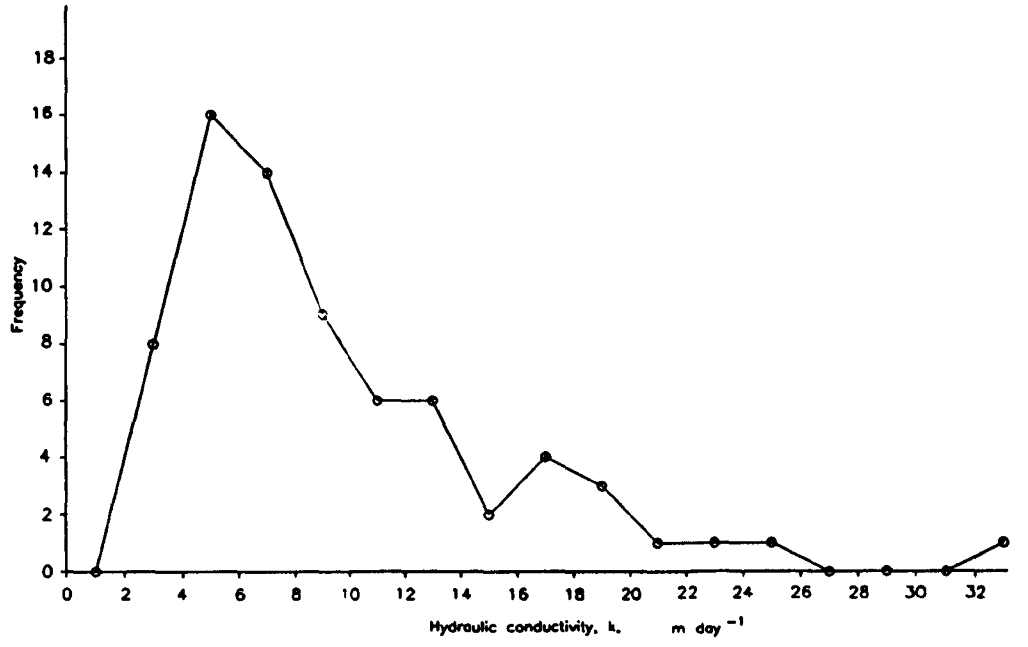


FIGURE 5.11: Frequency of hydraulic conductivity values for experimental area IPRS, Pontian (Frequency interval = 2 mday^{-1})

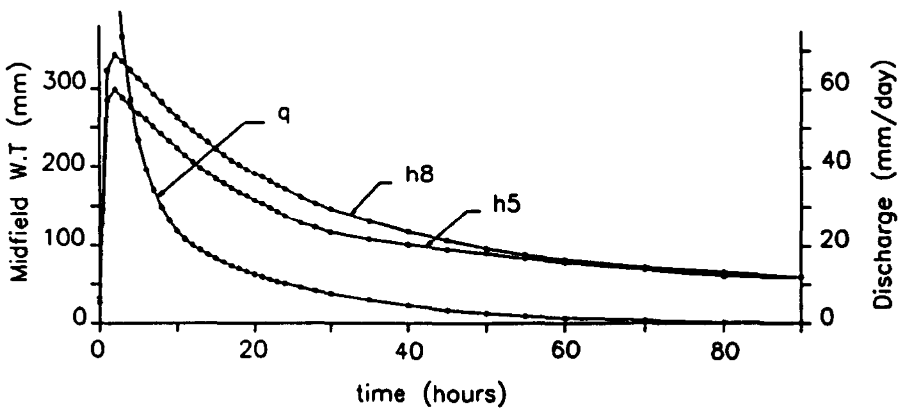


FIGURE 5.12: Mid-fields Water Tables and Drain Discharge
13th September 1988

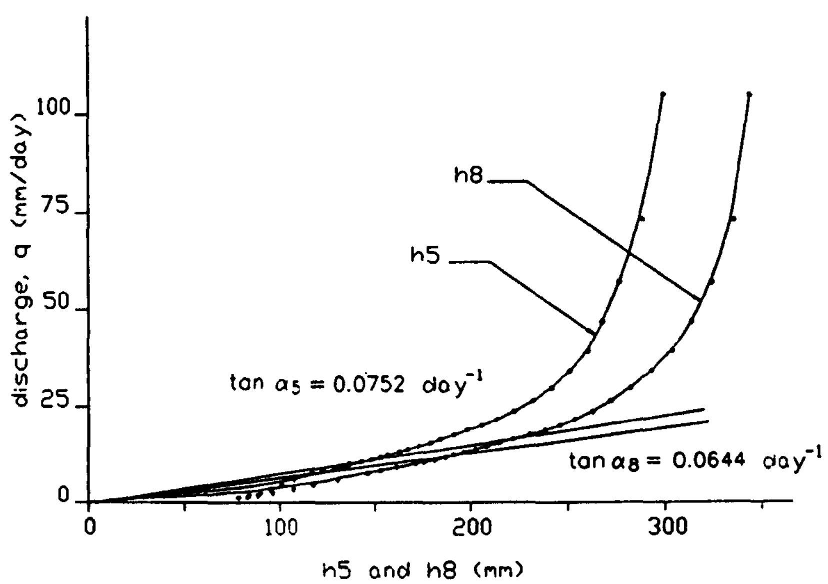


FIGURE 5.13: Discharge q against mid-field water table h_5 and h_8
13th September 1988

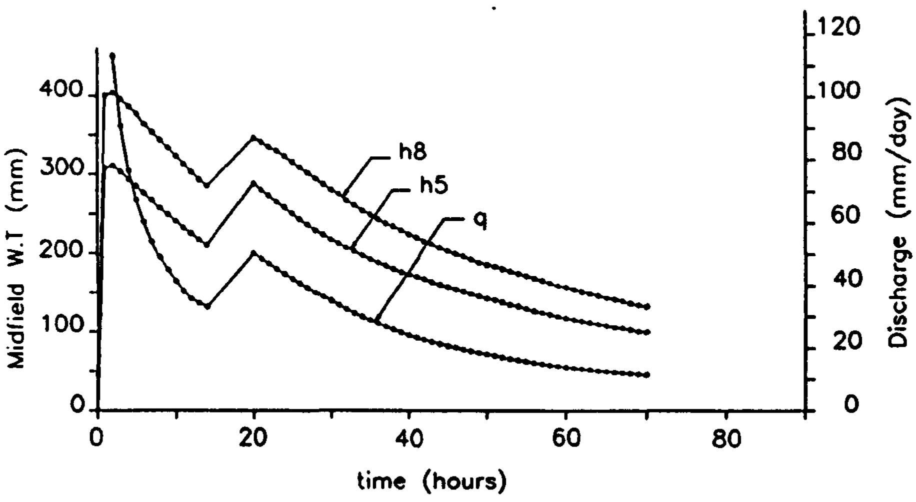


FIGURE 5.14: Midfield Water Tables and Drain Discharge 27th September 1988

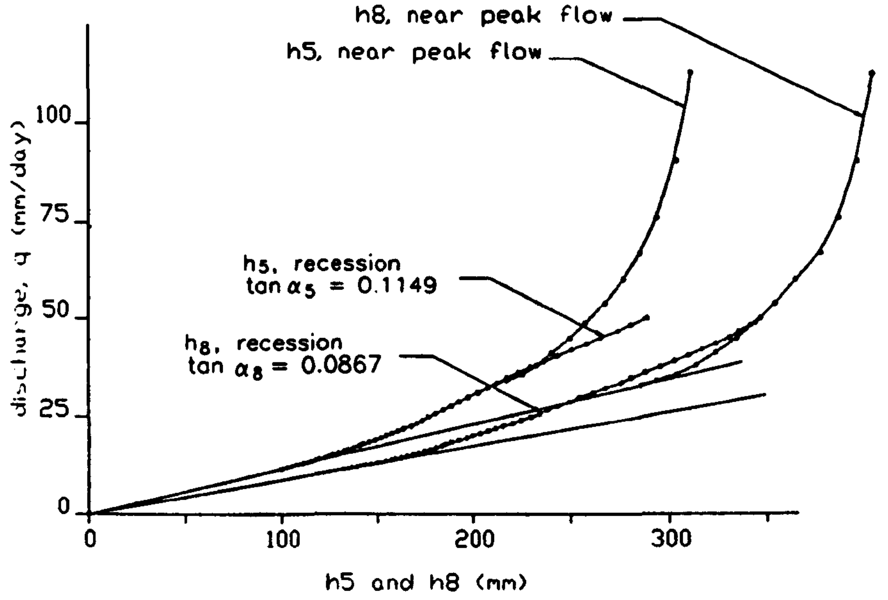


FIGURE 5.15: Discharge q against mid-field water table, h_5 and h_8, 27th September 1988

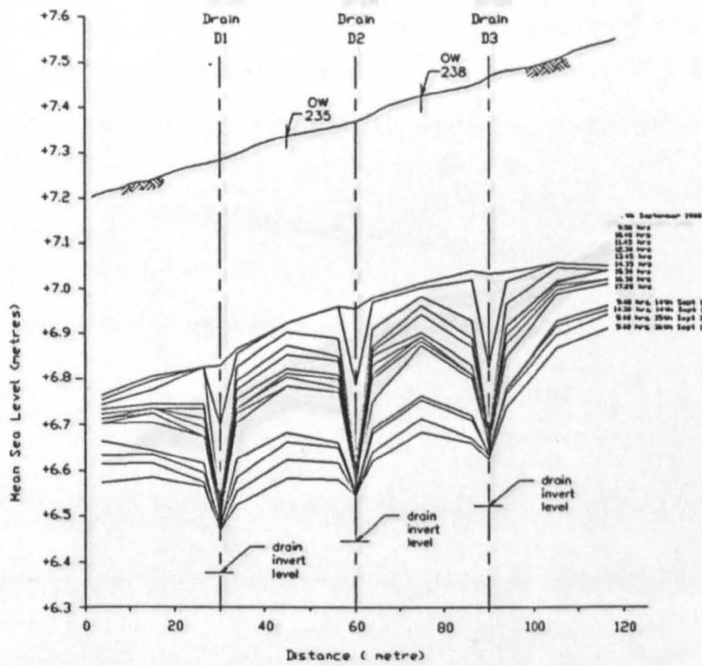


FIGURE 5.16 - Water table shape for drawdown on 13th September 1988
Row 3, Plot 2, IPRS Pontian

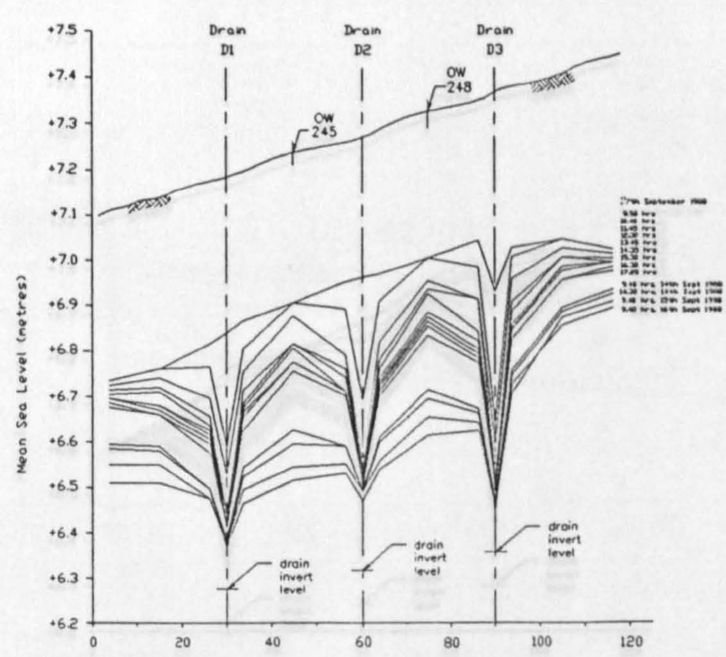


FIGURE 5.17 - Water table shape for drawdown on 13th September 1988
Row 4, Plot 2, IPRS Pontian

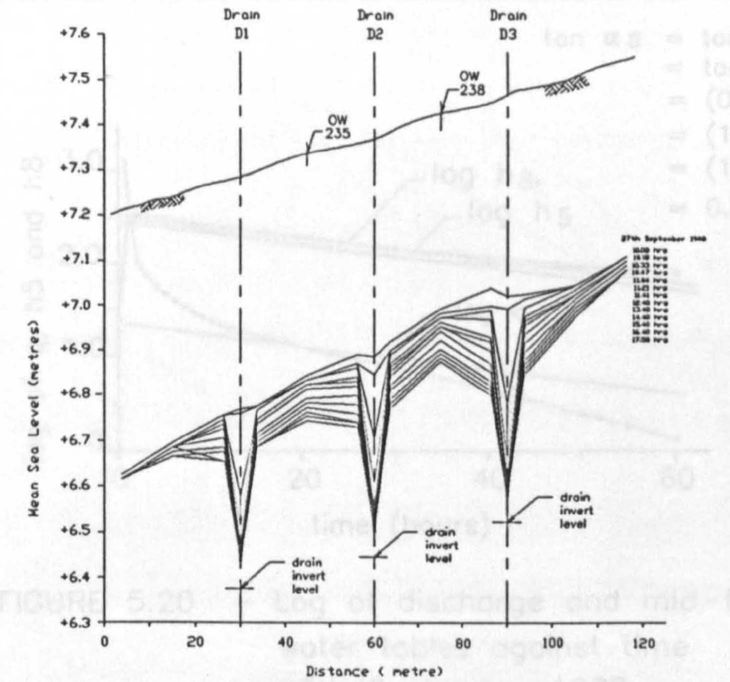


FIGURE 5.18 - Water table shape for drawdown on 27th September 1988

Row 3, Plot 2, IPRS Pontian

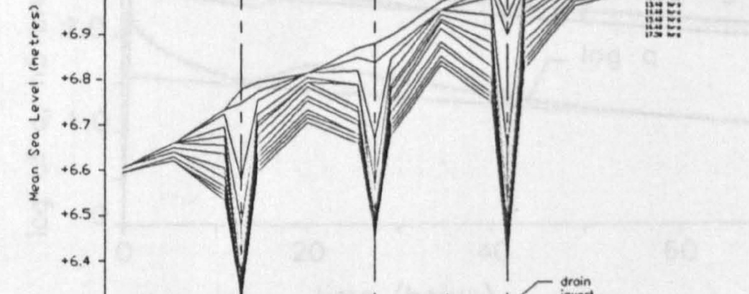


FIGURE 5.19 - Water table shape for drawdown on 27th September 1988

Row 4, Plot 2, IPRS Pontian

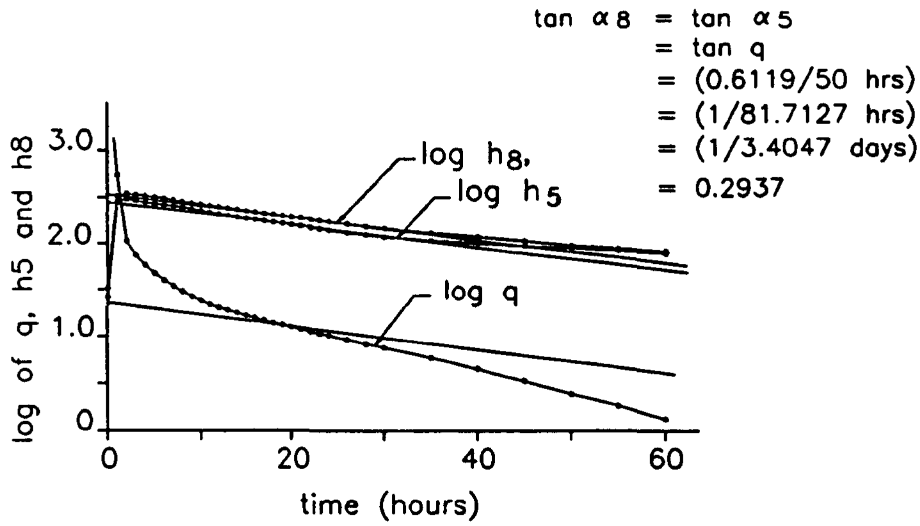


FIGURE 5.20 – Log of discharge and mid-field water tables against time 13th September 1988

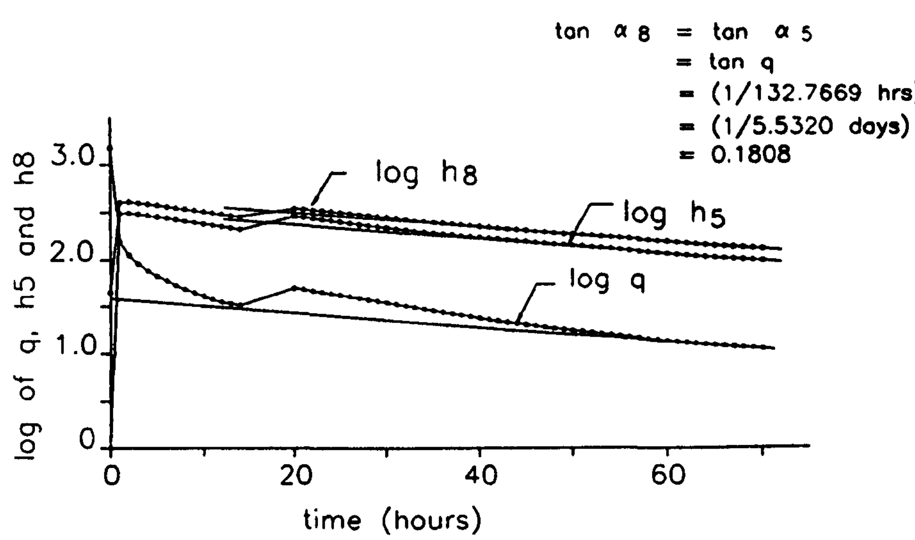


FIGURE 5.21 – Log of discharge and mid-field water tables against time 27th September 1988

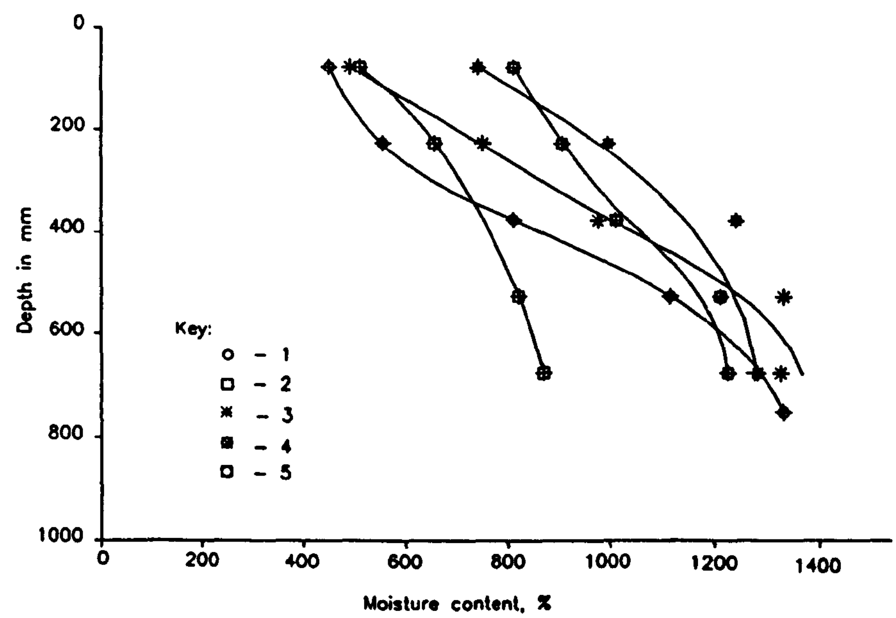


FIGURE 5.22a - Capillary Fringe

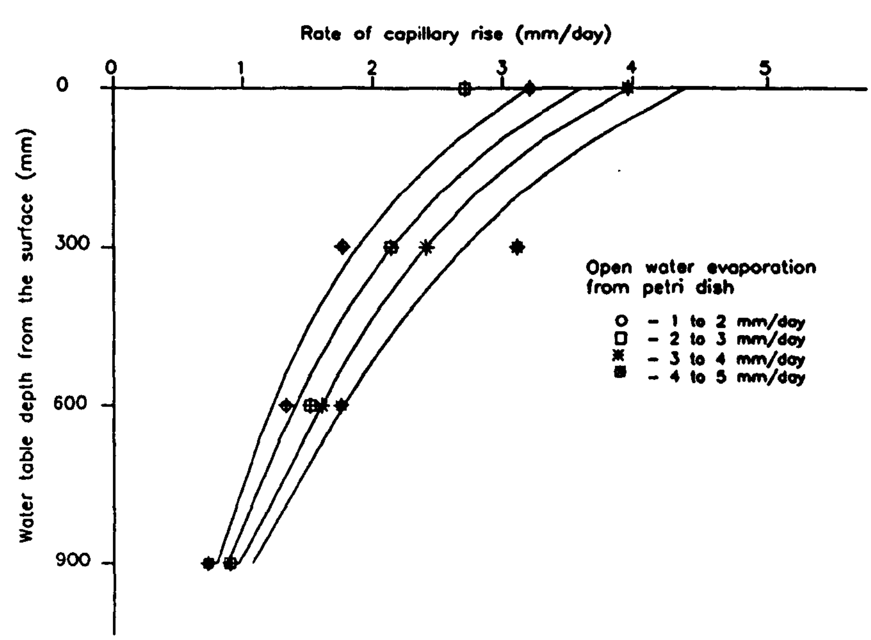


FIGURE 5.22b - Rate of Capillary Rise at varying water table depth

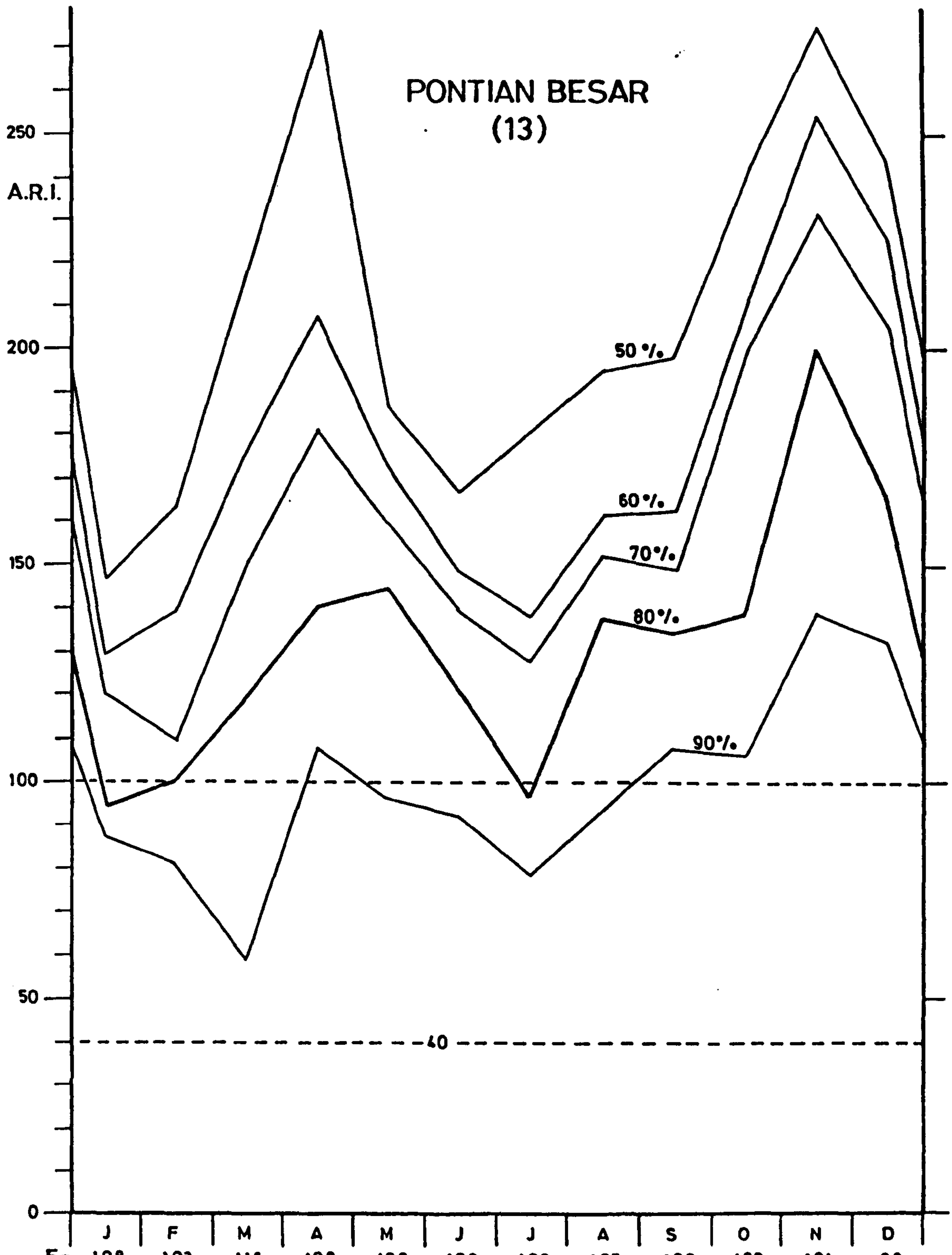


FIGURE 5.23 Monthly Values of the Agricultural Rainfall Index for various Rainfall Probabilities at Pontian Besar (From Figure 59, Nieuwolt, 1982)

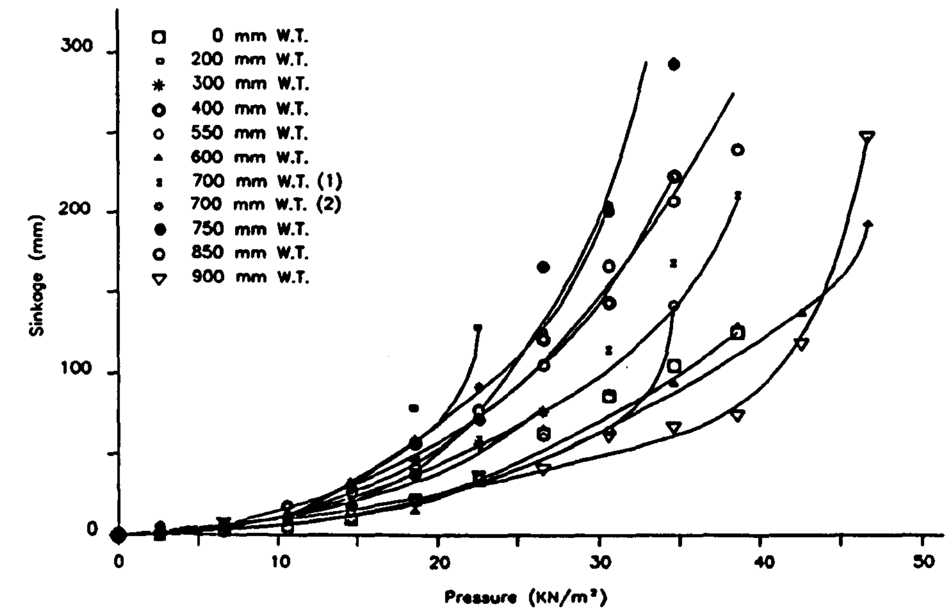


FIGURE 5.24 – Pressure Sinkage Relationship for all tests

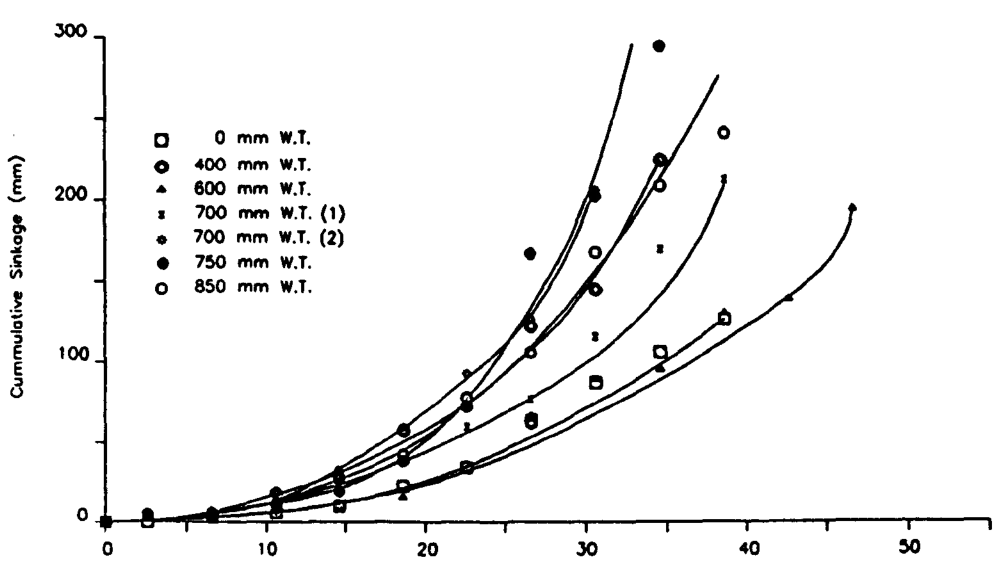


FIGURE 5.25 – Pressure Sinkage Relationship for tests with failures due to tilting over

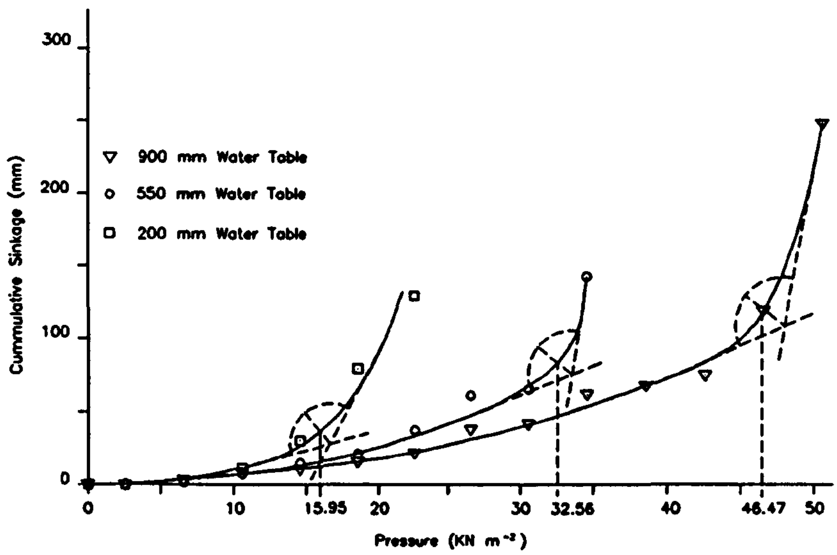


FIGURE 5.26 – Pressure Sinkage Relationship for unrestrained sinkage only

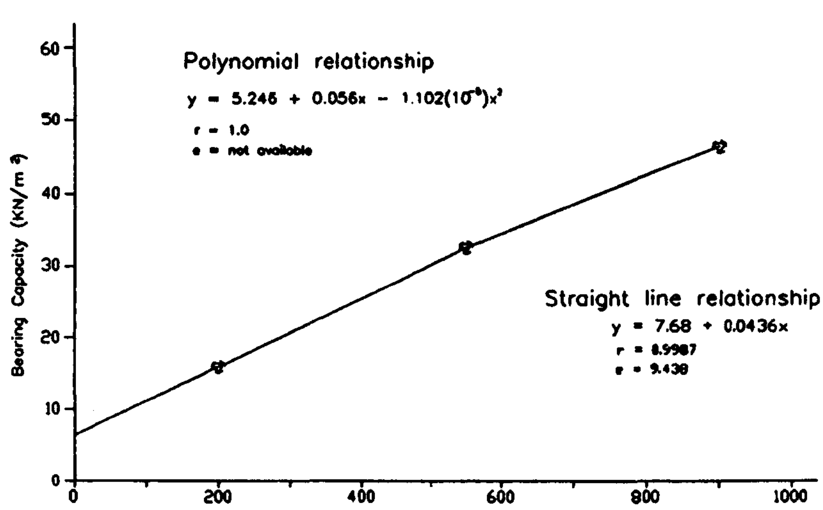
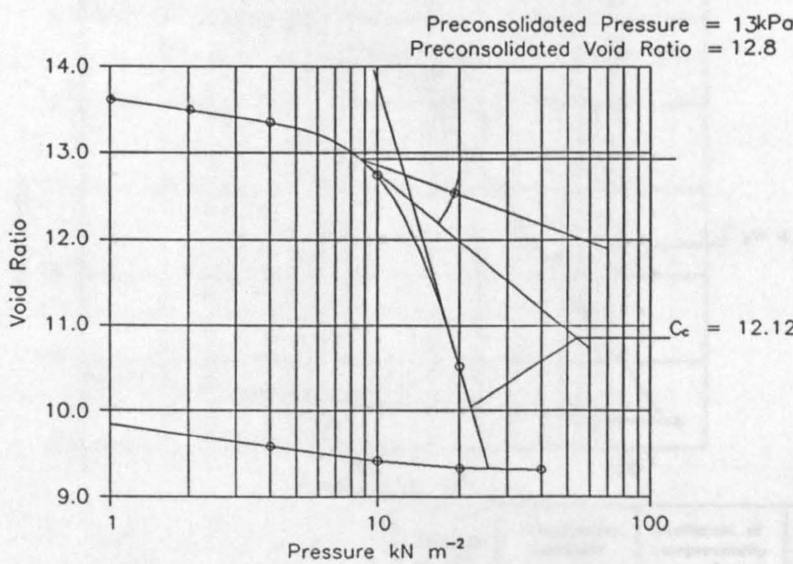


FIGURE 5.27 – Water Table Bearing Capacity Relationship

Location: IPRS Pontian
Date : 30th Jan to 8th Feb 1988

Description of Sample: Woody Peat
Ref: Consol 4, efpne1.dwg



Specific gravity: 1.34

Bulk density: 0.96 Mg m^{-3}

Dry density: 0.09 Mg m^{-3}

Natural moisture content: 853 %

Degree of saturation: 83 %

Initial void ratio: 13.9

Depth below ground level: 150mm

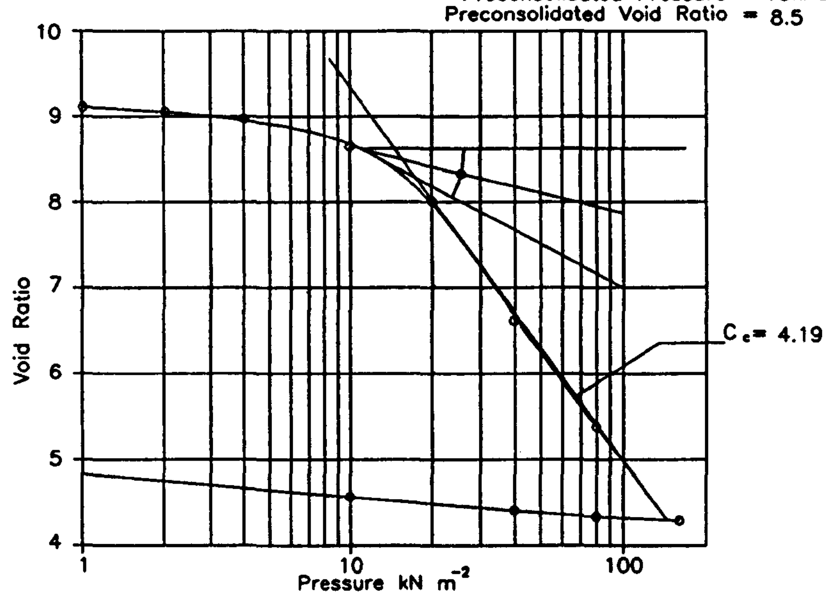
Pressure kN m^{-2}	Consolidation coefficient c_v m^{2}yr^{-1}	coefficient of compressibility m_v m^2 MN^{-1}	Secondary compression index C_t mm(log min)$^{-1}$
1	122.35	16.26	0.14
2	163.62	12.15	0.15
4	144.17	8.74	0.14
10	9.15	8.09	0.54
20	18.71	14.48	2.10
40	–	–	–
80	–	–	–
160	–	–	–

FIGURE 5.23 – Consolidation Results, IPRS Pontian
30th Jan – 8th Feb, 1988

Location: IPRS Pontian
Date : 15th to 26th Feb 1988

Description of Sample: Woody Peat
Ref: Consol 4, efpne2.dwg

Preconsolidated Pressure = 16kPas
Preconsolidated Void Ratio = 8.5



Specific gravity: ....1.34........

Bulk density:..............0.83........ Mg m^{-3}

Dry density: ....0.13........ Mg m^{-3}

Natural moisture content: .533.%

Degree of saturation: 78.%

Initial void ratio: ....9.14........

Depth below ground level: .300mm

Pressure kN m^{-2}	Consolidation coefficient c_v m^2yr^{-1}	coefficient of compressibility m_v $m^2 MN^{-1}$	Secondary compression index, C_t mm(log min)$^{-1}$
1	-	-	-
2	2531	4.93	0.32
4	44.06	4.24	0.26
10	16.07	5.56	0.75
20	6.15	7.11	0.48
40	3.55	9.10	2.90
80	2.37	4.88	2.20
160	1.54	2.56	0.60

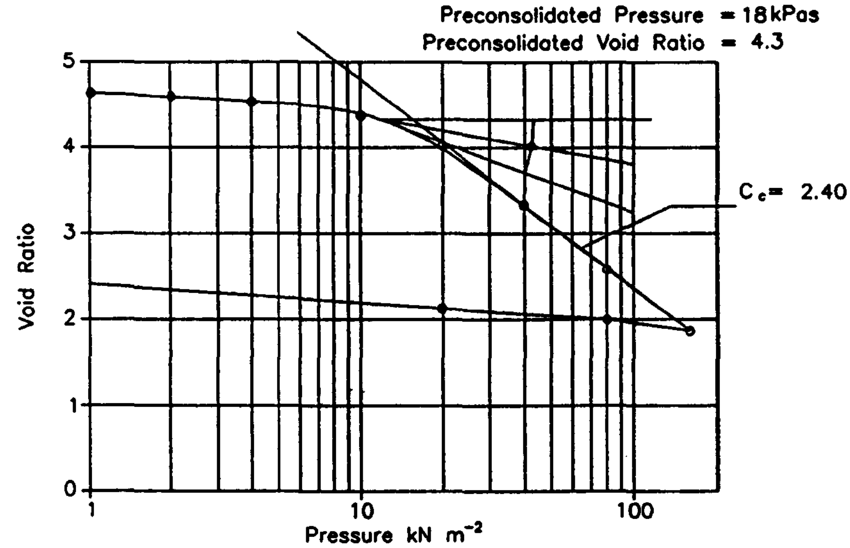
FIGURE 5.29 – Consolidation Results IPRS Pontian
15th Feb – 26th Feb 1988

Location: IPRS Pontian | Description of Sample: Woody Peat

Date : 13th to 23rd March 1988 | Ref: consol 4, efpne3.dwg

Preconsolidated Pressure = 18kPas

Preconsolidated Void Ratio = 4.3



Specific gravity: 1.34

Bulk density: 0.85 Mg m^{-3}

Dry density: 0.24 Mg m^{-3}

Natural moisture content: 262 %

Degree of saturation: 75 %

Initial void ratio: 4.69

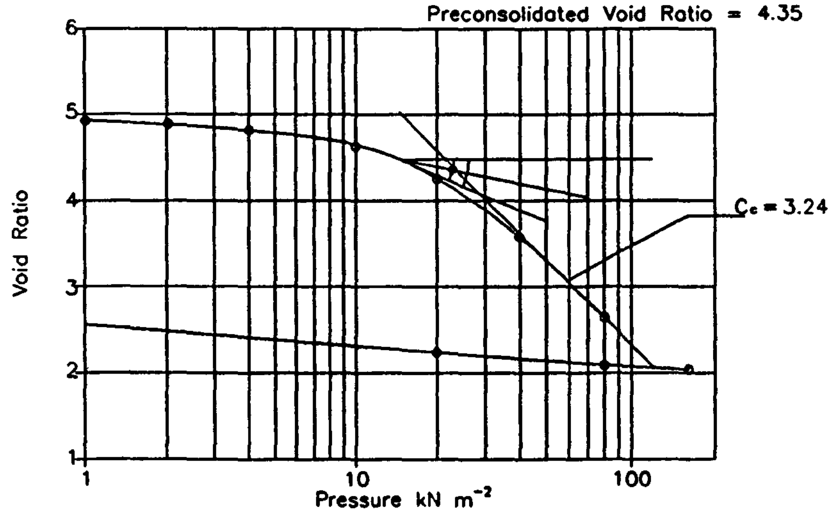
Depth below ground level: 150mm

Pressure kN m^{-2}	Consolidation coefficient c_v m^{2}yr^{-1}	coefficient of compressibility m_v m^2 MN^{-1}	Secondary Compression Index, C_α mm(log min)$^{-1}$
1	–	–	–
2	1133.51	6.43	0.16
4	535.64	6.06	0.20
10	295.53	4.93	0.47
20	26.03	6.39	1.10
40	5.93	7.39	2.75
80	2.53	5.32	2.40
160	1.43	3.07	3.20

FIGURE 5.30 – Consolidation Results IPRS Pontian
13th Mar – 23rd Mar 1988

Location: IPRS Pontian
Date : 27th March to 6th April 1988

Description of Sample: Woody Peat
Ref: Consol 4, efpne4.dwg



Specific gravity: 1.34

Bulk density: 0.91 Mg m^{-3}

Dry density: 0.22 Mg m^{-3}

Natural moisture content: 305 %

Degree of saturation: 82 %

Initial void ratio: 4.98

Depth below ground level: 150mm

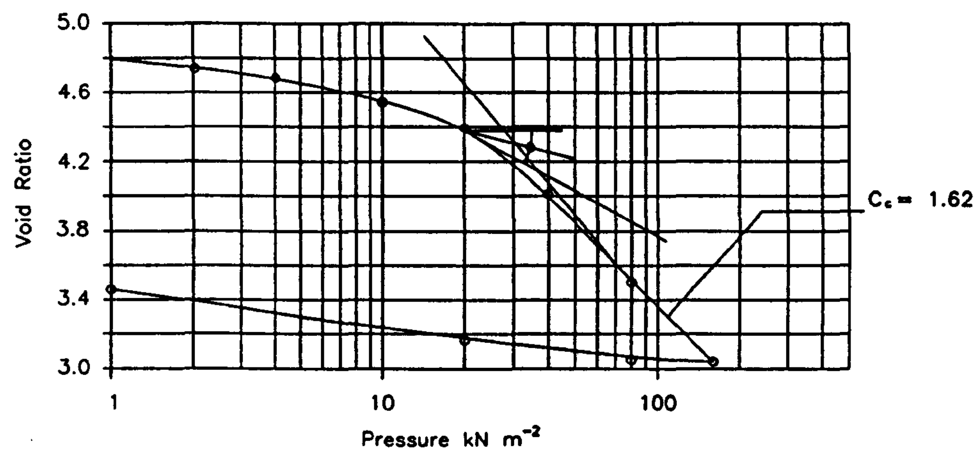
Pressure kN m^{-2}	Consolidation coefficient c_v m^2yr^{-1}	coefficient of compressibility m_v $m^2 MN^{-1}$	Secondary Compression Index, C_t mm(log min)$^{-1}$
1	–	–	–
2	36.99	6.26	0.011
4	815.35	6.33	0.190
10	176.12	5.32	0.350
20	60.35	7.35	1.100
40	17.59	7.32	1.900
80	3.35	6.39	3.600
160	1.62	2.44	0.300

FIGURE 5.31 – Consolidation Results, IPRS Pontian
27th Mar – 6th Apr 1988

Location: Parit Sikom
Date : 7th to 15th May 1988

Description of Sample: Woody Peat
Ref: Consol 3, pspne5.dwg

Preconsolidated Pressure = 31kPas
Preconsolidated Void Ratio = 4.3



Specific gravity: 1.34

Bulk density: 0.96 Mg m^{-3}

Dry density: 0.23 Mg m^{-3}

Natural moisture content: 314 %

Degree of saturation: 89 %

Initial void ratio: 4.74

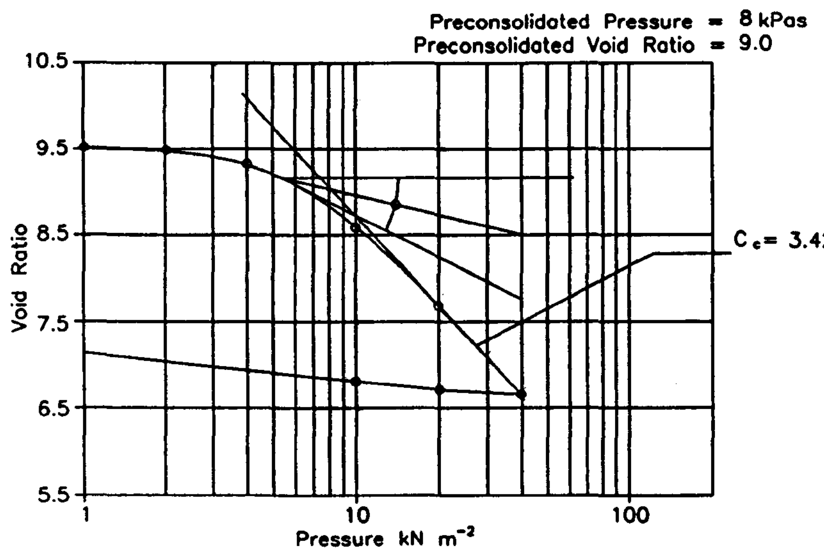
Depth below ground level: 150mm

Pressure kN m^{-2}	Consolidation coefficient c_v m^2yr^{-1}	coefficient of compressibility m_v $m^2 MN^{-1}$	Secondary Compression Index, C_α mm(log min)$^{-1}$
1	–	–	–
2	–	1.55	–
4	1422.19	5.50	0.20
10	1734.68	6.19	0.38
20	591.34	6.61	0.38
40	379.99	7.34	1.13
80	3.14	6.91	1.50
160	2.04	5.28	1.50

FIGURE 5.32 – Consolidation Results, Parit Sikom
7th May – 15th May 1988

Location: Parit Sikom
Date : 31st. May to 8th. June.

Description of Sample: Woody Peat
Ref: Consol 3, pspne6.dwg



Specific gravity: 1.34

Bulk density: 0.82 Mg m^{-3}

Dry density: 0.13 Mg m^{-3}

Natural moisture content: 547 %

Degree of saturation: 76 %

Initial void ratio: 9.61

Depth below ground level: 300mm

Pressure kN m^{-2}	Consolidation coefficient c_v $m^2 yr^{-1}$	coefficient of compressibility m_v $m^2 MN^{-1}$	Secondary Compression Index C_t mm(log min)$^{-1}$
1	-	-	-
2	-	2.96	0.13
4	202.67	7.72	0.25
10	156.05	12.82	0.97
20	70.92	10.41	1.13
40	2.76	6.71	0.27
80	-	-	-
160	-	-	-

FIGURE 5.33 – Consolidation Results, Parit Sikom
31st May – 8th June 1988

Location: Ulu Air Baloi

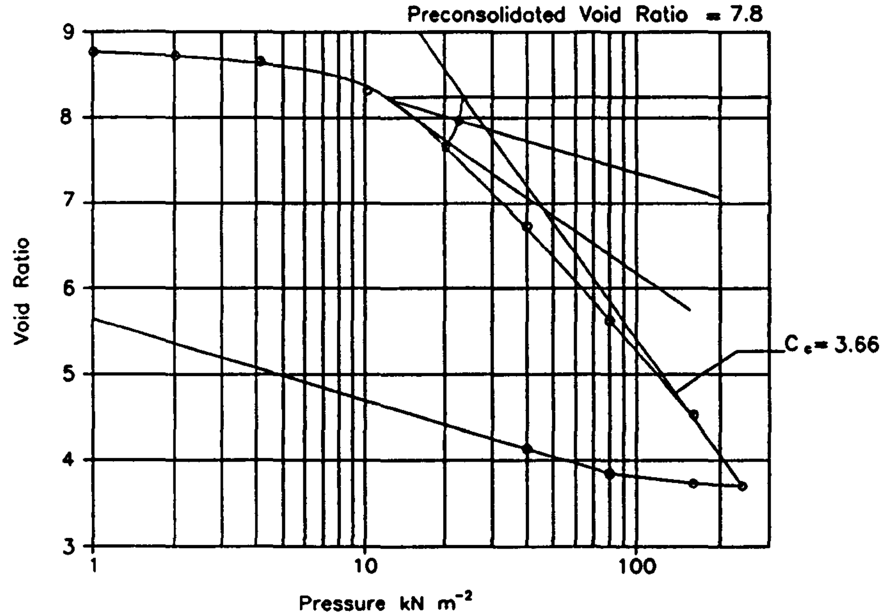
Date : 10th to 22nd July

Description of Sample: Woody Peat

Ref: Consol 3, ubpne7.dwg

Preconsolidated Pressure = 28kPas

Preconsolidated Void Ratio = 7.8



Specific gravity: 1.34

Bulk density: 0.84 Mg m^{-3}

Dry density: 0.14 Mg m^{-3}

Natural moisture content: 507 %

Degree of saturation: 78 %

Initial void ratio: 8.7

Depth below ground level: 150mm

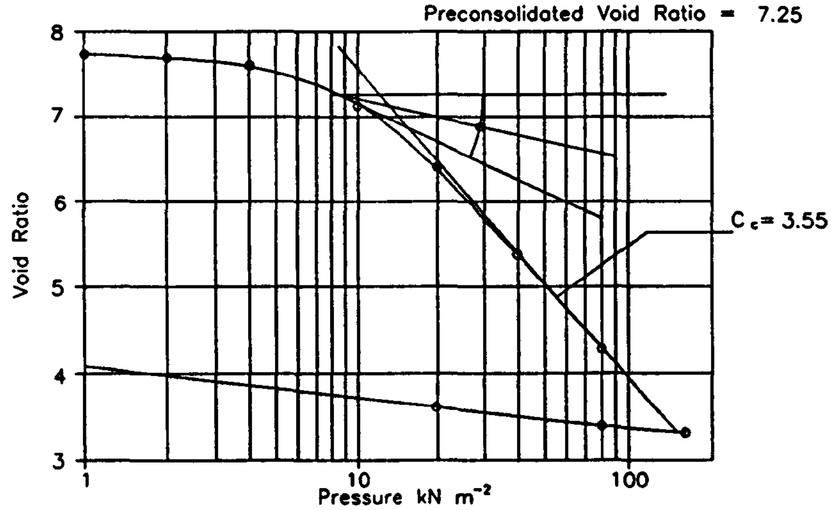
Pressure kN m^{-2}	Consolidation coefficient c_v m^2yr^{-1}	coefficient of compressibility m_v m^2 MN^{-1}	Secondary Compression Index, C_t mm(log min)$^{-1}$
1	–	–	–
2	52.04	4.38	0.08
4	26.65	3.49	0.10
10	82.94	5.96	0.50
20	131.72	7.57	1.00
40	91.97	6.05	1.58
80	2.99	4.15	2.48
160	1.30	1.87	3.00

FIGURE 5.34 – Consolidation Results, Ulu Air Baloi
10th Jul – 22nd Jul 1988

Location: Ulu Air Baloi
Date : 12th to 23rd August 1988

Description of Sample: Woody Peat
Ref: Consol 3, ubpne8.dwg

Preconsolidated Pressure = 16kPas
Preconsolidated Void Ratio = 7.25



Specific gravity: ....1.34.........

Bulk density:............0.80..........Mg m^{-3}

Dry density: ....0.15..........Mg m^{-3}

Natural moisture content: ..418.%

Degree of saturation: 73.%

Initial void ratio: ....7.70..

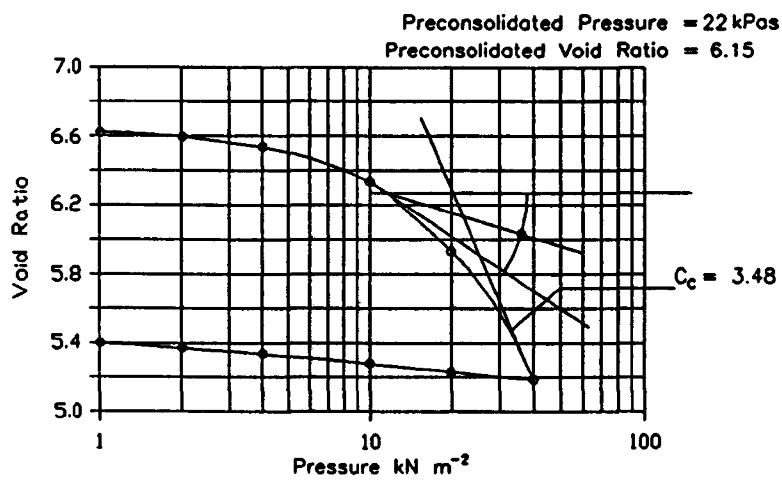
Depth below ground level: ..... mm

Pressure kN m^{-2}	Consolidation coefficient c_v m^{2}yr^{-1}	coefficient of compressibility m_v m^2 MN^{-1}	Secondary Compression Index, C_t mm/log min^{-1}
1	–	–	–
2	118.93	4.48	0.09
4	380.39	5.41	0.17
10	255.52	9.64	0.80
20	173.85	9.66	1.30
40	39.25	8.12	1.70
80	23.77	5.11	1.80
160	10.70	2.81	2.00

FIGURE 5.35 – Consolidation Results, Ulu Air Baloi
12th – 23rd August 1988

Location: IPRS, Pontian
Date : 5th Sep to 22nd Oct 88

Description of Sample: Woody Peat
Ref: Consol 2 efpne9.dwg



Specific gravity: 1.34

Bulk density: 0.88 Mg m^{-3}

Dry density: 0.17 Mg m^{-3}

Natural moisture content: 408 %

Degree of saturation: 82 %

Initial void ratio: 6.69

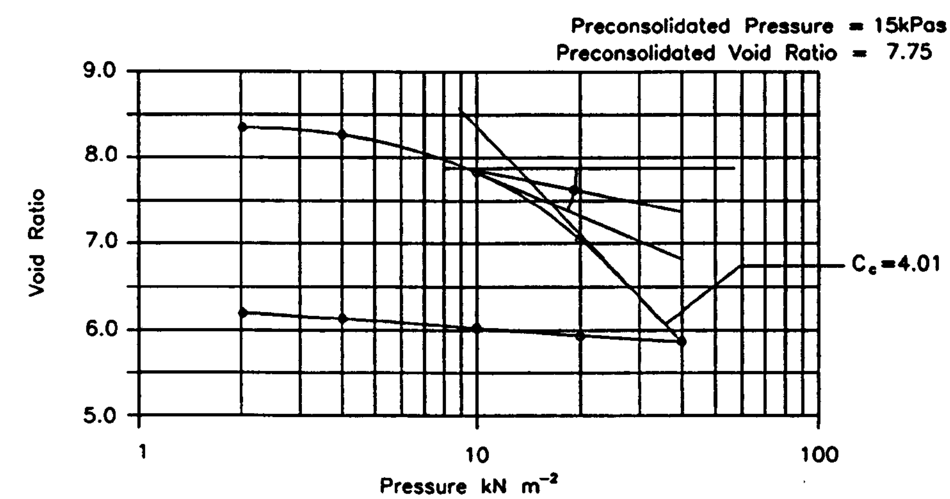
Depth below ground level: 150mm

Pressure kN m^{-2}	Consolidation coefficient c_v m^{2}yr^{-1}	coefficient of compressibility m_v m^2 MN^{-1}	Secondary Compression Index, C_t mm (log min)$^{-1}$
1	142.4	9.9	– 0.05
2	307.5	6.92	– 0.07
4	214.4	5.47	– 0.15
10	97.2	5.09	– 0.35
20	36.8	5.5	– 0.75
40	48.9	6.12	– 1.40
80	–	–	–
160	–	–	–

FIGURE 5.36 – Consolidation Results IPRS Pontian
5th Sep – 22nd Oct 1988

Location: Plot 6, IPRS
Date : 27th October to 5th Dec

Description of Sample: Woody Peat
Ref: Consol 2, efpne11.dwg



Specific gravity: 1.34

Bulk density: 0.79 Mg m^{-3}

Dry density: 0.14 Mg m^{-3}

Natural moisture content: 451 %

Degree of saturation: 72 %

Initial void ratio: 8.46

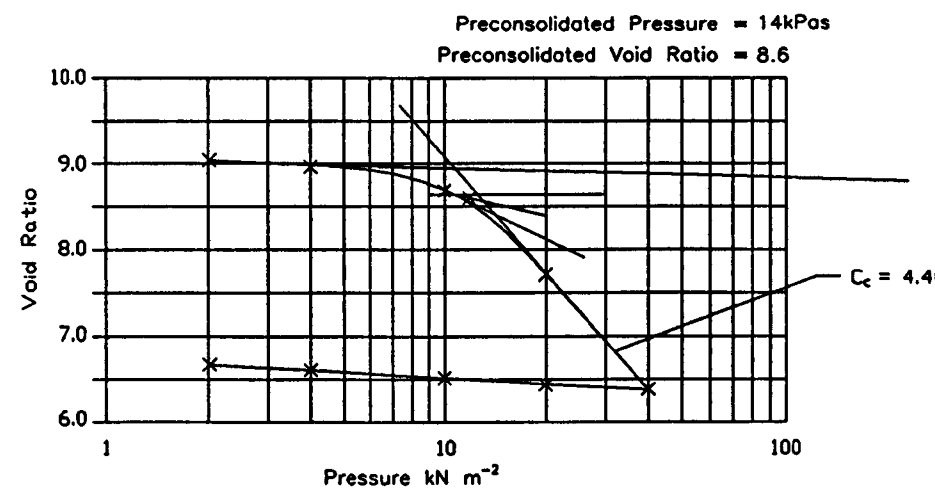
Depth below ground level: 150 mm

Pressure kN m^{-2}	Consolidation coefficient c_v m^2yr^{-1}	coefficient of compressibility m_v m^2 MN^{-1}	Secondary Compression Index, C_t mm (log min)$^{-1}$
1	-	-	-
2	83.73	5.46	0.95
4	139.70	4.35	0.14
10	75.90	8.21	0.45
20	48.99	9.67	1.32
40	7.31	8.60	1.50
80	-	-	-
160	-	-	-

FIGURE 5.37 – Consolidation Results, IPRS Pontian
27th Oct – 5th Dec 1988

Location: Lysimeter area
Date : 7th Dec 88 to 15th Jan 89

Description of Sample: Woody Peat
Ref: Consol 2, efpne12.dwg



Specific gravity: 1.34
Bulk density: 0.79 Mg m^{-3}
Dry density: 0.13 Mg m^{-3}
Natural moisture content: 495 %
Degree of saturation: 73 %
Initial void ratio: 9.14
Depth below ground level: 15 mm

Pressure kN m^{-2}	Consolidation coefficient c_v m^{2}yr^{-1}	coefficient of compressibility m_v m^2 MN^{-1}	Secondary Compression Index, C_t mm (log min)$^{-1}$
1	–	–	–
2	49.3	3.7	–0.24
4	49.7	3.6	–0.13
10	30.3	4.9	–0.37
20	26.1	11.2	–1.50
40	3.2	9.0	–1.80
80	–	–	–
160	–	–	–

FIGURE 5.38 – Consolidation Results, Lysimeter Area
7th Dec – 15th Jan 1989

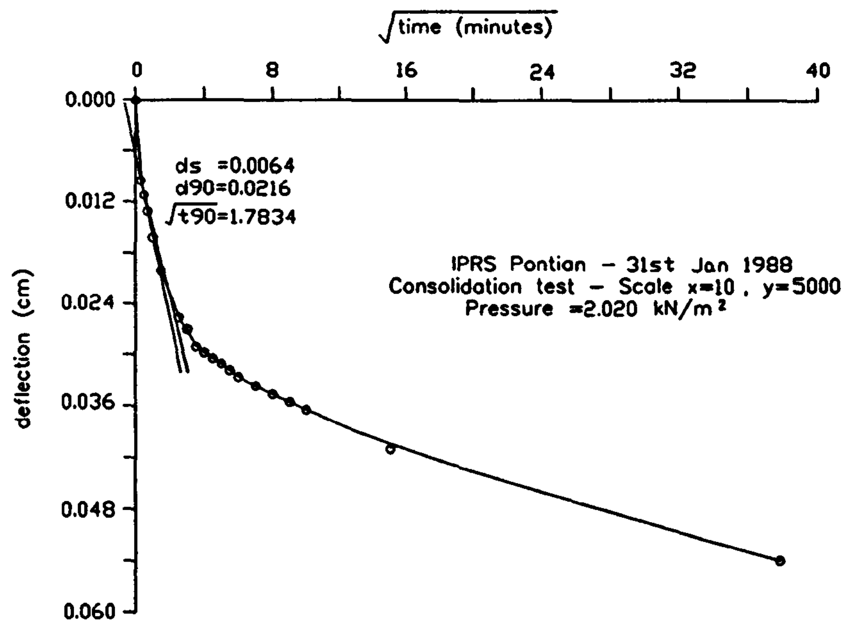


FIGURE 5.39 – Deflection versus Root Time Curve
IPRS Pontian, 31st January

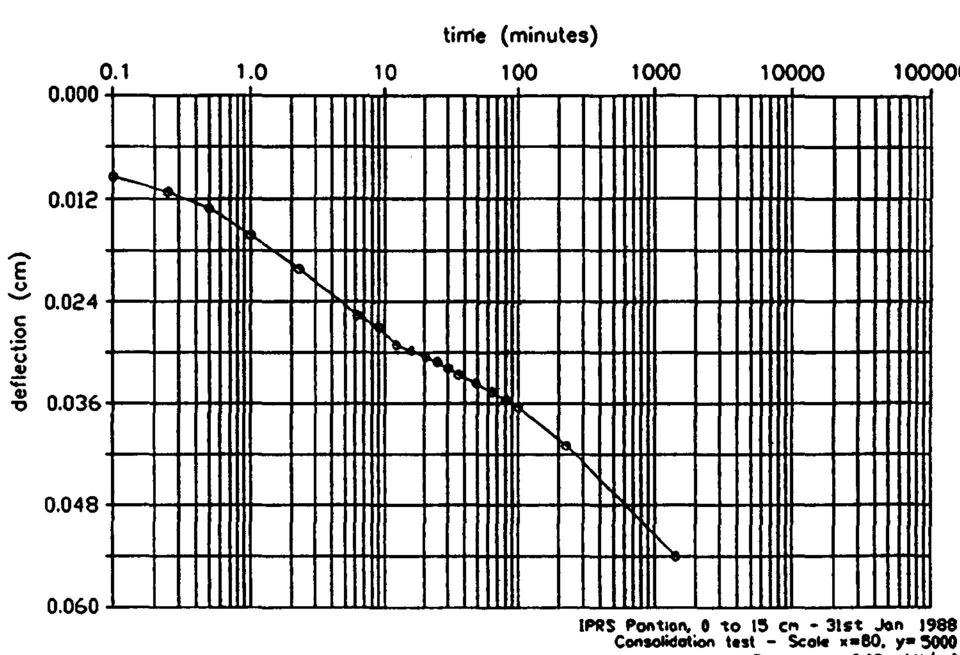


FIGURE 5.40 – Deflection versus Log Time Curve
IPRS, Pontian, 31st January 1988

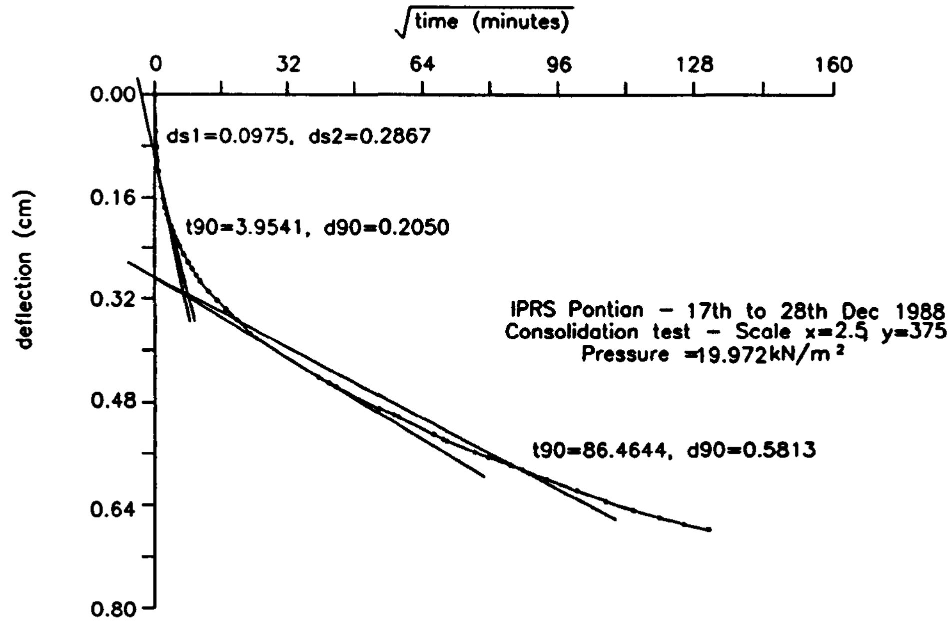


FIGURE 5.41 – Deflection versus Root Time Curve
IPRS Pontian, 17th to 28th December

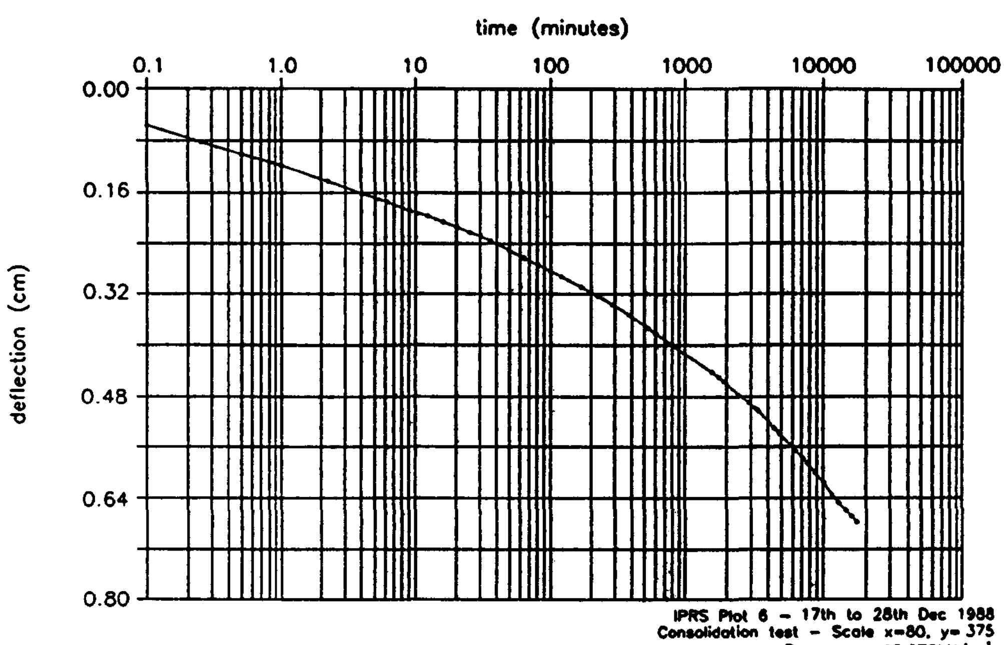


FIGURE 5.42 – Deflection versus Log Time Curve
IPRS Pontian, 17th to 28th December

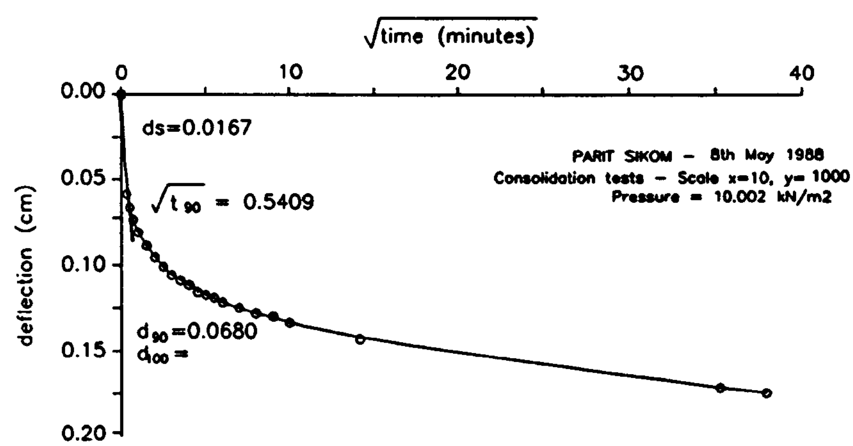


FIGURE 5.43 – Deflection versus Root Time Curve
Parit Sikom, 8th May 1988

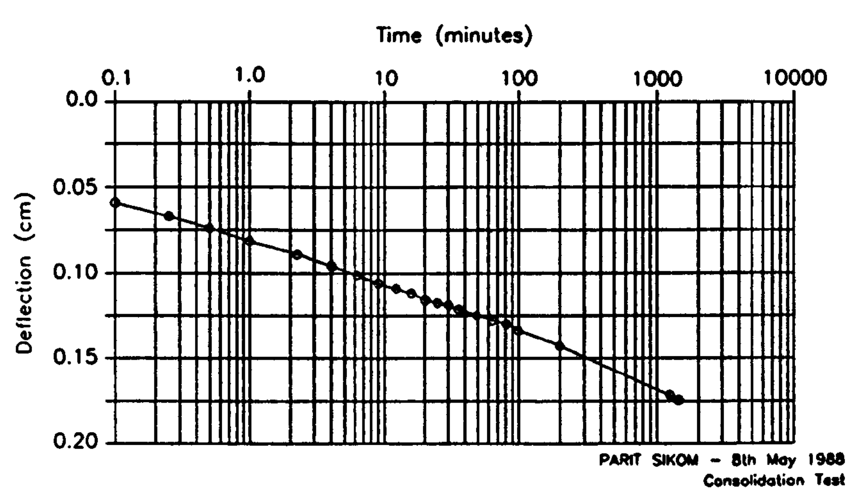


FIGURE 5.44 – Deflection versus Log Time Curve
Parit Sikom, 8th May 1988

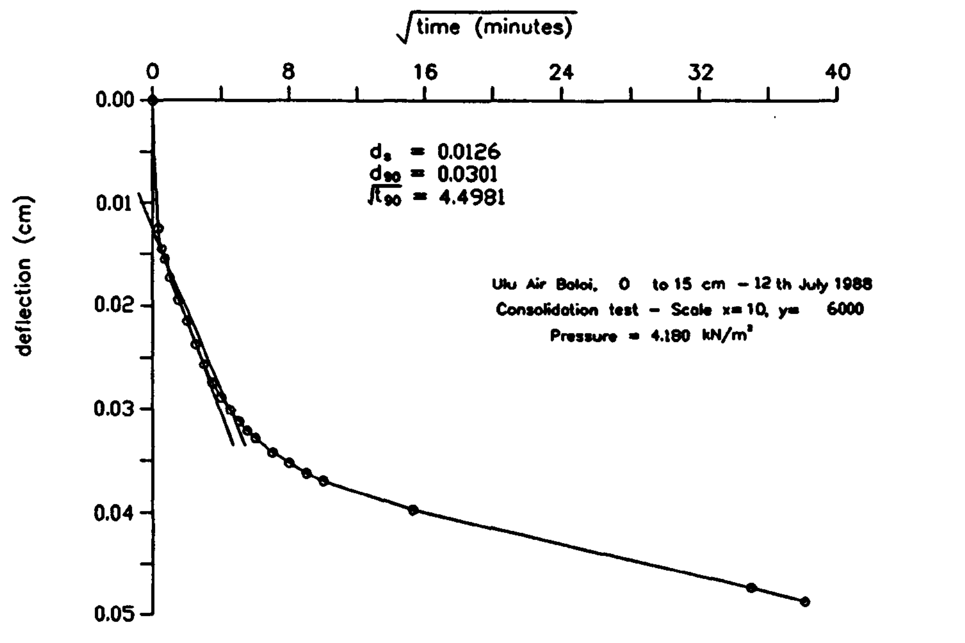


FIGURE 5.45 - Deflection versus Root Time Curve
Ulu Air Baloi, 12th July 1988

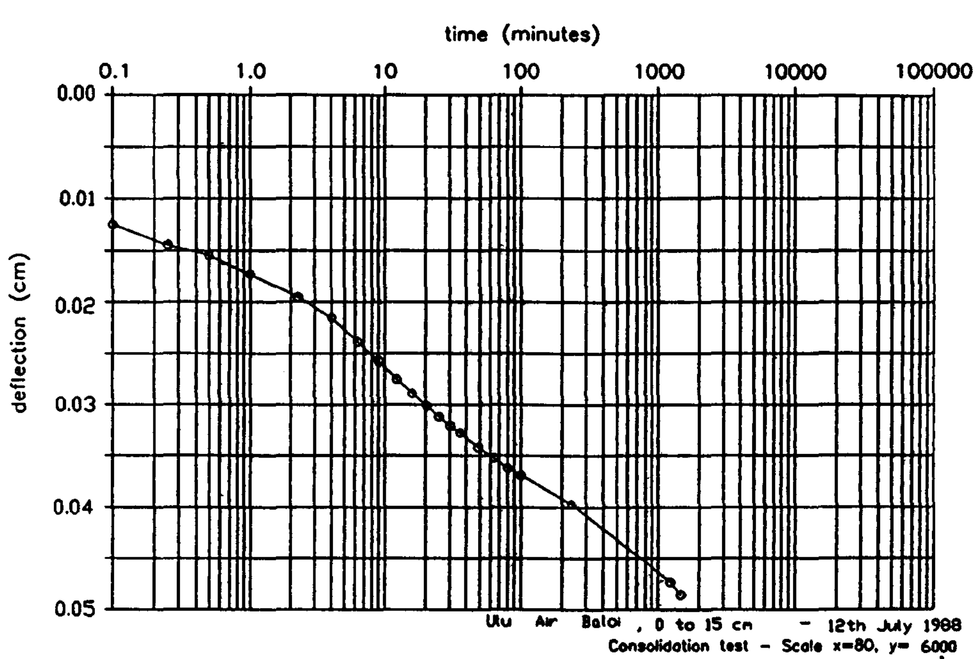


FIGURE 5.46 - Deflection versus Log Time Curve
Ulu Air Baloi, 12th July

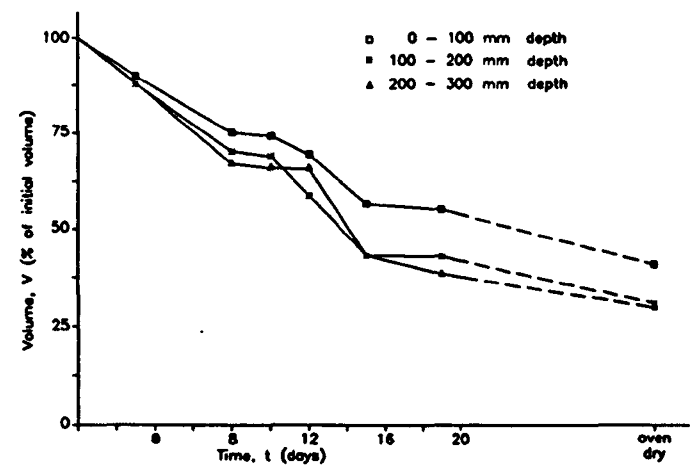


FIGURE 5.47 - Percentage volume change of peat on drying

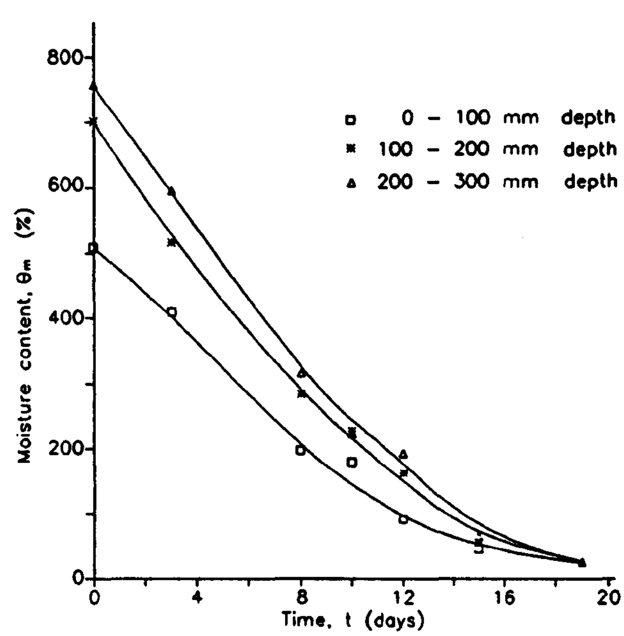


FIGURE 5.48 - Changing Moisture Content, θ_m on air drying

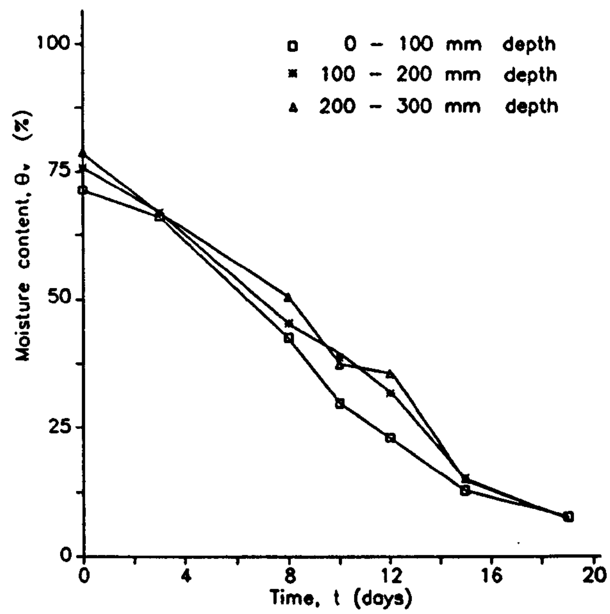


FIGURE 5.49 – Changing moisture content, θ_v on air drying

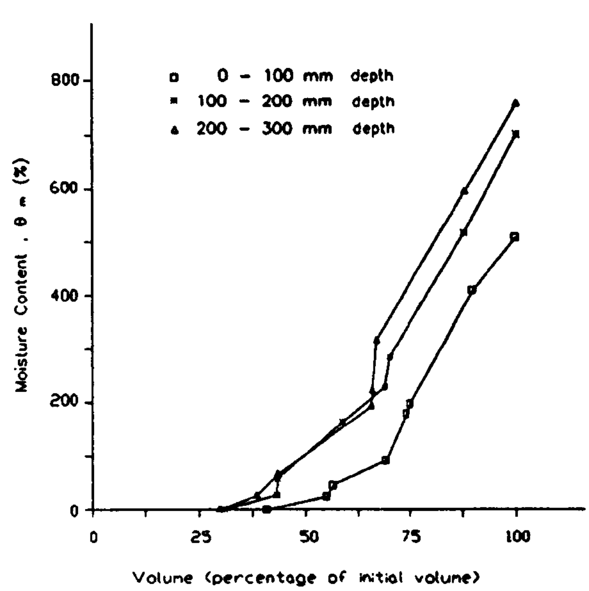


FIGURE 5.50 - Volume and θ_m relationship

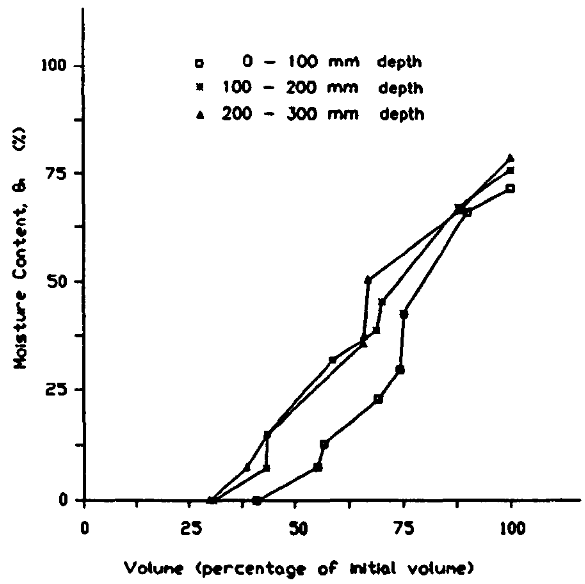


FIGURE 5.51 - Volume and θ_v relationship

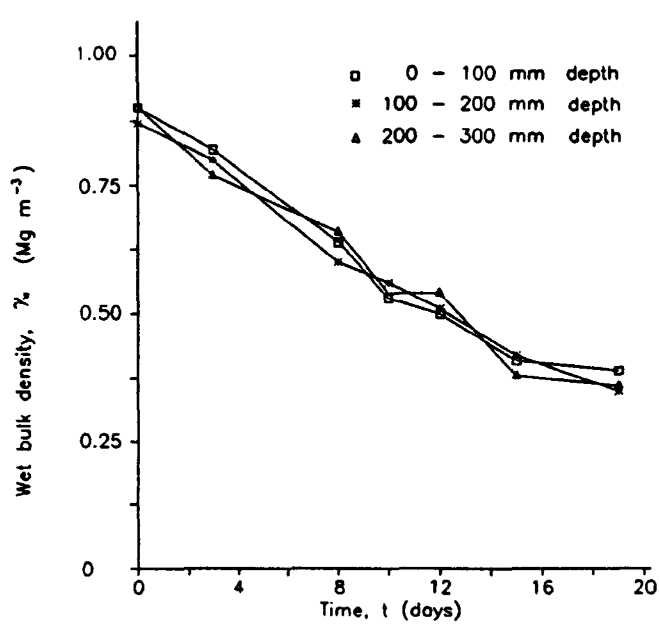


FIGURE 5.52 - Changing wet bulk density with air drying

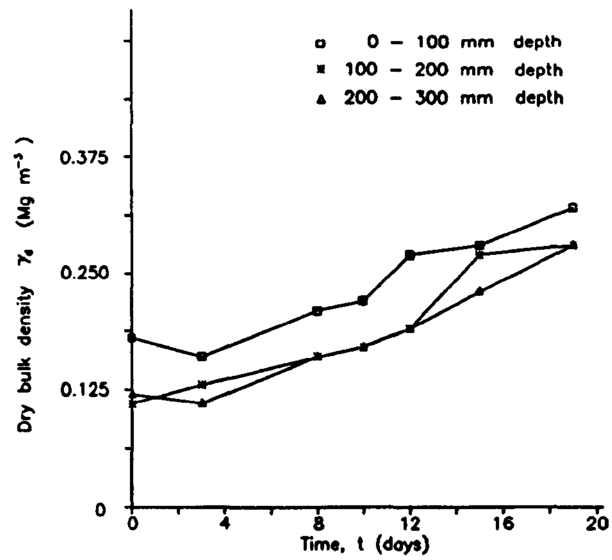


FIGURE 5.53 – Changing dry bulk density with air drying

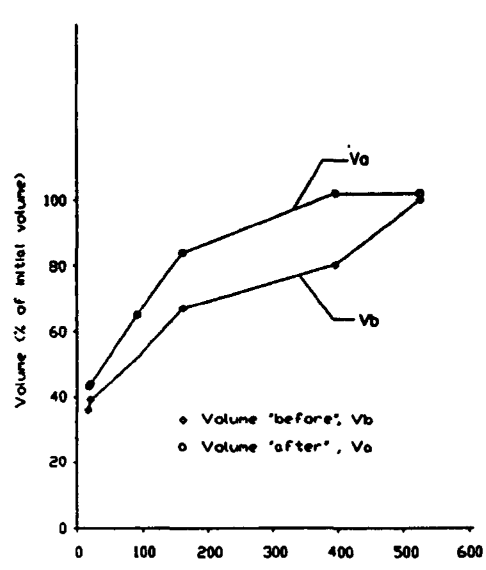


FIGURE 5.54 – Percentage volume change at different moisture content

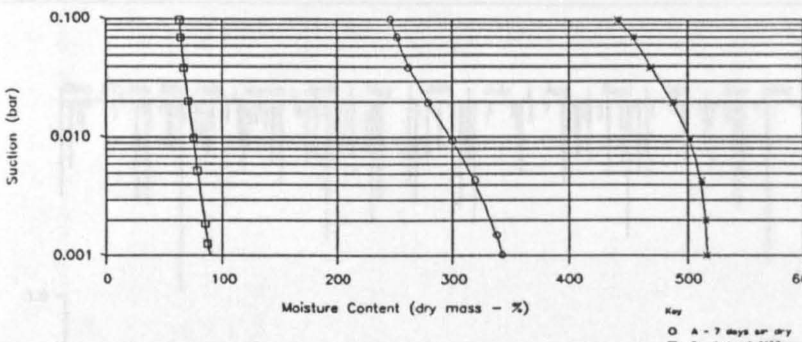


FIGURE 5.55 - Moisture Content, θm, Air Dry Sample
2 Weeks Storage (12th Oct 1988)

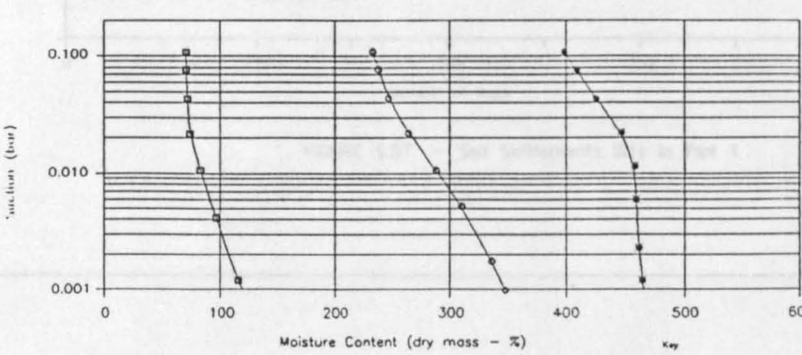


FIGURE 5.56 - Moisture Curve θm, Air Dry Sample
8 weeks storage (2nd December 1988)

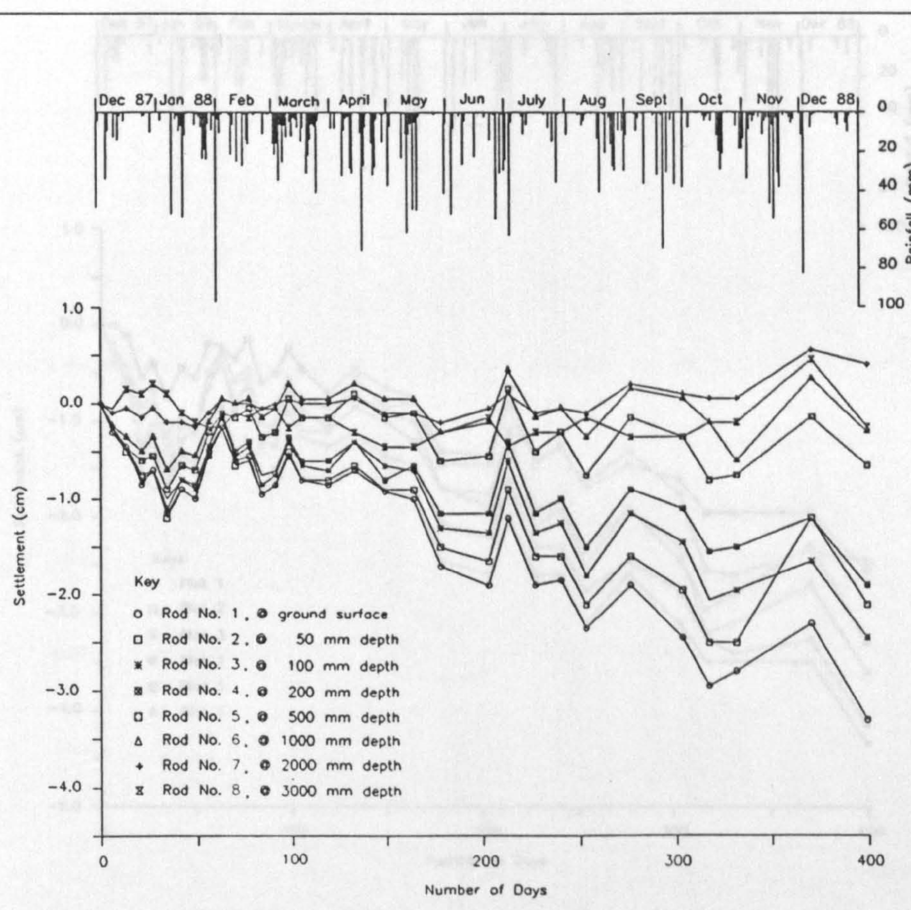


FIGURE 5.57 – Soil Settlements, SM1 in Plot 1

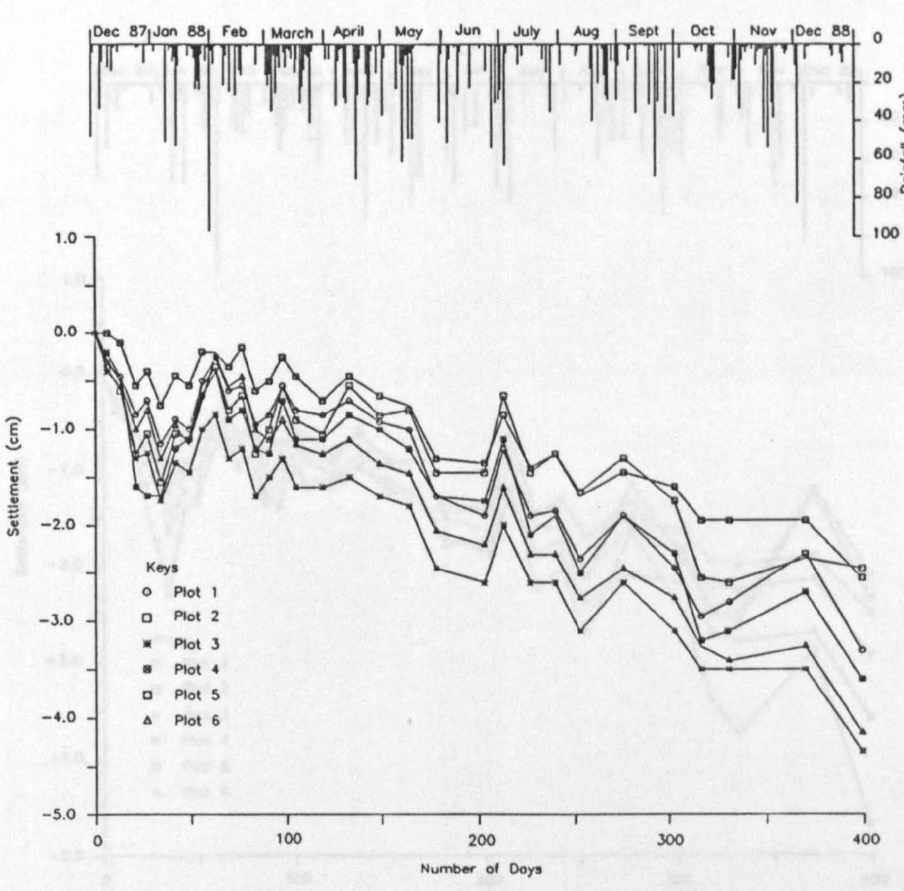


FIGURE 5.58 – Soil Settlements at Ground Surface (Rod No. 1)

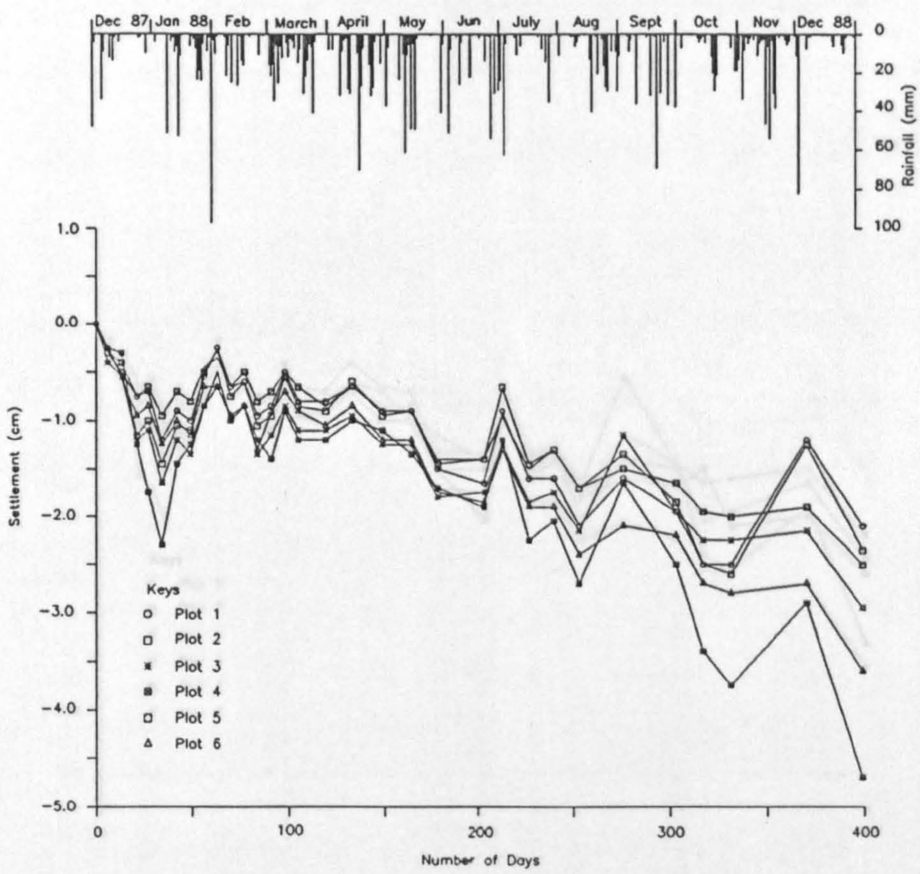


Figure 5.59 – Soil Settlements at 50 mm depth (Rod No. 2)

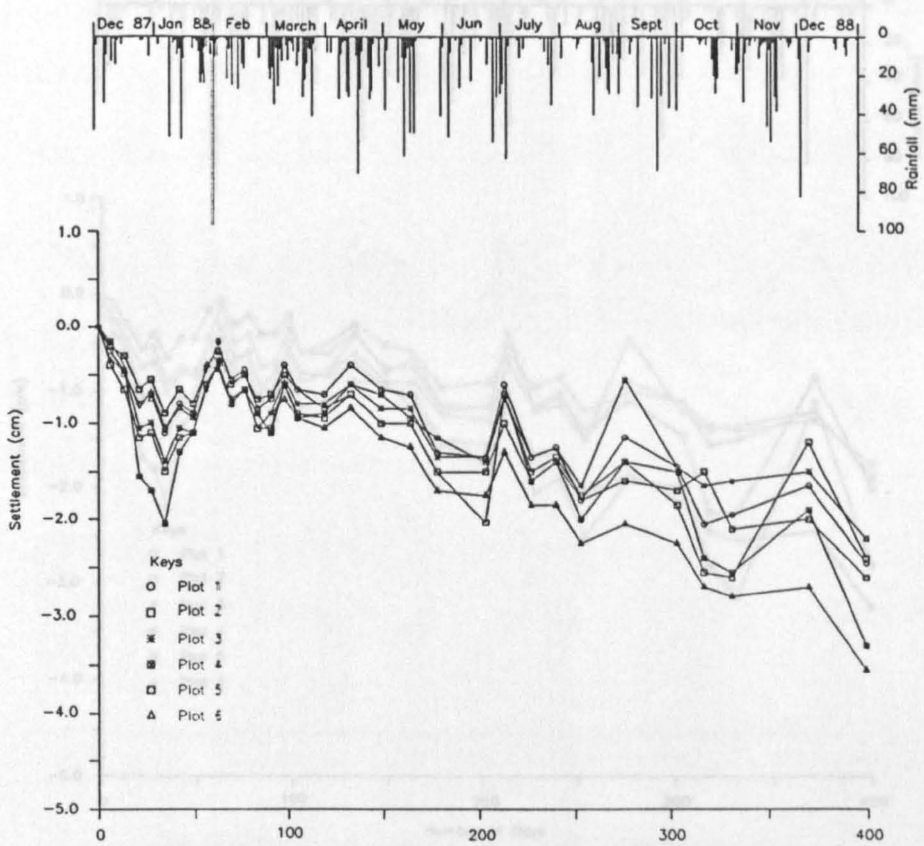


FIGURE 5.60 – Soil Settlements at 100 mm depth (Rod No 3)

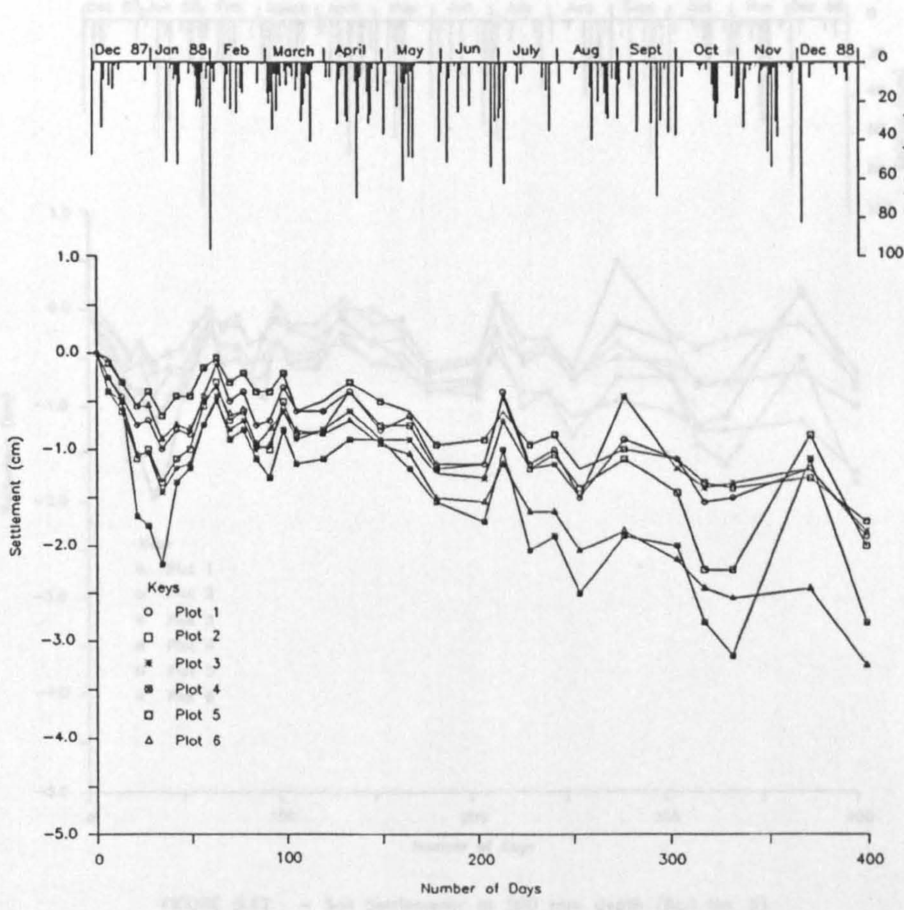


FIGURE 5.61 – Soil Settlements at 200 mm depth (Rod No. 4)

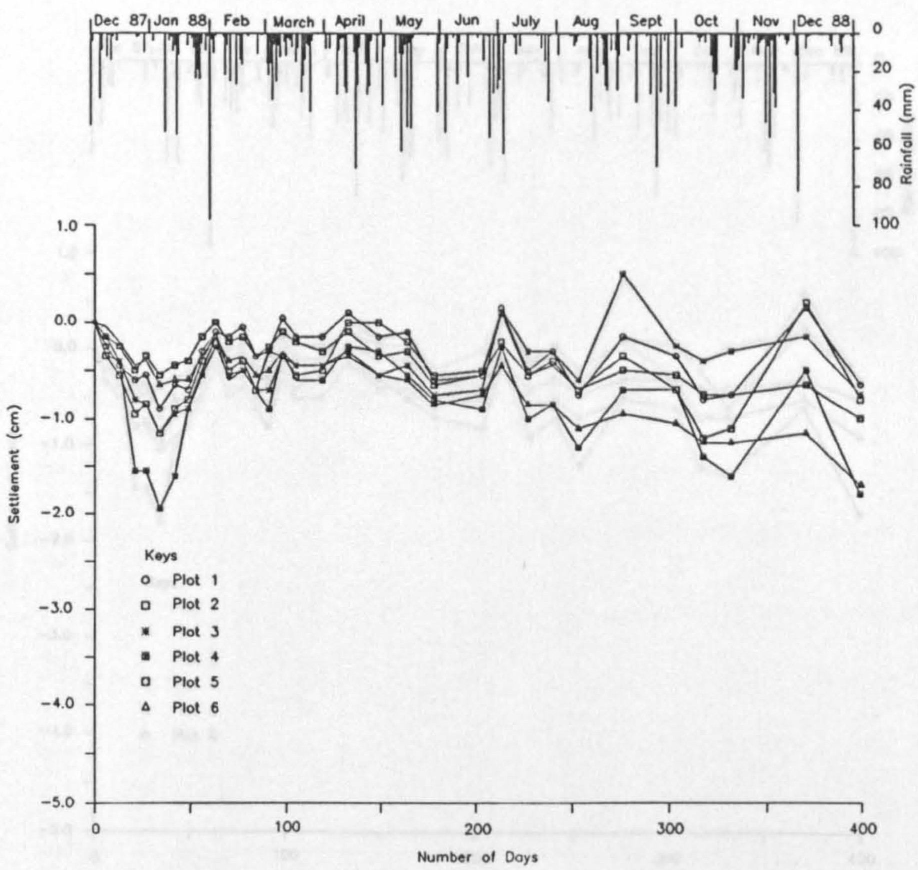


FIGURE 5.62 – Soil Settlements at 500 mm depth (Rod No. 5)

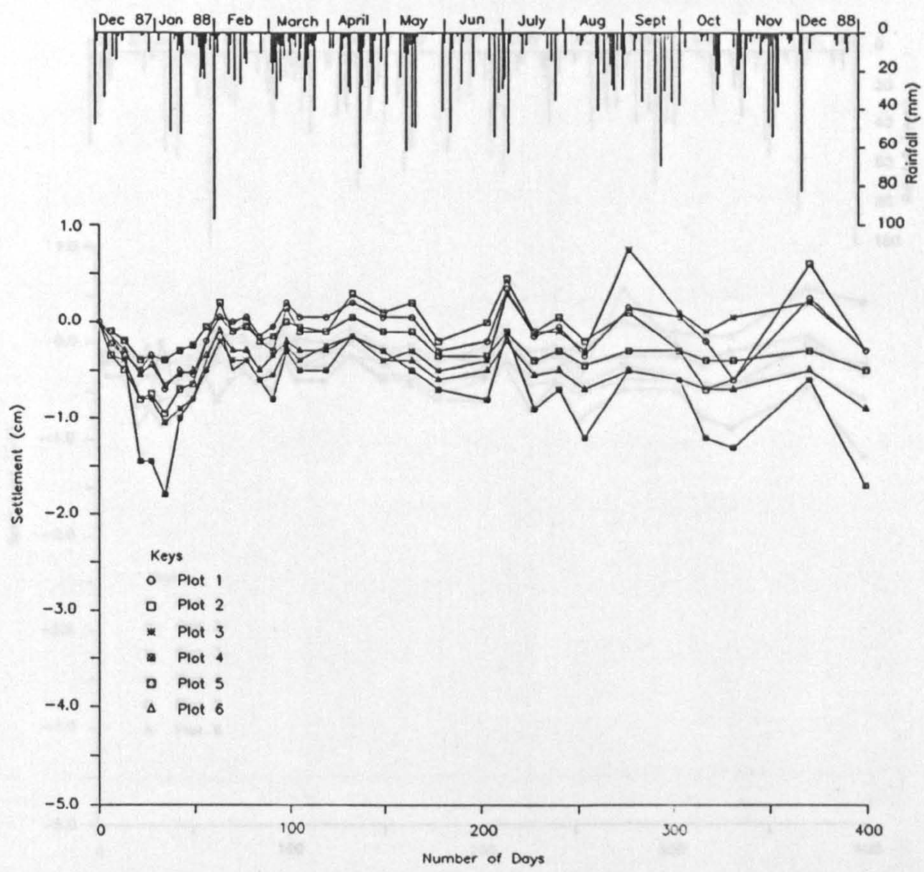


FIGURE 5.63 – Soil Settlements at 1000 mm depth (Rod No 6)

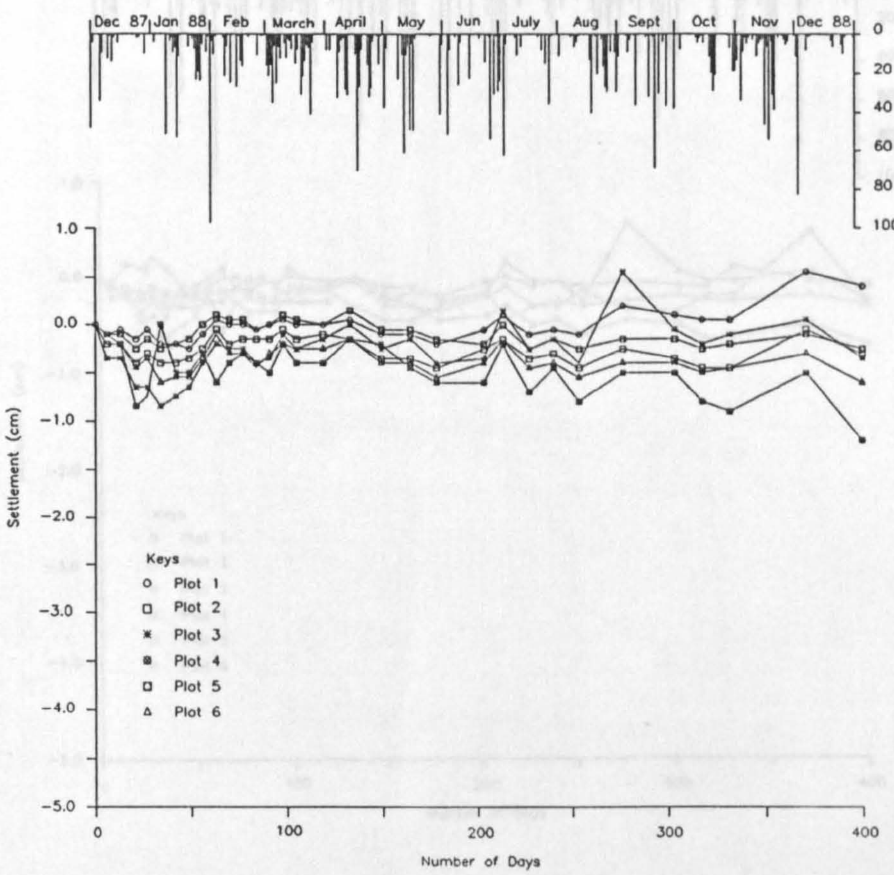


FIGURE 5.64 – Soil Settlements at 2000 mm depth (Rod No 7)

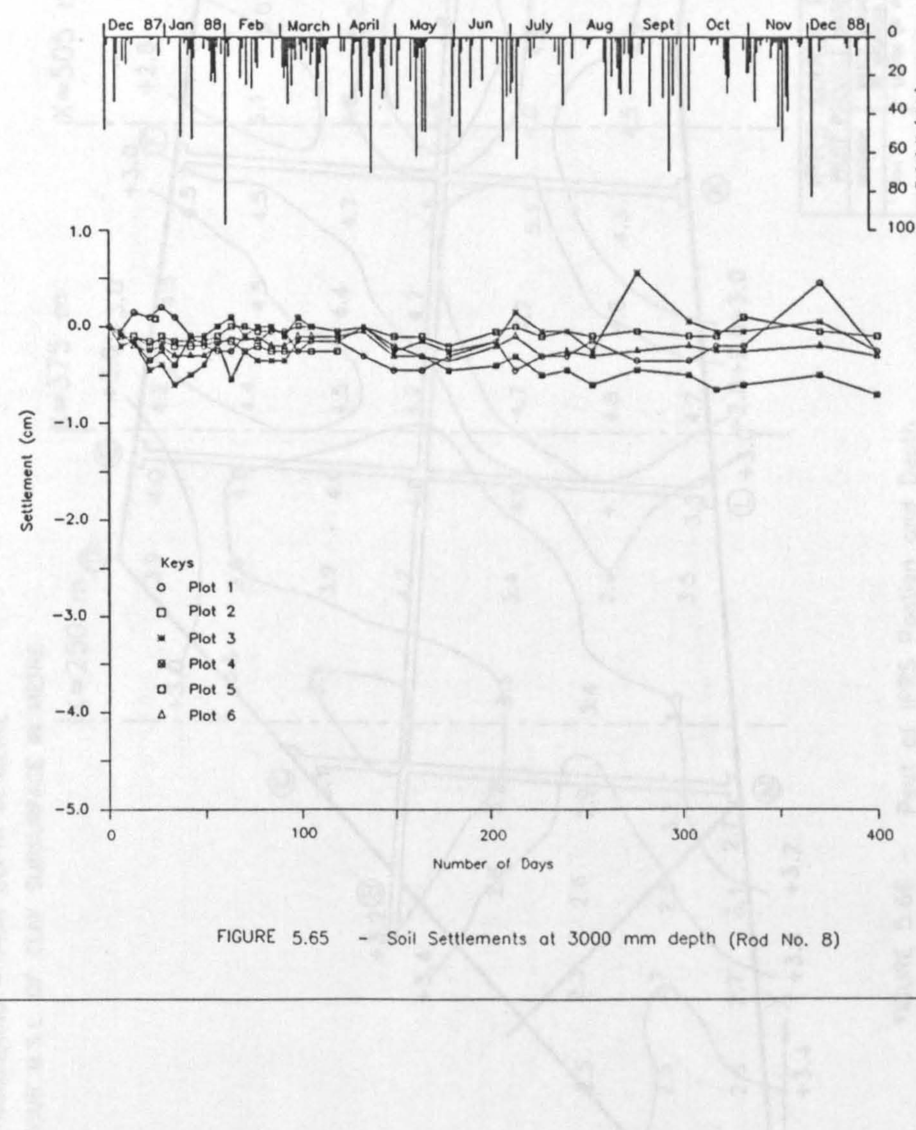


FIGURE 5.65 - Soil Settlements at 3000 mm depth (Rod No. 8)

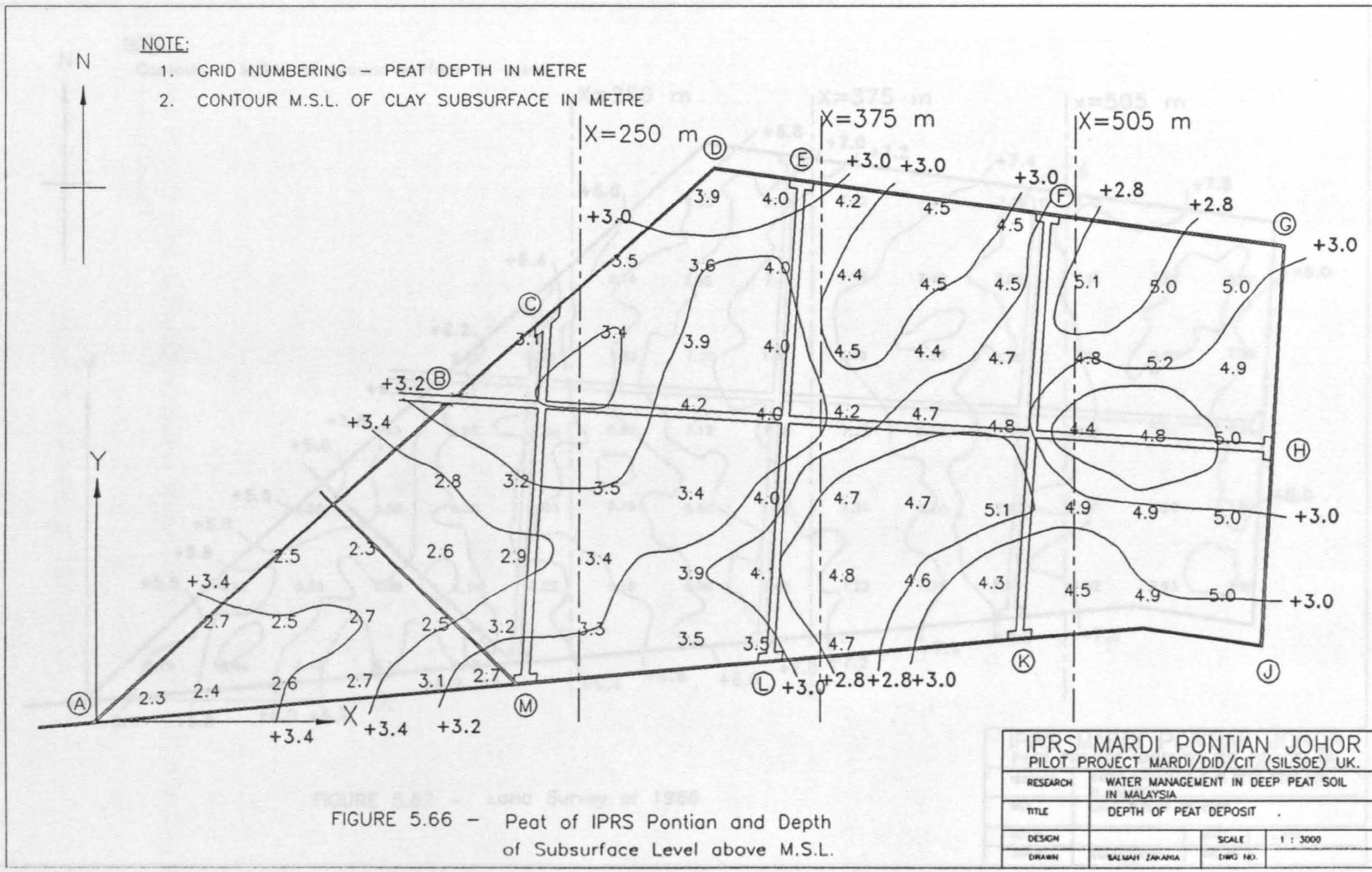


FIGURE 5.66 – Peat of IPRS Pontian and Depth of Subsurface Level above M.S.L.

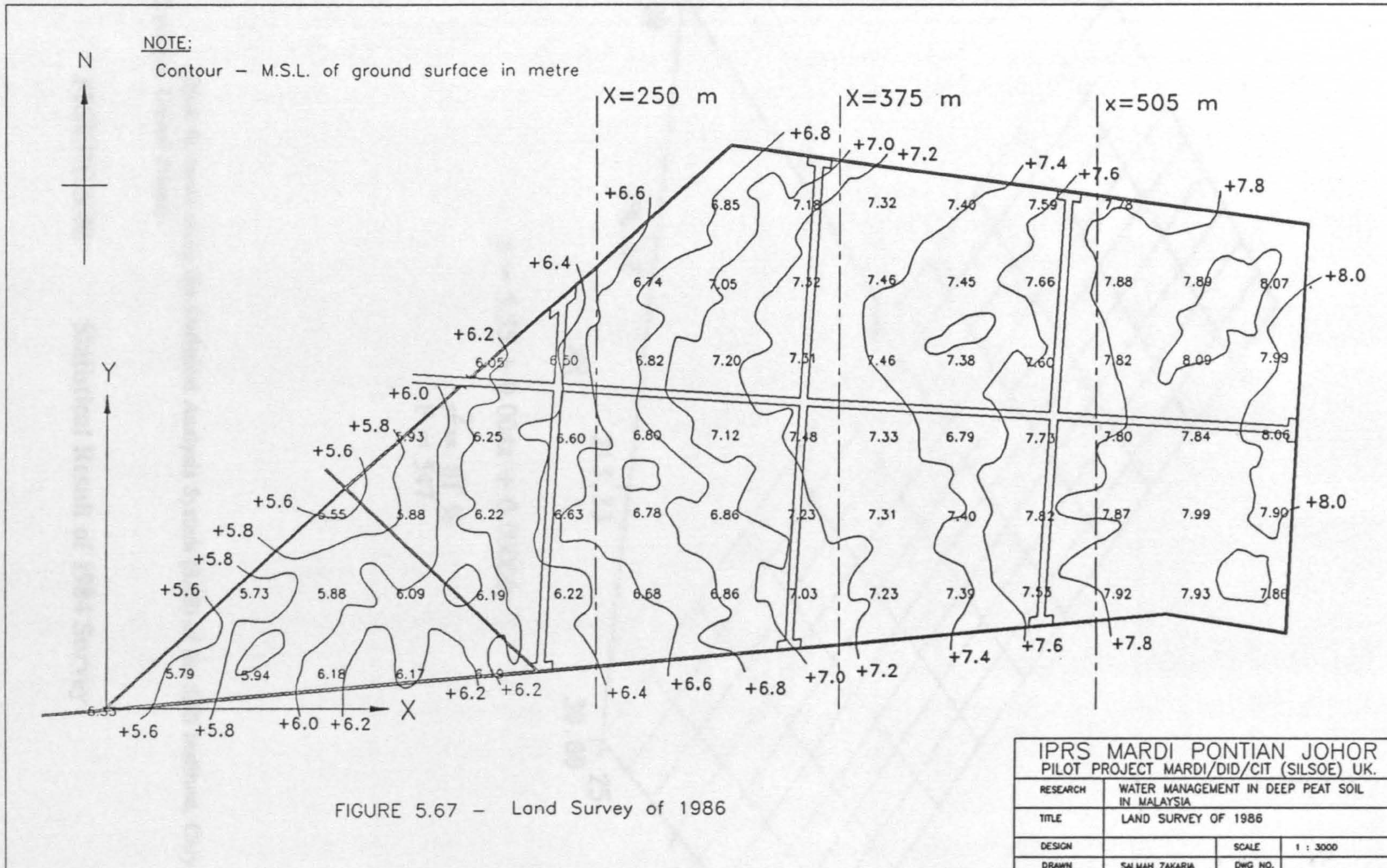
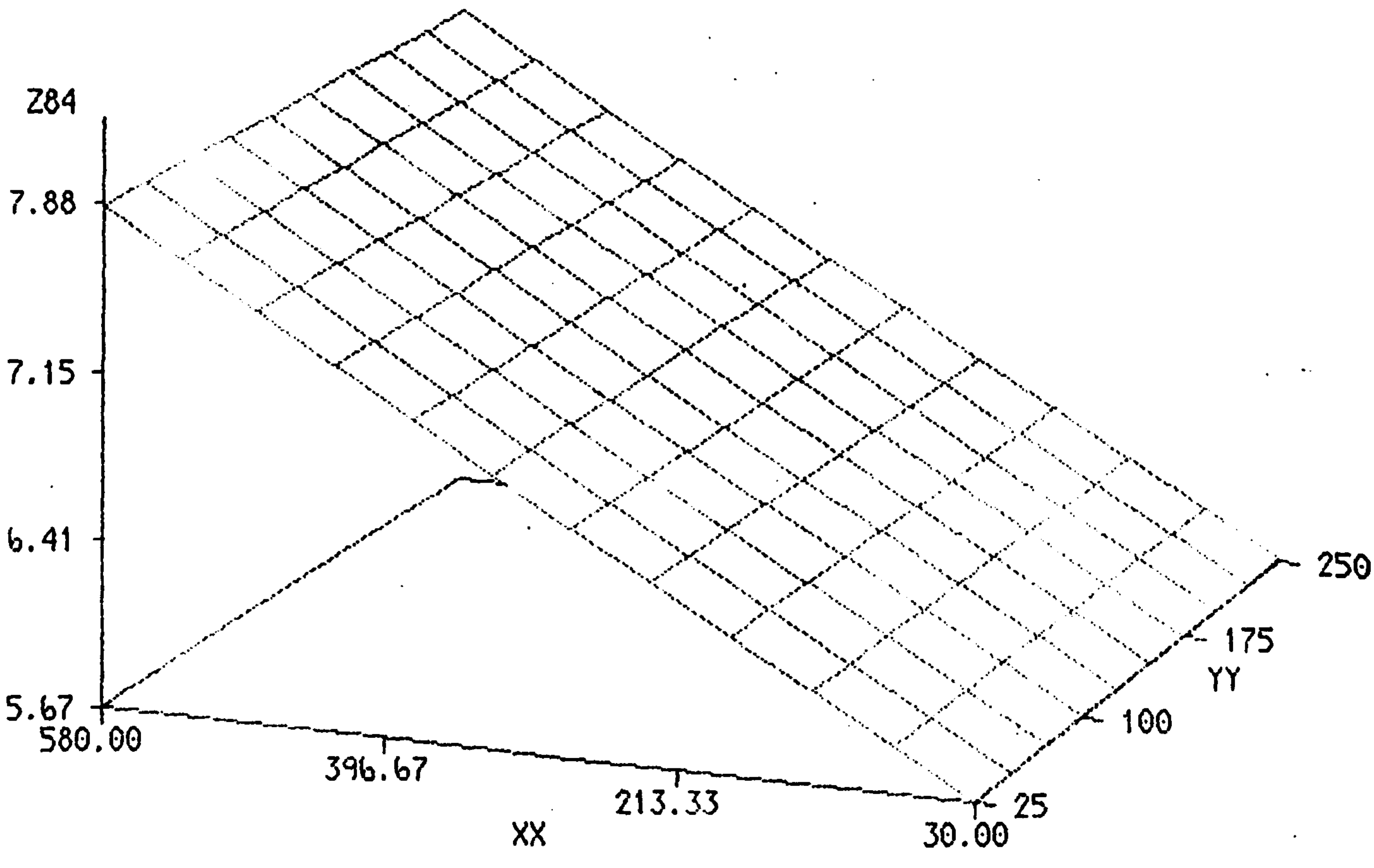


FIGURE 5.67 – Land Survey of 1986

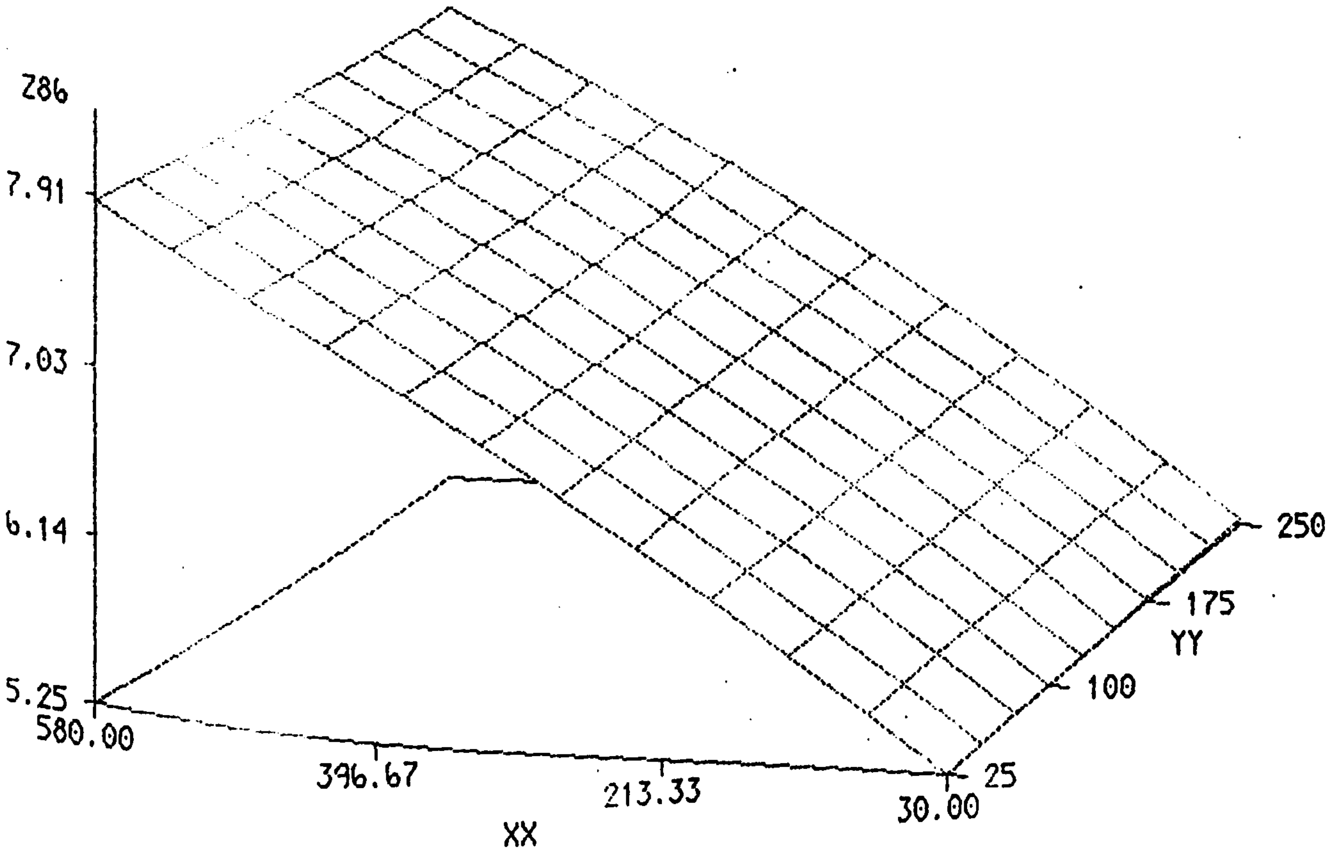


$$z = 5.55 + 0.004x + 0.00006y$$

$$r^2 = 81\ \%$$
$$F = 547$$

[best fit curve using the Statistical Analysis System (SAS) of the SAS Institute, Cary, North Carolina, United States]

FIGURE 5.68 Statistical Result of 1984 Survey



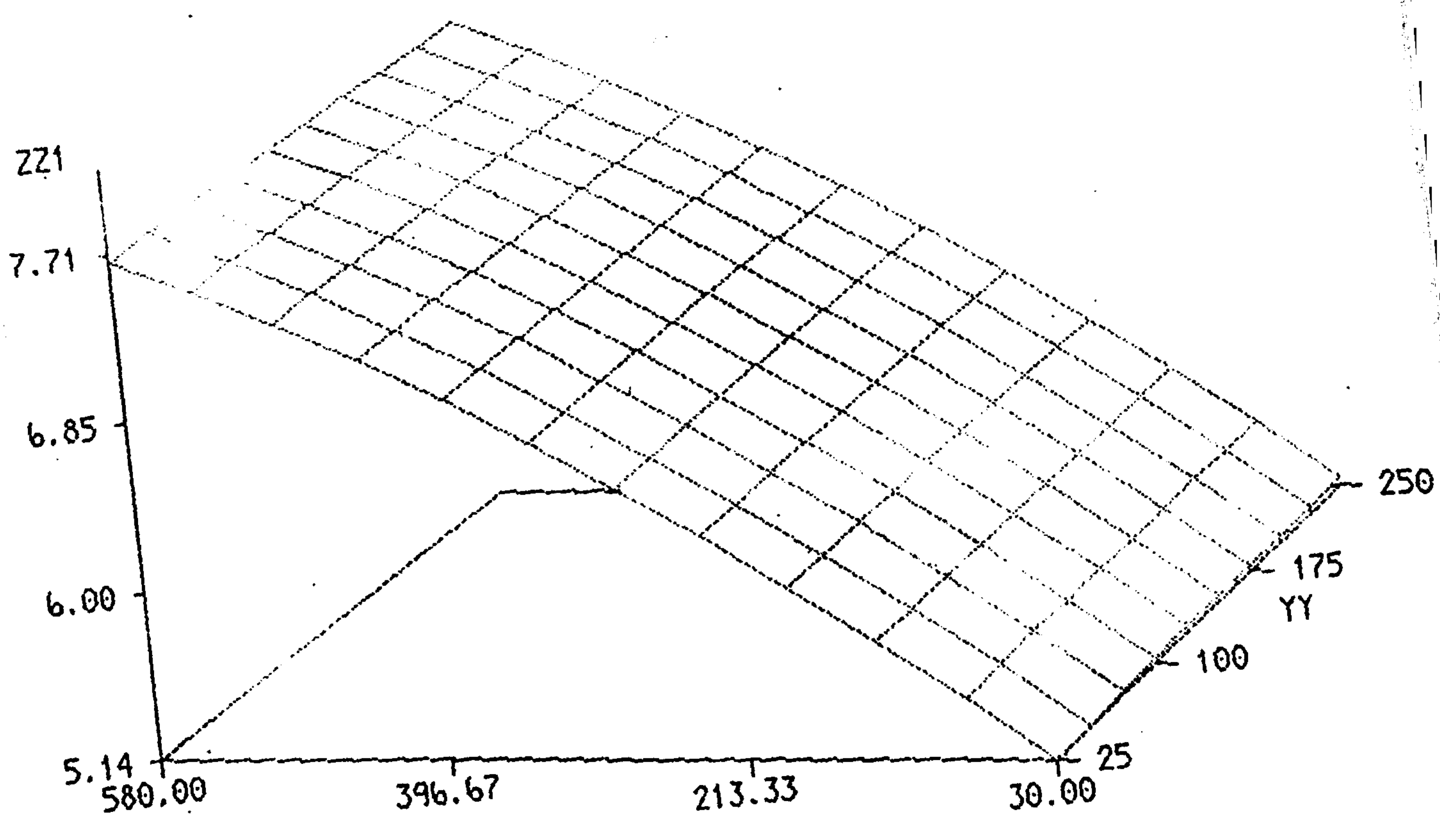
$$z = 5.074 + 0.006x - 0.000002x^2 + 0.0000005y^2$$

$$r^2 = 85\ \%$$

$$F = 1495$$

[best fit curve using the Statistical Analysis System (SAS) of the SAS Institute, Cary, North Carolina, United States]

FIGURE 5.69 Statistical Result of 1986 Survey



$$z = 4.941 + 0.006x - 0.000003x^2 + 0.0004y - 0.0000008y^2$$

$$r^2 = 95\ \%$$

$$F = 897$$

[best fit curve using the Statistical Analysis System (SAS) of the SAS Institute, Cary, North Carolina, United States]

FIGURE 5.70 Statistical Result of 1988 Survey

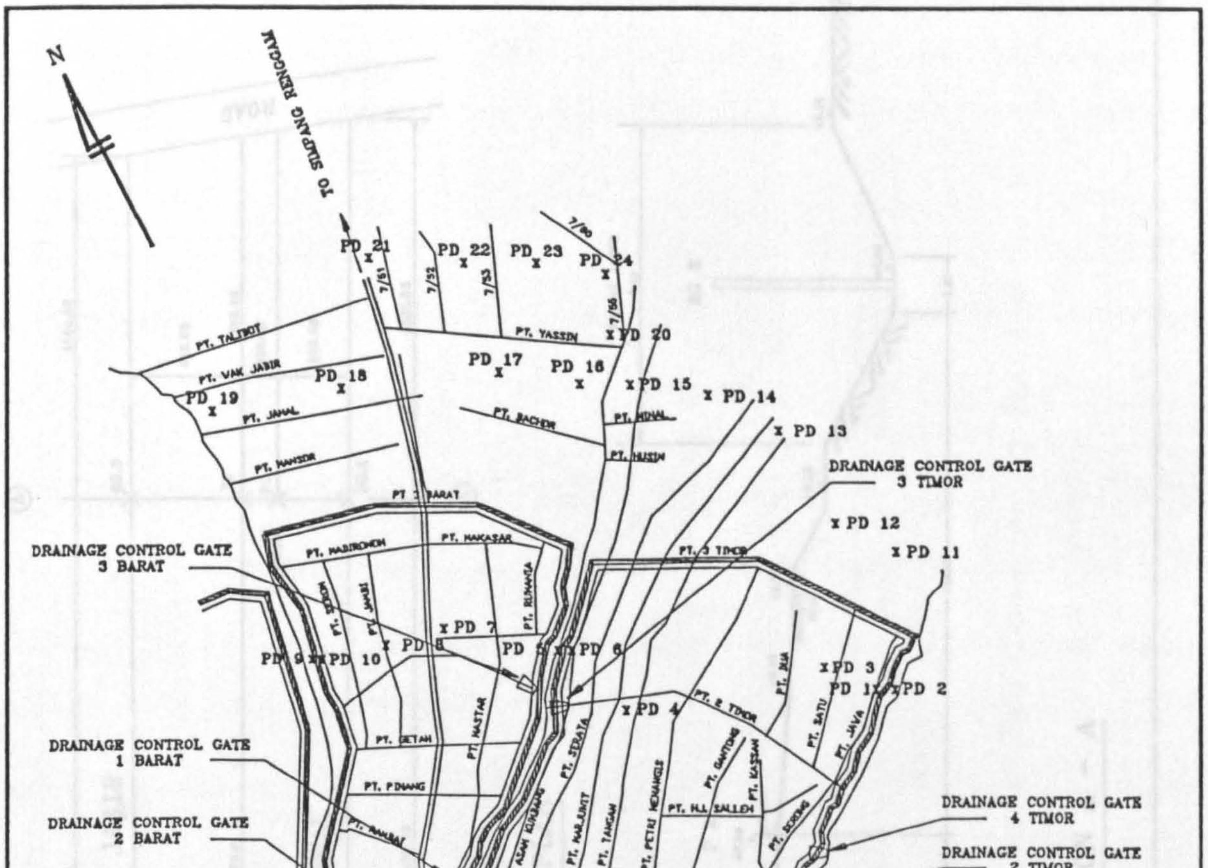


FIGURE 6.1 : LOCATION PLAN OF BENUT WATER-TABLE MONITORING AREA

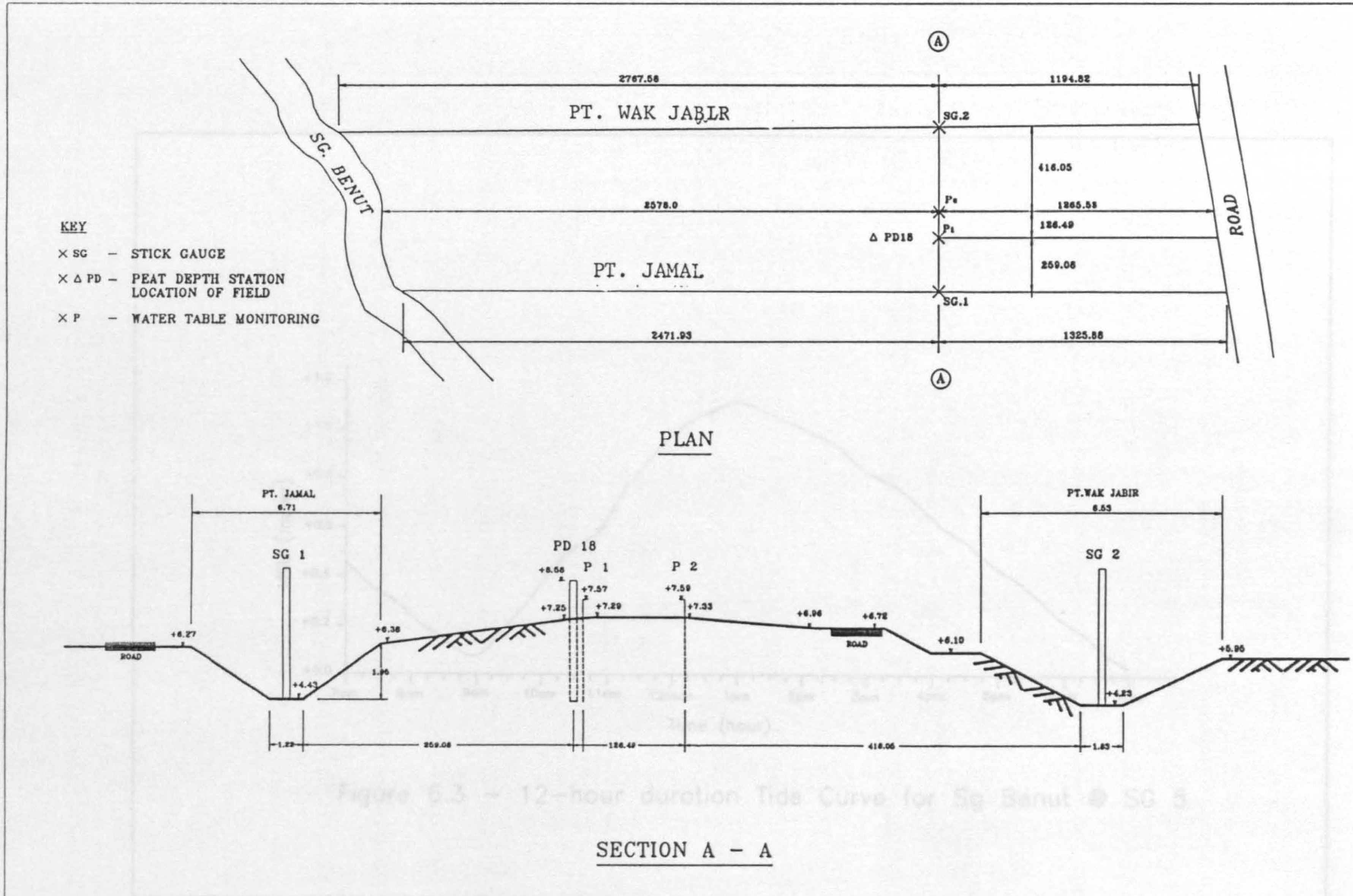


FIGURE 6.2 - PLAN AND CROSS-SECTION OF BENUT WATER-TABLE MONITORING AREA

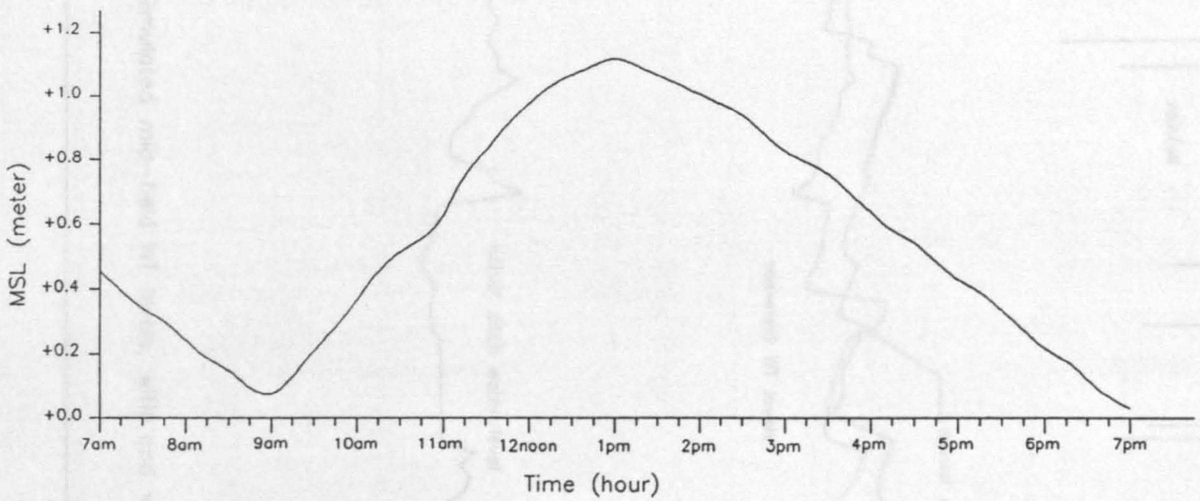


Figure 6.3 – 12-hour duration Tide Curve for Sg Benut @ SG 5

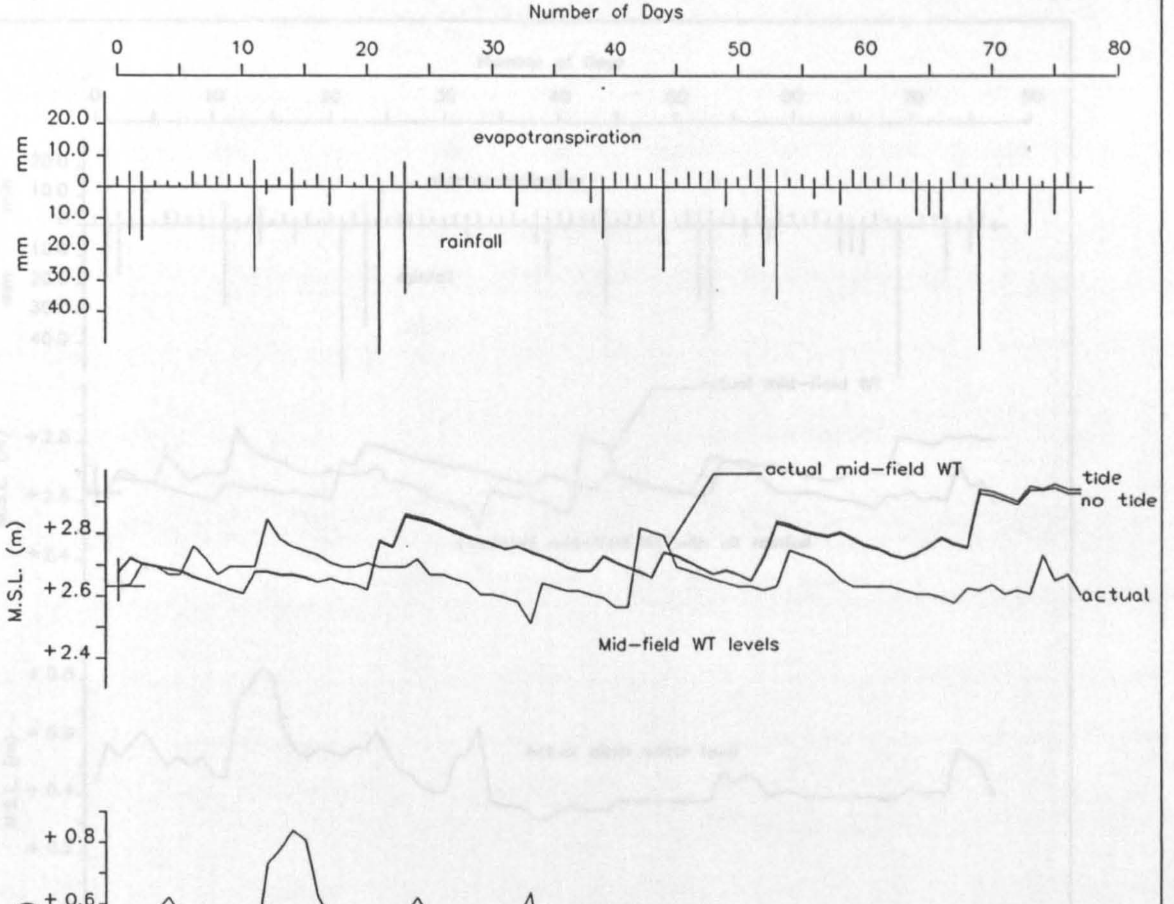


Figure 6.4 —Simulated mid-field WT levels, with and without tidal influence

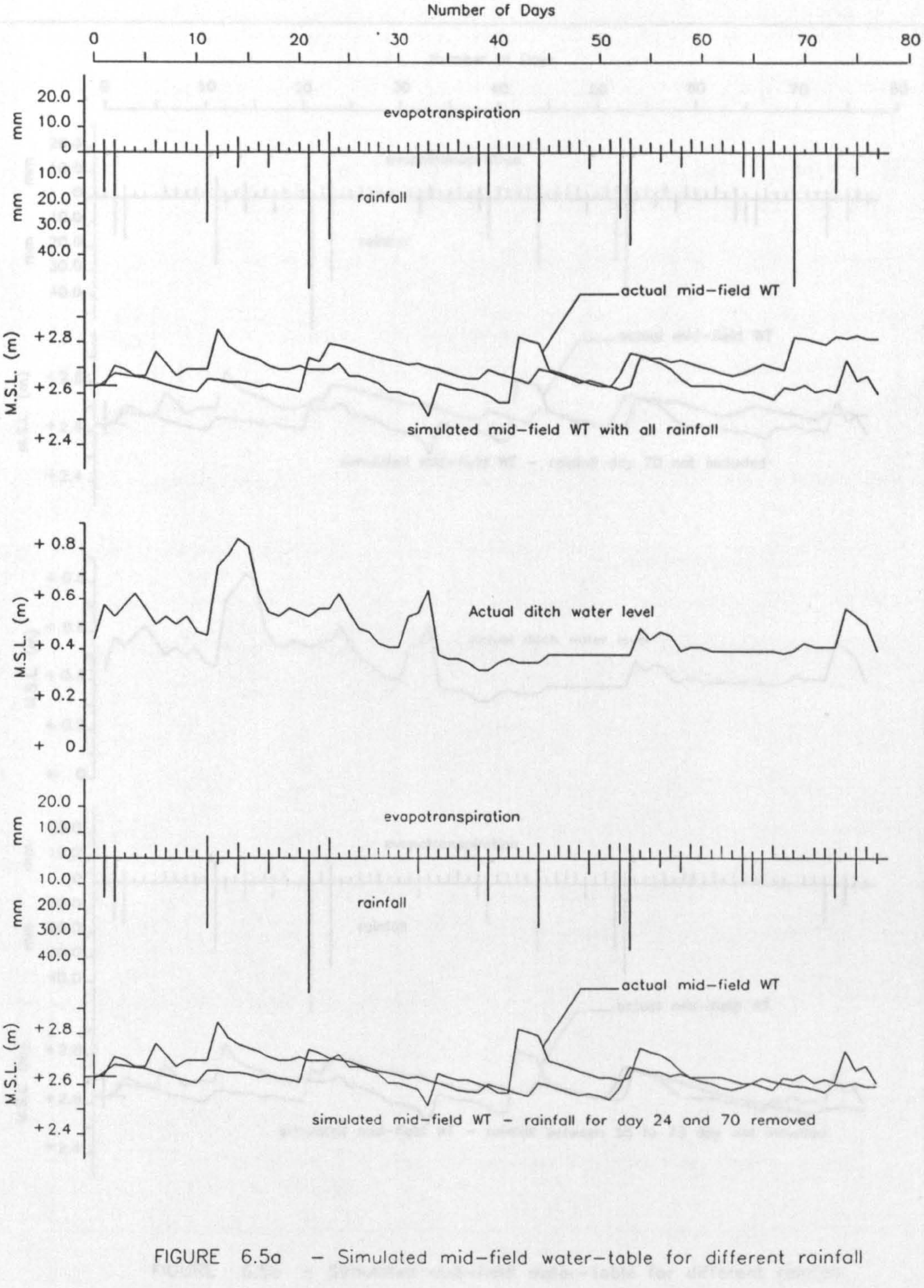


FIGURE 6.5a - Simulated mid-field water-table for different rainfall

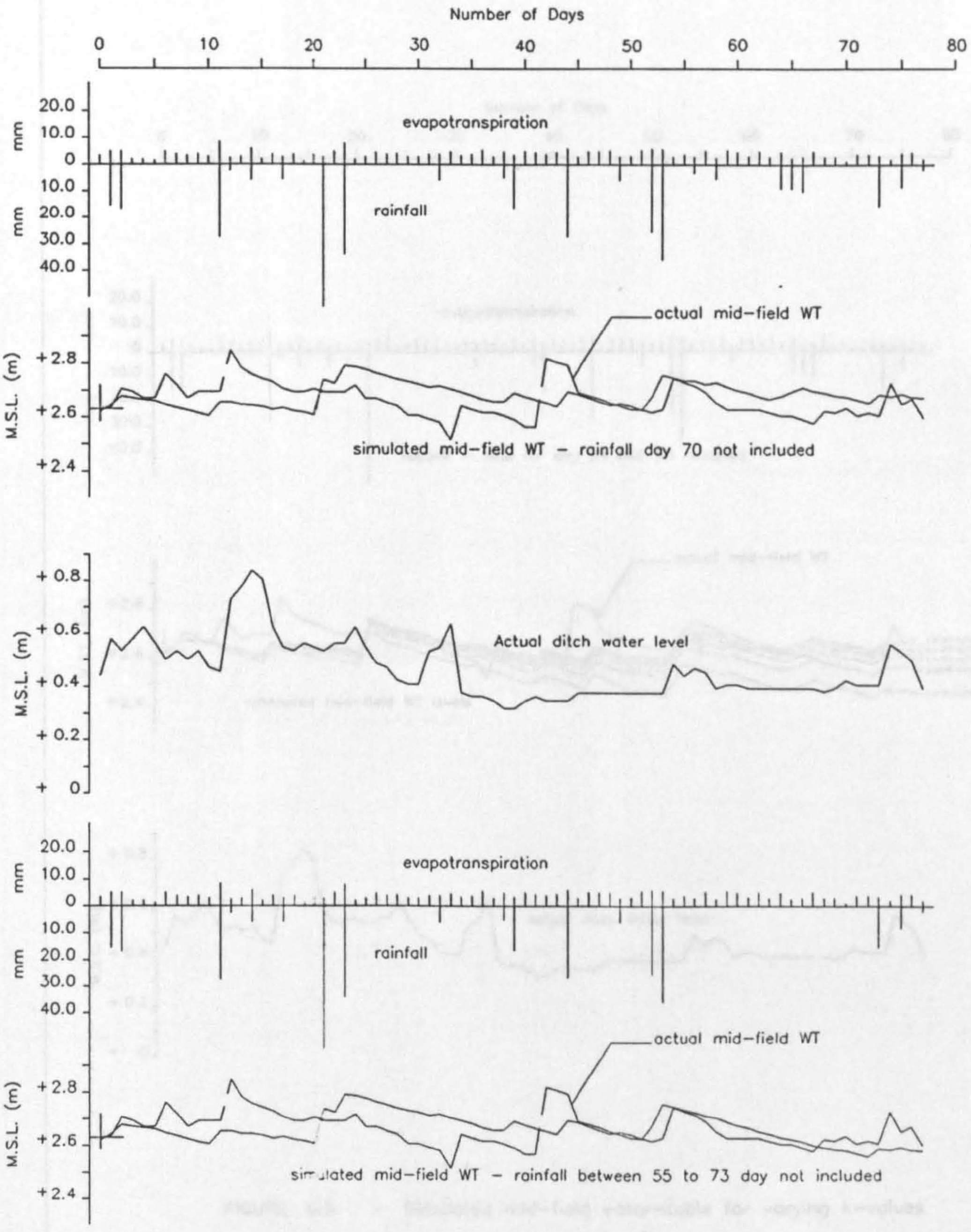


FIGURE 6.5b – Simulated mid-field water-table for different rainfall

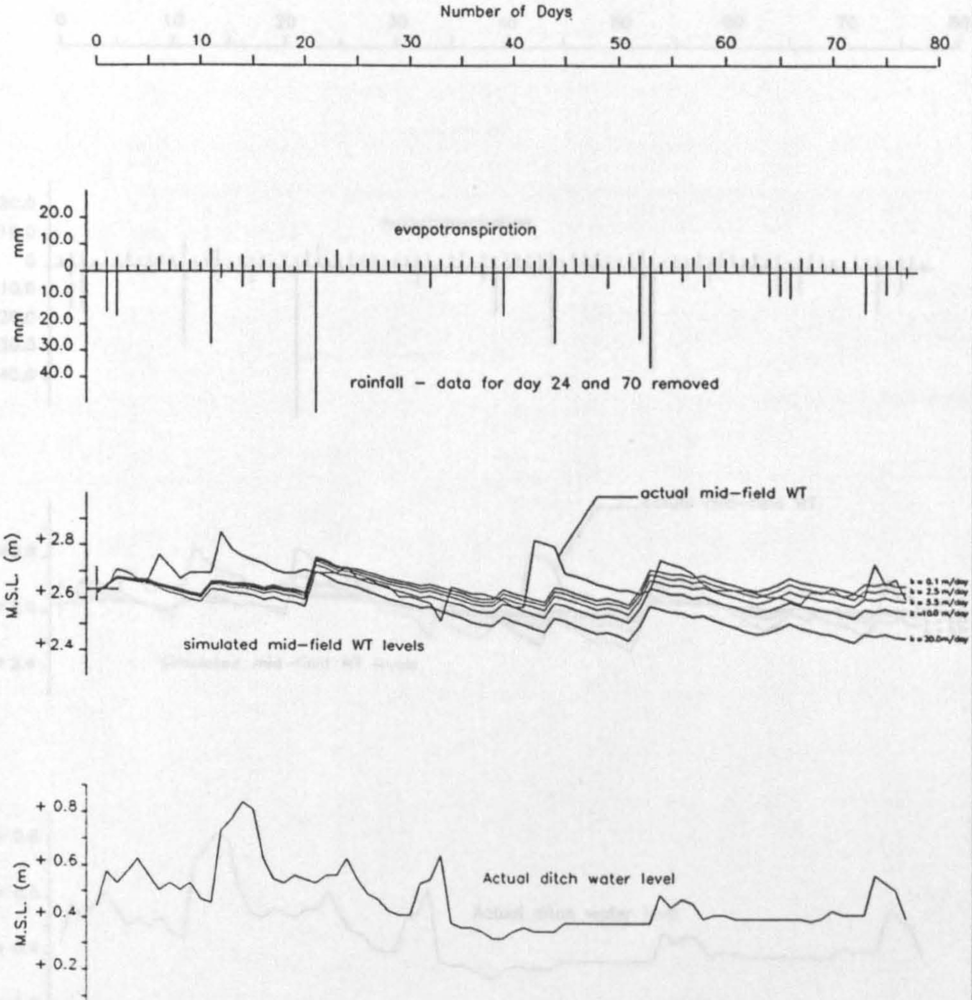


FIGURE 6.6 – Simulated mid–field water–table for varying k–values

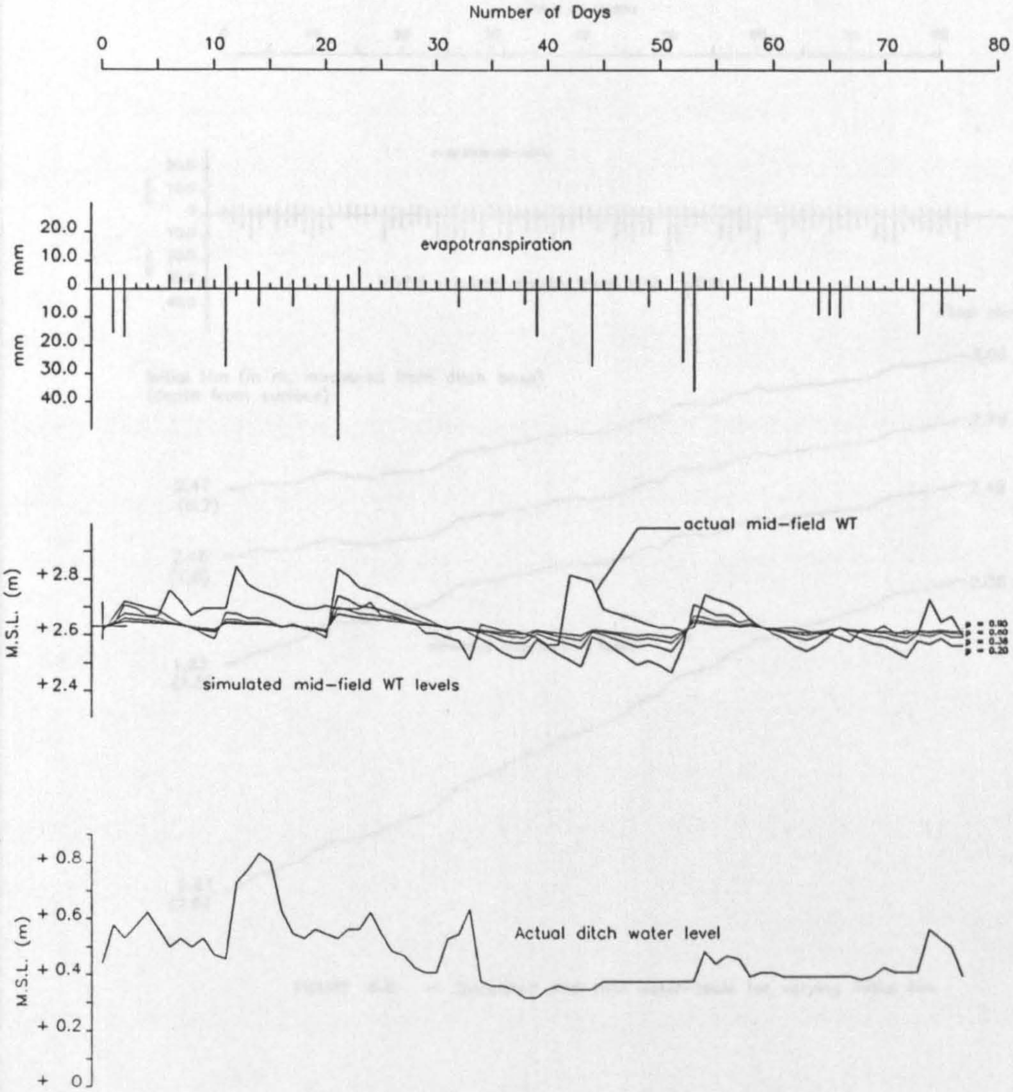


FIGURE 6.7 - Simulated mid-field water-tabble for varying porosity

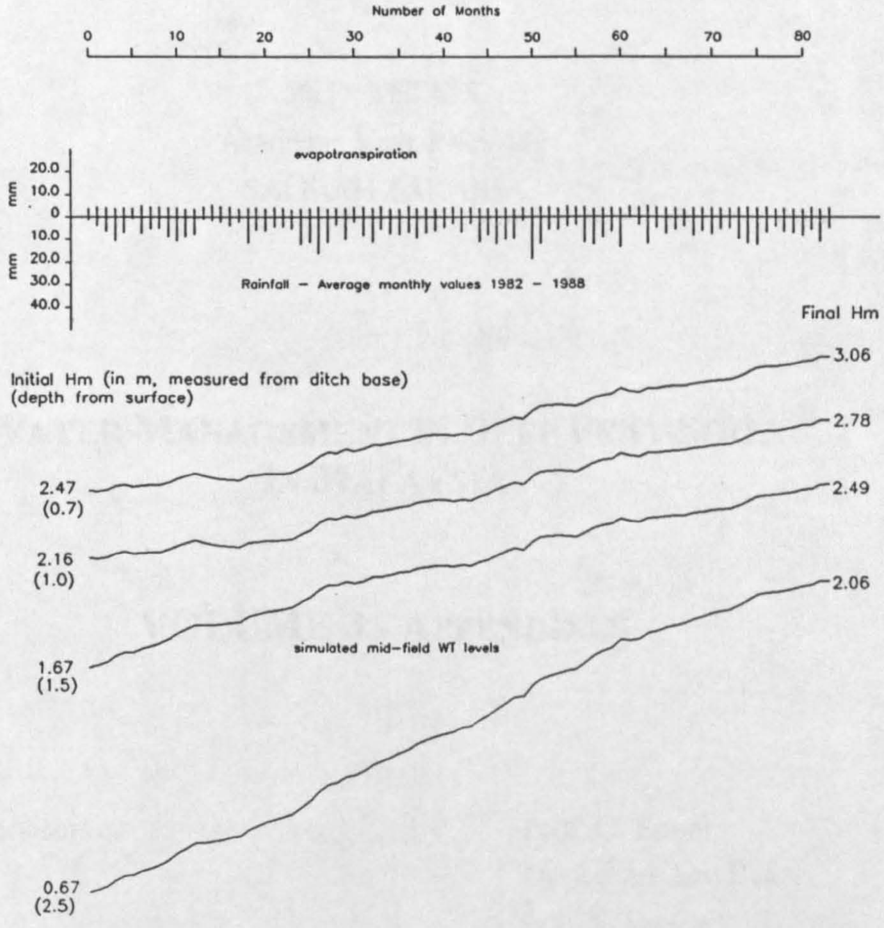


FIGURE 6.8 – Simulated mid-field water-table for varying initial Hm

CRANFIELD INSTITUTE OF TECHNOLOGY
SILSOE COLLEGE

Ph.D. THESIS

Academic Year 1985 - 89

SALMAH ZAKARIA

WATER MANAGEMENT IN DEEP PEAT SOILS IN MALAYSIA

VOLUME 3 - APPENDIXES

Supervisors : Prof. G. Spoor
Dr. Zahari Abu Bakar
Ir D.N. Welch

March 1992

This thesis is submitted in full fulfilment of the requirements for the degree of Doctor of Philosophy.

VOLUME 3 - APPENDIXES

APPENDIX A

Detail Design for Test Plot, Plot 4

APPENDIX A - Detail Design for Test Plot, Plot 4

A1. General

Plot 4 is approximately 120 m wide and with varying length of 127 m to 111 m. The planning and design was carried out using a 1984 survey plan. The design for the pilot plot was carried out for a midfield water table of 900 mm. The average natural ground slope of the area is about 1:300 with pockets of depression as deep as 300 to 400 mm. In plot 4, the surface gradient at some locations can be as much as 1:150. As land levelling is not able to be carried out several check structures were needed for water management purposes.

The drain capacities were designed using Manning's equation for a rainstorm of 72 hours and 5 years return period, and Manning's n of 0.025 for unlined canals. The DID HP No 1 by Heiler, 1973 was followed for the estimation of design rainstorms. The drainage rate was taken as 80 mm/day and estimated from a design rainstorm of 83.8 mm/day and average evaporation rate of 3.8 mm/day. The design of the entire adjacent perimeter drain A-M-L were also carried out.

The designed plot is as shown in Figure 3.2. The drains were of 1.2 m depth and spaced at 20 m interval. The 3 middle drains were connected and discharged through a 90° V-notch weir at W4. An automatic water level recorder was installed at W4. Dipwells or WT observation wells (OW) were installed prior to the construction of the drains, at 1/8, 1/4 and midfield of the distance between the drains.

A2 Drainage Discharge Coefficient

From HP No.1 (Heiler, 1973), the rainstorm for the respective return period and duration were calculated.

Research in IPRS include that on vegetables. The recommended design rainstorm for vegetable farming (Khoo et al, 1976) is a 24 hour storm duration, 1 in 10 years return period. The 24 hour one in 10 years drainage rate is 26.5 l/s/ha. However the 5 yrs 72 hrs return period rainstorm is preferred as this is design at field level and because of the expected drought stress problems associated with peat.

A3. Drain Design and Instrumentation

Using the discharge coefficient of 80.0 mm/day, the discharge flowing through each of the drains were estimated from the size of the contributing areas. The size of Plot 4 is approximately 1.43 ha and contribute a total of about 0.013 m^3s^{-1}. Discharge for perimeter drain AML increases from 0.059 to 0.115 m^3s^{-1}

The plot is designed for a rootzone of 900 mm depth. The assumed capillary fringe is 150 mm. The maximum midfield water table height, h, is assumed to be 150 mm above the drainage base. Thus a minimum drain depth of 1.2 m is required and designed for. The required sections were estimated using Manning's equation. Table A1 summarised the discharge for the minimum sections for bed width of 0.6 m and 0.4 m.

As all discharges for the drains are smaller than the values in Table A2, the section chosen, including the perimeter drain A-M-L, are more than adequate.

A V-notch weir fabricated as shown in FIGURE 4.1 was installed to straddle drain D4/3 just downstream of the intersection of the three drains D4/2, D4/3 and D4/4 (Figure 3.2). A weekly automatic water level recorder, modified from an old bulb type, was installed within the weir structure (Figure 4.1) to read the water level changes close to the nearest 1 mm.

Table A1 Discharge for minimum designed sections.

b metre	d metre	R=A/P metre	s	v velocity	q cumec
0.6	1.5	0.3689	1/1000	0.6506	0.8783
0.6	1.5	do	1/300	1.1879	1.6036
0.6	1.2	0.3307	1/1000	0.6049	0.6097
0.6	1.2	do	1/300	1.1044	1.1132
0.4	1.2	0.2697	1/1000	0.5280	0.4055
0.4	1.2	do	1/300	0.9639	0.7403

Detail design are given in the preceding pages.

HYDROLOGY BRANCH D.I.D. MALAYSIA
STATION NO.: 1534104 STATION NAME: IBU BEKALAN JKR. PONTIAN BESAR, JOHOR

SUMMARY OF RAINFALL (MM.)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1951	******	283.0	260.9	103.1	287.9	******	202.4	281.3	327.9	206.5	288.3	198.7	******
1952	299.9	300.7	403.9	319.3	244.2	167.9	274.7	310.7	149.4	226.3	217.1	168.0	3082.1
1953	143.7	200.7	458.4	347.1	192.6	136.7	274.5	131.1	183.3	215.8	201.9	125.2	2611.0
1954	267.5	240.8	266.5	307.5	185.5	293.7	206.1	356.3	228.5	364.8	190.3	448.9	3356.4
1955	290.8	96.8	161.6	384.3	147.4	159.2	199.4	314.2	134.2	268.9	108.1	234.7	2499.6
1956	324.7	195.0	365.9	148.8	119.4	82.2	361.2	262.5	240.2	230.4	433.2	161.2	2924.7
1957	157.9	118.4	184.2	242.3	255.9	93.0	341.0	203.8	179.9	221.1	418.6	307.3	2723.4
1958	134.3	93.9	280.3	195.4	324.0	159.8	44.7	164.0	106.2	308.2	438.1	138.0	2436.9
1959	196.4	139.5	434.1	434.7	86.8	177.6	148.0	244.7	200.2	296.5	348.0	247.8	2954.3
1960	159.2	224.9	199.4	217.5	304.4	204.8	209.0	152.0	270.9	239.0	235.7	354.5	2771.3
1961	181.7	201.3	302.3	423.7	85.4	254.7	197.4	89.1	50.6	92.3	366.6	226.9	2472.0
1962	234.7	74.3	300.3	312.0	266.1	249.9	150.1	206.6	164.3	227.1	377.3	239.9	2802.6
1963	161.9	149.6	70.0	109.9	224.6	179.4	222.1	154.1	128.8	220.1	234.7	316.7	2171.9
1964	204.9	374.0	232.1	456.2	203.6	148.4	316.3	103.9	256.8	318.8	184.1	354.7	3153.8
1965	9.7	215.5	245.7	217.3	240.6	228.5	71.4	288.6	228.3	353.6	358.8	250.4	2708.4
1966	117.0	165.7	406.5	289.6	201.1	124.5	177.6	224.5	177.1	118.0	276.5	257.9	2536.0
1967	215.2	435.2	63.2	361.1	307.1	369.9	119.2	117.4	344.4	298.7	352.2	418.3	3401.9
1968	123.4	37.3	281.4	472.3	153.6	168.6	75.1	179.3	62.5	338.5	240.9	212.3	2345.2
1969	130.4	91.3	259.3	160.8	292.0	226.7	246.2	428.5	215.9	262.1	265.4	469.8	3048.4
1970	85.9	105.8	136.9	455.4	180.8	250.0	240.9	154.6	318.9	411.6	328.9	185.1	2854.8
1971	138.7	128.5	150.0	145.3	168.7	98.6	138.7	161.2	158.1	112.8	99.3	409.3	1909.2
1972	100.3	233.4	51.5	383.1	181.9	123.5	14.0	237.5	240.2	133.9	283.3	245.4	2228.0
1973	132.6	265.7	205.6	313.4	204.9	93.8	93.1	226.0	232.4	308.8	188.5	207.6	2472.4
1974	73.1	105.3	66.8	221.5	154.1	79.8	141.2	180.5	300.5	113.5	310.0	137.5	1883.8
1975	247.5	228.0	124.4	133.5	199.0	222.5	112.0	76.0	165.5	354.0	264.0	164.0	2290.4
1976	52.5	34.0	202.5	193.0	91.0	66.0	437.5	170.0	147.5	562.0	293.0	483.0	2732.0
1977	51.0	303.2	94.0	101.0	268.2	231.5	399.5	364.5	251.0	256.0	349.5	223.0	2892.4
1978	178.5	147.0	281.0	356.0	******	203.0	154.5	166.5	199.0	239.0	258.0	224.0	******
1979	94.5	96.0	247.0	316.0	161.0	349.0	352.5	243.0	156.5	294.0	235.0	94.0	2638.5
1980	162.0	156.0	157.0	298.0	215.0	244.0	107.0	305.0	208.0	319.0	352.5	282.0	2805.5
1981	24.0	343.0	175.0	432.0	130.5	87.5	283.5	45.0	318.0	187.0	112.5	219.0	2357.0
1982	85.0	64.0	281.5	383.0	293.0	93.5	148.0	234.0	136.0	346.0	478.0	320.0	2862.0
1983	122.0	48.5	122.0	97.0	151.5	149.0	429.0	188.0	159.5	115.5	97.0	159.0	1838.0
1984	355.0	316.0	402.0	383.5	270.0	283.0	133.0	115.0	274.5	148.0	442.0	280.5	3402.5
1985	293.0	378.0	249.5	128.0	197.5	43.0	147.0	120.0	213.0	357.0	275.0	172.0	2573.0
MEAN	163.2	188.3	232.1	281.2	205.6	177.7	204.8	205.7	203.7	259.0	284.4	255.3	2660.9
1-DAY MAX.	115.8	143.0	104.6	112.0	105.9	115.6	187.0	163.0	94.0	198.0	102.9	250.0	
2-DAY MAX.	178.0	185.0	131.8	170.0	105.9	157.0	199.0	172.5	110.0	198.0	159.5	250.0	
3-DAY MAX.	206.7	192.0	161.0	203.0	115.0	170.0	242.6	172.5	132.0	198.0	192.5	250.0	

LONG-TERM MAXIMUM TOTALS (MM.) FOR DIFFERENT DURATIONS

PERIOD	1 DAY	2 DAY	3 DAY	5 DAY	7 DAY	14 DAY	30 DAY
1951-1985	250.0	253.0	276.0	313.9	381.0	430.5	643.7
(STARTING DATE)	(2/12/76)	(2/12/76)	(30/11/76)	(6/12/69)	(6/12/69)	(29/11/69)	(21/ 3/59)

N.B. MISSING OR INCOMPLETE DATA IS DENOTED BY ******. IF LESS THAN 50 % OF DATA ARE AVAILABLE, THE LONG-TERM MEAN VALUES ARE NOT COMPUTED. LONG-TERM MAXIMUM VALUES ARE COMPUTED IRRESPECTIVE OF INCOMPLETE DATA.

Pontian Kecil : Lat - 1° 30'
Long - 103° 27'

Check for rainstorm value using HP 1

X(5, ½) = 2.4"
X(5, 2) = 3.5"
X(5, 24) = 7.2"
X(5, 72) = 9.9"

X(10, ½) = 2.7"
X(10, 2) = 3.9"
X(10, 24) = 9.0"
X(10, 72) = 12.0"

Reading of from graph.

X(5, 48) = 8.75"
X(10, 48) = 10.75"

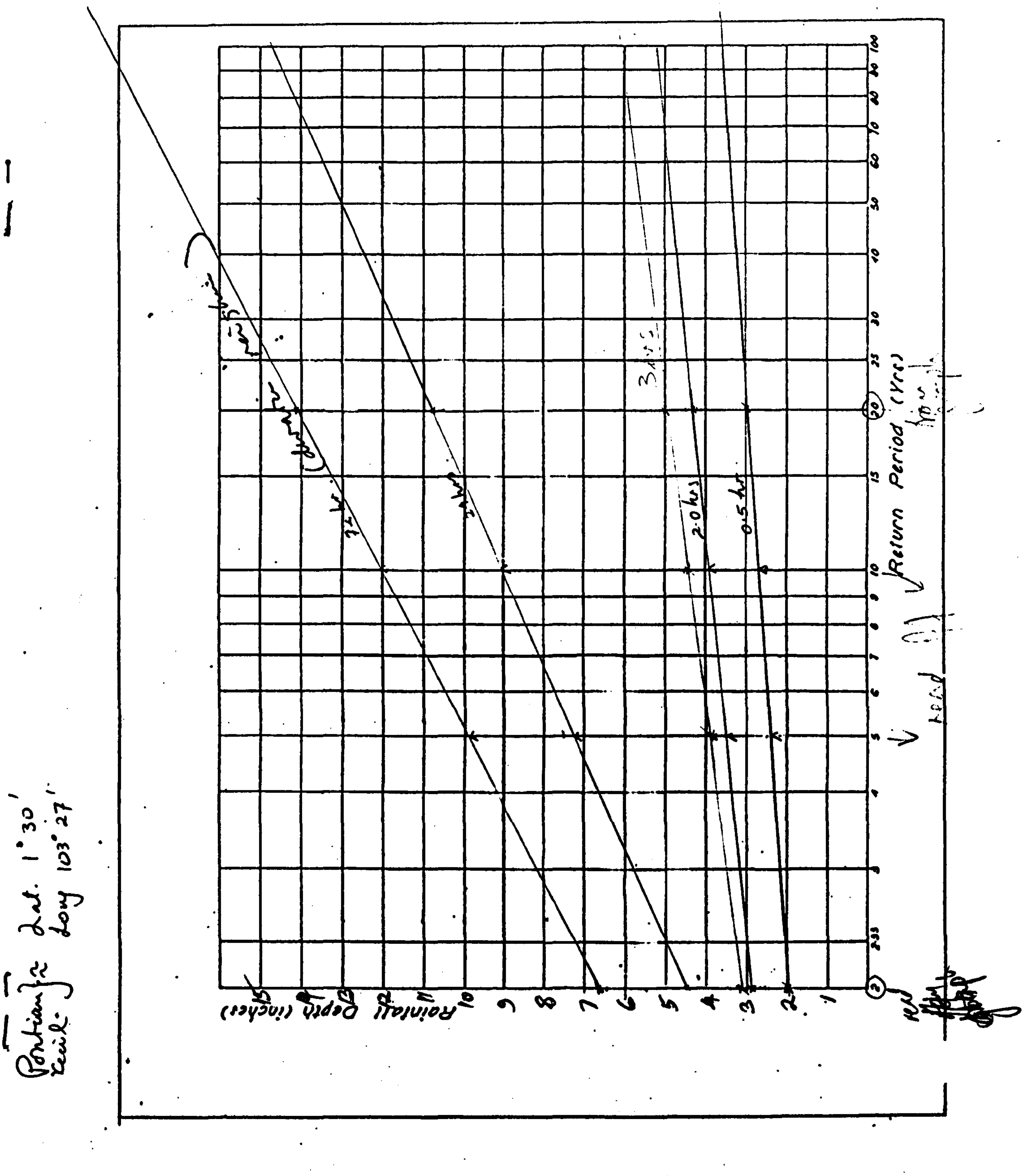
Thus.

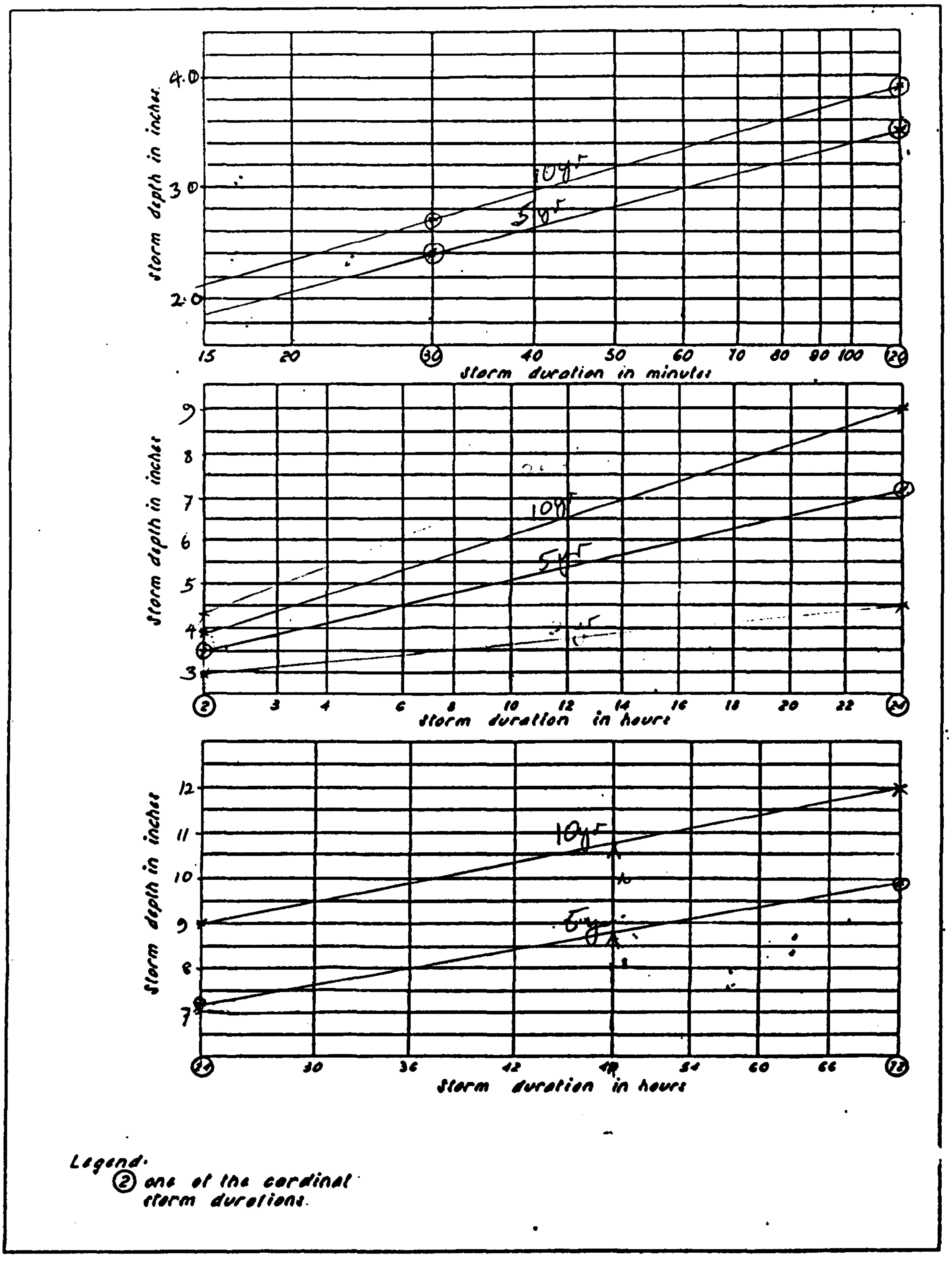
X(5,72)	= 9.9"	= 251.5 mm	= 83.8 mm/day
X(5,48)	= 8.75"	= 222.3 mm	= 111.2 mm/day
X(5,24)	= 7.2"	= 182.9 mm	= 182.9 "
X(10,72)	= 12.0"	= 304.8 mm	= 101.6 mm/day
X(10,48)	= 10.75"	= 237.1 mm	= 118.6 "
X(10,24)	= 9.0"	= 228.6 mm	= 228.6 "

Although vegetables are grown – choose 5,72 because of peat & grassland evaporation @ Pontian = 1300 mm/yr. or 3.56 mm/day.

∴ Design rainstorm for (5,72) = 83.8 − 3.56 = 80.24 mm/day

Take as 80 mm/day.


Pontian/Tecik Lat. 1°30'
Long 103°27'
Rainfall Depth (inches)
Return Period (Yrs)
12 hr
2.0 hrs
0.5 hr
3 hrs


4.0
3.0
2.0
Storm depth in inches
10 yr
5 yr
15
20
30
40
50
60
70
80
90
100
120
Storm duration in minutes
9
8
7
6
5
4
3
Storm depth in inches
10 yr
5 yr
2
3
4
6
8
10
12
14
16
18
20
22
24
Storm duration in hours
12
11
10
9
8
7
Storm depth in inches
10 yr
5 yr
24
30
36
42
48
54
60
66
72
Storm duration in hours
Legend.
② one of the cardinal storm durations.

BROKEN TEXT AND SOME POOR QUALITY IMAGES IN ORGINAL THESIS.

Text cut off in original

Particle density — a mass of a unit volume of soil solids
mineral soil — 2.6 g/cc (2.6–2.7)
organic soil — 1.1 g/cc (1.1–1.4)

Bulk density — a mass of a unit volume of dry soil
Volume includes both solids + pores

D_b = bulk density
D_p = particle density
W_s = Weight of soil (solids)
V_s = Volume of solids.
V_p = Volume of pores

$(V_s + V_p)$ = total soil volume

Simply — drainable porosity — f or μ — is volume fraction of the soil which which is emptied between condition of saturation + field capacity

$$D_p = \frac{W_s}{V_s} \qquad D_b = \frac{W_s}{V_s + V_p}$$

$$\therefore W_s = V_s D_p = D_b (V_s + V_p)$$

$$D_p V_s = D_b (V_s + V_p)$$

$$\therefore \frac{V_s}{V_s + V_p} = \frac{D_b}{D_p}$$

But $\left(\frac{V_s}{V_s + V_p}\right) \times 100\,\%$ = % solid space $(V_s + V_p = \ldots)$

$$\%\text{ pore space} = \left(100 - \left(\frac{V_s}{V_s + V_p}\right)100\right)\%$$

$$= 100\left(1 - \frac{D_b}{D_p}\right)\%$$

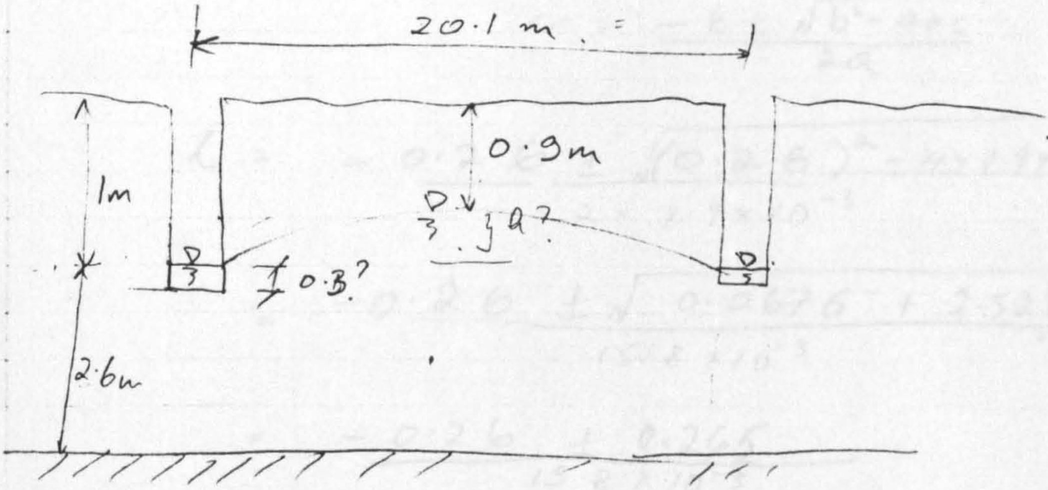
If saturated all pore space fill with water
∴ % moisture retention at saturation

$$= 100\left(1 - \frac{D_b}{D_p}\right)\%$$

D) Use steady state eqtn.

$$q = \frac{8 K_2 D_0 h}{L^2} + \frac{4 K_1 h^2}{L^2}$$

On plot LMNP.



Design for rainstorm = X(5, 72).

Estimation of rainstorm – Use DID HP 1

Pontian Kecil 2° 32' N, 103° 24' E } X(2,72) = 6.85", X(20,72) = 13.00", ∴ X(5,72) = 9.5"

∴ Rainstorm mm/day $\frac{9.5}{3} \times 25.4 = 80.4$ mm/day

Grassland evaporation @ Pontian 1300 mm/yr = 3.56 mm/day
(Water Resources Publication No 5.)

∴ Use q = 80.0 mm/day = 0.08 m/day

K: from Kamarudin Kimbale used. $K_1 = 0.8$ m/day
$K_2 = 5.0$ m/day

find h

$$0.08 = \frac{(8 \times 5.0 \times 2.6\, h)}{(20.1)^2} + 4 \times 0.8\, h^2$$

$$0.08 = 0.26\, h + 7.9 \times 10^{-3} h^2$$

$$ax^2 + bx + c = 0.$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$h = \frac{-0.26 \pm \sqrt{(0.26)^2 - 4 \times 7.9 \times 10^{-3}(-0.08)}}{2 \times 7.9 \times 10^{-3}}$$

.0040

$$= \frac{-0.26 \pm \sqrt{0.0676 + 2.528 \times 10^{-3}}}{15.8 \times 10^{-3}}$$

0.

$$= \frac{-0.26 \pm 0.265}{15.8 \times 10^{-3}}$$

+ve Value ⟶ $h = 0.32m$.

=

$L = 10$ m

$$\therefore 0.08 = \frac{8 \times 5 \times 2.6\, h}{10^2} + 4 \times 0.8\, h^2$$

$$0 = 1.04h + 0.032\, h^2 - 0.08.$$

$$h = \frac{-1.04 \pm \sqrt{1.04^2 + 4 \times 0.032 \times 0.08}}{2 \times 0.032}$$

$$= \frac{-1.04 \pm 1.015}{2 \times 0.032}$$

— No +ve h value $\therefore$ probably $h = 0$.

0.08 ~~m/hr~~ is a rainstorm of 1 in 5 yrs, 72 hrs duration

Use rainfall = 70 mm / day and assume drainflow factor = 0.7

∴ Drainage coefficient = 70 × 0.7
= 49 mm/day ≈ 50 mm/day.

$$0.050 = \frac{8 \times 5.0 \times 2.6\,h + 4 \times 0.8\,h^2}{400}$$

$$0 = 8\times10^{-3} h^2 + 0.26 h - 0.05$$

$$h = \frac{-0.26 \pm \sqrt{0.26^2 + 4\times8\times10^{-3}\times0.05}}{2\times8\times10^{-3}}$$

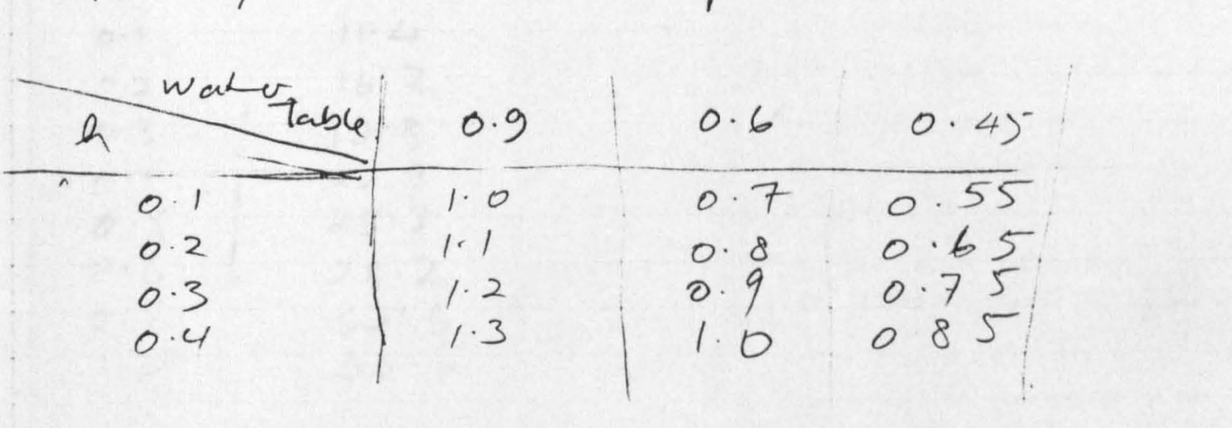
$$= \frac{-0.26 \pm 0.263}{16\times10^{-3}}$$

$$= 0.20 \text{ m.}$$

Depth of drains (m) [illegible]

h \ Water table	0.9	0.6	0.45
0.1	1.0	0.7	0.55
0.2	1.1	0.8	0.65
0.3	1.2	0.9	0.75
0.4	1.3	1.0	0.85

From discussions with Welch it seems vertical K_2 is minimal compared to horizontal K_1. The behaviour below have been noted.



h value ≈ 0.

$$q = \frac{8K_2 D_0 h}{L^2} + \frac{4k_1 h^2}{L^2}$$

$q = 0.08$ m
$D_0 = 2.6$ m
$K_2 = 5$ m/day
$k_1 = 0.8$ m/day

find h for various L from 40m to 5 m

$$0.08 = \frac{8 \times 5 \times 2.6\, h}{L^2} + \frac{4 \times 0.8 \times h^2}{L^2}$$

$$0.08 L^2 = 104\, h + 3.2\, h^2$$

$$L^2 = 1300 h + 40 h^2$$

$$L = \sqrt{1300 h + 40 h^2}$$

h(m)	L (m)
0	0
0.1	11.4
0.2	16.2
0.3	19.8
0.4	22.9
0.5	25.7
0.6	28.2
0.8	32.6
1.0	36.6

using Manning's Eqtn.

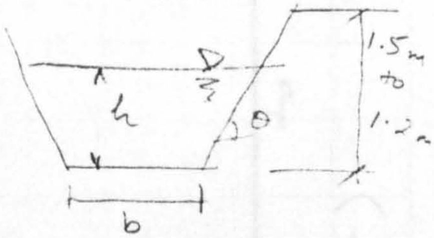
$$V = \frac{R^{2/3} S^{1/2}}{n} = R^{2/3} (1.265)$$

$$Q = VA$$

$$A = \left[b + \frac{h}{\tan\theta}\right] h$$

$$P = b + 2h\sqrt{\frac{1}{\tan^2\theta} + 1}$$

assumed
$n = 0.025$
(for unlined canals)



$S = \frac{1}{1000}$
$\tan\theta = 5$
$b = 0.6$ m.

From computer can estimate
h for given Q.

By hand calcn.

$$A = (0.6 + 0.2h)h = 0.6h + 0.2h^2$$
$$P = 0.6 + 2h\sqrt{1.04} = 0.6 + 2.04h$$

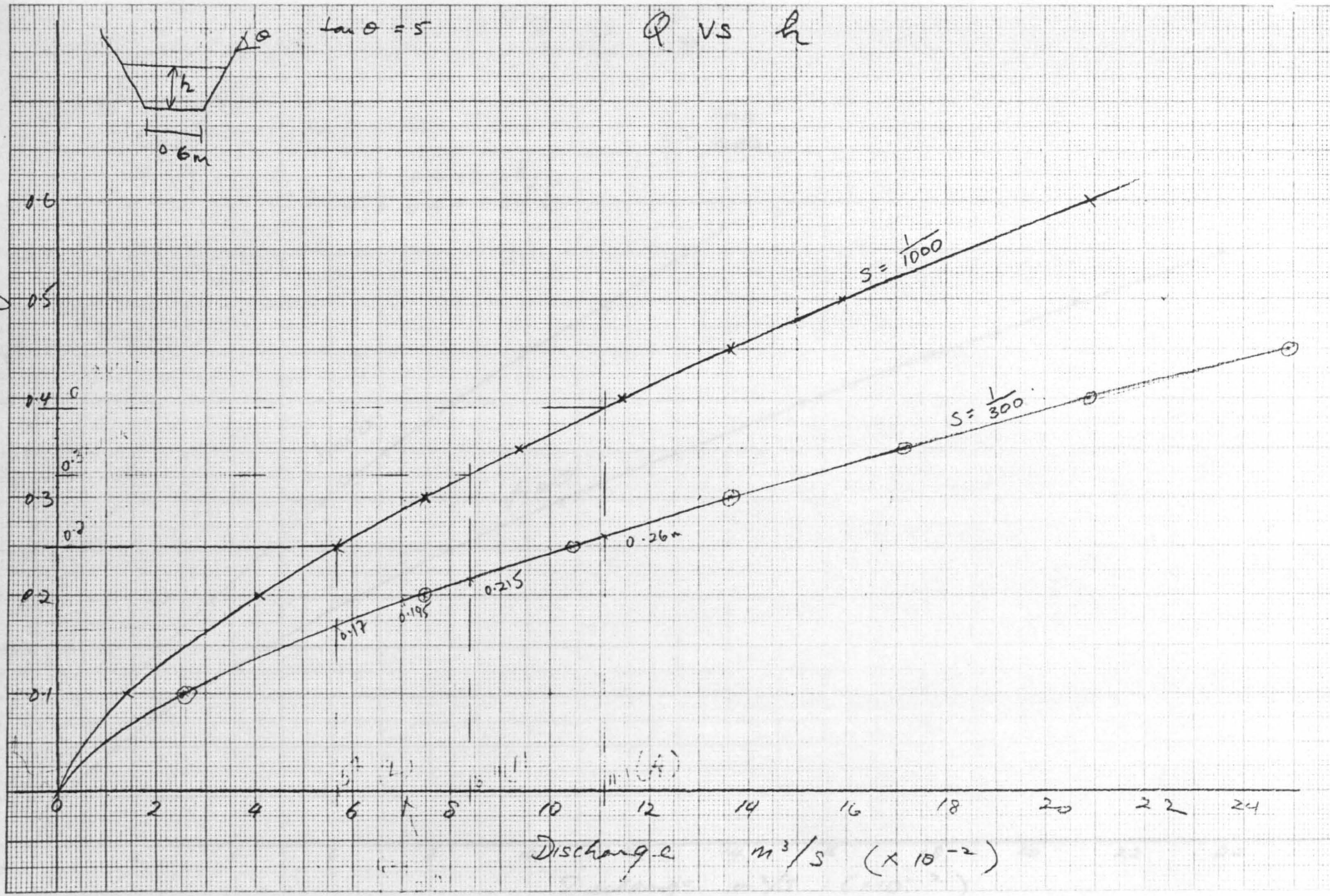
$h = 0.1$ ⟶
$A = 0.06 + 0.002 = 0.062$ m²
$P = 0.6 + 0.204 = 0.804$ m
$R = A/P = 0.077$ m
$V = 0.229$ m/s
$Q = 0.014$ m³/s $= 1.4 \times 10^{-2}$ m³/s

$h = 0.2$ ⟶
$A = 0.12 + 0.008 = 0.128$ m²
$P = 0.6 + 0.408 = 1.008$ m
$R = 0.127$
$V = 0.320$ m/s
$Q = 4.091 \times 10^{-2}$ m³/s

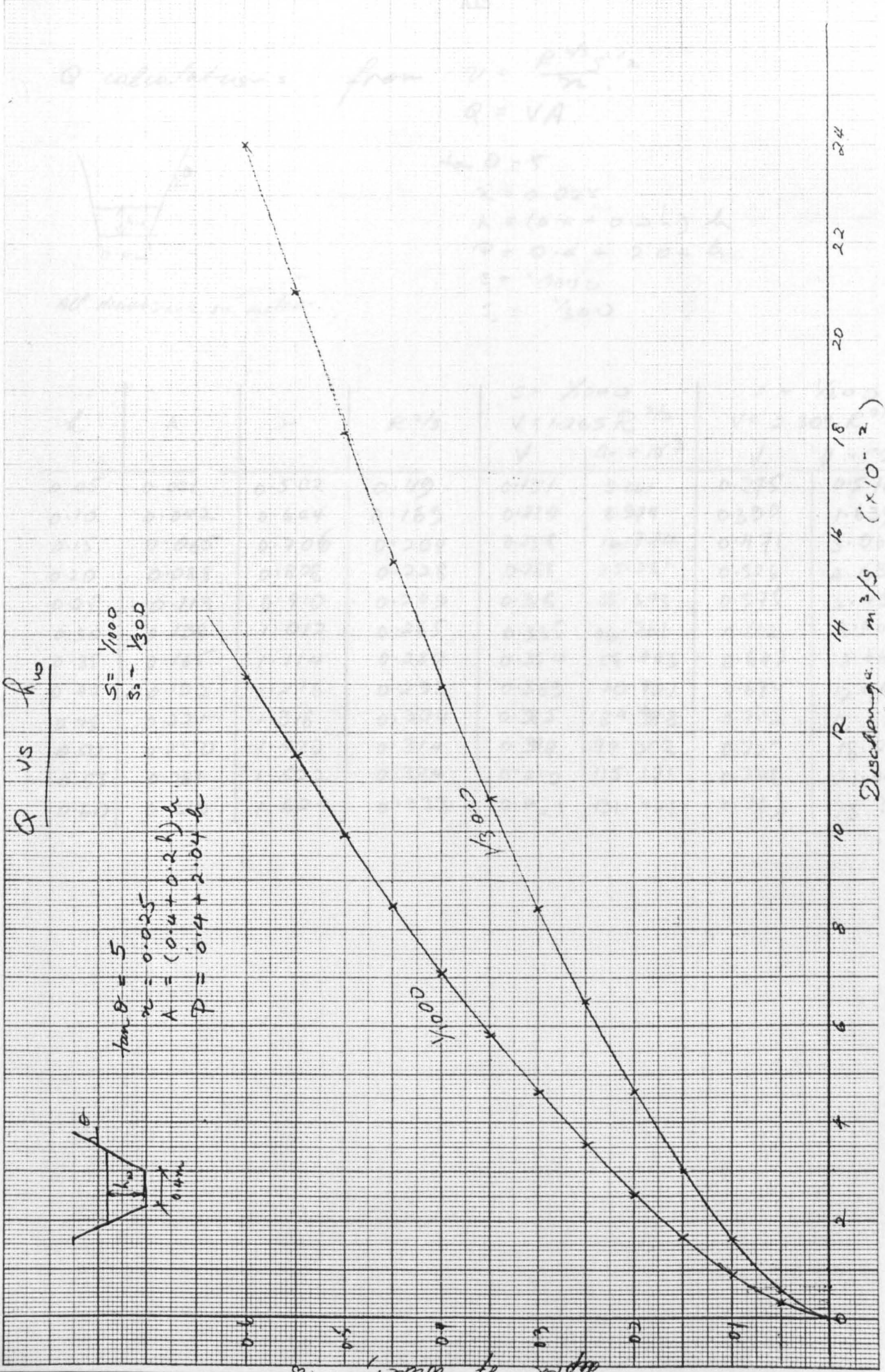
$h = 0.3$ ⟶
$A = 0.18 + 0.018 = 0.198$ m²
$P = 0.6 + 0.612 = 1.212$ m
$R = 0.163$
$V = 0.378$
$Q = 7.485 \times 10^{-2}$ m³/s

$h = 0.5$
$A = 0.3 + 0.05 = 0.35$ m²
$P = 0.6 + 1.02 = 1.62$ m
$R = 0.216$
$V = 0.459$ m/s
$Q = 15.946 \times 10^{-2}$ m³/s

$h = 0.25$ ⟶ $Q = 5.710 \times 10^{-2}$ m³/s
$h = 0.35$ ⟶ $Q = 9.403 \times 10^{-2}$ m³/s
$h = 0.40$ ⟶ $Q = 11.455 \times 10^{-2}$ m³/s
$h = 0.45$ ⟶ $Q = 13.636 \times 10^{-2}$ m³/s
$h = 0.48$ ⟶ $Q = 15.004 \times 10^{-2}$

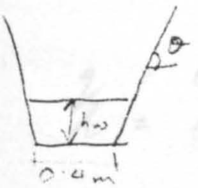


tan θ = 5
h
0.6m
Q VS h
S = 1/1000
S = 1/300
0.26m
0.215
0.195
0.17
Discharge m³/s (× 10⁻²)
0
2
4
6
8
10
12
14
16
18
20
22
24
0.1
0.2
0.3
0.4
0.5
0.6


Q vs h_w
S = 1/1000
S₂ = 1/300
tan θ = 5
n = 0.025
A = (0.4 + 0.2 h) h
P = 0.4 + 2.04 h
0.4m
1/1000
1/300
Discharge m³/s (×10⁻²)
depth of water, m
0
2
4
6
8
10
12
14
16
18
20
22
24
0.1
0.2
0.3
0.4
0.5
0.6

Q calculations from $v = \frac{R^{2/3} S^{1/2}}{n}$.

$Q = VA$.



- All dimensions in meters.

$\tan\theta = 5$

$n = 0.025$

$A = (0.4 + 0.5h)h$

$P = 0.4 + 2.04h$

$S = 1/1000$

$S_2 = 1/300$

h	A	P	$R^{2/3}$	S = 1/1000, $V = 1.265 R^{2/3}$: V	$Q \times 10^{-3}$	S = 1/300, $V = 2.309 R^{2/3}$: V	$Q \times 10^{-[illegible]}$
0.05	0.021	0.502	0.119	0.151	3.161	0.275	0.577
0.10	0.042	0.604	0.169	0.214	8.979	0.390	1.639
0.15	0.065	0.706	0.204	0.258	16.774	0.471	3.062
0.20	0.088	0.808	0.228	0.288	25.381	0.526	4.633
0.25	0.113	0.910	0.249	0.315	35.593	0.575	6.497
0.30	0.138	1.012	0.265	0.335	46.261	0.612	8.444
0.35	0.165	1.114	0.280	0.354	58.443	0.647	10.668
0.40	0.192	1.216	0.292	0.369	70.921	0.674	12.945
0.45	0.221	1.318	0.304	0.385	84.988	0.702	15.513
0.50	0.250	1.420	0.314	0.397	99.303	0.72[illegible]	18.126
0.55	0.281	1.522	0.324	0.410	115.171	0.748	21.022
0.60	0.312	1.624	0.333	0.421	131.428	0.769	23.990

Drain designs - hydraulics

For all designs use

$q = 0.08$ m/day. (5yrs, 72hrs) rainstorm

$h = 0.3$ m → ∴ Drain depths d_i for plots

(1) 1.2 m

(3) 0.9 m → use 1.0 m

(5) 0.80 → use 0.8 m

Plot ~~5~~ 6 (6)

Area: $(3\tfrac{1}{8} \times 2 \times 66)(2\tfrac{3}{8} \times 2 \times 66)$ ft² $= 3.125 \times 2.375 \times 132^2$ ft²

$= 3.125 \times 2.375 \times 1618.74$ m²

$= 1.2 \times 10^4$ m²

$= 1.2$ ha

6 panels ∴ each panel = 0.2 ha.

∴ q on each panel = 160 m³/day

$= 1.85 \times 10^{-3}$ m³/s

Q into ~~5a+5c~~ D61 + D65 $= 2.78 \times 10^{-3}$ m³/s

Q from plot (6) $= 1.11 \times 10^{-2}$ m³/s

Q into ~~5b,5c+5d~~ D62/3/4 $= 1.85 \times 10^{-3}$ m³/s

All field drains x-section

$1f = 0.3048$ 9

Field drains.

Plot 5 $s = 1/1000$, drain depth = 0.8 m.
= 2.6(2) ft.

drain e ½

length = 280 ft. GL u/s +25.4 ft
d/s +26.7 ft

Drain design for u/s IL. $(25.4 - 2.6) = +22.8$ ft

280 ft @ $\frac{1}{1000}$ ⇒ fall = 0.28 (0.3) → d/s IL = (+22.5) ft ✓

Discharge in drain e = 2.78×10^{-3} m³/s

h_w @ $s = 1/1000$ ≤ 0.05 m
< 0.16 ft ≈ 2 inches.

drain d

length = 270 ft   G.L u/s +25.5
d/s +26.9

Drain design, IL u/s +22.9
fall ≈ 0.27 ≈ 0.3 → IL @ corner +22.6

Turning losses. — assume 0.2
+22.4

Turning to control structure, ¼ ft. fall. 0.1
22.3 ← before structure.

$Q = 1.85 \times 10^{-3}$ m³/s

h_w @ $s = 1/1000$ < 0.03
< 0.1 ft ≈ 1.2 inch.

drain c

length .= 270 ft. GL u/s 25.5
d/s. 26.2

$Q = 1.85 \times 10^{-3}\ m^3/s$ ∴ h_w @ $S = 1/1000$ ≈ 1.2 inches

Drai I.L u/s (25.5 − 2.6) = 22.9

fall ≈ 0.3 IL before structure = 22.6

check with (brd) Allow losses for structure 0.5 ∴ IL = 22.1

between structure and perimeter drain 0.01 ft

∴ Required IL at outlet to main drain = +22.1

drain b.

length 270 ft G.L. u/s +26.9
d/s 25.5

$Q = 1.85 \times 10^{-3}\ m^3/s$. h_w @ $S = 1/1000$ ≈ 1.2 inches.

Drai I.L. u/s (26.9 − 2.6) = 24.3

fall ≈ 0.3

IL @ corner ≈ 24.0

assume turning losses 0.2 − 0.2

23.8

fall from turning to control 0.1 − 0.1

23.7

For drain d, c, b lowest I.L before structure is from drain d — +22.3

losses @ structure 0.5

21.8 ✓

between structure + perimeter drain — 0.01 ft.

∴ Required IL at outlet to main drain bet 21.8 to 21.7

$Q = 5.55 \times 10^{-3}\ m^3/s$

$h_w =$

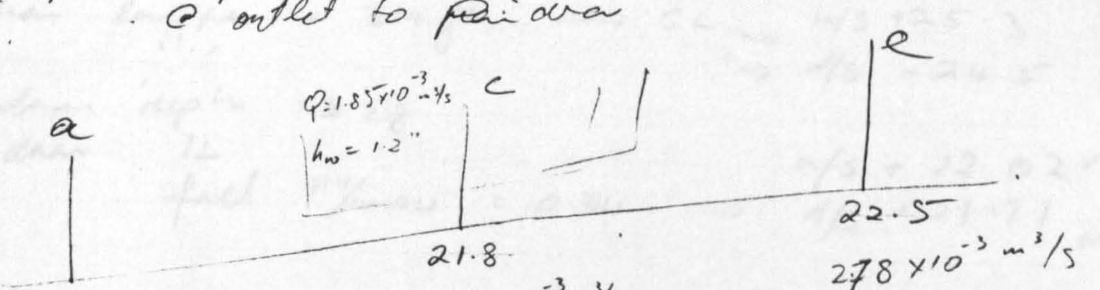
drain a.

length 295 ft. GL u/s +26.0
d/s +25.5.

$Q = 2.78 \times 10^{-3}\ m^3/s$
h_w @ $s = 1/1000$ < 0.16 ft $\approx$ 2 inches.

Drain design IL u/s + 23.4
fall $\approx$ 0.3 IL d/s + 23.1

Summary for plot 5.
@ outlet to field drain



I.L 23.1
Q $2.78 \times 10^{-3}\ m^3/s$
h_w $\approx 2''$

$\left(\begin{array}{l}0.07\ m\\ = 0.23\ ft = 2.75''\end{array}\right)$
$\approx 2.75''$

(12)

Plot ~~3~~ 5

$q = 0.08$ m/day
$h = 0.3$ → ∴ drain depth 0.9 m but use 1.0 m ≈ 3.28 ft

$s = 1/1000$

drain e

Average panel length 98 m
∴ area $98 \times 20.1 \times 1.5 = 2957\ m^2$
∴ Q $= 2.738 \times 10^{-3}\ m^3/s$
$h_w \approx 2''$

drain length = 314 ft. → GL → u/s +25.3 → d/s +24.5

drain depth = 3.28

drain IL u/s + 22.02 ✓

fall 314/1000 = 0.314 → d/s + 21.71 ✓

~~Drgm~~. 2.6~~25~~ 2~~2~~.67 22.~~396~~1

drain d.

Average panel length 101 m
∴ area $101 \times 20.1 \times 1 = 2030.1$
∴ Q $= 1.88 \times 10^{-3}$
$h_w \approx 0.03$ ft ≈ 1.2 "

Drain length = 312 ft

GL u/s +25.1 ft
d/s +22.9

Drain IL u/s + 21.82
fall @ turning = 0.31 @ corner IL + 21.51
turning losses 0.20
downstream of turning − 21.31
losses 20.1 m − say 0.07 0.07
IL before structure (21.24)

drain c.

Average panel length 103 m.
∴ area 103 × 20.1 × 1 = 2070.3
∴ Q 1.92 × 10^{-3}
∴ hw ≈ 0.03 m ≈ 1.2"

Drain length 320 ft

GL → u/s +24.5
d/s +23.9
Drain depth = 3.28
Drain IL → u/s +21.22
fall = 0.32) IL just before structure (+20.90)

drain b

Average panel length 106 m
∴ area 106 × 20.1 × 1 = 2130.6
∴ Q 1.97 × 10^{-3}
∴ hw ≈ 0.03 m ≈ 1.2"

Drain length 328 ft

GL → u/s +24.1
d/s +23.2

depth = 3.28
Drain IL → u/s 20.82
(fall 0.33) IL just bef. turning. 20.49
turning losses 0.20
20.29
losses for across panel 0.07
IL before structure 20.22

For drain d, c, b lowest I.L before is from drain b

+20.22
losses @ structure 0.5
19.72
IL just before p. drain 19.71 ⟹ Q = 5.77 × 10^{-3}
hw ≈ 0.075 m
≈ 2.95"

(14)

drain a.

Average panel length 108 m

∴ area = 108 × 20.1 × 1.5 = 2170.8

∴ Q = 3.02×10^{-3} ∴ h_w = ≈ 0.05 m ≈ 2"

Drain length 347 ft

GL u/s + 23.8

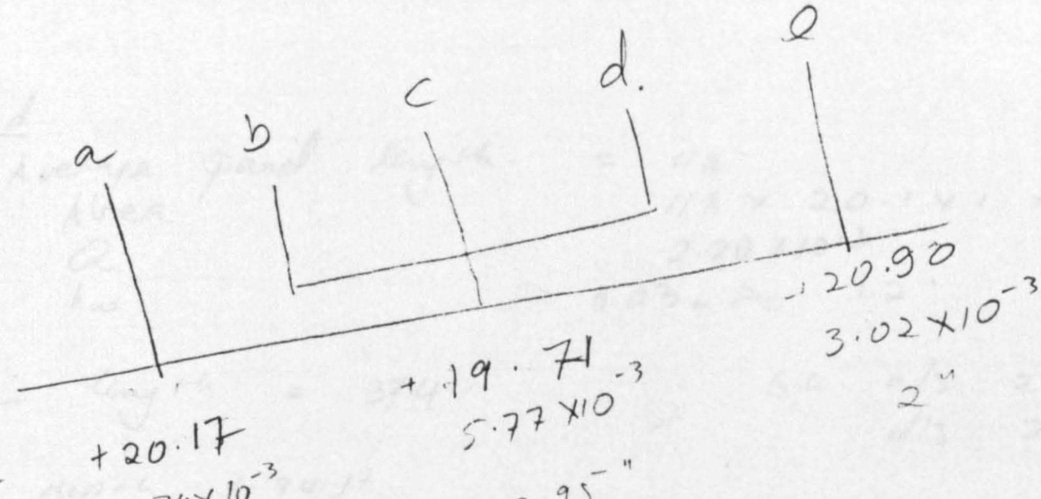
d/s + 23.2

drain depth = 3.28

drain IL u/s + 20.52

fall 0.347 d/s + 20.17

Summary for plot 5 @ outlet to perimeter drain



I.L

Q ≈ 2.74 × 10^{-3}

h_w ≈ 2"

Plot K

q = 0 08 m/day
h = 0.3 — ∴ drain depth 1.2 m.
= 3.94 ft

drain c
Average panel length = 116 m
∴ Area = 116 × 20.1 × 1.5 = 3497.4 m²
Q = 3.24 × 10⁻³
h_w ≈ 0.05 m ≈ 2"

Drain length = 374 ft ; → GL u/s 23.2
d/s 20.4

Drain depth 3.94 ft
Drain IL u/s 19.26
fall 374/1000 = 0.37 d/s 18.89

drain d
Average panel length = 118
∴ Area 118 × 20.1 × 1 = 2371.8
Q 2.20 × 10⁻³
h_w ≈ 0.03 m ≈ 1.2"

Drain length = 374 ; GL u/s 23.20
d/s 22.04

Drain depth 3.94 ft
Drain IL u/s 19.26
fall upto turning = 0.37 ; ∴ IL 18.89
turning loss 0.20
IL just after turning 18.69
fall across panel 0.07
IL before structure 18.62

drain c

Ave panel length = 121

∴ Area 121 × 20.1 × 1 = 2432.1 m^2

Q 2.25×10^{-3} m^3/s

h_w ≈ 0.03 m ≈ 1.2"

Drain length = 384 ; GL → u/s + 22.0
d/s + 21.9

Drain depth = 3.94

Drain I.L. → u/s +18.06

fall 0.38 — 0.38

I.L just before structure. 17.68

drain b

Ave panel length. = 123

Area 123 × 20.1 × 1 = 2472.3

Q 2.29×10^{-3} m^3/s

h_w. ≈ 0.03m ≈ 1.2"

Drain length. = 391 ; GL → u/s + 22.0
d/s + 21.0

Drain depth = 3.94

Drain I.L → u/s + 18.06

fall = 0.39 ; IL just before tuning 17.67

tuning losses 0.2

17.47

losses across panel − 0.07

I.L before structure 17.40

For drain d, c, b

lowest I.L before structure drain b. = 17.40

losses @ structure 0.50

16.90

losses to p. drain 0.01

I.L just before p drain → 16.89

$Q = 6.74 \times 10^{-3}$ m^3/s

$h_w = 0.08$ m

~ 3.15 inches

(17)

drain a

Average panel length = 126 m

∴ Area $126 \times 20.1 \times 1.5 = 3798.9$

Q $= 3.52 \times 10^{-3}$

h_w $0.055\text{m} \approx 2.2''$

Drain length 407 ft

G.L. → u/s = 21.5

d/s = 20.5

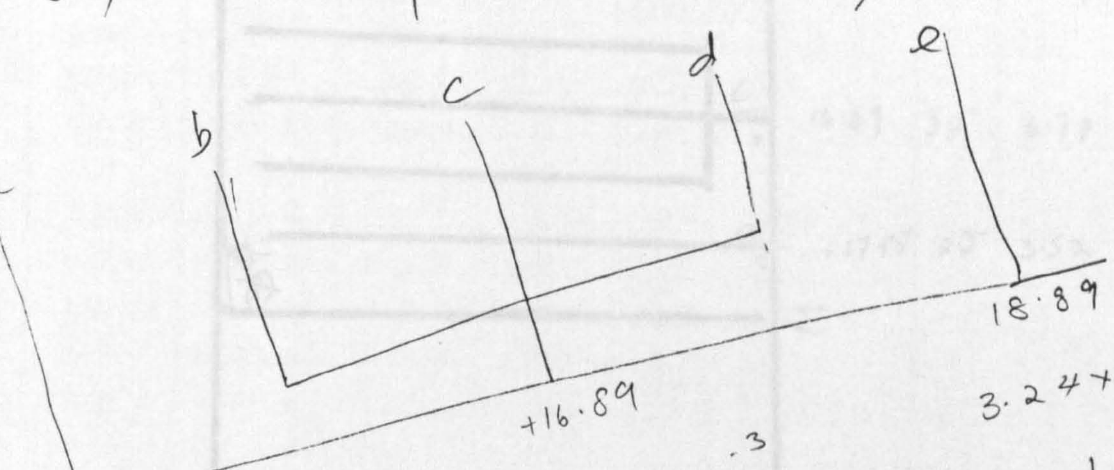
drain depth = 3.94

Drain I.L u/s = 17.56

fall 0.41 d/s = 17.15

(1)

Summary for plot 4 @ outlet to perimeter drain.



3.24×10^{-3}

2.1″

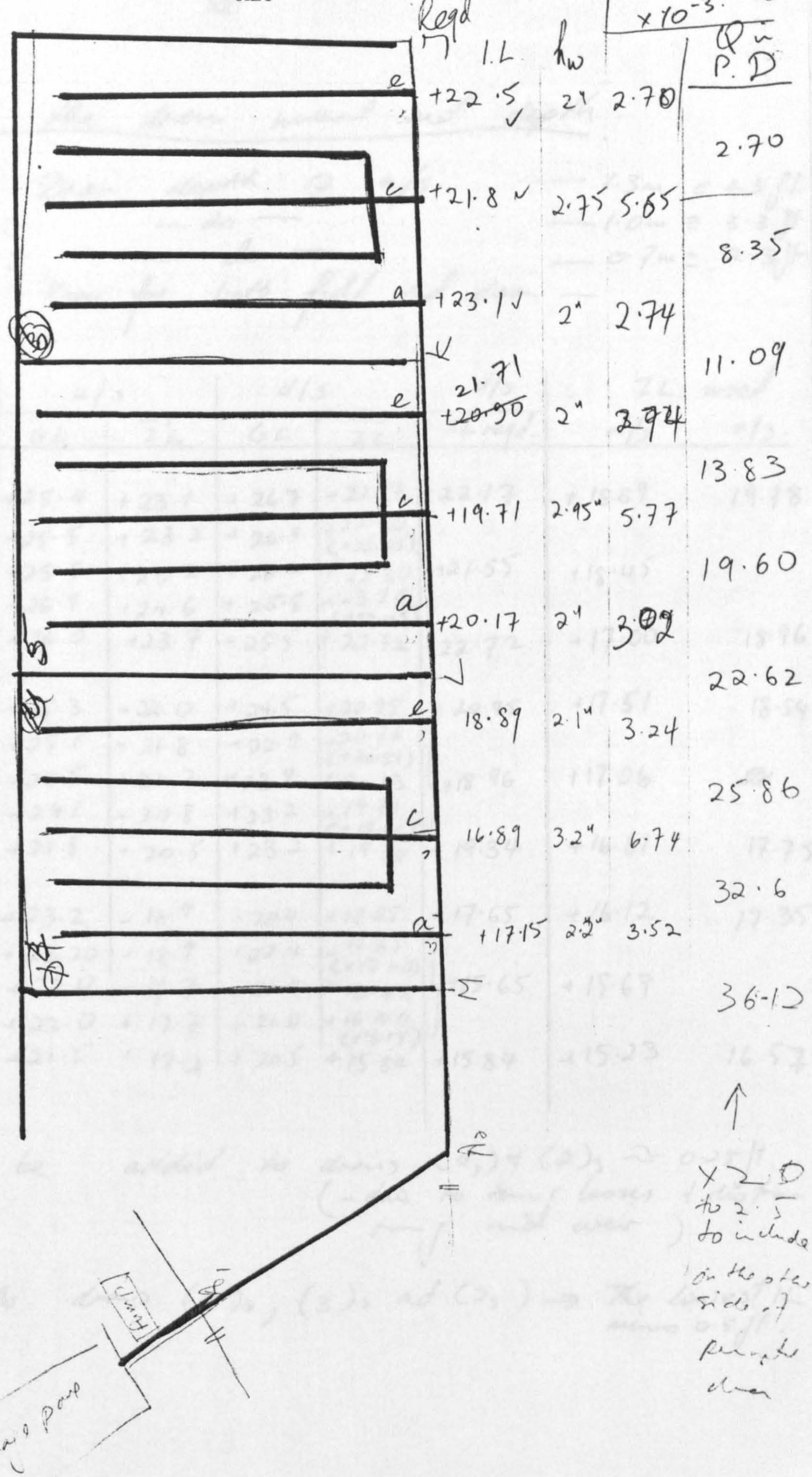
I.L +17.15

6.74×10^{-3}

≈ 3.2″

$Q \approx 3.52 \times 10^{3}$

$h_w \approx 2''2''$



Summary of reqd levels etc

Redesigned the drain ment and depth.

Plot 4 : Drain depth @ u/s. — 1.3m ≡ 4.3 ft
Plot 5 : — do — — 1.0m ≡ 3.3 ft
Plot 6 : — do — — 0.7m = 2.3 ft
slope : 1/300 for both field and drain —

Dr. Name.	Length ft	u/s GL	u/s des IL	d/s GL	d/s des IL	d/s IL reqd.	IL used d/s	IL used u/s.
D65	280	+25.4	+23.1	+26.7	+22.17	+22.17	+18.89	19.78
D64	270	+25.5	+23.2	+26.9	+22.30 (+22.05)	+21.55 (D64–D62)	+18.45	
D63	270	+25.5	+23.2	+26.2	+22.30			
D62	270	+26.9	+24.6	+25.5	+23.70 (+23.45)			
D61	295	+26.0	+23.7	+25.5	+22.72	+22.72	+17.00	18.96
D55	314	+25.3	+22.0	+24.5	+20.95	+20.95	+17.51	18.54
D54	312	+25.1	+21.8	+22.9	+20.76 (+20.51)	+18.96 (D54–D52)	+17.06	
D53	320	+24.5	+21.2	+23.9	+20.13			
D52	328	+24.1	+20.8	+23.2	+19.71 (+19.46)			
D51	347	+23.8	+20.5	+23.2	+19.34	+19.34	+16.61	17.75
D45	374	+23.2	+18.9	+20.4	+17.65	+17.65	+16.12	17.35
D44	374	+23.20	+18.9	+22.4	+17.65 (+17.40)	+15.65 (D44–D42)	+15.67	
D43	384	+22.0	+17.7	+21.9	+16.42			
D42	391	+22.0	+17.7	+21.0	+16.40 (+16.15)			
D41	407	+21.5	+17.2	+20.5	+15.84	+15.84	+15.23	16.57

losses to be added to drains (4s) & (2)s ≃ 0.25 ft
(— due to timing losses & distorting and over)

Reqd. IL for drains (4)s, (3)s and (2s) → The lowest IL minus 0.5 ft.

Main Drain Design – Slope 1/300

slope : 1/300

Location	Chainage	Length (ft)	GL	IL (s=1/300) Reqd	IL (s=1/300) Design	Depth ft	Depth m
A_1	0	340	+20.10	–	+13.38	6.72	2.05
A_2	340	134	+21.2	–	+14.51	6.69	2.04
M	474	74	+20.2	–	+14.96	5.24	1.60
D41	548	134	+20.5	+15.84	+15.21	5.29	1.61
D43	682	134	+21.9	+15.65	+15.65	6.25	1.91
D45	816	74	+20.4	+17.65	+16.10	4.30	1.31 < 1.5
L	890	74	+22.3	–	+16.35	5.95	1.80
D51	964	134	+23.2	+19.34	+16.59	6.61	2.01
D53	1098	134	+23.9	+18.96	+17.04	6.86	2.09
D55	1232	74	+24.5	+20.95	+17.49	7.01	2.14
K	1306	74	+25.0	–	+17.73	7.27	2.22
D61	1380	134	+25.5	+22.72	+17.98	7.52	2.29
D63	1514	134	+26.2	+21.55	+18.43	7.77	2.34
D65	1648		+26.7	+22.17	+18.85	7.85	2.39

Increase drain depth of D45 to 1.62 m
∴ all design invert lowered by 1 foot. i.e

	Corrected design Invert.
A_1	+12.38
A_2	+13.51
M	+13.96
D41	+14.21
D43	+14.65
D45	+15.10
L	+15.35
D51	+15.59
D53	+16.04
D55	+16.49
K	+16.73
D61	+16.98
D63	+17.43
D65	+17.85

APPENDIX B

Detail Design for IPRS Project Area

APPENDIX B - Detail Design for IPRS Project Area

B1 General and Drainage Discharge Coefficient

From experiences gathered from pilot test plot (Appendix A), there was insufficient head loss between weir and outfall. To monitor k field, there must be sufficient head loss. This is achieved by exchanging the 300 mm and the 900 mm WT plots. The drainage depth of the constructed drains in Plot 4 were raised using a combination of sand bags and wooden check structures. The location of the various WT control plots is shown in Figure 3.3. The drainage rate used was 80 mm/day or an equivalent to 9.3 l/s/ha, similar to that in Appendix A.

The design drainage depths of the various plots were arrived at by considering the depth of root zone, capillary fringe, peat depths, porosity, hydraulic conductivity, allowable maximum midfield water table depth and allowable fluctuation in WT depths. A fluctuation of ± 100 mm for the WT was assumed. Details of the parameters used are given in Table B1.

B2 Drain Design and Instrumentation

For the overall planning and design, the whole area was resurveyed (Figure 5.67). All survey points were tied to the Survey Department permanent bench mark located beside the main road just outside IPRS. During the survey the peat depth over the whole area was also investigated using a combination of gouge auger and graduated steel rod (Figure 5.66).

The same design rainstorm as in Appendix A were used. A slightly bigger evaporation were used resulting in similar drainage coefficient as in Appendix A. Drain spacing calculations were made using Hooghout steady state equation as well as the Glover-Dumm falling WT equation. The result of the analysis is given in Table B1.

TABLE B1 - Assumptions for the Design of the Project Area

	Plot 1 & 4	Plot 2 & 5	Plot 3 & 6
Type and layout of system	ditches	ditches	ditches
Design rainstorm	5 years 72 hours (83.83 mm/day)	5 years 72 hours (83.83 mm/day)	5 years 72 hours (83.83 mm/day)
Evaporation	5 mm/day	5 mm/day	5 mm/day
Drainage rate	80 mm/day	80 mm/day	80 mm/day
Depth of rootzone	300 mm	600 mm	900 mm
Capillary fringe	150 mm	150 mm	150 mm
Rise in water table shape (parabolic shape)	100 mm	200 mm	300 mm
Required depth of field drainage base	550	950	1350
Depth of peat	3.5 m	4.5 m	5.0 m
Hydraulic conductivity	5 m/day	5 m/day	5 m/day
Drain Spacing Hooghout steady state	< 10 m	13 m	18 m
Drain Spacing Glover-Dumm falling water table	20 m	30 m	40 m

Drain spacing using Glover-Dumm equation was chosen. Details of the design is given in the preceding pages.

Pore Space of Mineral Soils

By defn: particle density, $\gamma_p = \frac{W_s}{V_s} = \frac{\text{Weight of Solid}}{\text{Volume of Solid}}$

bulk density, $\gamma_b = \frac{W_s}{V} = \frac{\text{Weight of Solid}}{\text{Total Volume}}$

∴ Solving for W_s

$$W_s = \gamma_p V_s$$

$$W_s = \gamma_b V = \gamma_b (V_s + V_p)$$

$$\gamma_p V_s = \gamma_b (V_s + V_p) = \gamma_b V$$

$$\frac{V_s}{V} = \frac{\gamma_b}{\gamma_p}$$

But porosity, $n \longrightarrow = \frac{V_p}{V}$

$$= 1 - \frac{V_s}{V} = \frac{V_s + V_p - V_s}{V} = \frac{V_p}{V}$$

But $\frac{V_s}{V} = \frac{\gamma_b}{\gamma_p}$

$$\therefore n = \frac{V_p}{V} = 1 - \frac{V_s}{V}$$ (pore)

$$= 1 - \frac{\gamma_b}{\gamma_p}$$

$$\therefore n \times 100\% = \left(1 - \frac{\gamma_b}{\gamma_p}\right) 100\%$$

Assume γ_p for peat $= 1.1$ gm/cc.

	depth (cm)	γ_b	γ_p	n %
∴ Fr IPRS, Pontian Beluko.	0-15	0.15	1.1	86.4
	15-30	0.10	1.1	90.9
	30-45	0.10	1.1	90.9
	45-60	0.09	1.1	91.8

For <u>Saturated Condition</u>.

$$\eta \text{ or } \eta_{sat} = \frac{V_v}{V} = \frac{V_w}{V}$$

$\therefore$ for $1 m^3$ of sample (ie $V = 1$) — $V_W = \eta \; m^3$
$V_S = (1-\eta) \; m^3$

density of water = $1 gm/cc$
= $1000 \, kg/m^3$

$\therefore$ Weight of water = $\eta \times 1000$ kg.

ie $W_W = (\eta \times 1000)$ kg.

But $m = \frac{W_w}{W_s}$

$$\therefore \quad W_S = \frac{W_{w \, sat}}{m_{sat}}$$

<u>At field Capacity</u>.

But $W_{S_{sat}} = W_{S_{f.c.}} = W_S$.

$$m_{f.c.} = \frac{W_{w f.c}}{W_s}$$

$$\therefore W_{wf.c} = m_{f.c} \times W_S.$$

$$V_{w_{fc}} = W_{w_{fc}} / \rho_w.$$

$$\eta_{fc} = \frac{V_{wfc}}{V} = \frac{V_{wfc}}{1} = V_{wfc}.$$

drainable porosity = $\eta_{sat} - \eta_{f.c.}$

IPRS, Portion Bdukev – Physical properties
– Kamamdi Ambak (unpublished)

Depth (cm)	% Moisture Retention, m: Field	Saturation	1/3 bar	15 bar	γ_b
0 – 15	365.6	578.2	437.86	265.40	0.5
15 – 30	668.0	858.5	382.64	243.20	0.[illegible]
30 – 45	809.8	917.9	–	–	0.[illegible]
45 – 60	1055.2	1133.7	–	–	0.09

Assume $\gamma_p = 1.1$ gm/cc and cal for 1 m³ sample.

At saturation $V_w = V_v$.   v = void, s = solid.

$$\frac{V_v}{V} = 1 - \frac{V_s}{V}$$

$$= 1 - \frac{\gamma_b}{\gamma_p}$$

$$\therefore \frac{V_v}{V} = \frac{V_w}{V}$$

$$\rho_w = 1000 \text{ kg/m}^3 = \frac{W_w}{V_w}$$

$$\therefore W_w = \rho_w V_w$$

$$= 1000 V_w \text{ kg/m}^3.$$

$$W_s = \frac{W_w}{m}$$ ⟶

1. weight of water can only be infered from saturated condition for per m³
2. Assume weight of solid, W_s, same for varying % moisture Reten
3. From 2nd Assumption weight of water for varying m obtain
4. From 3rd Assumption – $V_w = \frac{W_w}{\rho_w}$.
: Obtain % water, volume [illegible]

Still @ saturation

0–15 cm $\frac{V_w}{V} = 1 - \frac{0.15}{1.1} = 0.864$

Let $V = 1\ m^3 \longrightarrow \therefore V_w = 0.864\ m^3$

$W_w = \rho_w V_w \quad /m^3$

$= 1000 \times 0.864$ kg.

$= 864$ kg.

$W_s = \frac{864}{5.782}$ kg

$= \underline{149.43}$ kg ← assume constant for each depth.

15–30 cm: $W_w = 1000\left(1 - \frac{0.1}{1.1}\right) \times 1$

$= 909.1$ kg.

$\therefore W_s = \frac{909.1}{8.585}$ kg

$= \underline{105.89}$ kg.

$W_w = m W_s \rightarrow V_w = \frac{W_w}{1000}$

Depth	Field Condition		Saturation		1/3 bar		15 bar	
	m	V_w/m^3 (wet data)	m	V_w/m^3	m	V_w/m^3	m	$V_w\ m^3$
0–15	365.6	0.546 64.8	578.2	0.864	437.86	0.653 63.8	265.4	0.397
15–30	668.0	0.707 85	858.5	0.909	382.64	0.405 48.6	243.2	0.258

The Field Condition — not defined.

AW = Moisture @ 1/3 bar — Moisture @ 15 bar.

P = Moisture @ saturation — " @ 1/3 bar.

	A.W (fraction of V)	P
0–15 cm	0.256	0.211
15–30 cm	0.146	0.504
Average	0.201	0.358

AW

0.251

0.176

0.214

P can also be calculated from.

① $P = \frac{\text{rainfall or Irrigation Input } (-E_p)}{\text{Water Table Rise}}$

② Falling water table monitoring (still not successful)

Assume evaporation to be ~~4~~ to 5 mm per day.

From graphs of water table vs time 3 distinct /W rises have been observed ie — 25/8 — 6/9/86
17/9 — 27/9/86
18/10 — 2/11/80

25/8 — 6/9/86

	Water Table. m	Rainfall mm	Evaporation	Nett Recharge.
4/11				
25/8	+ 5.623	0.0	3.9	
26/8		0	4.4	
27/8		0	4.1	
28		37.8	8.2	
29		0	3.4	
30		2.0	3.0	
31/8		4.0	2.8	
1/1		22.9	3.8	
2		6.5	4.8	
3		7.3	1.1	
4		29.2	6.2	
5		27.8	6.2	
6		0.0	4.8	
7		1.1	6.1	
8/9		3.2	0.3	
9/9	+ 5.983	1.2	2.0	
	Diff = 0.36m.	Total = 143mm.	Total = 61.3mm	Diff = 81.7mm
			/16 = 3.83mm	

$P = \frac{81.7}{360} = 0.227$

~~17/9~~	Rainfall (mm)	Evaporation (mm)	Nett Recharge
17/9	13.0	6.5	
18/9	0	4.2	
19/9	0	4.9	
20/9	23.4	7.6	
21/9	0	4.1	
22/9	37.4	5.0	
23/9	3.9	4.4	
24/9	1.5	3.6	
25/9	34.9	5.5	
26/9	4.2	3.8	
27/9	7.0	0.7	
28/9.	~~11.7~~	~~4.5~~	
29/9.	~~40.4~~	~~7.2~~	
Total.	~~177.4~~ 125.3	62 50.3	~~115.4 mm~~ 75.0 mm

18/10	10.8	5.2	
19	42.3	7.5	
20	3.8	3.8	
21	8.7	8.8	
22	21.4	3.7	
23	0.0	1.7	
24	1.0	3.9	
25	67.9	–	
26	14.2	3.2	
27	0	3.2	
28	0	3.8	
29	3.1	1.1	
30	3.4	3.0	
31/10	27.6	5.4	
1/11	68.9	–	
2/11	16.3	1.2	
	289.4	55.5.	233.9 mm

(29 – 2/11: Rainfall 115.9; Evaporation 10.7; = 105.2)

25/8 — 6/9/86 — Nett Recharge 81.7 mm

Location	Initial WT @ 25/8 (m)	WT @ 6/9 (m)	ΔH mm	P Recharge (mm) / ΔH (mm)	
411	5.623	5.983	360	0.227	Ave = 0.247
412	5.715	6.060	345	0.237	
413	5.838	6.163	325	0.251	
414	5.934	6.234	300	0.272	
424	5.635	5.980	345	0.237	0.263
429	5.747	6.072	325	0.251	
4214	5.854	6.154	300	0.272	
4219	5.963	6.243	280	0.292	
434	5.674	5.944	270	0.303	0.287
439	5.759	6.039	280	0.292	
4314	5.849	6.119	270	0.303	
4319	5.869	6.194	325	0.251	
444	5.887	6.132	245	0.333	0.304
449	5.635	5.954	319	0.256	
4414	5.807	6.062	255	0.320	
4419	5.858	6.123	265	0.308	

12 days → ΔH ≈ 300.

Average : 0.275

17/9 — 27/9 — Nett Recharge 75.0 mm.

Location.	WT on 17/9	W.T. on 27/9	ΔH	P.
411	5.808	5.888	80 *	0.94
412	5.920	6.050	130	0.577
413	6.028	6.158	130	0.577
414	6.114	6.244	130	0.577
				~~0.577~~
424	5.820	5.850	30 *	2.5
429	5.927	6.037	110	0.682
4214	6.029	6.149	120	0.625
4219.	6.128	6.258	130	0.577

Cont. 17/9 – 29/9

Location	WT on 17/9	W.T. on 29/9	ΔH	P.
43 4	5.804	5.784	-20 *	
43 9	5.919	5.939	20	
43 14	5.999	6.069	70	
43 19	6.079	6.209	130	
44 4	6.017	5.947	-70 *	
44 9	5.849	5.779	70	
44 14	5.947	6.017	70	
44 19	6.008	6.118	110	

(Drainage probably impeded for this ditch as drain has not been completed.

18/10 – 2/11 – Nett Recharge 233.9 mm.
29/10 – 2/11 Nett Recharge. 105.2 m-

	WT on 29/10	WT on 2/11	ΔH	Ave	P.
411	5.578	5.828	250		0.42
412	5.700	5.900	200	0.51	0.53
413	5.808	6.018	210		0.50
414	5.874	6.054	180		0.58
424	5.300	5.550	250		0.42
429	5.357	5.667	310	0.37	0.34
4214	5.434	5.719	285		0.37
4219	5.393	5.698	305		0.34
434	5.194	5.504	310		0.34
439	5.259	5.519	260	0.36	0.40
4314	5.289	5.629	340		0.31
4319	5.369	5.629	260		0.40
444	5.367	5.667	300		0.35
449	5.299	5.509	210	0.41	0.50
4414	5.287	5.527	240		0.44
4419	5.248	5.558	310		0.34

Take p values for 29/10 to 2/11 – for recharge
Cal p values for receding from 2/11 to 12/11
→ the gradient from graph of WT vs time indicate gradient same as for calc. for recharge bet. 25/8 → 6/9.
thus p on receding ≈ 0.275 ≈ 0.300

P values different for recharge & recession and also depending on antecedent condition.

2 recharge p values — each average @ ~~2.75~~ 0.275 and 0.41 respectively and one recession value of about 0.275.

Calculate from Lab analysis of m and assuming δ_p = 1.1 gm/c — p was obtain to be 0.358 average over 30 cm depth.

Use 2 p values for comparison ie 0.3 and 0.4.

Kamaruddin Ambaks unpublished data gives K for the 27 Acres varying from 142.02 m/day to 2.97 m/day. Some of the data using auger hole methods seems to indicate such pattern (no statistical analysis as yet). The data also indicate a reduction of K values with cultivation

~~then~~ Use 2 K values — 1) 2 m/day
2) 5 m/day.

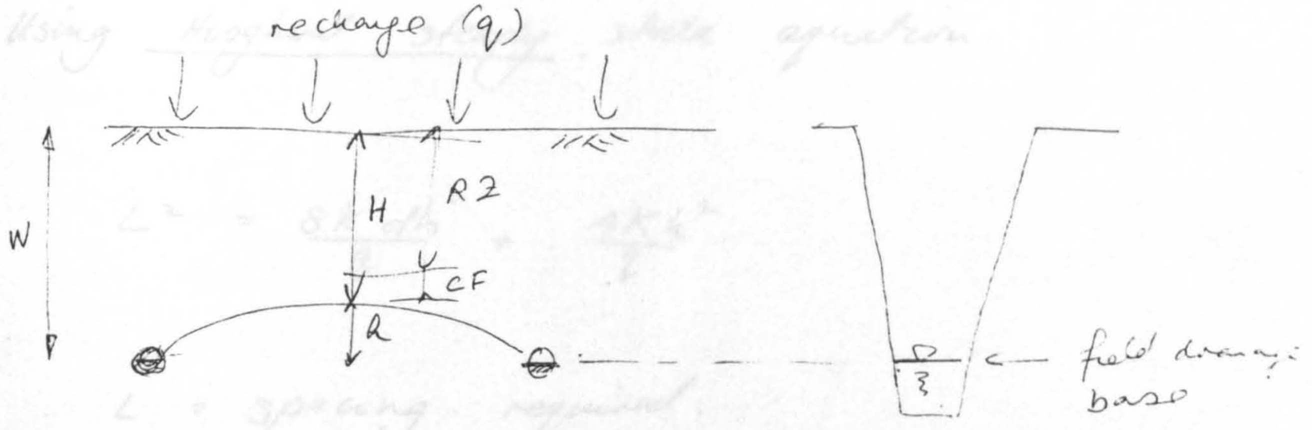
Check for L using Hooghoudt & Glover Dumm. Once drains have been installed check using Fluctuating water table equations.

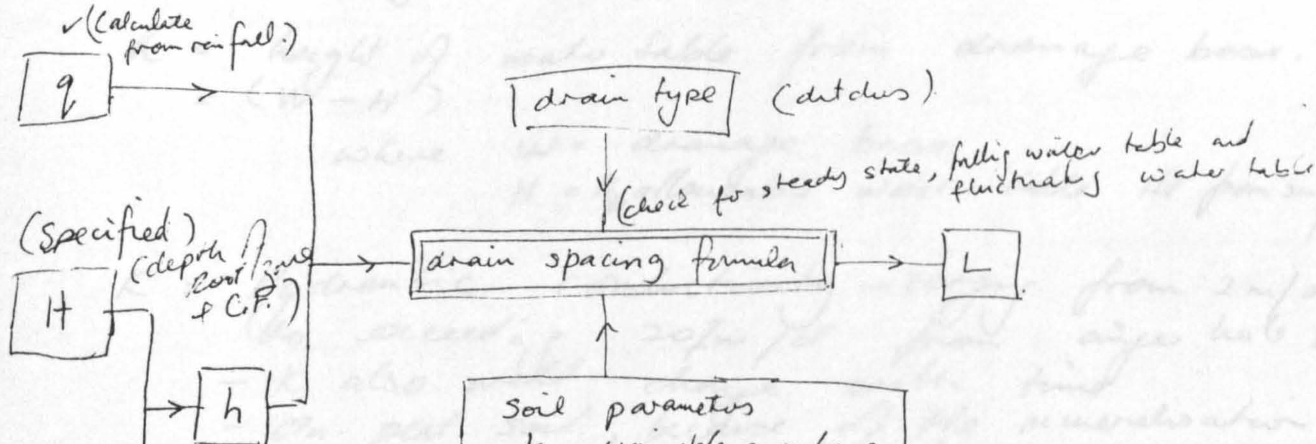
For IPRS, Pontian, Beluku:

depth cm	γ_b g/cc	γ_p (assume) g/cc	$\eta_{sat} = \frac{W_w}{V}$	W_s kg/m³	$m_{f.c.}$	$W_{wf.c.}$ kg/m³	$V_{wf.c}$ m³/m³	$\eta_{fc.}$	Drainable porosity
0-15	0.15	↑	0.864	149.43	4.3786	654.29	0.654	0.654	0.21
15-30	0.10	1.1	0.909	105.88	3.834	405.14	0.405	0.405	0.504
30-45	0.10		0.909	99.03	–	–	–	–	–
45-60	0.09	↓	0.918	80.97	–	–	–	–	–

For ground water drainage systems the following main variables have been defined below.

	Plot 1 + 4	Plot 2 + 5	Plot 3 + 6.
a) Type and layout of system.	field ditches	field ditches	field ditches.
b) discharge capacity [X (10yr, 24hrs) for most vegetables.]	X(10yrs, 24) = 228.6 mm/day; x(10yrs, 48) = 118.5 mm/day	do	X(5, 48) = 111.15 mm/day; ~~X(5, 10)~~ X(5, 72) = 83.83 mm/day
c) Water table depths H	30 cm (±10) 20 cm → 40 cm	60 cm (±10) 50 – 70 cm	90 cm ± 10 (80–100 cm)
d) field drainage base depth W (to be determined)	55 cm	85 cm	115 cm
Standing Water Depth of Ditch	10	10	10
e) spacing (to be determined)	65	75	125
f) others	To be backflush	To be backflush	No back flushing
g) Depth of peat.	≈ 4.0 m for Plot 4; ≈ 5.0 m for Plot 1	Plot 2 ≈ 6.5 m; Plot 5 ≈ 6.0 m	Plot 3 ≈ 7.0 m. Plot 6 ≈ 6.5 m.
h) Capillary fringe	10 – 15 cm	10 – 15 cm	10 – 15 cm.
i) K (hydraulic conductivity.	Plot 1 ≈ Plot 4 ≈	Plot 2 ≈ Plot 5 ≈	Plot 3 ≈ Plot 6 ≈





Plot 4

Drains at 20 m. spacing have been constructed.

h → 0 within 1 day as K values are very high ie bet 2 m/day to 32 m/day.

Capillary fringe ≈ 10 cm to 15 cm.

∴ Suggest $W = [RZ + 15\,cm] + 10\,cm$ — assume $h \approx 10$ cm.
$= RZ + 25$ cm.

For ditches — have to dig deeper to ensure design W is attain
— add another 10 cm to the depth for standing water in ditch

Using Hooghout steady state equation.

$$L^2 = \frac{8Kdh}{q} + \frac{4Kh^2}{q}$$

L = spacing required.

h = height of water table from drainage base.
= (W − H)

where W = drainage base
H = allowable water table Ht from surface

K = Hydraulic conductivity – varying from 2 m/d. to exceeding 20 m/d from auger hole test.
- K also will change with time
- On peat soil, because of the mineralisation and consolidation it will decrease
- Some past data have indicate that it can reduce to around 2.0 m/d after about 5 yrs cultivation — need to check this.
- But for this design K will be design for 2, 5, 10 m/day.

q = drainage coefficient and is taken as.
q = discharge = recharge → for steady state condition

recharge = Rainfall − Evaporation

The design rainstorm for most tree crop area is (5, 72) storm. For Pontian area, using HP1 this gives a value of 251.5 mm/72 hrs or 83.8 mm/day.
Assume evaporation = 5 mm/day.
∴ Recharge = 78.8 mm/day
ie ≈ 80 mm/day.

For vegetables and high value crops, in developed country, the system may be design for (10, 24) storm. The value of this storm for Pontian

X(10, 24) = 228.6 mm/day.

Deducting evaporation.

$$q(10, 24) = 224 \text{ mm/day}$$
$$= 0.225 \text{ m/day}.$$

For the 27 Acre plot the q will be taken as 0.08 m/day or q(5,72)! Any modification or other necessary inputs will be taken up later.
[Ideally a benefit cost analysis should be carried out to determine the return period for diff type of crops (Rycroft & Smedema - Pg 125). The available data on yield and cost of infrastructures at the end of this excercise will be used later (after project have been completed)]

WJAP WCS (Phase II)

drainage criteria / drainage coefficient of

6 l/s/ha for oil palm
and 8 l/s/ha for coconut / coffee.

@ a conversion of 1mm/day for 0.1157 l/s/ha.
80 mm/day is equivalent to 9.256 l/s/ha.

d = the equivalent depth.

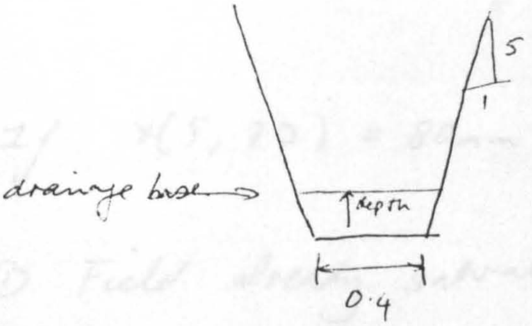
$$d = \frac{D}{\frac{8D}{\pi L} \ln \frac{D}{u} + 1} \quad \text{for } D > 1/4 L$$

and $$d = \frac{\pi L}{8 \ln L/u} \quad \text{for } D < 1/4 L$$

where D = Depth to impermeable layer. from drainage base.
u = wetted perimeter.

Depth to impermeable layer is obtained from field and varies from 3.5 m to 7.0 m.

u – Wetted perimeter is calculated for the following section



$$u = 0.4 + 2\left(\text{depth} \times \frac{\sqrt{26}}{5}\right)$$

<u>To check water</u> table ht 'h'

From page — Assume AM = 0.2 % volume.

For H = 30 cm — and assuming minimal capillary fringe

Available Water = 0.2 × 300 mm
= 60 mm.

Average E_T/day = 5 mm.
Irrigation or flushed in after ½ AW has been depleted.
∴ Interval before flushing/irrigation need to be supplied

$$= \frac{(60 \div 2)\ \text{mm}}{5\ \text{mm/day}} = 30/5$$
$$= 6\ \text{days}.$$

Assume Irrigation η = 60 %.
∴ Quantity reqd to back flushed = $\frac{30}{0.6}$
= 50 mm.

At 6 days interval — number of flushing = 5 ×
∴ Amount of deep percolation (50 − 30)5 = 100 mm/month.

Deep percolation losses per flushing = 20 mm.

∴ Porosity, p = 0.3

Taking into account the parabolic shape ($\times \frac{3}{2}$).

Rise in water $= \frac{3}{2} \times \frac{0.02}{0.3}$

$= 0.1\,m$ or 100 mm.

If $X(5, 72) = 80\,mm$ falls.

(1) Field already saturated — then the whole area will be surface flow and will have to drain away through surface flows.

(2) Field at ½ AW depletion. → ∴ voids to field is $p + \frac{1}{2}AM$

$= 0.3 + 0.1 = 0.4$

ie $0.4 \times 300 = 120\,mm$.

∴ need only $0.1 \times 300 = 30\,mm$ to top up to F.C.

The rest $80 - 30 = 50\,mm$ — will be percolation

∴ Rise in water table due to $X(5, 72)$

$= \frac{3}{2} \times \frac{0.05}{0.3} = 0.25\,m$.

But if the drain are too close apart the area will be over drain. Records have shown that 'h' ~~after~~ after rain has ~~stop for about~~ stabilised is only a max of about 0.1m from about 5m from the ditch.

Design for $h_t = 0.1\,m$.

$h_0 = 0.5\,m$. @ the surface.

Thus $W_1 = 0.6\,m$.

Estimate for rate of rise of water 'h' due back flushing or rain

Assumptions: 1. porosity, $p = 0.3$
B.M. (Vol basis) $= 0.2$
$E_T = 5$ mm/day
$\eta = 60\%$

2. Irrigation to be effected once ½ R.W have been reached.

Rooting depth ≈ H	30cm = 300mm	60cm = 600mm	90cm = 900mm
A.W. = A.M. × H	60 mm	120mm	180 mm
½ A.W	30 mm	60mm	90 mm
Max Interval before each irrgn assuming no rain = $\frac{½AW}{E_T}$	6 days	12 days	18 days.
No irrigation per month. (30 days/interval ~~(illegible)~~), N	5 ×	2.5 ×	1.667 ×
Q_s for each backflushed. (½A.W./η)	50mm	100 mm	150 mm
Q_T for one month $Q_s \times N$	250 mm	250 mm	250 mm.
Deep percolation after each flushing, (Q_s − ½A.W), P	20 mm	40mm	60mm
Rise in (parabolic shape) of water table $= \frac{3}{2} \times \frac{P}{p}$	0.1 m	0.2 m	0.3 m.
max h Rise in water table @ each rain assuming no allowed to go down to ½ A.W $(R - ½A.W) \times \frac{3}{2} \times \frac{1}{p}$			
80 mm/day = × (5, 72)	0.25 m	0.1 m	(80 < ½ AW.)
180 mm/day = × (5, 24)	0.75 m N.+	0.6 m	0.45 m
220 mm/day = × (10, 24)	0.95 m − N+	0.8 m = W+	0.65 m
	Wst = 0.5m.		Wst = 1.1m

① Steady State condition

Use Hooghout spacing formula:

$$q = \frac{8K_2dh}{L^2} + \frac{4K_1h^2}{L^2}$$

K_1 – above drainage base.
K_2 – below drainage base

Requirements are

a) basic design criteria q and H

b) field drainage base W; $h = W - H$.

c) Soil parameters K and D.

d) drain type (ie ditches and u – wetted perimeter.

e) with a, b, c & d above → determine L.

$$d = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u}+1} \quad \text{for } D > \tfrac{1}{4}L$$

$$d = \frac{\pi L}{8\ln\frac{L}{u}} \quad \text{for } D < \tfrac{1}{4}L$$

} only for pipe Drains.

1 litre/s/ha ≡ 8·64 mm/day

NB

1) Use q

x(10, 24)	9.5 mm/hr	228·6 mm/day
x(10, 48)	4·9 mm/hr	118·5 mm/day
x(5, 72.)	3.5 mm/hr	83·8 mm/day

2) Wetted perimeter – will vary depending on where field drainage base will be.
– Let depth for drain from design field drainage base be 25 cm
ie invert of drain @ depth H+50cm from surface
– Calculate for 3 field drainage base
1. – @ H + 15 cm – h = 0
2. – @ H + 25 cm – h = 10
3. @ H + 35 cm – h = 20

Thus for <u>steady state</u> calculation where

$$L^2 = \frac{8kdh + 4kh^2}{q}$$

The only thing that varies for all 3 plots is D and K. — K may be taken as constant unless there is a distinct difference – However cal for various values.

Estimation of u for 6 × (5,72). ie 80 mm/day or 9.256 l/s/ha

If 5 drains in each field – area contributing to each drain ≈ 0.2 ha.

∴ Q = 0.2 × 9.256 l/s
= 1.85 l/s

Using Manning's $v = (R^{2/3} S^{1/2})/n$ and Q = VA

For the section designed (which primarily caters for construction)

depth of water for S = 1/1000 → < 0.05 m
S = 1/300 → 0.1 m

Values of u for different depth of water in channel.

depth of water	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
u	0.4	0.5	0.6	0.71	0.81	0.91	1.01	1.11	1.22	1.32	1.42

✓

Use this u value to estimate 'd', the equivalent depth. and to get L value through iteration.

The following are tables ~~showing~~ giving 'd' values for known D and L values

CALCULATION FOR ℓ.

FORMULA : $\ell = \dfrac{D}{\frac{8}{\pi} \frac{D}{L} \ln \frac{D}{u} + 1}$ for $D < \frac{L}{4}$

$\ell = \dfrac{\pi L}{8 \ln \frac{L}{u}}$ for $D \geq \frac{L}{4}$.

$u = 0.4$

3.5

1.780

L \ D	4.0	4.5	5.0	5.5	6.0	6.5	7.0
10	1.220	1.220	1.220	1.220	1.220	1.220	1.220
15	1.625	1.625	1.625	1.625	1.625	1.625	1.625
20	1.841	1.885	2.008	2.008	2.008	2.008	2.008
25	2.064	2.133	2.187	2.228	2.260	2.374	2.374
30	2.245	2.338	2.413	2.473	2.522	2.561	2.592
35	2.395	2.511	2.606	2.684	2.750	2.803	2.848
40	2.522	2.657	2.772	2.868	2.949	3.018	3.076
45	2.630	2.784	2.916	3.029	3.126	3.209	3.281
50	2.723	2.894	3.043	3.172	3.283	3.381	3.465
55	2.804	2.991	3.155	3.298	3.424	3.534	3.631
60	2.876	3.077	3.255	3.412	3.551	3.674	3.783
65	2.939	3.154	3.345	3.515	3.666	3.801	3.922
70	2.996	3.223	3.426	3.608	3.771	3.917	4.049
75	3.047	3.285	3.499	3.693	3.867	4.024	4.166
80	3.093	3.342	3.566	3.770	3.955	4.122	4.274
85	3.135	3.393	3.628	3.841	4.036	4.213	4.374
90	3.173	3.440	3.684	3.907	4.110	4.297	4.467
95	3.208	3.483	3.736	3.967	4.180	4.375	4.554
100	3.240	3.523	3.783	4.023	4.244	4.448	4.635
105	3.270	3.560	3.828	4.075	4.304	4.515	4.711
110	3.297	3.594	3.869	4.124	4.360	4.579	4.782
115	3.322	3.626	3.907	4.169	4.412	4.639	4.849
120	3.346	3.655	3.943	4.212	4.462	4.695	4.912

CALCULATION FOR δ

FORMULA : $\delta = \dfrac{D}{\frac{8}{\pi} D/L \ln D/u + 1}$ for $D < \frac{L}{4}$

$\delta = \dfrac{\pi L}{8 \ln \frac{L}{u}}$ for $D \geqslant \frac{L}{4}$

$u = 0.5$

L \ D	4.0	4.5	5.0	5.5	6.0	6.5	7.0
10	1.311	1.311	1.311	1.311	1.311	1.311	1.311
15	1.732	1.732	1.732	1.732	1.732	1.732	1.732
20	1.943	1.992	2.129	2.129	2.129	2.129	2.129
25	2.165	2.242	2.301	2.347	2.382	2.510	2.510
30	2.345	2.447	2.529	2.595	2.648	2.691	2.726
35	2.492	2.617	2.721	2.807	2.878	2.937	2.986
40	2.615	2.762	2.885	2.990	3.078	3.153	3.217
45	2.720	2.886	3.028	3.149	3.254	3.345	3.422
50	2.810	2.993	3.152	3.290	3.410	3.515	3.607
55	2.888	3.087	3.261	3.293	3.550	3.668	3.773
60	2.956	3.170	3.359	3.406	3.675	3.807	3.924
65	3.017	3.244	3.446	3.509	3.788	3.932	4.061
70	3.071	3.340	3.524	3.602	3.890	4.044	4.187
75	3.119	3.369	3.595	3.687	3.983	4.151	4.302
80	3.163	3.423	3.659	3.765	4.069	4.246	4.408
85	3.202	3.472	3.718	3.836	4.147	4.335	4.506
90	3.238	3.516	3.771	3.902	4.220	4.417	4.597
95	3.271	3.557	3.821	3.962	4.287	4.492	4.682
100	3.301	3.595	3.866	4.018	4.349	4.563	4.761
105	3.329	3.630	3.909	4.071	4.407	4.629	4.834
110	3.354	3.662	3.948	4.119	4.460	4.690	4.903
115	3.378	3.692	3.984	4.165	4.511	4.747	4.968
120	3.400	3.720	4.018	4.207	4.558	4.801	5.029

CALCULATION FOR ℓ

FORMULA : $\ell = \dfrac{D}{\frac{8}{\pi} D/L \ln D/u + 1}$ for $D < \frac{L}{4}$

$\ell = \dfrac{\pi L}{8 \ln \frac{L}{u}}$ for $D \geq \frac{L}{4}$

$u = 0.6$

L \ D	4.0	4.5	5.0	5.5 5.7	6.0	6.5	7.0
10	1.396	1.396	1.396	1.396	1.396	1.396	1.396
15	1.830	1.830	1.830	1.830	1.830	1.830	1.830
20	2.034	2.087	2.240	2.240	2.240	2.240	2.240
25	2.256 0.50?	2.339 0.064	2.404 0.050	2.454 2.469	2.492	2.632	2.632
30	2.433	2.543	2.632	2.704 2.728	2.762	2.808	2.846
35	2.577	2.711	2.823	2.915	2.992	3.056	3.109
40	2.697	2.853	2.985	3.097	3.192	3.273	3.342
45	2.798	2.974	3.125	3.255 3.300	3.367	3.464	3.548
50	2.885	3.078	3.247	3.394 3.445	3.522	3.634	3.732
55	2.960	3.169	3354	3.516 3.573	3.659	3.786	3.897
60	3.026	3.250	3.448	3.625 3.688	3.782	3.922	4.047
65	3.083	3.321	3.533	3.723	3.893	4.045	4.182
70	3.135	3.384	3.608	3.811	3.993	4.158	4.306
75	3.181	3.441	3.677	3.890	4.084	4.260	4.419
80	3.222	3.492	3.738	3.963	4.167	4.354	4.524
85	3.259	3.539	3.795	4.029	4.244	4.440	4.620
90	3.293	3.581	3.846	4.090	4.314	4.520	4.709
95	3.324	3.620	3.894	4.146	4.379	4.593	4.791
100	3.352	3.656	3.937	4.197	4.438	4.662	4.868
105	3.378	3.689	3.977	4.245	4.494	4.725	4.940
110	3.402	3.719	4.015	4.290	4.546	4.785	5.007
115	3.425	3.748	4.049	4.331	4.594	4.840	5.070
120	3.445	3.774	4.082	4.370	4.640	4.892	5.128

CALCULATION FOR δ

FORMULA : $$\delta = \frac{D}{\frac{8}{\pi} D/L \ln D/u + 1} \quad \text{for } D < \frac{L}{4}$$

$$\delta = \frac{\pi L}{8 \ln \frac{L}{u}} \quad \text{for } D \geq \frac{L}{4}$$

$u = 0.7$

L \ D	4.0	4.5	5.0	5.5	6.0	6.5	7.0
10	1.477	1.477	1.477	1.477	1.477	1.477	1.477
15	1.922	1.922	1.922	1.922	1.922	1.922	1.922
20	2.119	2.178	2.343	2.343	2.343	2.343	2.343
25	2.339	2.429	2.498	2.552	2.594	2.746	2.746
30	2.513	2.630	2.726	2.803	2.865	2.915	2.956
35	2.654	2.796	2.915	3.014	3.096	3.165	3.222
40	2.770	2.935	3.075	3.194	3.296	3.382	3.455
45	2.868	3.053	3.213	3.350	3.469	3.572	3.661
50	2.952	3.155	3.332	3.487	3.622	3.741	3.844
55	3.024	3.243	3.436	3.607	3.757	3.891	4.009
60	3.087	3.320	3.528	3.713	3.878	4.025	4.157
65	3.142	3.388	3.600	3.808	3.987	4.147	4.291
70	3.191	3.449	3.683	3.894	4.085	4.257	4.413
75	3.234	3.504	3.749	3.971	4.178	4.357	4.524
80	3.274	3.553	3.808	4.041	4.254	4.449	4.626
85	3.309	3.598	3.862	4.106	4.328	4.533	4.721
90	3.341	3.638	3.912	4.164	4.396	4.610	4.808
95	3.370	3.675	3.957	4.218	4.459	4.682	4.888
100	3.397	3.709	3.999	4.268	4.517	4.748	4.963
105	3.421	3.740	4.037	4.314	4.571	4.810	5.033
110	3.444	3.769	4.073	4.357	4.621	4.768	5.098
115	3.465	3.796	4.106	4.396	4.668	4.921	5.159
120	3.484	3.821	4.137	4.433	4.711	4.972	5.216

CALCULATION FOR d'

FORMULA : $d' = \dfrac{D}{\frac{8}{\pi} D/L \ln D/u + 1}$ for $D < \frac{L}{4}$

$d' = \dfrac{\pi L}{8 \ln \frac{L}{u}}$ for $D \geq \frac{L}{4}$

$u = 0.8$.

L \ D	4.0	4.5	5.0	5.5	6.0	6.5	7.0
10	1.555	1.555	1.555	1.555	1.555	1.555	1.555
15	2.000	2.010	2.010	2.010	2.010	2.010	2.010
20	2.198	2.262	2.440	2.440	2.440	2.440	2.440
25	2.416	2.512	2.586	2.644	2.689	2.852	2.852
30	2.587	2.711	2.813	2.895	2.961	3.015	3.058
35	2.724	2.874	3.000	3.105	3.192	3.265	3.326
40	2.837	3.010	3.158	3.284	3.391	3.482	3.559
45	2.932	3.125	3.293	3.437	3.563	3.671	3.765
50	3.012	3.224	3.409	3.571	3.714	3.838	3.947
55	3.082	3.309	3.511	3.689	3.847	3.987	4.110
60	3.142	3.384	3.600	3.793	3.965	4.119	4.257
65	3.194	3.450	3.679	3.886	4.072	4.239	4.389
70	3.241	3.508	3.750	3.969	4.167	4.347	4.509
75	3.283	3.560	3.814	4.044	4.254	4.445	4.619
80	3.320	3.607	3.871	4.122	4.333	4.535	4.719
85	3.353	3.650	3.923	4.174	4.405	4.617	4.811
90	3.384	3.689	3.971	4.231	4.471	4.692	4.896
95	3.411	3.724	4.014	4.283	4.532	4.762	4.975
100	3.437	3.756	4.054	4.331	4.588	4.826	5.048
105	3.460	3.786	4.091	4.375	4.640	4.886	5.116
110	3.481	3.814	4.125	4.416	4.688	4.942	5.179
115	3.501	3.839	4.157	4.454	4.733	4.994	5.239
120	3.519	3.863	4.186	4.490	4.775	5.043	5.294

CALCULATION FOR ℓ

FORMULA : $\ell = \dfrac{D}{\frac{8}{\pi} D/L \ln D/u + 1}$ for $D < \frac{L}{4}$

$\ell = \dfrac{\pi L}{8 \ln \frac{L}{u}}$ for $D \geq \frac{L}{4}$

$u = 0.9$

L \ D	4.0	4.5	5.0	5.5	6.0	6.5	7.0
10	1.631	1.631	1.631	1.631	1.631	1.631	1.631
15	2.094	2.094	2.094	2.094	2.094	2.094	2.094
20	2.273	2.341	2.533	2.533	2.533	2.533	2.533
25	2.488	2.590	2.669	2.731	2.779	2.953	2.953
30	2.655	2.787	2.894	2.981	3.052	3.109	3.155
35	2.789	2.947	3.079	3.190	3.282	3.359	3.423
40	2.899	3.080	3.080	3.366	3.479	3.575	3.657
45	2.990	3.192	3.192	3.518	3.649	3.763	3.862
50	3.068	3.287	3.490	3.650	3.798	3.929	4.043
55	3.134	3.370	3.579	3.765	3.929	4.075	4.205
60	3.192	3.442	3.666	3.866	4.046	4.206	4.349
65	3.242	3.505	3.743	3.957	4.150	4.323	4.480
70	3.287	3.562	3.811	4.038	4.243	4.429	4.598
75	3.326	3.612	3.873	4.111	4.328	4.525	4.706
80	3.362	3.657	3.928	4.176	4.404	4.613	4.804
85	3.393	3.698	3.978	4.236	4.474	4.693	4.895
90	3.422	3.735	4.024	4.291	4.538	4.767	4.978
95	3.448	3.768	4.066	4.341	4.597	4.835	5.055
100	3.472	3.799	4.104	4.388	4.652	4.897	5.126
105	3.494	3.828	4.139	4.430	4.702	4.955	5.192
110	3.515	3.854	4.172	4.470	4.749	5.010	5.254
115	3.533	3.878	4.202	4.507	4.792	5.060	5.311
120	3.550	3.901	4.230	4.541	4.833	5.107	5.365

u = 1 B27, J: L

CALCULATION FOR δ

FORMULA (1) $\delta = \dfrac{D}{\frac{8}{\pi} D/L \ln D/u + 1}$ for $D < \frac{L}{4}$ or $\frac{D}{L} < 0.2$

(2) $\delta = \dfrac{\pi L}{8 \ln \frac{L}{u}}$ for $D \geq \frac{L}{4}$

u = 1.0

L \ D	4.0	4.5	5.0	5.5	6.0	6.5	7.0
10	1.705	1.705	1.705	1.705	1.705	1.705	1.705
15	2.175	2.175	2.175	2.175	2.175	2.175	2.175
20	2.345	2.417	2.622	2.622	2.622	2.622	2.622
25	2.556	2.664	2.748	2.813	2.864	3.050	3.050
30	2.720	2.858	2.971	3.063	3.137	3.198	3.246
35	2.850	3.015	3.154	3.270	3.367	3.448	3.516
40	2.956	3.145	3.306	3.444	3.562	3.663	3.749
45	3.045	3.254	3.436	3.593	3.731	3.850	3.953
50	3.119	3.346	3.547	3.722	3.877	4.013	4.133
55	3.183	3.426	3.643	3.835	4.006	4.158	4.293
60	3.238	3.496	3.727	3.934	4.120	4.287	4.436
65	3.286	3.559	3.802	4.022	4.222	4.402	4.564
70	3.329	3.611	3.868	4.101	4.313	4.506	4.681
75	3.366	3.659	3.927	4.172	4.396	4.600	4.786
80	3.400	3.702	3.980	4.236	4.470	4.685	4.883
85	3.430	3.741	4.029	4.294	4.538	4.764	4.971
90	3.458	3.777	4.073	4.347	4.601	4.835	5.053
95	3.482	3.809	4.113	4.395	4.658	4.901	5.128
100	3.505	3.838	4.150	4.440	4.710	4.963	5.197
105	3.526	3.865	4.184	4.481	4.759	5.019	5.262
110	3.545	3.890	4.215	4.519	4.804	5.072	5.322
115	3.563	3.913	4.244	4.554	4.846	5.120	5.378
120	3.579	3.935	4.271	4.587	4.885	5.16[illegible]	5.430

Plot 1 & 4 : D = 5

~~83.78~~

$$L^2 = \frac{8KDh}{q} + \frac{4Kh^2}{q}.$$

$$= \frac{8\times5\times5h + 4\times5h^2}{83.8/1000}.$$

$$= \frac{8\times25\times h + 20h^2}{0.0838}$$

$h = 0.15m \rightarrow L^2 = \frac{30 + 0.45}{0.0838}$

$L^2 = 363.4$ m.

$L = 19.1$ m.

Try $L = 20$ m.

$D = 5$ m $\longrightarrow \frac{D}{L} = \frac{5}{20} = 1/4$

$$d = \frac{5}{\frac{8\times5}{\pi 20}\ln\frac{5}{0.114}+1} = \frac{5}{3.23} = 1.54$$

$$d = \frac{\pi\times20}{8\ln\frac{20}{0.115}} = \frac{62.83}{23.1} = 2.72$$

Take $d = 2.72$ m.

$$L^2 = \frac{8Kdh}{q} + \frac{4Kh^2}{q}$$

$$= \frac{(8\times5\times2.72\times0.15) + (4\times5\times0.15^2)}{0.0838}$$

$= 200$

$\therefore L = 14$ m.

Try → $L = 18$ m. ∴ $\frac{D}{L} = \frac{5}{18} = 0.27$

$D > \frac{1}{4} L$.

∴ $d = \frac{5}{\left(\frac{8 \times 5}{\pi \times 18} \ln \frac{5}{1.114}\right) + 1} = \frac{5}{2.06} = 2.42$.

$L^2 = \frac{(8 \times 5 \times 2.42 \times 0.15) + (4 \times 5 \times 0.15^2)}{0.0838}$

$= 178.6$

$L = 13.4$ m.

Try → $L = 15$ → $d = \frac{5}{\frac{8 \times 5}{\pi \times 15} \ln \frac{5}{1.114} + 1} = \frac{5}{2.27} = 2.20$

$L^2 = \frac{(40 \times 2.2 \times 0.15) + 0.45}{0.0838}$

$= 162$

$L = 12.8$ m.

Try → $L = 10$ → $d = \frac{5}{\frac{40}{\pi \times 10} \ln \frac{5}{1.114} + 1} = \frac{5}{2.91} = 1.72$.

∴ $L^2 = \frac{40 \times 1.72 \times 0.15 + 0.45}{0.0838} = 128.5$

$L = 11.3$ m.

Try → $L = 11$ → $d = \frac{5}{\frac{40}{\pi \times 11} \ln \frac{5}{1.114} + 1} = \frac{5}{2.74} = 1.83$

∴ $L^2 = (40 \times 1.83 \times 0.15 + 0.45)/0.0838 = 136.4$

$L = 11.6$ m.

Try → 11.5 → $d = \dfrac{5}{\frac{40}{\pi \times 11.5} \ln \frac{5}{1.114} + 1} = \dfrac{5}{2.66} = 1.88$

$\therefore L^2 = 139.9$

$L = 11.8$ m.

Try → 12 → $d = \dfrac{5}{2.593} = 1.93$

$L^2 = 143.56$

$L = 11.98 \approx 12$ m.

$h = 0.25$ m.

$$L^2 = \frac{8KDh}{q} + \frac{4Kh^2}{q} = \frac{8 \times 5 \times 5 \times 0.25 + 4 \times 5 \times 0.25^2 \;(1.25)}{0.0838}$$

$$= \frac{50 + 1.25}{0.0838} = 611.6$$

$L = 24.7$

Try → $L = 20$ → est d, for $D/L > 1/4$.

$$\therefore d = \frac{D}{\frac{8D}{\pi L} \ln \frac{D}{u} + 1} = \frac{5}{\frac{8}{\pi} \times \frac{5}{20} \ln \frac{5}{0.91} + 1} = \frac{5}{2.01} = 2.4$$

$L^2 = (8 \times 5 \times 2.4 \times 0.25 + 1.25) / 0.0838$

$= 301.3$

$L = 17.4$ m

Try → $L = 18$ m → $d = \frac{5}{2.21} = 2.27$

$L^2 = (8 \times 5 \times 2.27 \times 0.25 + 1.25) / 0.0838$

$L = 16.9$ m

Try $L = 15 \longrightarrow$ $d = \dfrac{5}{\frac{8}{\pi} \times \frac{5}{15} \ln \frac{5}{0.71} + 1} = \dfrac{5}{2.45} = 2.04$

$L^2 = 258.4$

$L = 16$ m.

Try $L = 16 \longrightarrow$ $d = \dfrac{5}{\frac{8}{\pi} \times \frac{5}{16} \ln \frac{5}{0.71} + 1} = \dfrac{5}{2.356} = 2.12$

$L^2 = 267.9$

$L = 16.4$

//

$h = 0.35\,m$

$$L^2 = \{(8 \times 5 \times 5 \times 0.35) + (4 \times 5 \times 0.35^2)\} / 0.0838$$

$$= \{70 + 2.45\} / 0.0838$$

$$= 864.56$$

$$L = 29.4 \text{ m.}$$

try $L \Rightarrow 22$ m. $\longrightarrow$ $d = \dfrac{\pi L}{8 \ln \frac{L}{u}} = \dfrac{\pi \times 22}{8 \ln \frac{22}{0.71}} = 2.52$

$$\therefore L^2 = [40 \times 2.52 \times 0.35 + 2.45] / 0.0838$$

$$= (35.28 + 2.45) / \ldots = 450.2$$

$$L = 21.22 \text{ m.}$$

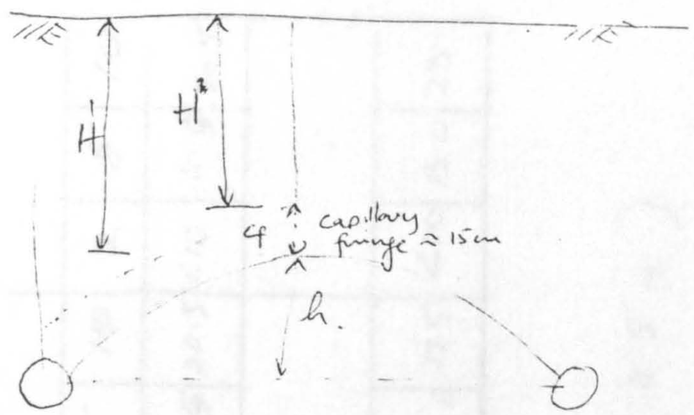
Try $L \to 21.5$m $\longrightarrow$ $d = \dfrac{\pi L}{8 \ln L/u} = 2.48$

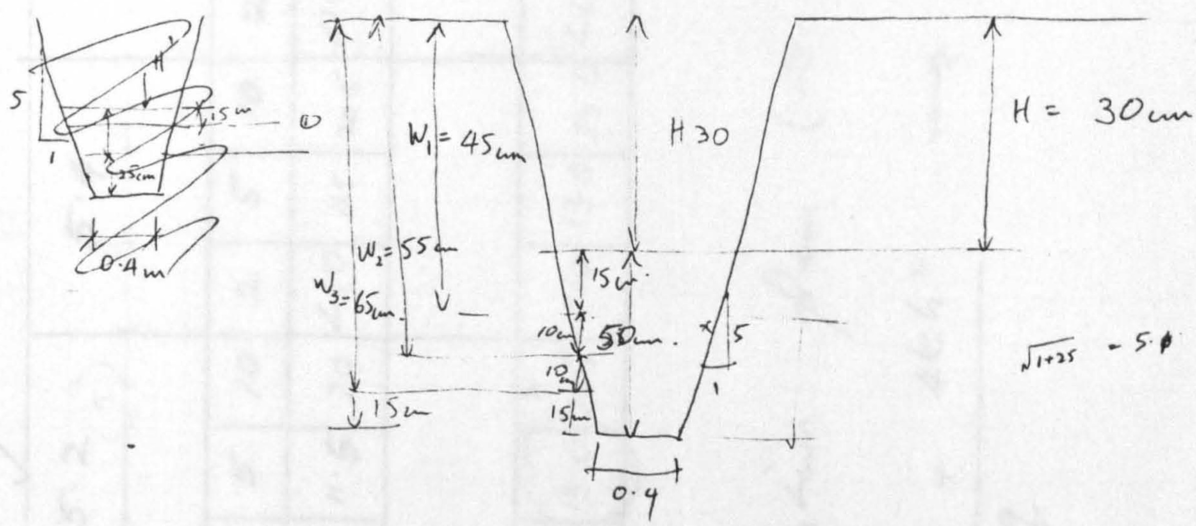
$L^2 = 443.5$

$L = 21.06$

//

Plot 1 : $H^* = 30$ cm ; Cf = 15 cm ∴ $H' = 45$ cm.





Plot 1 :
$K \approx 5$ m/day. ✓
$D = 5$ m. ✓
$q = 83.8$ mm/day. ✓ — some will flow as run off, need to know the component.
$H = 30$ ✓

W (cm)	h = W−H (cm)	u (wetted perimeter)	L (calculated.)
45 cm	15	1.114	12 m.
55 cm	25	0.91	16 m.
65 cm	35	0.71	21 m.

Use.
$$q = \frac{8KDh}{L^2} + \frac{4Kh^2}{L^2}.$$

$u = 0.4$, $h = 0.2$																	
D = 3.5*			D = 4.5			5.2			5.4			5.7			5.9		
K (m/d)																	
2	5	10	2	5	10	2	5	10	2	5	10	2	5	10	2	5	10
<10	11.5	19	<10	11.5	19.5	<10	11.5	20	<10	11.5	20.5	<10	11.5	20.5	<10	11.5	20.5
$u = 0.6$			$h = 0.2$														
<10	13.0	20.5*	<10	13.0	21.0	<10	13.0	21.5*	<10	13.0	22.0	<10	13.0	22.5	<10	13.0	23

L values by iteration from ($\simeq$ to 0.5 m)

$$L^2 = \frac{8khd + 4kh^2}{q} \longrightarrow$$

$K = 2\,m/d \rightarrow L^2 = 40d + 4$

$K = 5\,m/d \rightarrow L^2 = 100d + 10$

$K = 10\,m/d \rightarrow L^2 = 200d + 20$

(L in meters)

* - estimated.

For $k = 5\,m/day$

$$L^2 = \frac{8khd + 4kh^2}{q}$$

$$= \frac{8 \times 5hd + 4 \times 5h^2}{0.08}$$

$$= 500hd + 250h^2$$

For $h = 0.1 \longrightarrow L^2 = 50d + 2.5$

$h = 0.2 \longrightarrow L^2 = 100d + 10$

$h = 0.3 \longrightarrow L^2 = 150d + 22.5$

for $\left.\begin{array}{l} D = 3.5\,m \\ h = 0.1\,m \\ u = 0.6\,m \end{array}\right\}$ $L^2 = 50d + 2.5$

try $L = 10\,m \longrightarrow D/L = 0.35$

$d = 1.36$

$L^2 = 70.6$

$L = 8.4$

$\therefore L < 10\,m$.

$\left.\begin{array}{l} D = 4.5 \\ h = 0.2 \\ u = 0.6 \end{array}\right\}$ $L^2 = 100d + 10$

try $L = 13\,m \longrightarrow D/L = 0.35$

$d = 1.6564$

$L^2 = 175.64$

$L = 13.3$

$\therefore L \simeq 13\,m$

$$\left.\begin{aligned} D &= 5.0 \\ h &= 0.3 \\ a &= 0.6 \end{aligned}\right\} \quad L^2 = 150\,d + 22.5$$

try $L = 15$ $\longrightarrow$ $D/L = 0.33$
$d = 1.830$
$L^2 = 297$
$L = 17$ m

try $L = 17$ m $\longrightarrow$ $d = 1.994$
$L^2 = 321.6$
$L = 17.9$ m

try $L = 18$ m $\longrightarrow$ $d = 2.076$
$L^2 = 333.9$
$L = 18.3$ m

$\therefore L \approx 18$ m

(2) Check using falling water table.

Glover - Dumm mid spacing water table head.

$$\frac{h_t}{h_0} = 1.16\, e^{-\alpha t}$$

$$\alpha = \frac{\pi^2 K d}{\mu L^2}$$

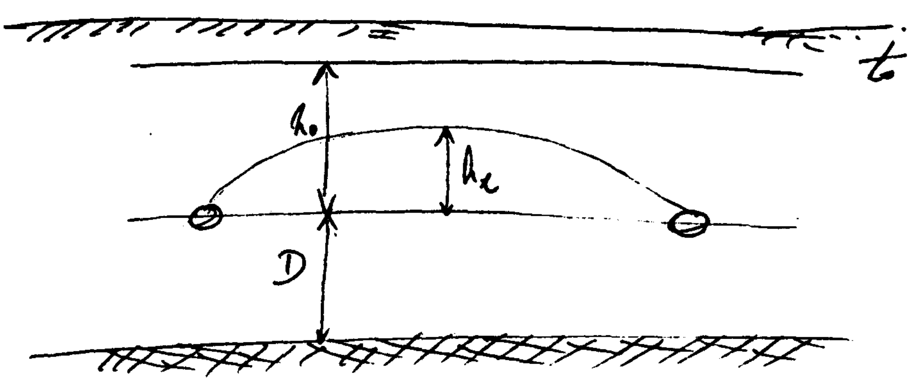
$\rightarrow$ $e^{\alpha t} = 1.16 \frac{h_0}{h_t}$

$\alpha t = \ln 1.16 \frac{h_0}{h_t}$

$\frac{\pi^2 K d t}{\mu L^2} = \ln 1.16 \frac{h_0}{h_t}$

$\frac{\pi^2 K d t}{\mu} \left[\ln 1.16 \frac{h_0}{h_t}\right]^{-1} = L^2$

t = time (days)
h_0 = initial water table head, @ $t = t_0$ (m)
h_t = water table head @ $t = t$ (m)
α = reaction factor (days^{-1})
μ = drainable pore space m^3/m^3.
L = drain spacing
d = equivalent depth
K = hydraulic conductivity.



$$L^2 = \frac{\pi^2 K d\, t}{\mu} \left[\ln 1.16 \frac{h_0}{h_t}\right]^{-1}$$

(2) Check using falling water table.

Glover - Dumm mid spacing water table head.

$$\frac{h_t}{h_0} = 1.16 e^{-\alpha t} \quad \rightarrow \quad e^{\alpha t} = 1.16 \frac{h_0}{h_t}$$

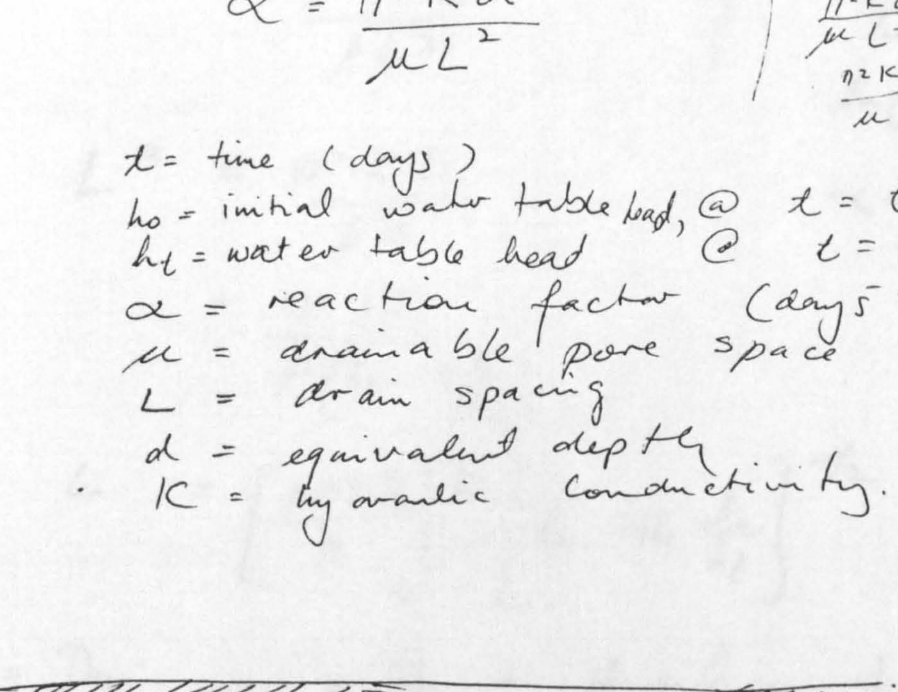
$$\alpha t = \ln 1.16 \frac{h_0}{h_t}$$

$$\alpha = \frac{\pi^2 K d}{\mu L^2}$$

$$\frac{\pi^2 K d t}{\mu L^2} = \ln 1.16 \frac{h_0}{h_t}$$

$$\frac{\pi^2 K d t}{\mu}\left[\ln 1.16 \frac{h_0}{h_t}\right]^{-1} = L^2$$

t = time (days)
h_0 = initial water table head, @ $t = t_0$ (m)
h_t = water table head @ $t = t_t$ (m)
α = reaction factor (days^{-1})
μ = drainable pore space m^3/m^3.
L = drain spacing
d = equivalent depth
K = hydraulic conductivity.



$$L^2 = \frac{\pi^2 K d t}{\mu}\left[\ln 1.16 \frac{h_0}{h_t}\right]^{-1}$$

Dumm – Non steady state Solution

from $KD\frac{\partial^2 h}{\partial x^2} = p\frac{\partial h}{\partial t}$.

solved and reduced to

$h_t = \frac{4}{\pi} h_0 e^{-\alpha t} \rightarrow \frac{h_t}{h_0} =$ parabolic shape of water table

α = reaction factor $= \frac{\pi^2 K' D}{p L^2}$

thus $h_t = 1.16\, h_0 e^{-\alpha t}$

$\therefore \frac{h_t}{h_0} = 1.16\, e^{-\alpha t}$.

$\ln\left(1.16\frac{h_0}{h_t}\right) = \alpha t$.

$\alpha = \ln(1.16\{h_0/h_t\})$

$L^2 = \frac{\pi^2 KD}{p\alpha}$.

$= \frac{\pi^2 KD}{p\left\{\ln 1.16 \frac{h_0}{h_t}\right\}}$

$L = \left[\frac{\pi^2 K D_{av}}{P}\right]^{1/2} \left[\ln 1.16 \frac{h_0}{h_t}\right]^{-1/2}$

$D = D_{av} \rightarrow$ & $D_{av} = d + h_{av}$ & $h_{av} = \frac{h_0 + h_t}{4}$.

Monograph prepared for values of $\frac{K' D_{av} t}{p L^2}$

for each values of $\frac{h_t}{h_0}$.

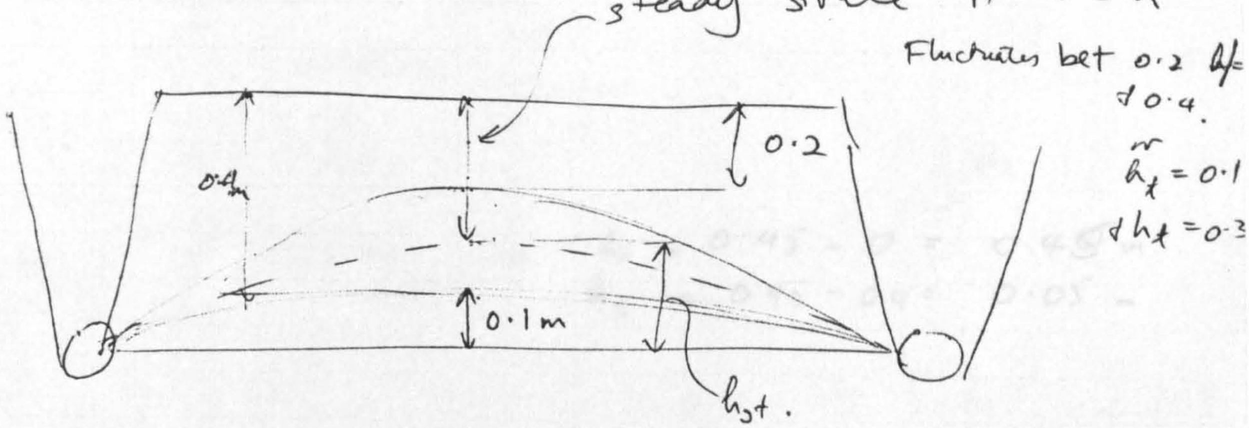
Method : 1. Define h_0 & h_t & t reqd.

2. find ratio $\frac{h_t}{h_0}$

3. Use the graph to get $\frac{K D_{av} t}{p L^2}$.

4. For given value of d, t, K & p iterate for values of L.

ie Plot 1 & Plot 4.



ie $h_{steady\ state} = 0.2\ m.$ & $H_{st} = 0.3\ m.$

$W_{st} = 0.5\ m$ (+1) for drain depth from estimate

$D_{st_1} = 4.5\ m$

$D_{st_4} = 3.5\ m.$

Dunn/Glover → $h_o = 0.5\ m$, $h_t = 0.1\ m.$

3+1 ✓

Similarly for Plots 2 & 5.

$h_{st} = 0.2\ m$ → $H_{st} = 0.6\ m$, $W_{st} = 0.8\ m$, $D_{st_2} = 5.7\ m$, $D_{st_5} = 5.2\ m$

Dunn & Glover $h_o = 0.8\ m.$, $h_t = 0.1\ m.$

6+1 ✓

Acceptable for water to fluctuate from $h_t = 0.1, 0.3.$
ie H bet 0.7 & 0.5

Plots 3, & 6

$h_{st} = 0.2\ m$ → $H_{st} = 0.9\ m$, $W_{st} = 1.1\ m.$, $D_{st_3} = 5.9\ m$, $D_{st_6} = 5.4\ m$, $h_o = 1.0\ m.$, $h_t = 0.1\ m$

Fluctuates bet. $h_t = 0.1$ & 0.3

or H be 0.8 & 1.0

Plot 6

$t = 0 \qquad H_o = 0m.$

$t = 3 \qquad H_o = 0.4m.$

$K = 5 \ m/day.$

$D = 5 \ m.$

$\mu = 0.35$

Try → $W = 0.45m.$ → $h_o = 0.45 - 0 = 0.45 m$

$h_3 = 0.45 - 0.4 = 0.05 \ m$

$$L^2 = \frac{\pi^2 K D t}{\mu} \left[\ln 1.16 \frac{h_o}{h_t} \right]^{-1}$$

$$= \frac{\pi^2 \times 5 \times 5 \times 3}{0.35} \left[\ln 1.16 \times \frac{0.45}{0.05} \right]^{-1}$$

$= 901.6$

$L = 30 \ m.$

Try → $W = 0.55m$ → $h_o = 0.55 \ m$

$h_3 = 0.15 \ m.$

$$L^2 = \frac{\pi^2 \times 5 \times 5 \times 3}{0.35} \left[\ln 1.16 \times \frac{0.55}{0.15} \right]^{-1}$$

$= 1460.9$

$L = 38.2 \ m.$

Try → $W = 0.65m$ → $h_o = 0.65$

$h_3 = 0.25$

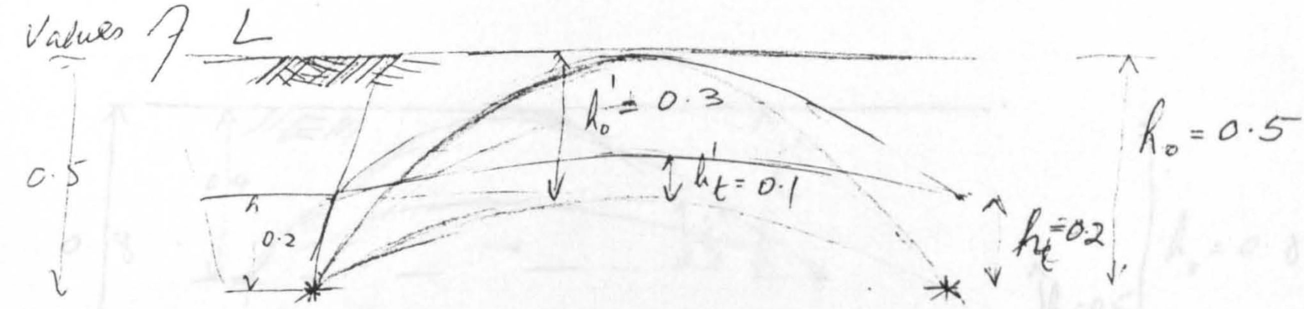
$$L^2 = \frac{\pi^2 \times 75}{0.35} \left[\ln 1.16 \times \frac{0.65}{0.25} \right]^{-1}$$

$= 1915.8$

$= 43.8 \ m.$

Plots 1 & 4

Values of L



$D = 4.5$, $u = 0.4$, $t = 1\,day$.

$\frac{h_o + h_t}{4} = 0.175 \Rightarrow \frac{h_t}{h_o} = 0.4 \Rightarrow \frac{K D_{av} t}{pL^2} = 0.109$

~~K = 2m/day~~ $\rightarrow \frac{K D_{av} t}{pL^2} = \frac{K D_{av} t}{0.3 L^2} = 0.19$

~~$L^2 = 30 D_{av} t$~~

$\frac{h_t}{h_o} = 0.4 \Rightarrow L^2 = 30 K D_{av} t$.

	t	1 day	2 days	3 days
$K = 2m/day \rightarrow L^2 = 60 D_{av} t$		<10m	15 m	20 m
$K = 5m/day \rightarrow L^2 = 150 D_{av} t$		15<L<20	25	30
$K = 10m/day \rightarrow L^2 = 300 D_{av} t$		25	40	50.

$\left.\begin{array}{l} h_o' = 0.3 \\ h_t' = 0.1 \end{array}\right\} \frac{0.1}{0.3} = 0.33 \rightarrow \frac{h_o + h_t}{4} = 0.1 \Rightarrow u =$

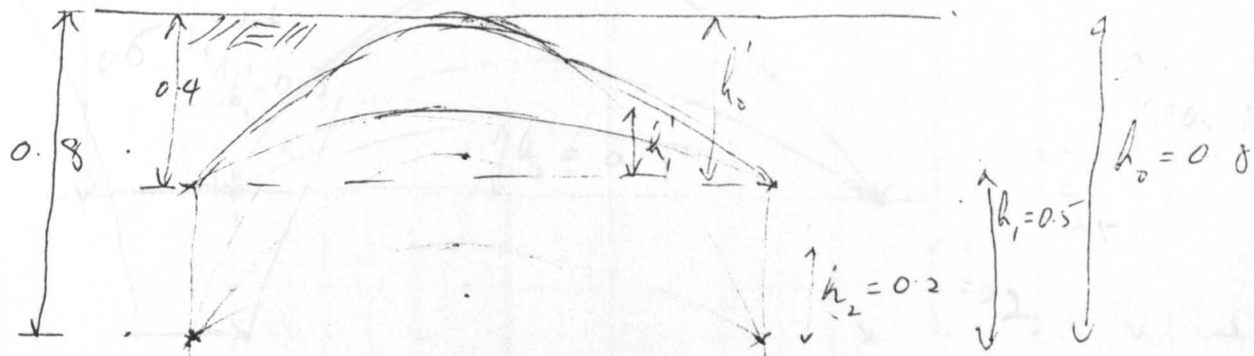
$u = 0.81$

$\frac{h_t'}{h_o'} = 0.33 \rightarrow \frac{K . D_{av} t}{0.3 L^2} = 0.127 \rightarrow L^2 = \frac{K D_{av} t}{0.3 \times 0.127}$

$= 26.25 K D_{av} t$

	days → 1 day	2	3
$K = 2m/day \rightarrow L^2 = 52.49 D_{av} t$	~~<~~10	<15	~~≈~~≈20.
$K = 5m/day \rightarrow L^2 = 131.23 D_{av} t$	≈15	>25	
$K = 10m/day \rightarrow L^2 = 262.47 D_{av} t$			

Plots 2 + 5



$D = 5.5, \quad u = 0.4 \quad p = 0.3$

$\frac{h_1}{h_0} = 0.625 \longrightarrow \frac{K D_{av} t}{p L^2} = 0.062$

$\frac{h_2}{h_0} = 0.25 \longrightarrow = 0.157$

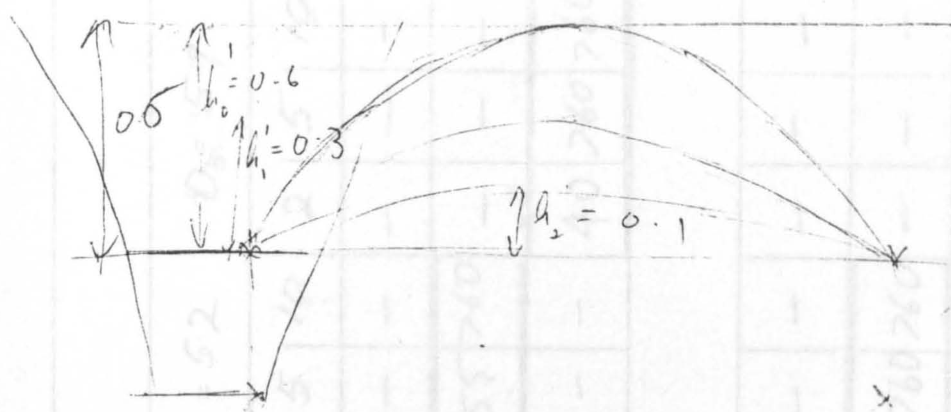
$\frac{h_2}{h_1} = 0.4 \longrightarrow = 0.11$

$\frac{h_0 + h_1}{4} = 0.325 \; ; \; \frac{h_0 + h_2}{4} = 0.25 \; ; \; \frac{h_2 + h_1}{4} = 0.175$

h	K	L^2	1 day	2 days	3 days	5 days
$h_0 \to h_1$	2	$107.53 D_{av} t$	15 m	21 m	30 m	41 m
$h_1 \to h_2$	2	$60.61 D_{av} t$	<10 m	15 m	20 m	26 m
$h_0 \to h_2$	2	$42.46 D_{av} t$	<10 m	11 m	15 m	21 m
$h_0 \to h_1$	5	$268.82 D_{av} t$	26	41	55	>60
$h_1 \to h_2$	5	$151.52 D_{av} t$	18	29	38	50
$h_0 \to h_2$	5	$106.16 D_{av} t$	14	21	30	40
$h_0 \to h_1$	10	$537.63 D_{av} t$	41	>60	>60	>60
$h_1 \to h_2$	10	$303.03 D_{av} t$	28	41	55	>60
$h_0 \to h_2$	10	$212.31 D_{av} t$	21	35	45	>60

Plots 3 & 6

$D = 5.5$; $\mu = 0.4$ $p = 0.3$.



$h_0 = 1.1$
$h_1 = 0.8$
$h_2 = 0.5$
$h_3 = 0.2$

		$\frac{K D_{av} t}{p L^2}$	
$\frac{h_1}{h_0} = 0.73$	$\longrightarrow$	0.047	$\frac{h_0 + h_1}{4} = 0.475$
$\frac{h_1}{h_2} = 0.625$	$\longrightarrow$	0.063	$\frac{h_1 + h_2}{4} = 0.325$
$\frac{h_2}{h_3} = 0.4$	$\longrightarrow$	0.11	$\frac{h_2 + h_3}{4} = 0.175$
$\frac{h_3}{h_4} = 0.18$	$\longrightarrow$	0.19	$\frac{h_3 + h_0}{4} = 0.325$

	K	L^2	1 day	2 days	3 days	5 days
$h_0 \to h_1$	2	141.84 $D_{av}t$	<20	27	36	50
$h_1 \to h_2$	2	105.82 $D_{av}t$	<20	21	30	40
$h_2 \to h_3$	2	60.60 $D_{av}t$	<20	<20	20	26
$h_0 \to h_3$	2	35.09 $D_{av}t$	<10	10	15	20
$h_0 \to h_1$	5	354.61 $D_{av}t$	33	50	>60	>60
$h_1 \to h_2$	5	264.55 $D_{av}t$	25	40	50	>60
$h_2 \to h_3$	5	151.52 $D_{av}t$	–	–	35	50
$h_0 \to h_3$	5	87.72 $D_{av}t$			–	35
$h_0 \to h_1$	10	709.22 $D_{av}t$				
$h_1 \to h_2$	10	529.10 $D_{av}t$				
$h_2 \to h_3$	10	303.03 $D_{av}t$				
$h_0 \to h_3$	10	175.44 $D_{av}t$				

Values of L for various h_o, h_t, W, D, K, u

Depth of drainage base below surface (m) W	h_o (m)	h_t (m)	$\frac{h_o+h_t}{4}$	$\frac{h_t}{h_o}$	$\frac{KD_{av}t}{\phi L^2} = a$	$D_1 = 4.5$, K (m/d) 2	5	10	$D_4 = 3.5$, 2	5	10	$D_2 = 5.7$, 2	5	10	$D_5 = 5.2$, 2	5	10	$D_3 = 5.9$, 2	5	10	$D_6 = 5.4$, 2	5	10
$u = 0.4$																							
0.5 (for t = 6 day)	0.5	0.1	0.15	0.2	0.18	22	39	>60	20	37	55	–	–	–	–	–	–	–	–	–	–	–	–
0.8 (t = 12 days)	0.8	0.1	0.225	0.125	0.23	–	–	–	–	–	–	30	57	>60	30	55	>60	–	–	–	–	–	–
1.1 (t = 18 days)	1.1	0.1	0.3	0.091	0.26	–	–	–	–	–	–	–	–	–	–	–	–	40	>60	>60	39	>60	>60
$u = 0.6$																							
0.5						23	40	>60	21	38	56	–	–	–	–	–	–	–	–	–	–	–	–
0.8						–	–	–	–	–	–	31	59	>60	31	>60	>60	–	–	–	–	–	–
1.1						–	–	–	–	–	–	–	–	–	–	–	–	40	>60	>60	40	>60	>60

Value of $\frac{KD_{av}t}{\phi L^2}$ obtain from graph

Values of L – found by iteration

$D_{av} = d + \frac{h_o + h_t}{4}$

$K = 2 \rightarrow L^2 = \frac{2}{0.3}\frac{D_{av}t}{a} \rightarrow W = 0.5\text{m} \rightarrow L^2 = 22.22 D_{av}$ ($t = 6$ days)

$K = 5 \rightarrow L^2 = \frac{5}{0.3}\frac{D_{av}t}{a} \rightarrow W = 0.5\text{m} \rightarrow L^2 = 555.56 D_{av}$ ($t = 6$ days)

$K = 10 \rightarrow L^2 = \frac{10}{0.3}\frac{D_{av}t}{a} \rightarrow W = 0.5\text{m} \rightarrow L^2 = 1111.11 D_{av}$ ($t = 6$ days)

Fluctuating Water Table. ('de. Zeeuw & Helinga formula)

$W = 0.65\ m.$
$L = 40\ m.$
$K = 5\ m/d.$
$D = 5\ m.$
$\mu = 0.35.$

$\Delta t = 1\ day.$
evaporation = 4 mm/day. to 5 mm/day.
R = rainfall.
R = recharge.

$$\alpha = \frac{\pi^2 K d}{\mu L^2}. \rightarrow \text{use } d = D. \quad \pi^2 = 10$$

$$= \frac{10 \times 5 \times 5}{0.35 \times 40^2} = 0.45.$$

$$h_t = h_{t-1} e^{-\alpha \Delta t} + \frac{R_{\Delta t}}{0.8 \mu \alpha} (1 - e^{-\alpha \Delta t})$$

$$\therefore h_t = h_{t-1} e^{-0.45 \times 1} + \frac{R \times \Delta t}{0.8 \times 0.35 \times 0.45} (1 - e^{-0.45 \times 1})$$

$$" = h_{t-1} e^{-0.45} + \frac{R_{\Delta t}}{0.126} (1 - e^{-0.45})$$

$$\therefore h = h_{t-1} \times 0.64 + 2.88 R_{\Delta t}.$$

Must have rainfall data. → take August data and work out till Dec for plot A. to check the water table

$$q_t = q_{t-1} e^{-\alpha \Delta t} + R_{\Delta t} (1 - e^{-\alpha \Delta t})$$

This equation to be use when checking water table level with drain construction.

Area bounded by JPT Main drains
and perimeter drain of Project Area.

A = 0.5 in² = 20.73 ha =

B = 2.0 in² = 82.91 ha =

C = 0.3 in² = 12.44 ha

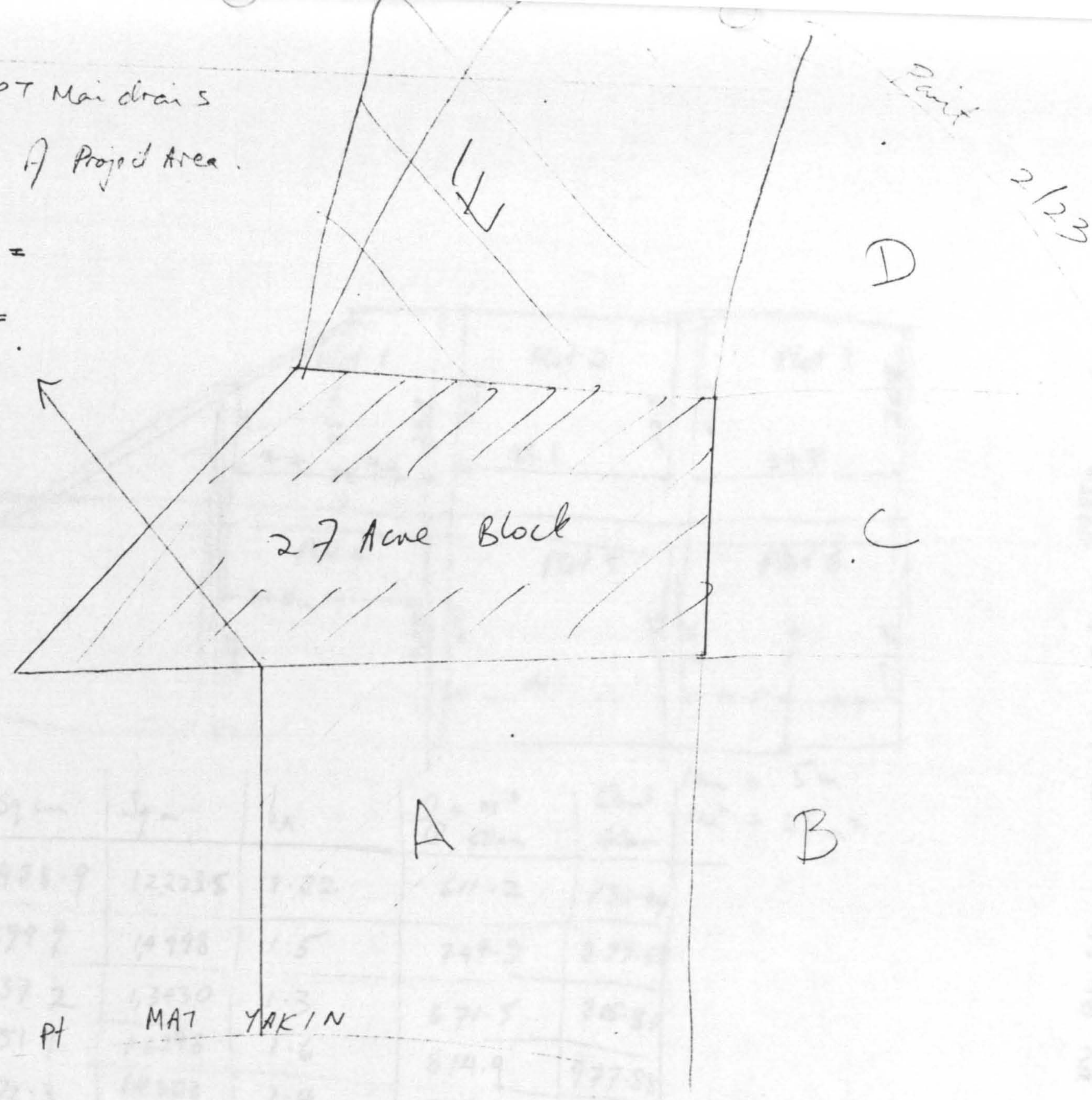
D = 0.2 in² = 8.29 ha

E = 0.3 in² = 12.44 ha

136.81 ha

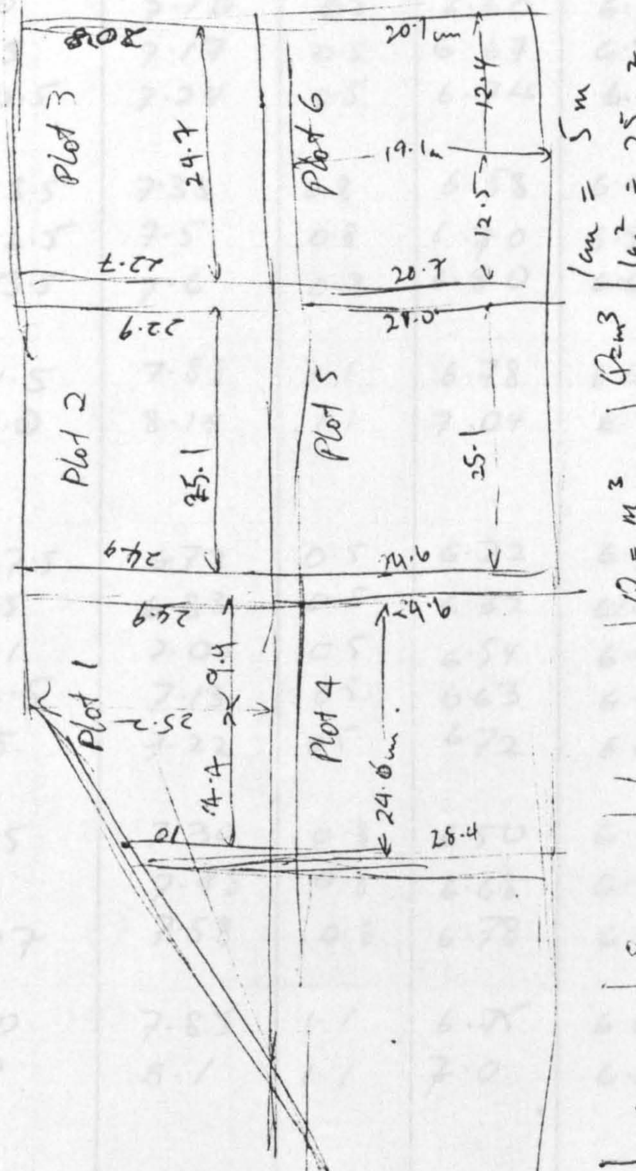
Above @ 1" = 32 ch.

1 acre = 43560 ft²
1 ha = 10,000 m²
1 ha = 2.47 acre.



1" ≡ 32 chain
≡ 32 × 66 = 2112 ft

$1"\,sq = \frac{2112^2}{43560} = 102.4$ Acres. = 41.46 ha



Area	Sq cm	Sq m	ha	Q = m³ @ 50mm	Q = m³ @ 60mm
Plot 1	488.9	12,223.5	1.22	611.2	733.44
Plot 2	599.9	14,998	1.5	749.9	899.88
Plot 3	537.2	1,3430	1.3	671.5	805.80
Plot 4	651.9	16298	1.6	814.9	977.88
Plot 5	572.3	14308	1.4	715.4	858.48
Plot 6	491.8	12295	1.2	614.8	737.76
				2891.4	

Total 1,2,4+5.

Field drains — Invert Levels
Measurement in metrics unless otherwise stated

Drain.	Length.	u/s GL.	Depth	u/s IL.	d/s IL.	Remark.
D11	69	+6.7	0.5	+6.2	6.13	C1 → 6.13
D12*	107.5	6.85	0.5	6.35	6.19*	} D1 → 6.19 − 0.3 (weir) = 5.89
D13	110	7.10	0.5	6.60	6.50	
D14	115	7.17	0.5	6.67	6.51*	}
D15	122.5	7.24	0.5	6.74	6.62	D2 → 6.62
D21	118.5	7.38	0.8	6.58	6.46	E1 → 6.46
D22	116.5	7.5	0.8	6.70	6.58	E2 → 6.58 − 0.3 = 6.28
D23	113.5	7.6	0.8	6.80	6.69	E3 → 6.69.
D31*	111.5	7.88	1.1	6.78	6.67*	} F1 ⇒ 6.62 − 0.3 6.32. Length from Junction to P.R. = 12.5 m.
D32*	111.0	8.14	1.1	7.04	6.88*	}
D41	137.5	6.72	0.5	6.22	6.08	M1 → 6.08
D42	135	6.83	0.5	6.32	6.14*	} M2 → 6.14 − 0.3 = 5.84
D43	131	7.04	0.5	6.54	6.41	
D45	132.5	7.13	0.5	6.63	6.45*	}
D46	125.	7.22	0.5	6.72	6.60	M3 → 6.60
D51	115	7.30	0.8	6.50	6.39	L1 → 6.39 ✓
D52	111	7.48	0.8	6.68	6.57	L2 → 6.57 − 0.3 = 6.27
D53	107	7.58	0.8	6.78	6.67	L3 → 6.67 ✓
D61	100	7.85	1.1	6.75	6.60	} K1 ⇒ 6.6 − 0.3 = 6.31
D62	99.	8.1	1.1	7.0	6.85	}

Perimeter Drain (G – A1)

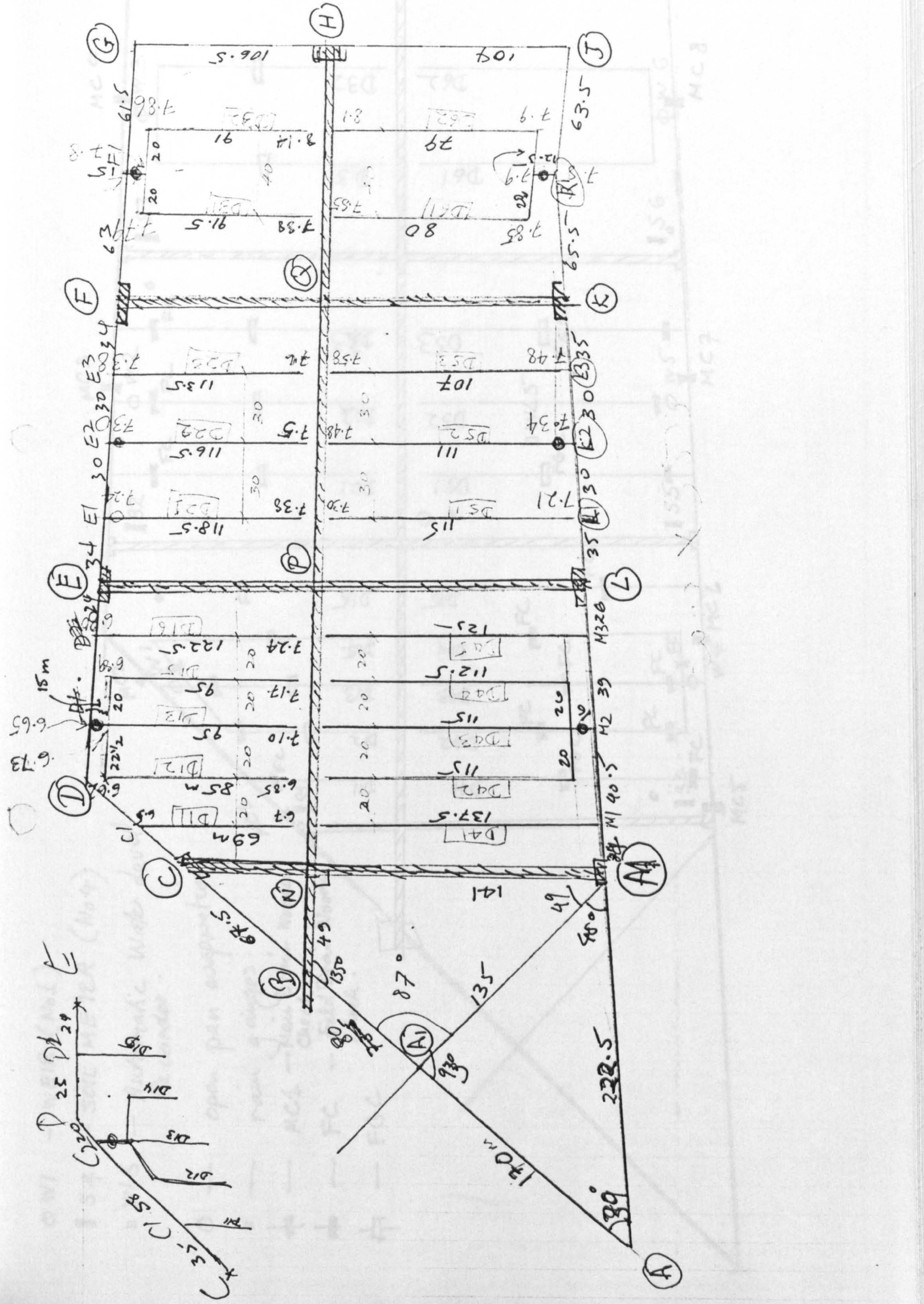
S = 1/1000.

Drain Section	Length	Reqd IL	IL Proposed: Design	IL Proposed: Adjusted	Remarks and my final IL
			6.85	6.61	G
G – F1	61.5				
		6.32	6.79	6.55	F1
F1 – F	63				
			6.73 / 6.58	6.49 / 6.34	F ← 0.15 m losses F
F – E3	34				
		6.69	6.55	6.31	E3
E3 – E2	30				
		[6.28]	6.52	[6.28]	E2
E2 – E1	30				
		6.46	6.49	6.25	E1
E1 – E	34				
			6.46 / 6.31	6.22 / 6.07	E ← 0.15 m losses E
E – D1	24				
		6.62	6.29	6.05	D1
D1 – D	25				
		(bend – 0.05 losses)	6.26 / 6.21	6.02 / 5.97	D ← 0.05 m losses D
D – C2	20				
		6.28	6.19	5.95	C2
C2 – C1	58				
		[6.13]	[6.13]	5.89	C1
C1 – C	35				
			6.10 / 5.95	5.86 / 5.71	C ← 0.15 m losses C
C – B	67.5				
			~~5.88~~ 5.85 / 5.73	5.64 / 5.49	B ← 0.15 m loss B (5.45)
B – A1	73.5				
			5.66	5.42.	A1 (5.38)

Perimeter Drain (A1 – J)/(J – A1)

S = 1/1000

Drain Section	Length	Reqd I.L.	I.L Proposed		Remarks
			Design	Adjusted	
			6.48	6.36	J
J-K1	63.5	+6.3	6.42	6.30	K1 ← adjusted from here.
K1-K.	65.5		6.35	6.23	K
			(-0.15)		— Losses @ control
			6.20	6.08	K
K-L3	35	+6.67	6.16	6.04	L3
L3-L2	30	6.27	6.13	6.01	L2
L2-L1	30	6.39	6.10	5.98	L1
L1-L	35		6.06	5.94	L
			(-0.15)		— Losses @ control
			5.91	5.79	L
L-M3	26	6.60	5.88	5.76	M3
M3-M2	39	5.84	5.84	5.72	M2
M2-M1	40.5	6.08	5.80	5.68	M1
M1-M	24		5.78	5.66	M
			(-0.15)		— Losses @ control.
			5.63	5.51	M
M-A1	135		5.50	5.38	A1



STRUCTURES.

FIG 4

O W1 — WEIR (No1)

▮ S4 — SOIL METER (No4)

▫ WL5 — Automatic Water Level Recorder.

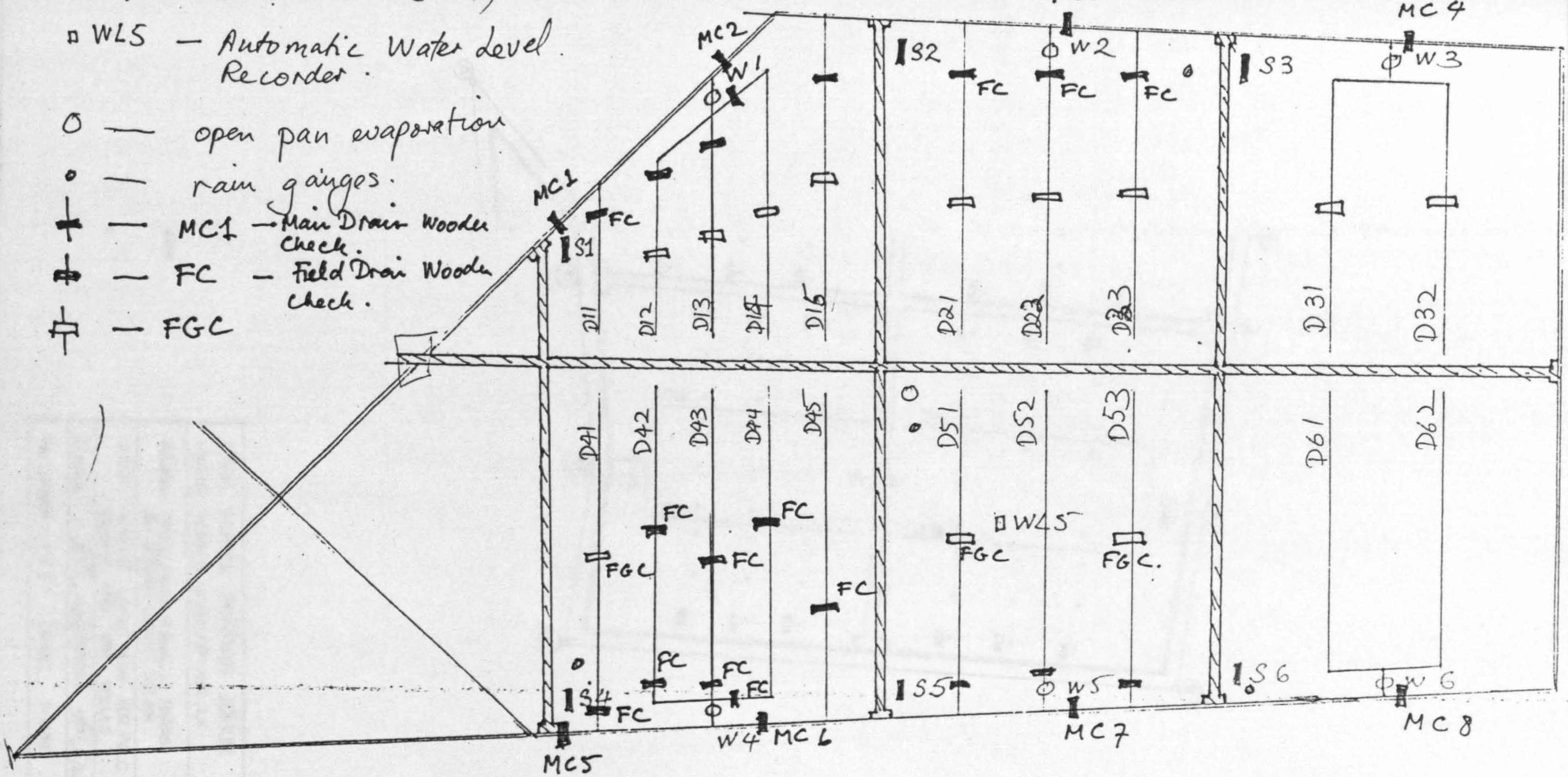
O — open pan evaporation

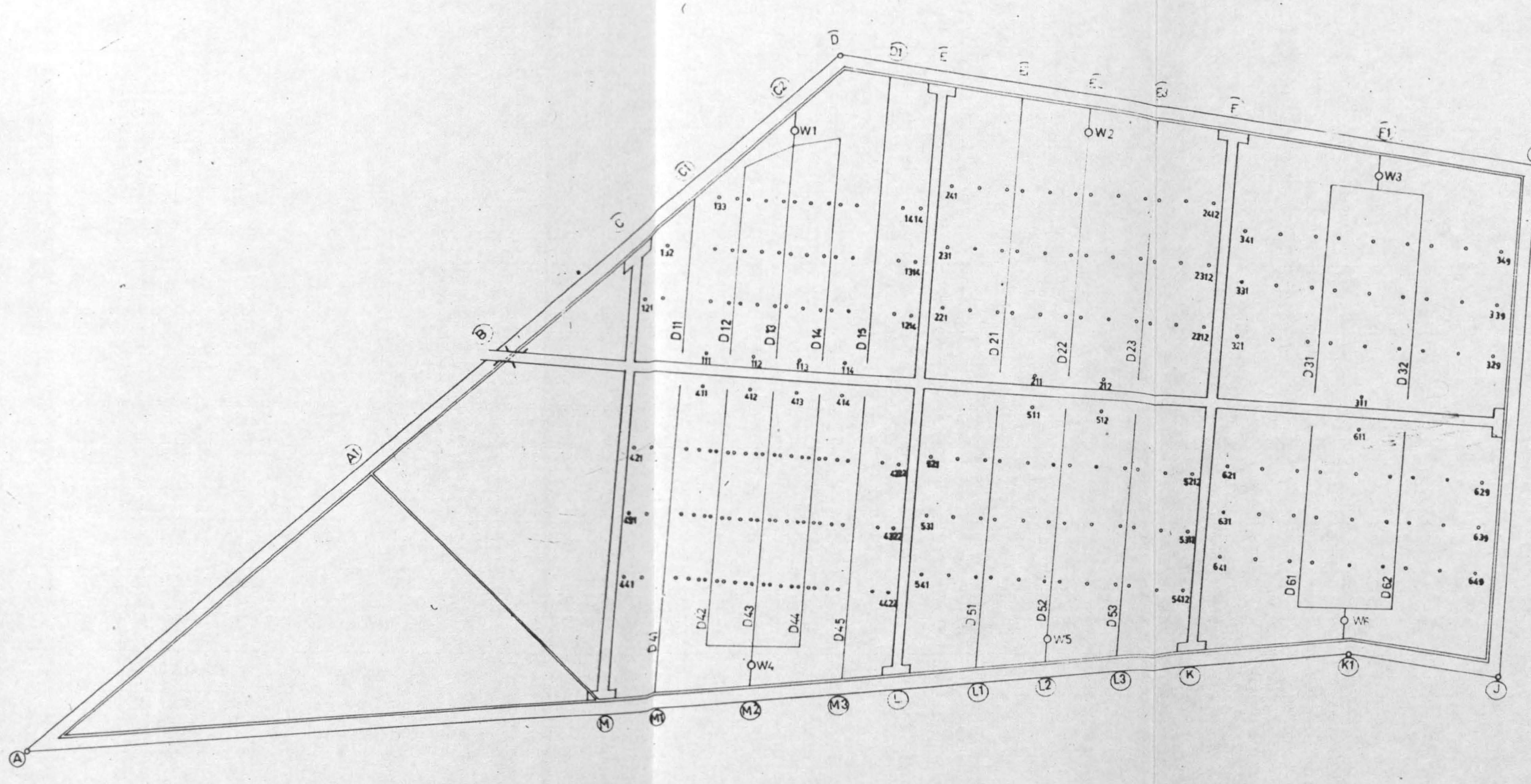
∘ — rain gauges.

MC1 — Main Drain Wooden Check.

FC — Field Drain Wooden Check.

FGC

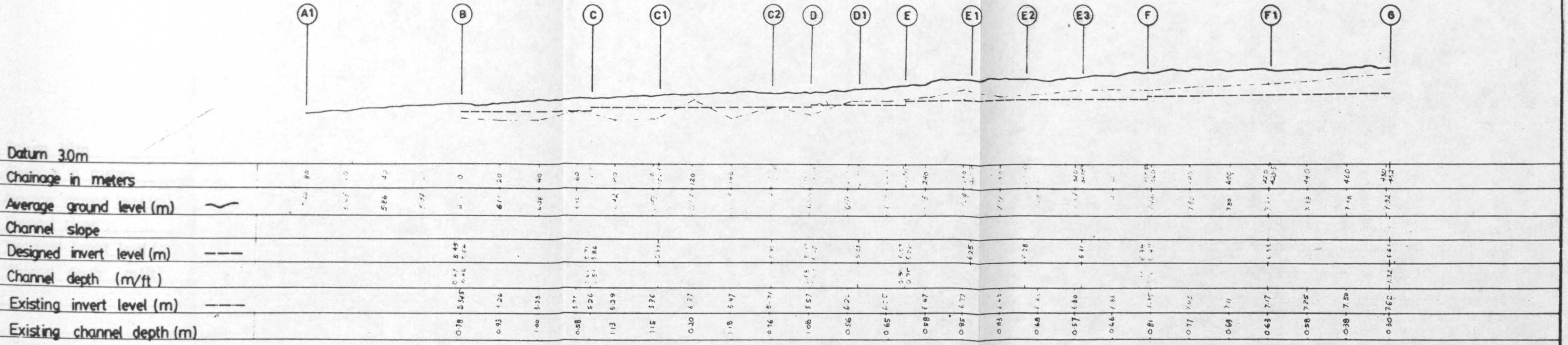




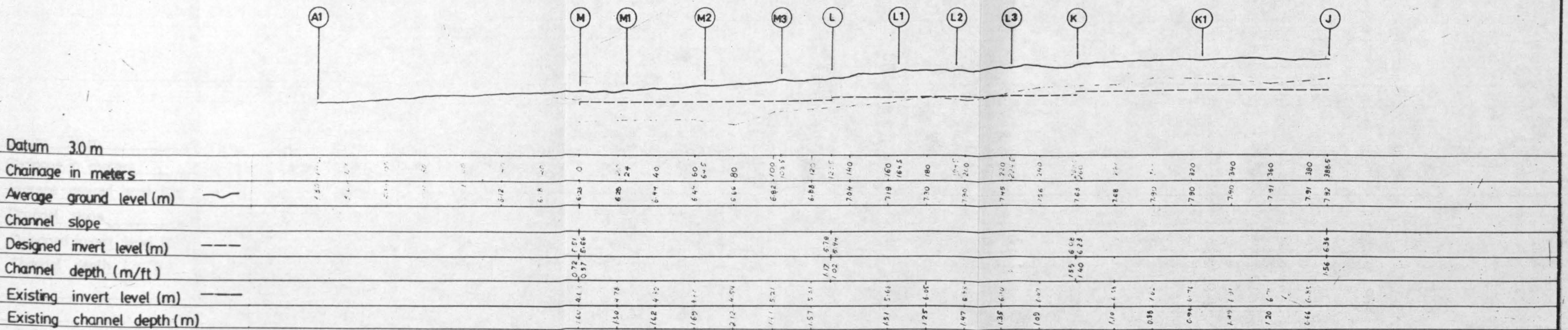
LEGEND

═══	Farm roads
━━━	Perimeter drains
───	Field drains
—o—	Control outlet
⫨	Culvert
•	Dip wells

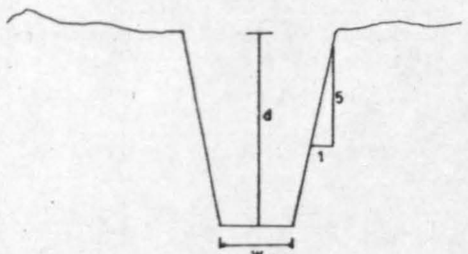
IPRS. MARDI PONTIAN JOHOR PROJEK PERINTIS MARDI/JPT/CIT. UK	
KAJIAN : PENYELIDIKAN KAWALAN PARAS AIR DITANAH GAMBUT DALAM	
JUDUL : GENERAL LAYOUT PLAN FOR FIELD DRAINS AND DIP WELLS	
DIREKA	DILUKIS
NO LUKISAN : P2/1	SEKIL: 1:1000



PERIMETER DRAIN A1-B-G



PERIMETER DRAIN A1-M-J



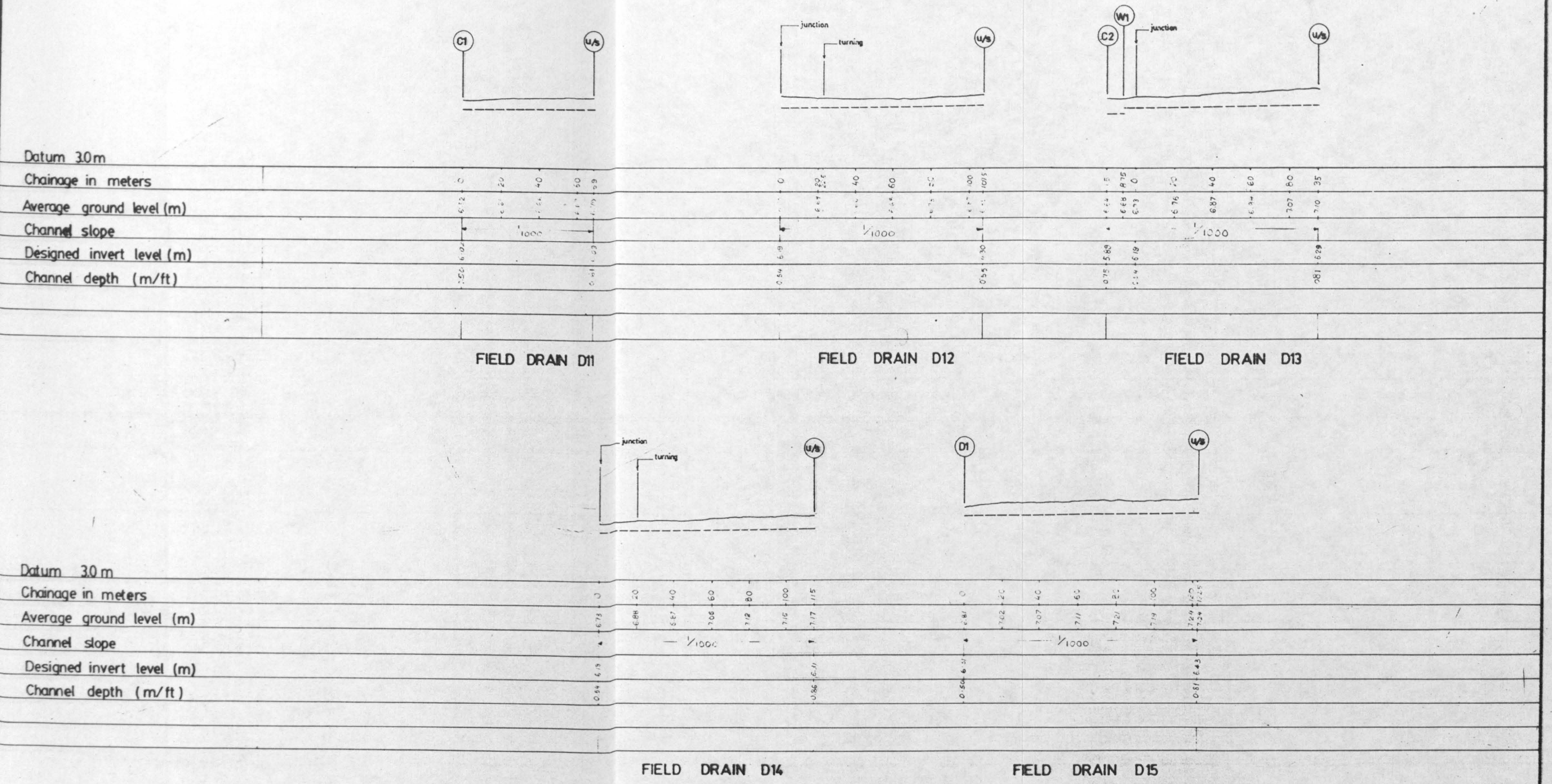
Cross - section

1. Field drains
   w, width = 0.4m
   d, depth = as approximated in the long section.

2. Main drains
   w, width = 0.6m
   d, depth = as approximated in the long section.

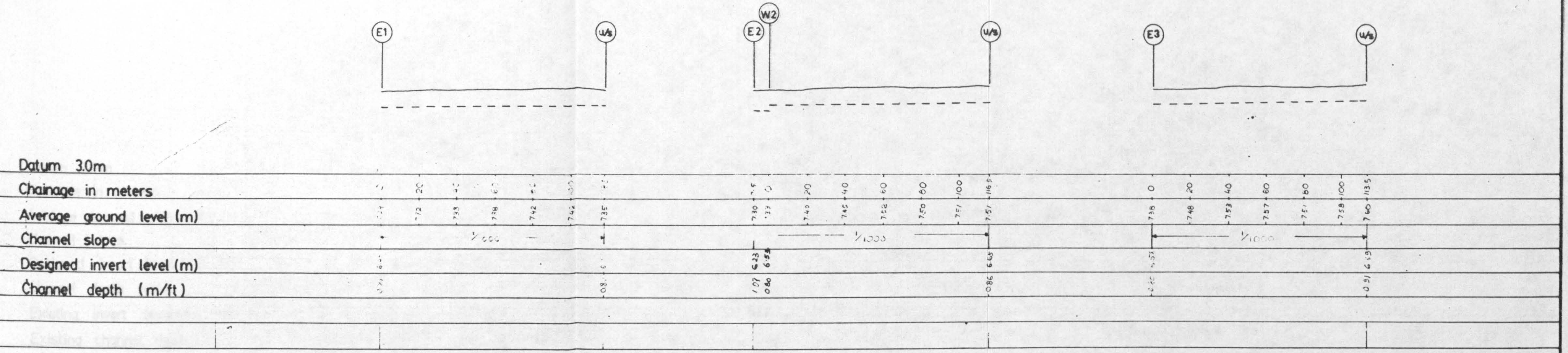
IPRS MARDI PONTIAN JOHOR PROJEK PERINTIS MARDI/JPT/CIT. UK	
KAJIAN : PENYELIDIKAN KAWALAN PARAS AIR DITANAH GAMBUT DALAM	
JUDUL : LONG SECTION OF PERIMETER DRAINS A1-B-G & A1-M-J	
DIREKA:	DILUKIS:
NO LUKISAN: P2/2	SEKIL: hor: 1 1000 ver. 1 100

D/G22

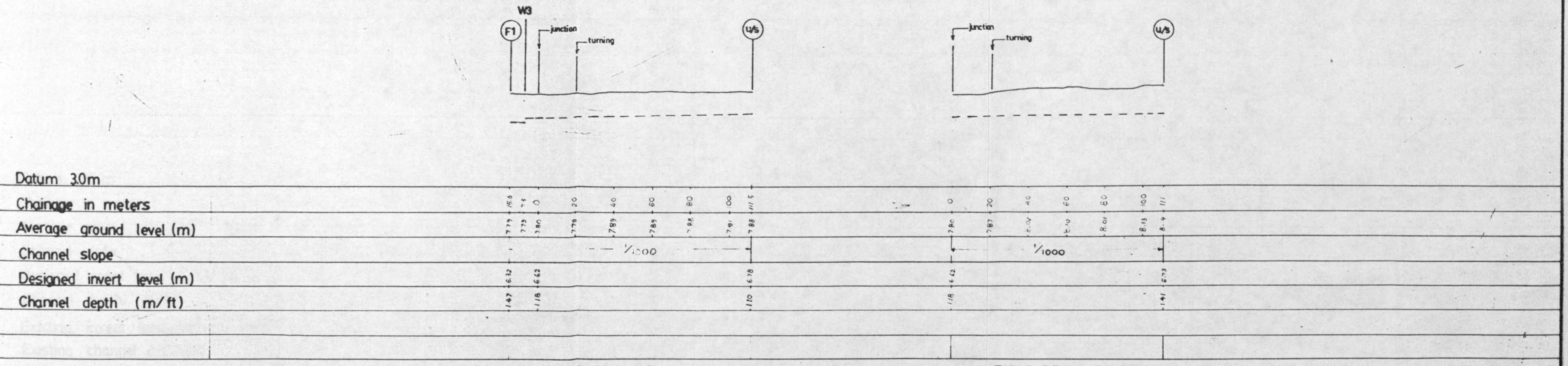


IPRS MARDI PONTIAN JOHOR PROJEK PERINTIS MARDI/JPT/CIT.UK	
KAJIAN: PENYELIDIKAN KAWALAN PARAS AIR DITANAH GAMBUT DALAM	
JUDUL: LONG SECTIONS OF FIELD DRAINS D11, D12, D13, D14 & D15.	
DIREKA:	DILUKIS
NO LUKISAN: P.2/3	SEKIL: hor: 1:1000 ver: 1:100

D/G23



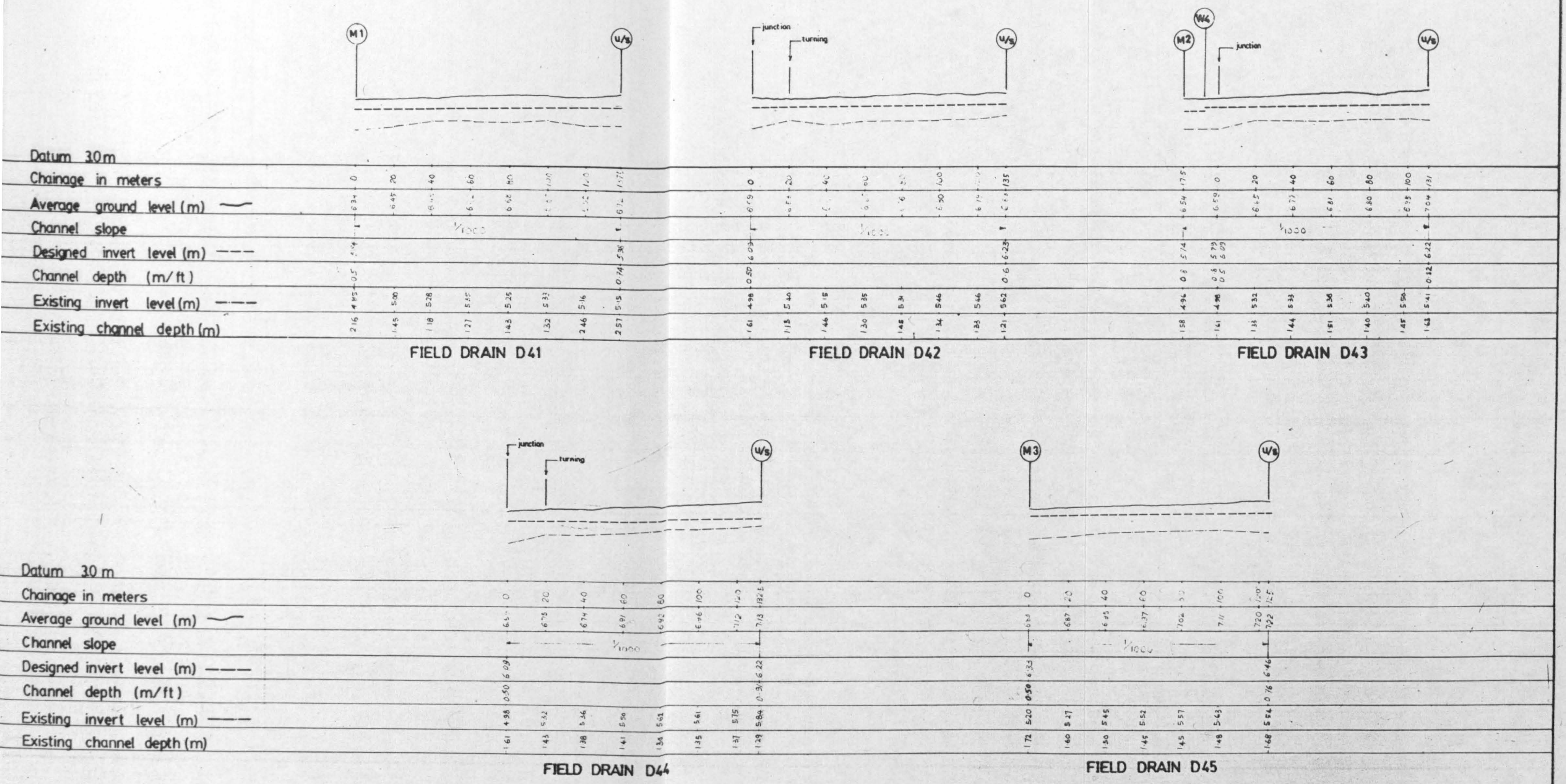
FIELD DRAIN D21 FIELD DRAIN D22 FIELD DRAIN D23



FIELD DRAIN D31 FIELD DRAIN D32

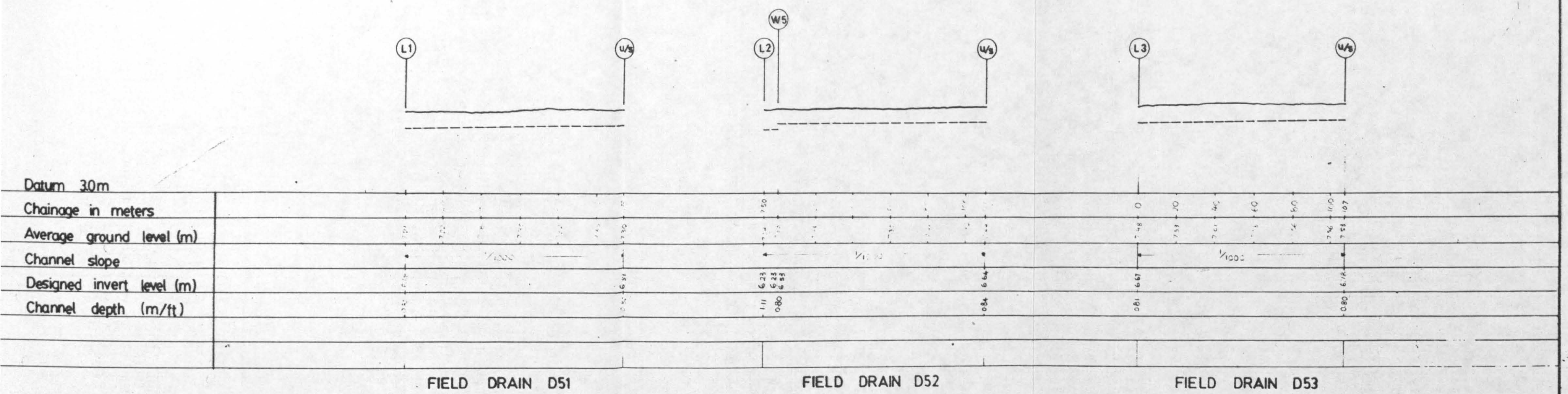
IPRS MARDI PONTIAN JOHOR PROJEK PERINTIS MARDI /JPT /CIT, UK	
KAJIAN: PENYELIDIKAN KAWALAN PARAS AIR DITANAH GAMBUT DALAM	
JUDUL: LONG SECTIONS OF FIELD DRAINS D21, D22, D23, D31 & D32.	
DIREKA:	DILUKIS:
NO LUKISAN: P2/4	SEKIL: hor: 1:1000 ver: 1:100

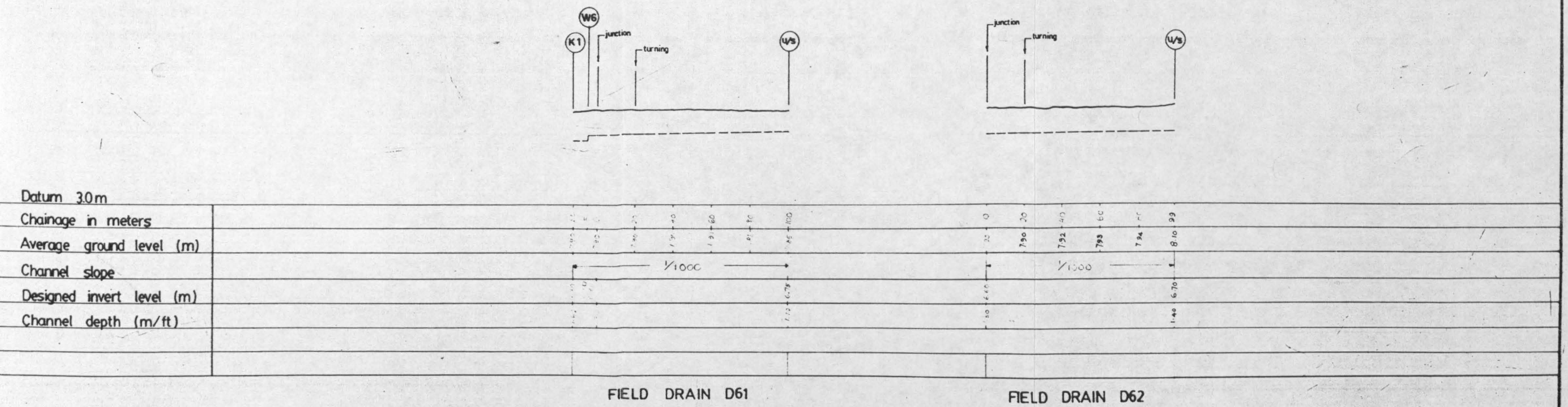
D/624



IPRS MARDI PONTIAN JOHOR	
PROJEK PERINTIS MARDI/JPT/CIT. UK	
KAJIAN: PENYELIDIKAN KAWALAN PARAS AIR DITANAH GAMBUT DALAM	
JUDUL: LONG SECTIONS OF FIELD DRAINS D41, D42, D43, D44 & D45.	
DIREKA:	DILUKIS:
NO LUKISAN: P2/5	SEKIL: hor: 1:1000 ver: 1:100

D/625





IPRS MARDI PONTIAN JOHOR	
PROJEK PERINTIS MARDI / JPT / CIT. UK	
KAJIAN: PENYELIDIKAN KAWALAN PARAS AIR DITANAH GAMBUT DALAM	
JUDUL: LONG SECTIONS OF FIELD DRAINS D51, D52, D53, D61 & D62.	
DIREKA:	DILUKIS:
NO LUKISAN: P2/6	SEKIL: hor: 1:1000 ver: 1:100

D/626

APPENDIX C

Field Drainage Testing, Plot 2

APPENDIX C - Field Drainage Testing, Plot 2

The records of the water levels at V-notch weir, W2, OW235 and OW238 were monitored using automatic water level recorders. The records at W2 were converted into discharge using principles of sharp crested V-notch. Records at OW235 and OW238 were converted to height above MSL. The water table readings of OW rows 3 and 4 were also monitored with time and plotted as changing watertable shape in Figures 5.16 to 5.19.

The k values given in Table 5.22 were estimated from the van der Leurs derived equation of

$$k = \frac{q}{h}\frac{L^2}{2\pi d}$$

where

$\frac{q}{h}$ = slope of graph q versus h (Figures 5.13 and 5.15)

$$d = \frac{D}{(8D/\pi L)\ \ln(D/u) + 1}$$

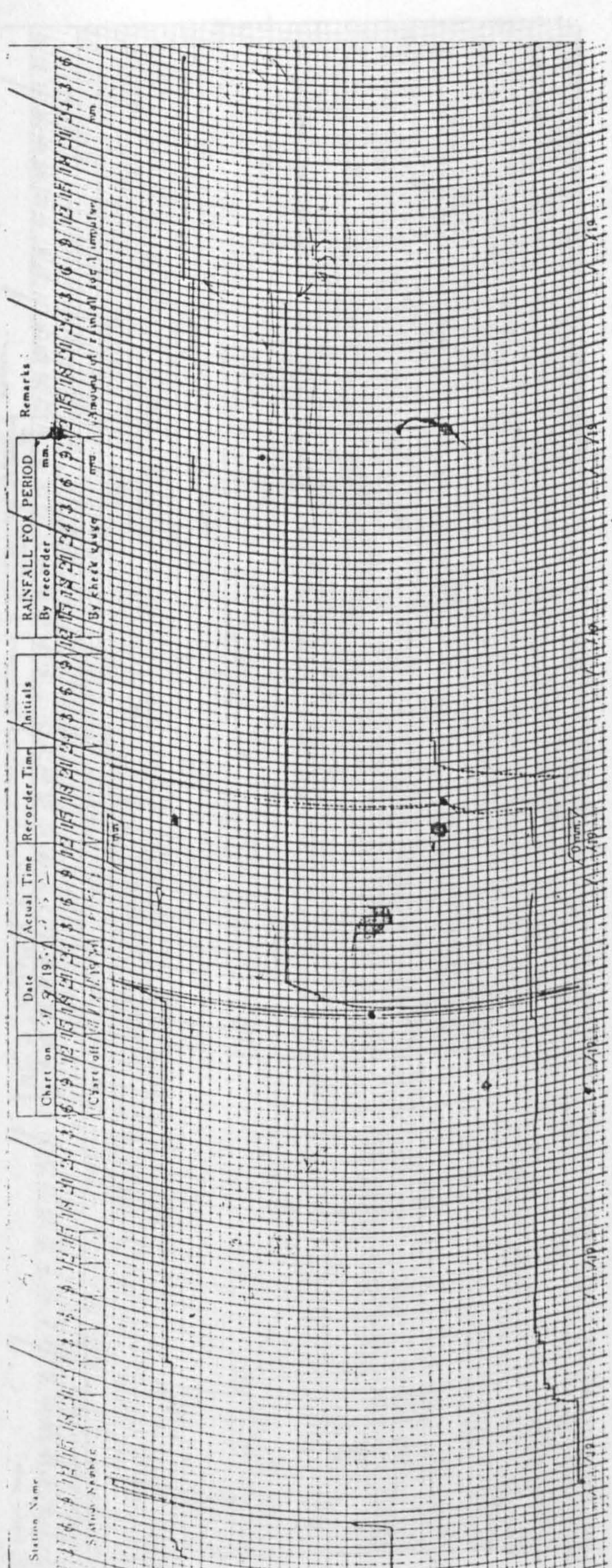
D = 4.5 m
= depth to impermeable layer for Plot 2

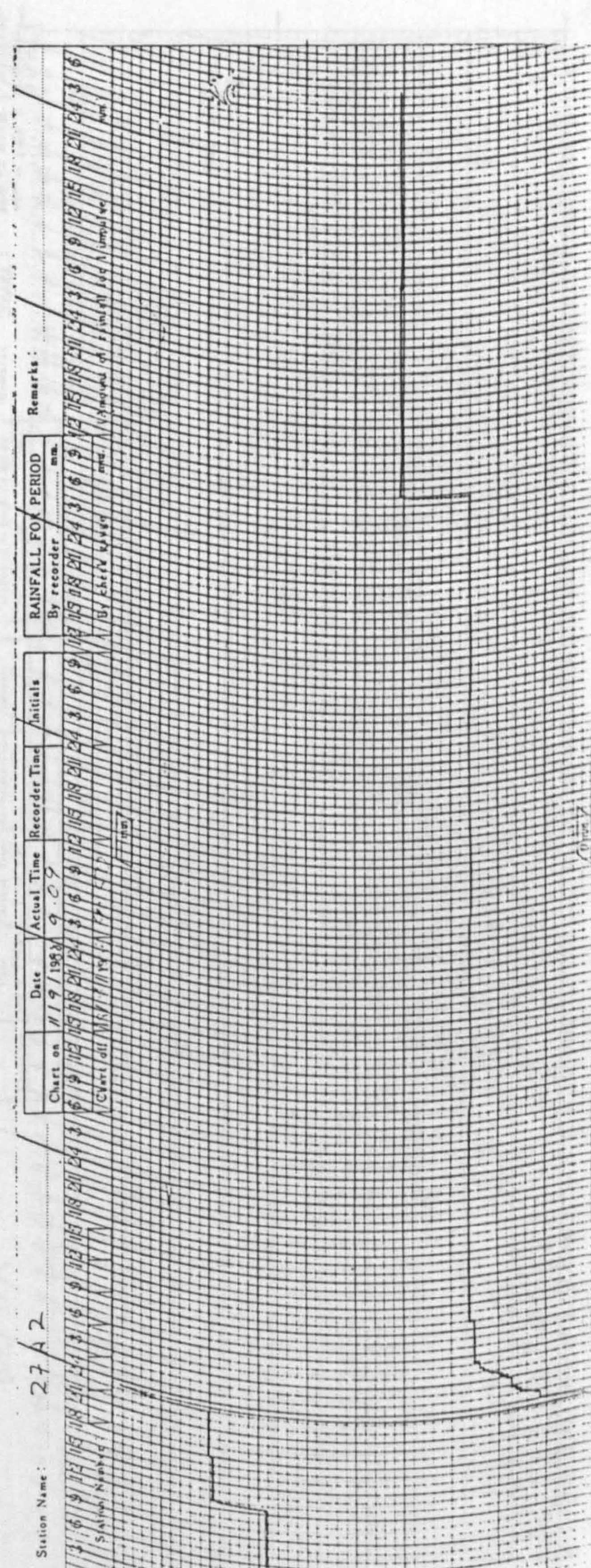
u = wetted perimeter ranging from 0.7 m to 1.0 m
(b=0.4 m and max height of water in
the ditch is 0.2 m)

The respective charts and converted discharge and watertable levels and water table readings for rows 3 and 4 are given in the preceding pages.

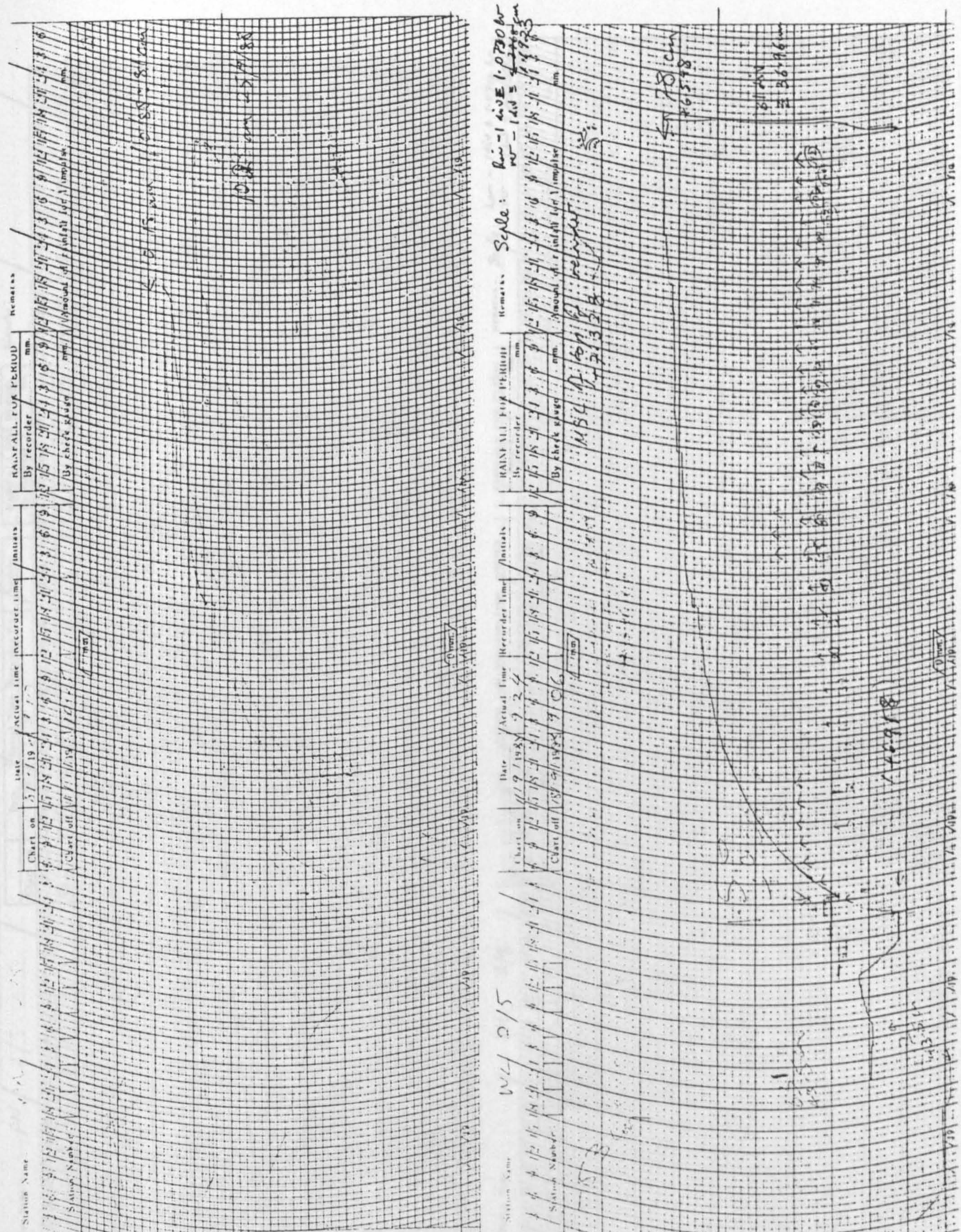
C2

Rainfall Recording Charts for Plot 2
11th September to 1st October 1988

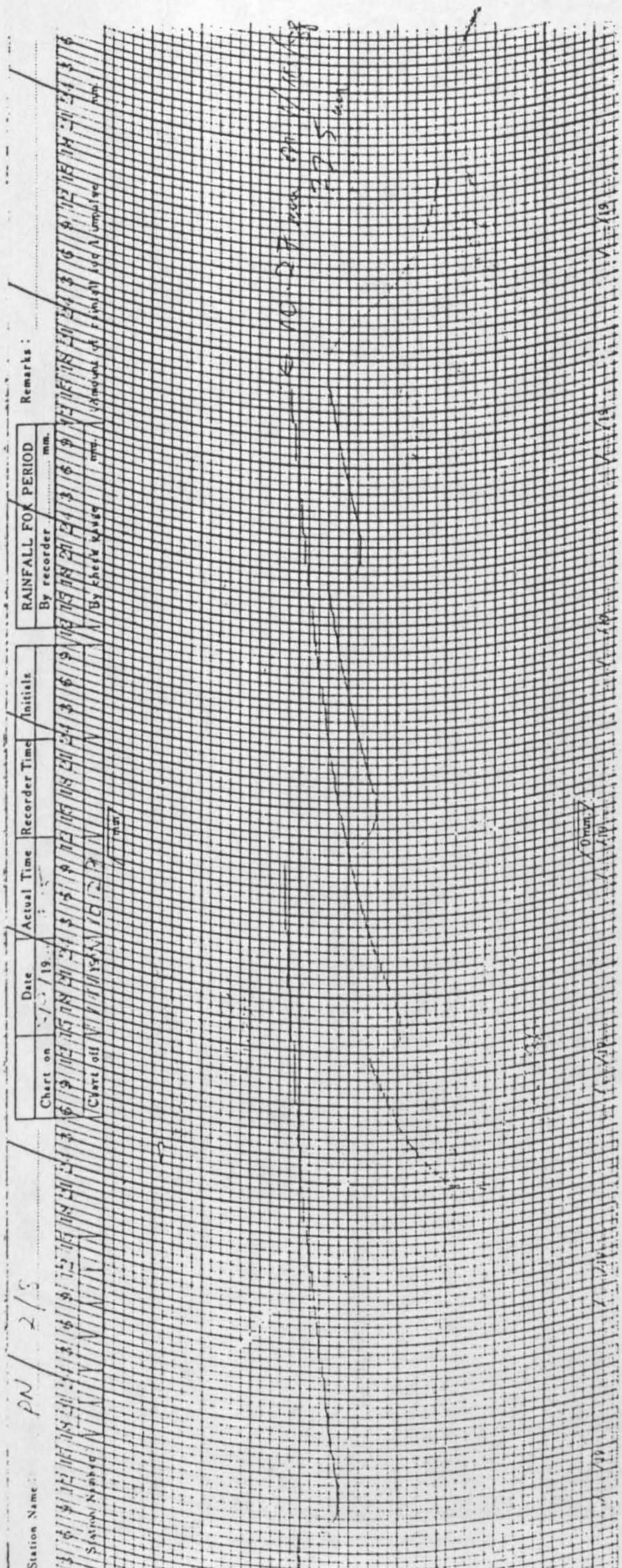


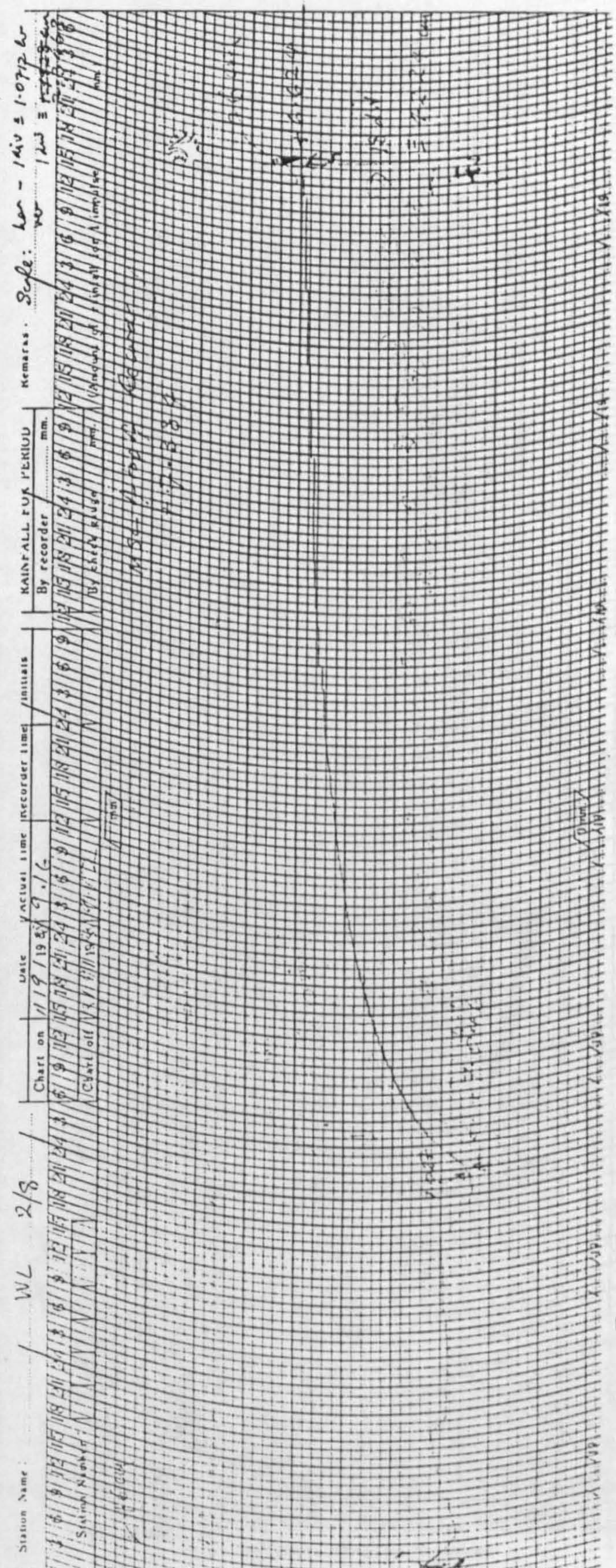


Water Level Recording Charts for OW 235
11th September to 1st October 1988

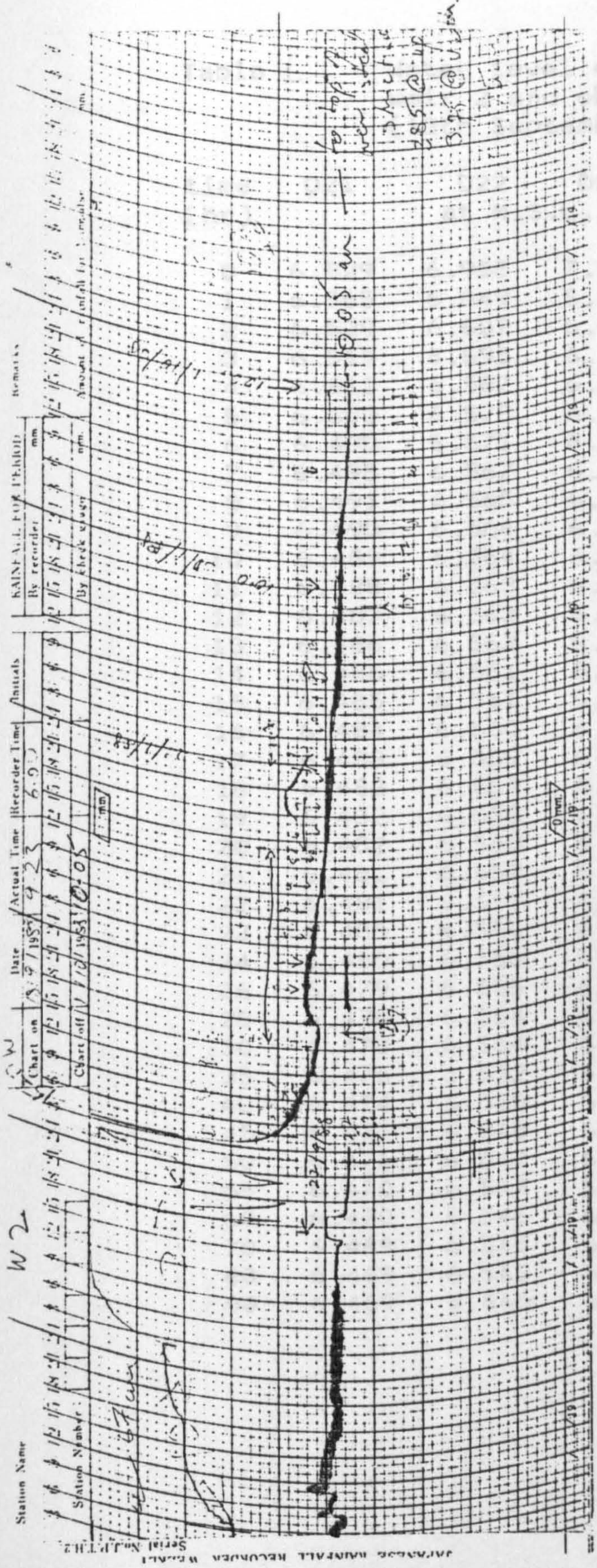


Water Level Recording Charts for OW 238
11th September to 1st October 1988





Water Level Recording Charts for W2
11th September to 1st October 1988



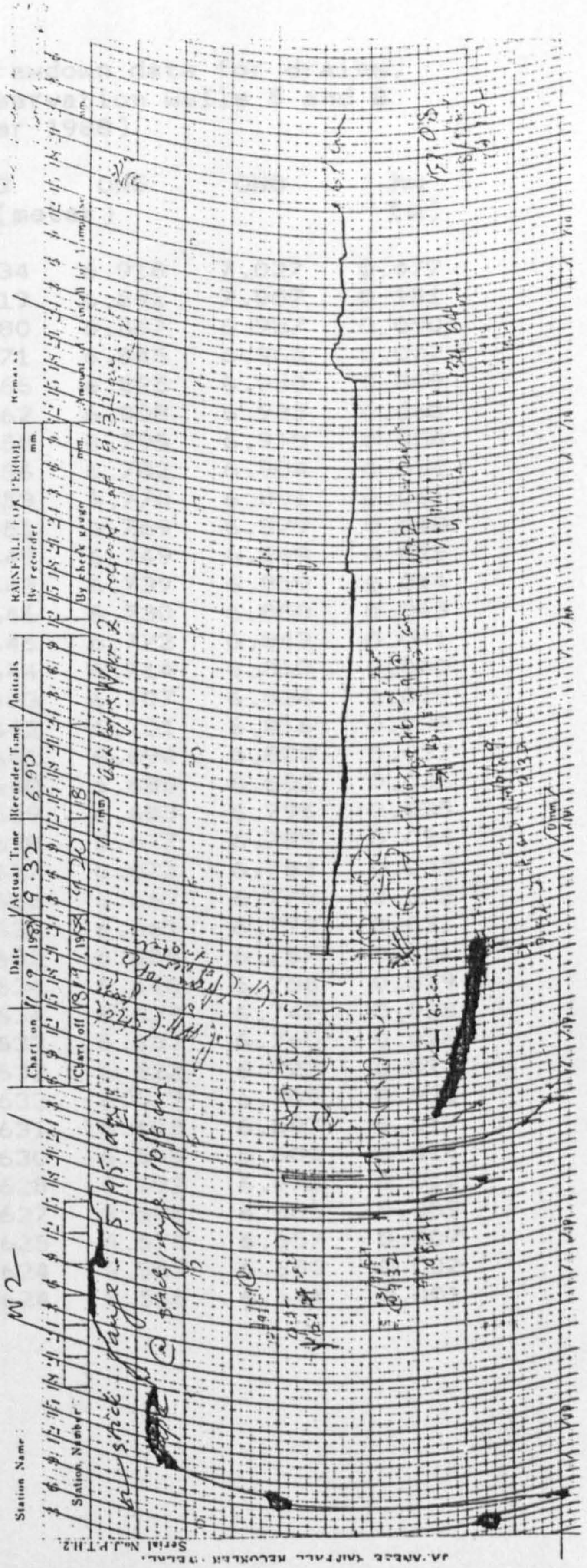


Table 1 - Water level drawdown data for drains, weir 2 and observation wells 5 and 8 (13th September 1988)

time (hr)	D21	D22	D23	OW5	OW8	hw (m)
		at M.S.L. (meter)				
0	6.829	6.955	7.034	6.918	7.027	0.477
1	6.565	6.649	6.719	6.892	7.007	0.181
2	6.529	6.607	6.680	6.867	6.987	0.090
3	6.519	6.595	6.671	6.845	6.968	0.077
4	6.511	6.587	6.666	6.825	6.950	0.069
5	6.503	6.578	6.662	6.808	6.933	0.063
6	6.498	6.571	6.658	6.795	6.918	0.058
7	6.495	6.567	6.656	6.782	6.904	0.054
8	6.491	6.565	6.653	6.770	6.891	0.051
9	6.490	6.564	6.651	6.759	6.879	0.048
10	6.489	6.564	6.649	6.749	6.869	0.046
11	6.488	6.563	6.648	6.739	6.859	0.044
12	6.487	6.562	6.646	6.730	6.850	0.043
13	6.486	6.562	6.645	6.722	6.842	0.041
14	6.485	6.561	6.644	6.714	6.833	0.040
15	6.485	6.561	6.643	6.707	6.824	0.039
16	6.484	6.560	6.642	6.701	6.816	0.038
17	6.483	6.559	6.641	6.694	6.808	0.037
18	6.483	6.559	6.640	6.688	6.802	0.036
19	6.482	6.558	6.639	6.683	6.795	0.035
20	6.482	6.558	6.638	6.677	6.789	0.034
21	6.481	6.557	6.637	6.672	6.784	0.033
22	6.481	6.557	6.636	6.667	6.778	0.032
23	6.480	6.556	6.636	6.661	6.772	0.031
24	6.480	6.556	6.635	6.655	6.767	0.031
26	6.479	6.555	6.634	6.646	6.756	0.029
28	6.478	6.554	6.634	6.639	6.747	0.028
30	6.478	6.554	6.633	6.633	6.740	0.026
35	6.476	6.552	6.632	6.622	6.723	0.023
40	6.474	6.550	6.632	6.613	6.709	0.020
45	6.472	6.548	6.631	6.605	6.697	0.017
50	6.471	6.547	6.630	6.599	6.685	0.014
55	6.470	6.547	6.628	6.592	6.676	0.012
60	6.470	6.546	6.627	6.586	6.669	0.009
70	6.469	6.545	6.625	6.575	6.657	0.007
80	6.469	6.545	6.624	6.567	6.650	0.002
90	6.469	6.545	6.624	6.566	6.644	0.001

Table 2 - Water level drawdown data for drains, weir 2 and observation wells 5 and 8 (13th September 1988) - derived data

time (hr)	Dav12 MSL	h5 (meter)	Dav23 MSL	h8 m	Q (m^3/s)	q (mm/hr)	Ce
0	6.892	0.026	6.995	0.032	0.26836	284.9	0.6934
1	6.607	0.285	6.684	0.323	0.02132	22.64	0.5818
2	6.568	0.299	6.643	0.343	0.00413	4.385	0.5784
3	6.557	0.288	6.633	0.335	0.00288	3.056	0.5784
4	6.549	0.276	6.627	0.324	0.00224	2.380	0.5784
5	6.541	0.268	6.620	0.313	0.00184	1.949	0.5784
6	6.535	0.261	6.615	0.303	0.00154	1.636	0.5784
7	6.531	0.251	6.611	0.292	0.00133	1.417	0.5784
8	6.528	0.242	6.609	0.282	0.00117	1.237	0.5784
9	6.527	0.232	6.608	0.271	0.00103	1.096	0.5784
10	6.527	0.222	6.607	0.262	0.00093	0.983	0.5784
11	6.525	0.213	6.606	0.254	0.00085	0.899	0.5783
12	6.524	0.206	6.604	0.246	0.00079	0.836	0.5783
13	6.524	0.198	6.603	0.238	0.00074	0.787	0.5783
14	6.523	0.191	6.602	0.230	0.00069	0.736	0.5783
15	6.523	0.184	6.602	0.222	0.00065	0.691	0.5783
16	6.522	0.179	6.601	0.215	0.00061	0.651	0.5783
17	6.521	0.173	6.600	0.208	0.00058	0.613	0.5783
18	6.521	0.167	6.600	0.203	0.00055	0.579	0.5782
19	6.520	0.163	6.598	0.197	0.00051	0.547	0.5782
20	6.520	0.157	6.598	0.191	0.00049	0.518	0.5782
21	6.519	0.153	6.597	0.187	0.00046	0.491	0.5782
22	6.519	0.148	6.596	0.182	0.00044	0.464	0.5782
23	6.518	0.143	6.596	0.176	0.00042	0.441	0.5782
24	6.518	0.137	6.595	0.171	0.00040	0.422	0.5781
26	6.517	0.129	6.595	0.162	0.00036	0.382	0.5781
28	6.516	0.123	6.594	0.153	0.00033	0.347	0.5781
30	6.516	0.117	6.594	0.147	0.00030	0.316	0.5780
35	6.514	0.108	6.592	0.131	0.00023	0.247	0.5779
40	6.512	0.101	6.591	0.118	0.00018	0.190	0.5778
45	6.510	0.095	6.589	0.108	0.00013	0.140	0.5777
50	6.509	0.090	6.589	0.097	0.00010	0.103	0.5775
55	6.509	0.083	6.588	0.089	0.00007	0.077	0.5774
60	6.508	0.078	6.587	0.083	0.00005	0.055	0.5773
70	6.507	0.068	6.585	0.072	0.00004	0.038	0.5771
80	6.507	0.060	6.584	0.065	0.00001	0.015	0.5767
90	6.507	0.059	6.584	0.060	0.00001	0.011	0.5766

Table - Water level drawdown data for drains, weir 2 and observation wells 5 and 8 (27th September 1988)

time (hr)	D21	D22	D23	OW5	OW8	hw (m)
		at M.S.L. (meter)				
0	6.769	6.885	7.024	6.828	6.999	0.274
1	6.463	6.543	6.618	6.811	6.981	0.107
2	6.447	6.521	6.597	6.795	6.963	0.093
3	6.441	6.512	6.586	6.780	6.945	0.084
4	6.436	6.505	6.580	6.764	6.929	0.078
5	6.433	6.501	6.576	6.752	6.916	0.074
6	6.430	6.499	6.574	6.741	6.901	0.070
7	6.429	6.496	6.574	6.730	6.889	0.067
8	6.429	6.496	6.574	6.720	6.879	0.064
9	6.428	6.495	6.574	6.711	6.869	0.062
10	6.428	6.495	6.574	6.702	6.858	0.059
11	6.428	6.495	6.574	6.694	6.848	0.057
12	6.428	6.495	6.574	6.687	6.838	0.056
13	6.428	6.495	6.574	6.679	6.828	0.055
14	6.428	6.495	6.574	6.672	6.820	0.054
20	6.428	6.495	6.574	6.750	6.881	0.065
21	6.428	6.495	6.574	6.742	6.876	0.064
22	6.428	6.495	6.574	6.735	6.870	0.063
23	6.428	6.495	6.574	6.727	6.865	0.062
24	6.428	6.495	6.574	6.720	6.858	0.061
25	6.428	6.495	6.574	6.712	6.851	0.060
26	6.428	6.495	6.574	6.705	6.844	0.059
27	6.428	6.495	6.574	6.698	6.837	0.058
28	6.428	6.495	6.574	6.691	6.830	0.057
29	6.428	6.495	6.574	6.685	6.822	0.056
30	6.428	6.495	6.574	6.679	6.815	0.055
31	6.428	6.495	6.574	6.674	6.815	0.054
32	6.428	6.495	6.574	6.669	6.810	0.053
33	6.428	6.495	6.574	6.664	6.796	0.052
34	6.428	6.495	6.574	6.659	6.789	0.051
35	6.428	6.495	6.574	6.654	6.784	0.050
36	6.428	6.495	6.574	6.650	6.778	0.049
37	6.428	6.495	6.574	6.646	6.773	0.049
38	6.428	6.495	6.574	6.642	6.769	0.048
39	6.428	6.495	6.574	6.638	6.764	0.047
40	6.428	6.495	6.574	6.635	6.759	0.046
41	6.428	6.495	6.574	6.632	6.755	0.046
42	6.428	6.495	6.574	6.629	6.750	0.045
43	6.428	6.495	6.574	6.625	6.746	0.044
44	6.428	6.495	6.574	6.622	6.742	0.044
45	6.428	6.495	6.574	6.619	6.738	0.043
46	6.428	6.495	6.574	6.616	6.734	0.042
47	6.428	6.495	6.574	6.613	6.731	0.042
48	6.428	6.495	6.574	6.610	6.727	0.041
49	6.428	6.495	6.574	6.607	6.723	0.041
50	6.428	6.495	6.574	6.604	6.720	0.040

51	6.428	6.495	6.574	6.602	6.718	0.040
52	6.428	6.495	6.574	6.599	6.715	0.039
53	6.428	6.495	6.574	6.596	6.712	0.039
54	6.428	6.495	6.574	6.594	6.709	0.038
55	6.428	6.495	6.574	6.591	6.706	0.038
56	6.428	6.495	6.574	6.588	6.703	0.037
57	6.428	6.495	6.574	6.586	6.700	0.037
58	6.428	6.495	6.574	6.584	6.697	0.036
59	6.428	6.495	6.574	6.581	6.694	0.036
60	6.428	6.495	6.574	6.579	6.692	0.036
61	6.428	6.495	6.574	6.577	6.689	0.035
62	6.428	6.495	6.574	6.575	6.686	0.035
63	6.428	6.495	6.574	6.573	6.684	0.034
64	6.428	6.495	6.574	6.571	6.681	0.034
65	6.428	6.495	6.574	6.569	6.678	0.034
66	6.428	6.495	6.574	6.567	6.676	0.033
67	6.428	6.495	6.574	6.566	6.674	0.033
68	6.428	6.495	6.574	6.564	6.671	0.033
69	6.428	6.495	6.574	6.562	6.669	0.033
70	6.428	6.495	6.574	6.561	6.667	0.032

Table - Water level drawdown data for drains, weir 2 and observation wells 5 and 8 (27th September 1988) - derived data

time (hr)	Dav12	h5 (meter)	Dav23	h8	Q (m^3/s)	q (mm/hr)	Ce
0	6.827	0.001	6.955	0.045	0.05898	62.63	0.5912
1	6.503	0.308	6.581	0.400	0.00613	6.510	0.5786
2	6.484	0.311	6.559	0.404	0.00442	4.697	0.5784
3	6.477	0.304	6.549	0.396	0.00355	3.771	0.5784
4	6.470	0.293	6.543	0.386	0.00299	3.175	0.5784
5	6.467	0.285	6.538	0.377	0.00263	2.789	0.5784
6	6.464	0.277	6.536	0.365	0.00235	2.499	0.5784
7	6.463	0.268	6.535	0.354	0.00211	2.240	0.5784
8	6.463	0.257	6.535	0.344	0.00192	2.034	0.5784
9	6.462	0.249	6.535	0.334	0.00176	1.868	0.5784
10	6.462	0.241	6.535	0.323	0.00161	1.710	0.5784
11	6.462	0.232	6.535	0.314	0.00149	1.580	0.5784
12	6.462	0.225	6.535	0.303	0.00139	1.480	0.5784
13	6.462	0.217	6.535	0.294	0.00134	1.418	0.5784
14	6.462	0.210	6.535	0.286	0.00129	1.369	0.5784
20	6.462	0.289	6.535	0.347	0.00196	2.082	0.5784
21	6.462	0.281	6.535	0.341	0.00189	2.012	0.5784
22	6.462	0.274	6.535	0.335	0.00183	1.944	0.5784
23	6.462	0.266	6.535	0.330	0.00177	1.876	0.5784
24	6.462	0.258	6.535	0.323	0.00171	1.811	0.5784
25	6.462	0.250	6.535	0.316	0.00164	1.746	0.5784
26	6.462	0.243	6.535	0.309	0.00159	1.684	0.5784
27	6.462	0.236	6.535	0.302	0.00153	1.623	0.5784
28	6.462	0.229	6.535	0.295	0.00147	1.564	0.5784
29	6.462	0.223	6.535	0.288	0.00142	1.506	0.5784
30	6.462	0.217	6.535	0.281	0.00136	1.449	0.5784
31	6.462	0.212	6.535	0.281	0.00131	1.394	0.5784
32	6.462	0.208	6.535	0.275	0.00126	1.341	0.5784
33	6.462	0.203	6.535	0.262	0.00121	1.290	0.5784
34	6.462	0.197	6.535	0.255	0.00117	1.240	0.5784
35	6.462	0.192	6.535	0.249	0.00112	1.194	0.5784
36	6.462	0.189	6.535	0.243	0.00108	1.150	0.5784
37	6.462	0.184	6.535	0.238	0.00104	1.109	0.5784
38	6.462	0.181	6.535	0.235	0.00101	1.069	0.5784
39	6.462	0.177	6.535	0.229	0.00097	1.031	0.5784
40	6.462	0.174	6.535	0.224	0.00094	0.996	0.5784
41	6.462	0.170	6.535	0.221	0.00091	0.962	0.5784
42	6.462	0.168	6.535	0.215	0.00088	0.932	0.5783
43	6.462	0.163	6.535	0.211	0.00085	0.904	0.5783
44	6.462	0.161	6.535	0.208	0.00083	0.878	0.5783
45	6.462	0.157	6.535	0.203	0.00080	0.853	0.5783
46	6.462	0.155	6.535	0.200	0.00078	0.829	0.5783
47	6.462	0.151	6.535	0.196	0.00076	0.805	0.5783
48	6.462	0.149	6.535	0.193	0.00074	0.783	0.5783
49	6.462	0.145	6.535	0.189	0.00072	0.762	0.5783
50	6.462	0.143	6.535	0.185	0.00070	0.742	0.5783

51	6.462	0.141	6.535	0.183	0.00068	0.722	0.5783
52	6.462	0.137	6.535	0.181	0.00066	0.704	0.5783
53	6.462	0.135	6.535	0.177	0.00064	0.684	0.5783
54	6.462	0.132	6.535	0.175	0.00063	0.666	0.5783
55	6.462	0.130	6.535	0.171	0.00061	0.648	0.5783
56	6.462	0.126	6.535	0.169	0.00059	0.632	0.5783
57	6.462	0.124	6.535	0.165	0.00058	0.616	0.5783
58	6.462	0.123	6.535	0.163	0.00057	0.601	0.5783
59	6.462	0.119	6.535	0.159	0.00055	0.588	0.5783
60	6.462	0.117	6.535	0.157	0.00054	0.575	0.5782
61	6.462	0.116	6.535	0.155	0.00053	0.564	0.5782
62	6.462	0.113	6.535	0.151	0.00052	0.552	0.5782
63	6.462	0.111	6.535	0.150	0.00051	0.540	0.5782
64	6.462	0.110	6.535	0.147	0.00050	0.528	0.5782
65	6.462	0.107	6.535	0.143	0.00049	0.518	0.5782
66	6.462	0.105	6.535	0.142	0.00048	0.508	0.5782
67	6.462	0.104	6.535	0.139	0.00047	0.499	0.5782
68	6.462	0.103	6.535	0.137	0.00046	0.490	0.5782
69	6.462	0.100	6.535	0.135	0.00045	0.482	0.5782
70	6.462	0.099	6.535	0.133	0.00045	0.473	0.5782

Drawdown test on 13/9/88 – Row 3 (for calc of field k)
-Release @ 9.32 am

	D1 (m)	D2 (m)	D3 (m)	mid D1-D2 (m)	mid D2-D3 (m)	P25 (m)	h_5 (cm)	P28 (m)	h_8 (cm)
13/9/88									
9.35 am	6.699	6.785	6.824	6.742	6.805	6.922	18	7.003	19.9
10.25	6.539	6.625	6.684	6.582	6.655	6.902	32	6.983	32.9
11.35	6.529	6.605	6.674	6.567	6.640	6.872	30.5	6.983	34.3
12.30 pm	6.519	6.595	6.674	6.558	6.635	6.852	29.5	6.943	30.8
1.50	6.509	6.585	6.674	6.547	6.630	6.822	27.5	6.903	27.3
2.40	6.499	6.575	6.664	6.537	6.620	6.812	27.5	6.893	27.3
3.35	6.499	6.575	6.664	6.537	6.620	6.802	26.5	6.893	27.3
4.40	6.489	6.565	6.654	6.527	6.610	6.782	25.5	6.883	27.4
5.25	6.489	6.565	6.644	6.527	6.605	6.782	25.5	6.873	26.9
14/9/88									
9.30 am	6.479	6.555	6.634	6.517	6.595	6.682	16.5	6.763	16.9
2.40 pm	6.479	6.545	6.634	6.512	6.590	6.662	15.0	6.753	16.4
15/9/88									
9.45 am	6.469	6.545	6.634	6.507	6.590	6.662	15.5	6.713	12.4
16/9/88									
9.40 am	6.469	6.545	6.624	6.507	6.585	6.582	7.5	6.683	9.9

Variation in WL in Drains after 8 hrs of drawdown is small

		D1		D2		D3	
13/9/88 5.25 pm	} 16 hrs 5 mins	6.489	} 1 cm	6.565	} 1 cm	6.644	} 1 cm
14/9/88 9.30 am	} 23 hrs 45 mins	6.479	} 1 cm	6.555	} 1 cm	6.634	} 0 cm
15/9/88 9.45 am	} 23 hrs 55 mins	6.469	} 0 cm	6.545	} 0 cm	6.634	} 1 cm
16/9/88 9.40 am		6.469		6.545		6.624	

Drawdown test on 13/9/88 – For calc of field k
Row 4,

	D1 m	D2 m	D3 m	mid D1-D2	mid D2-D3	PZ5	h_5	PZ8	h_8
13/9/88									
9.50 am	6.589	6.691	6.640	6.640	6.666	6.905	26.5	7.004	33.8
10.40 .	6.529	6.561	6.590	6.545	6.576	6.875	33.0	6.954	37.8
11.45 .	6.449	6.541	6.520	6.495	6.531	6.815	32.0	6.934	40.3
12.30 noon	6.439	6.531	6.520	6.485	6.526	6.815	33.0	6.924	39.8
1.45 pm	6.419	6.531	6.510	6.475	6.521	6.805	33.0	6.884	36.3
2.35 pm	6.419	6.521	6.510	6.470	6.516	6.775	30.5	6.874	35.8
3.30 pm	6.409	6.521	6.500	6.465	6.511	6.775	31.0	6.864	35.3
4.30 pm	6.409	6.511	6.490	6.460	6.501	6.755	29.5	6.854	35.3
5.25 pm	6.409	6.501	6.490	6.455	6.496	6.755	30.0	6.834	33.8
14.9/88									
9.40 am	6.389	6.491	6.470	6.440	6.481	6.625	18.5	6.714	23.3
2.30 pm	6.379	6.491	6.460	6.435	6.476	6.595	16.0	6.694	21.8
15/9/88									
9.40 am	6.379	6.491	6.460	6.435	6.476	6.545	11.0	6.654	17.8
16/9/88									
9.40 am	6.369	6.471	6.45	6.420	6.461	6.515	9.5	6.614	15.3

Drawdown test on 27/9/88 – R3
Release at 10.10 am

27/9/88	D1 (m)	D2 (m)	D3 (m)	mid D1-D2 (m)	mid D2-D3 (m)	P25	h_5	P28	h_8
10.18	6.759	6.845	6.994	6.802	6.920	6.832	3.0	6.983	6.4
10.35	6.579	6.705	6.784	6.642	6.745	6.832	19.0	6.973	22.9
10.47	6.509	6.605	6.664	6.557	6.635	6.832	27.5	6.973	33.9
11.04	6.469	6.555	6.624	6.512	6.590	6.822	31.0	6.963	37.4
11.21	6.459	6.535	6.614	6.497	6.575	6.822	32.5	6.953	37.9
11.41	6.449	6.525	6.604	6.487	6.565	6.812	32.5	6.953	38.9
12.40	6.449	6.515	6.584	6.482	6.550	6.792	31.0	6.943	39.4
1.43	6.449	6.505	6.574	6.477	6.540	6.782	30.5	6.923	38.4
2.40	6.439	6.505	6.574	6.472	6.540	6.772	30.0	6.903	36.4
3.42	6.429	6.495	6.574	6.462	6.535	6.762	30.0	6.893	35.9
4.40	6.429	6.495	6.574	6.462	6.535	6.752	29.0	6.883	34.8
5.40	6.429	6.495	6.574	6.462	6.535	6.742	28.0	6.873	33.8

Drawdown test on 27/9/88 – R4
Release at * 10:10 am – (* check all time when doing detail analysis

	D1 (m)	D2 (m)	D3 (m)	mid D1-D2 (m)	mid D2-3 (m)	P25	h_5	P28	h_8
27/9/88									
10·20 am	6·749	6·841	6·90	6·795	6·571	6·815	2·0	6·954	8·4
10·35	6·579	6·671	6·65	6·625	6·661	6·815	19·0	6·954	29·4
10·47	6·479	6·571	6·53	6·525	6·551	6·805	28·0	6·954	40·4
11·04	6·409	6·511	6·48	6·460	6·496	6·795	33·5	6·944	44·9
11·21	6·369	6·491	6·46	6·430	6·476	6·795	36·5	6·934	46·5
11·41	6·359	6·481	6·45	6·420	6·466	6·785	36·5	6·924	45·9
12·40	6·339	6·471	6·45	6·405	6·461	6·765	36·0	6·914	45·4
1·40	6·329	6·461	6·42	6·395	6·441	6·755	36·0	6·884	44·4
2·40	6·319	6·451	6·41	6·385	6·431	6·735	35·0	6·874	44·4
3·40	6·309	6·451	6·40	6·380	6·426	6·725	34·5	6·854	42·9
4·40	6·309	6·451	6·40	6·380	6·426	6·715	33·5	6·844	41·9
5·50	6·309	6·451	6·40	6·380	6·426	6·705	32·5	6·834	40·9

APPENDIX D

Rate of Capillary Rise

APPENDIX D - Rate Of Capillary Rise

Below are processed results for all data collected in the lysimeter monoliths. Section D1 are the results for lysimeters No 4, 6 and 14 which are subjected to WT changes from 0 to 600 mm (a change of 100 mm every 2 weeks). Section D2 give the results for lysimeters No 3, 5, 9, 17 and 19 in which the WT have been maintained at about 300 mm. Section D3 are the results for lysimeters No 7, 10 and 12 in which the WT is maintained at 300 mm and then reduced to and maintained at 600 mm. Section D4 are resluts for lysimeters No 2, 8 and 18 in which the WT are reduced every 300 until it reaches WT=900 mm. Section D5 is the result of Lysimeter No 11 which is filled with water only.

Section D1

Lysimeter No. : ly4
Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
24.3.88	4.2500	1.7648	33.0000	2.0369
25.3.88	4.2500	2.2461	35.0000	3.1572
26.3.88	3.7500	1.0161	27.0000	0.9166
27.3.88	4.3500	5.3478	41.0000	2.2661
28.3.88	4.7000	5.3478	48.0000	3.3609
29.3.88	4.8000	5.3478	50.0000	3.8447
30.3.88	5.0500	2.1926	53.0000	3.9975

Lysimeter No. : ly6
Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
24.3.88	5.4000	1.3468	34.0000	1.7823
25.3.88	5.2500	2.2626	38.9999	3.2845
26.3.88	5.1000	0.5926	28.0000	0.1273
27.3.88	5.3500	4.7408	37.0000	1.6805
28.3.88	5.4500	3.8788	37.0000	2.6735
29.3.88	5.5000	6.2492	36.0001	3.4118
30.3.88	5.9500	1.8317	41.0000	3.7428

Lysimeter No. : ly14
Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
24.3.88	3.1500	1.7716	61.0000	6.9255
25.3.88	2.7000	2.5856	62.0000	4.9395
26.3.88	2.8000	0.8619	54.0000	4.3539
27.3.88	1.5000	3.5911	33.9999	2.4952
28.3.88	1.2500	4.0699	41.0001	2.7244
29.3.88	1.6000	4.3093	48.0000	3.3355
30.3.88	1.7000	2.5856	44.0000	1.0999

Lysimeter No. : ly4
Water Table : 10 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	15.3500	2.5135	27.0000	2.3323
13.4.88	15.3500	2.9413	25.0000	2.5971
14.4.88	15.2000	2.5669	22.0000	1.9351
15.4.88	15.4500	4.1713	27.0000	3.2998
16.4.88	15.3000	2.5669	24.0000	2.6735
17.4.88	15.5000	2.5135	28.0000	2.5818
18.4.88	15.3500	1.8182	25.0000	2.2813
19.4.88	15.4500	2.5135	27.0000	2.1388
20.4.88	15.3500	2.6204	25.0000	1.9758
21.4.88	15.2500	3.5295	23.0000	2.9383

Lysimeter No. : ly6
Water Table : 10 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	16.1000	1.9394	32.0000	1.8332
13.4.88	16.0000	2.9091	30.0000	2.3832
14.4.88	16.1500	2.2626	31.0000	1.5684
15.4.88	16.3000	3.6094	36.0000	3.0197
16.4.88	16.2000	2.5320	32.0000	2.4952
17.4.88	16.3000	2.1549	34.0000	2.4850
18.4.88	16.2500	1.5623	35.0000	1.9605
19.4.88	16.4500	2.4781	37.0000	1.8332
20.4.88	16.3500	2.5320	35.0000	1.6550
21.4.88	16.3000	3.6094	34.0000	3.1318

Lysimeter No. : ly14
Water Table : 10 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	7.6000	2.0110	28.0000	1.8332
13.4.88	7.6000	2.3462	26.0000	2.1897
14.4.88	7.5000	2.3941	26.0001	1.6550
15.4.88	7.5500	3.3517	27.0000	2.8008
16.4.88	7.5500	2.4419	27.0000	2.6684
17.4.88	7.6000	2.4898	28.0000	2.2101
18.4.88	7.5500	1.1970	23.0000	1.7212
19.4.88	7.6000	2.5377	26.0000	1.9249
20.4.88	7.6000	2.1068	28.0000	1.3647
21.4.88	7.6500	3.3996	25.0000	2.4443

Lysimeter No. : ly4
Water Table : 20 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	20.3000	3.3156	26.0001	2.3374
8.5.88	20.6000	3.2622	28.0000	3.4118
9.5.88	20.6000	1.8182	28.0000	3.0554
11.5.88	20.2500	1.7648	21.0000	2.0980
12.5.88	20.0000	1.6578	16.0000	1.9504
13.5.88	19.9000	1.6043	16.0000	1.0948
14.5.88	20.1000	2.3530	18.0000	1.6601
15.5.88	20.3500	3.4761	27.0000	3.3202
19.5.88	20.0000	1.6043	18.0000	1.1305
20.5.88	20.1000	2.7274	20.0000	1.5786
27.5.88	20.3000	3.0482	23.9999	2.7091
28.5.88	20.7500	3.8504	23.0000	3.1827
29.5.88	20.4500	3.7435	25.0000	3.2081
30.5.88	20.3500	1.6043	21.0000	3.0656
31.5.88	20.1000	1.2300	18.0000	1.3647

Lysimeter No. : ly6
Water Table : 20 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	21.0500	2.9630	27.0000	2.5563
8.5.88	21.1000	3.2323	28.0000	3.2234
9.5.88	21.2000	1.7778	26.0000	2.6735
11.5.88	20.9500	2.4242	27.0000	2.3017
12.5.88	20.6500	1.9394	18.9999	2.2406
13.5.88	20.4500	1.4007	17.0000	1.5175
14.5.88	20.1500	2.2626	13.0000	1.1356
15.5.88	20.3500	3.0707	17.0000	2.4290
19.5.88	20.7000	1.4545	26.0000	2.3781
20.5.88	20.3000	3.0168	14.0000	1.1712
27.5.88	20.9500	2.9630	27.0000	2.7651
28.5.88	21.2000	2.9630	24.0000	3.6155
29.5.88	20.8500	3.4478	25.0000	1.8078
30.5.88	21.1500	1.4545	31.0001	3.2336
31.5.88	21.0500	1.2929	25.0000	2.0115

Lysimeter No. : ly14
Water Table : 20 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	20.0000	2.8250	16.0001	1.8230
8.5.88	20.0500	2.9208	19.0000	2.3170
9.5.88	20.2000	1.5801	20.0000	2.4952
11.5.88	19.9000	3.8305	16.0000	1.7314
12.5.88	19.9000	1.8674	14.0000	1.9096
13.5.88	19.6500	1.1970	9.0000	0.7638
14.5.88	19.7500	1.9631	11.0001	0.9064
15.5.88	19.9000	2.8729	18.0000	2.5971
19.5.88	19.6000	1.5322	12.0000	0.8453
20.5.88	19.6500	2.2025	11.0000	0.8046
27.5.88	20.1000	2.2504	16.0000	2.4290
28.5.88	20.2000	2.8729	18.0000	2.1337
29.5.88	20.1000	2.8729	14.0000	2.3679
30.5.88	19.4500	1.1491	25.0000	2.1999
31.5.88	19.9000	1.0055	14.0000	1.2629

Lysimeter No. : ly4
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
8.6.88	30.6000	3.6365	22.0000	2.1897
9.6.88	30.4500	2.8878	21.0000	2.4545
10.6.88	30.5000	2.3530	20.0000	2.5461
11.6.88	30.4500	2.8343	19.0000	2.4443
12.6.88	30.4000	3.3156	18.0000	2.1133
13.6.88	30.6000	3.3156	22.0000	2.6480
14.6.88	30.3500	3.2087	19.0000	2.1795
15.6.88	30.3500	3.3156	19.0000	2.8008
16.6.88	30.6000	1.0696	24.0000	2.6480
17.6.88	30.4000	3.1017	20.0000	2.0369
18.6.88	30.1000	2.5135	16.0000	1.8230
19.6.88	30.1000	2.5669	14.0000	1.5277
20.6.88	30.4500	3.2622	21.0000	2.3017
21.6.88	30.3500	2.5669	21.0000	2.1388

Lysimeter No. : ly6
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
8.6.88	28.7500	3.5556	23.0000	2.3425
9.6.88	28.6500	2.4242	19.0000	2.3934
10.6.88	28.7000	2.4242	24.0000	2.9026
11.6.88	28.5500	2.4242	21.0001	2.3170
12.6.88	28.5000	2.9630	20.0000	2.1133
13.6.88	28.8500	2.5859	25.0000	2.5461
14.6.88	28.5500	3.2323	23.0000	2.1744
15.6.88	28.7000	3.2862	22.0000	3.3100
16.6.88	28.7000	0.7542	28.0000	2.3425
17.6.88	28.6500	2.6397	23.0000	2.0878
18.6.88	28.3500	2.4781	21.0000	1.9351
19.6.88	28.3000	2.4242	18.0000	1.4870
20.6.88	28.5500	3.8788	25.0000	2.2915
21.6.88	28.6500	2.4781	23.0000	2.4137

Lysimeter No. : ly14
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
8.6.88	30.3500	2.7771	13.0000	1.4360
9.6.88	30.1000	2.2504	16.0000	1.5786
10.6.88	30.2000	2.1068	16.0000	2.1642
11.6.88	30.2000	2.2504	14.0000	1.6550
12.6.88	30.1000	2.5856	12.0000	1.6957
13.6.88	30.1500	2.2025	17.0000	1.8078
14.6.88	30.0000	2.4898	13.9999	1.4360
15.6.88	30.0500	2.8729	17.0000	2.1388
16.6.88	30.2500	0.8140	18.9999	2.1286
17.6.88	30.1500	2.6813	15.0000	1.3393
18.6.88	30.0000	2.0589	12.0000	1.6805
19.6.88	30.0500	2.0110	13.0000	1.4513
20.6.88	30.0500	2.3941	15.0000	1.7568
21.6.88	30.1500	2.1068	17.0000	1.9351

Lysimeter No. : ly4

Water Table : 40 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
2.7.88	40.8000	2.0322	14.0000	1.5786
3.7.88	40.7000	1.9252	12.0000	1.6194
4.7.88	40.6000	1.6043	16.0000	2.1133
5.7.88	40.3000	0.0749	10.0000	0.3055
6.7.88	40.3500	1.7648	13.0000	0.6875
7.7.88	40.4500	2.2995	15.0000	0.6620
8.7.88	40.6000	3.0482	18.0000	1.5532
9.7.88	40.6500	2.6204	17.0000	1.9605
10.7.88	40.7500	2.1391	17.0000	2.4698
11.7.88	40.5500	0.6417	13.0000	2.4698
12.7.88	41.2500	1.9787	11.0001	0.6620
13.7.88	41.4000	2.4065	14.0000	0.9523
14.7.88	41.6500	3.2087	17.0000	1.3749

Lysimeter No. : ly6
Water Table : 40 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
2.7.88	40.2000	2.1010	18.0000	1.6397
3.7.88	40.0000	1.7239	16.0000	1.8027
4.7.88	39.9500	1.1852	15.0000	1.8842
5.7.88	39.7000	0.0862	12.0000	0.2801
6.7.88	40.0000	1.5084	12.0000	0.4685
7.7.88	40.0000	2.1549	16.0000	0.3055
8.7.88	40.1500	2.6397	17.0000	1.5532
9.7.88	40.2500	2.5320	19.0000	1.7823
10.7.88	40.4000	1.9394	18.0000	2.1082
11.7.88	40.4000	0.9697	18.0000	2.3526
12.7.88	39.6500	1.9394	11.0000	0.9166
13.7.88	39.6500	1.6162	15.0000	0.8861
14.7.88	39.9000	2.8014	18.0000	1.4920

Lysimeter No. : ly14

Water Table : 40 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
2.7.88	39.6500	1.7716	13.0000	1.0185
3.7.88	39.5500	1.5801	11.0000	1.2222
4.7.88	39.5000	1.5801	12.0000	1.6550
5.7.88	39.0500	0.0431	5.0000	0.1528
6.7.88	39.0500	1.4364	9.0000	0.1833
7.7.88	39.2000	1.7716	10.0000	0.5958
8.7.88	39.2500	2.3462	15.0000	1.0439
9.7.88	39.3000	3.0165	16.0000	1.2120
10.7.88	39.4000	0.9576	16.0000	2.0369
11.7.88	39.2500	0.5746	13.0000	1.0694
12.7.88	39.1000	1.9152	10.0000	0.6111
13.7.88	39.2500	1.3886	13.0000	0.6365
14.7.88	39.4500	2.5856	15.0000	1.2731

Lysimeter No. : ly4
Water Table : 50 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
31.7.88	50.4000	4.1713	20.0000	1.9860
1.8.88	50.2500	2.9948	17.0000	2.4341
2.8.88	50.2000	1.4974	16.0001	1.2120
3.8.88	50.2000	2.8343	16.0001	1.0032
4.8.88	50.3500	2.8343	19.0000	2.3934
8.8.88	50.4500	2.0322	18.9999	1.0948
9.8.88	50.4000	3.8504	20.0000	2.1388
10.8.88	50.4000	2.2568	20.0000	3.0299
11.8.88	50.2500	1.4439	17.0000	1.3749
12.8.88	50.1500	2.0322	15.0000	0.6009
13.8.88	50.4000	3.5295	20.0000	2.4188
14.8.88	50.1500	1.1230	15.0000	1.5277
15.8.88	50.0000	2.4065	12.0000	1.4971
16.8.88	49.9000	1.7113	10.0000	0.5500

Lysimeter No. : ly6
Water Table : 50 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
31.7.88	47.0000	2.9630	22.0000	1.6550
1.8.88	47.0500	2.2088	21.0001	3.1674
2.8.88	46.9000	1.5623	18.0000	1.4666
3.8.88	46.9500	2.2088	19.0000	0.8148
4.8.88	47.0500	2.4242	21.0001	2.6480
8.8.88	47.1500	1.5084	23.0000	1.1407
9.8.88	47.1500	5.1717	23.0000	2.3934
10.8.88	47.1500	1.6700	23.0000	3.0045
11.8.88	46.9500	1.4007	19.0000	1.6194
12.8.88	46.8000	1.7239	16.0001	0.4430
13.8.88	47.1000	3.0707	22.0000	4.1146
14.8.88	46.5500	1.0774	11.0001	0.4838
15.8.88	46.8500	1.9933	17.0000	1.9351
16.8.88	46.6500	1.3468	13.0000	0.8402

Lysimeter No. : ly14
Water Table : 50 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
31.7.88	46.0000	2.6335	22.0000	1.6550
1.8.88	46.0500	1.9631	21.0001	3.1674
2.8.88	45.9000	1.3886	18.0000	1.4666
3.8.88	45.9500	1.9631	19.0000	0.8148
4.8.88	46.0500	2.1547	21.0001	2.0216
8.8.88	48.2500	1.3886	15.0000	1.1712
9.8.88	48.1000	2.8729	14.0000	1.7314
10.8.88	48.1500	1.6758	15.0000	2.1897
11.8.88	48.0500	1.4843	13.0000	1.4157
12.8.88	47.9500	1.4364	11.0000	0.5856
13.8.88	48.1000	2.7292	14.0000	2.0369
14.8.88	48.0000	1.0055	12.0000	1.0439
15.8.88	48.0500	1.7716	13.0000	1.5481
16.8.88	48.0000	1.2449	12.0000	0.8402
17.8.88	47.9000	1.3407	10.0000	-2.6633
18.8.88	20.2000	2.8729	18.0000	2.1337

Lysimeter No. : ly4
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
25.8.88	60.8000	2.5135	16.0000	1.8078
26.8.88	60.4500	2.2995	9.0000	0.7537
27.8.88	60.7000	1.4974	14.0000	1.6295
28.8.88	60.3500	2.4600	7.0000	0.3157
29.8.88	60.8000	2.2461	16.0000	1.4004
3.9.88	60.6000	2.2461	12.0000	0.6620
4.9.88	60.6000	2.8343	12.0000	1.7314
5.9.88	60.3500	3.6365	7.0000	0.7129
6.9.88	60.7000	1.9252	14.0000	0.8657
7.9.88	60.7500	2.6739	15.0000	1.8587
8.9.88	60.7500	1.6043	15.0000	0.8402
9.9.88	60.7000	2.4600	14.0000	1.0083
10.9.88	60.7500	2.8343	15.0000	1.5277

Lysimeter No. : ly6
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
25.8.88	57.0500	2.2088	27.0000	2.2915
26.8.88	56.8500	1.8317	23.0000	2.1286
27.8.88	56.8500	1.2929	23.0000	0.9777
28.8.88	56.9500	2.0471	25.0000	1.6550
29.8.88	57.0500	2.2088	27.0000	2.0471
3.9.88	56.6500	1.5623	19.0000	0.7893
4.9.88	56.8500	2.6936	23.0000	1.1458
5.9.88	56.8000	2.9630	22.0000	2.0777
6.9.88	56.8000	1.6700	22.0000	1.4666
7.9.88	56.8500	2.5320	23.0000	2.2406
8.9.88	56.8000	1.4007	22.0000	1.2222
9.9.88	56.8000	2.2088	22.0000	1.1458
10.9.88	56.8500	2.7475	23.0000	2.1489

Lysimeter No. : ly14
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
25.8.88	58.3000	2.4419	14.0000	1.4157
26.8.88	58.2500	1.9152	13.0000	1.3087
27.8.88	58.2500	1.1970	13.0000	0.9930
28.8.88	58.2500	1.8674	13.0000	1.0898
29.8.88	58.4000	1.7716	16.0000	1.5888
3.9.88	58.1500	2.0110	11.0000	0.8657
4.9.88	58.2500	2.1068	13.0000	0.7638
5.9.88	58.2500	2.8250	13.0000	1.4513
6.9.88	58.3500	1.7716	15.0000	1.3138
7.9.88	58.4000	1.9152	16.0000	1.7059
8.9.88	58.4000	1.7716	16.0000	1.2323
9.9.88	58.3500	1.9344	15.0000	1.0694
10.9.88	58.3500	2.2983	15.0000	1.7823

Section D2

Lysimeter No. : ly3
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
27.3.88	31.5000	3.8896	16.0001	3.0554
28.3.88	31.5500	5.4348	25.0000	3.8192
29.3.88	31.6500	4.1560	29.0000	4.0484
13.4.88	31.6000	2.7707	22.0000	3.3100
14.4.88	31.5000	2.7174	20.0000	2.8008
15.4.88	31.5500	3.9962	25.0000	3.5646
16.4.88	31.6500	2.5576	25.0000	3.0554
17.4.88	31.5500	2.3444	27.0000	3.0554
18.4.88	31.5000	1.4919	22.0000	2.8008
19.4.88	31.6500	2.2379	23.0000	3.1572
20.4.88	31.7000	2.4510	24.0000	3.0554
21.4.88	31.6000	3.7830	22.0000	3.0554
7.5.88	31.4500	3.4101	21.0000	4.0738
8.5.88	31.6000	3.1437	24.0000	3.0554
9.5.88	31.7000	2.1313	24.0000	3.0554
10.5.88	31.2000	2.3444	16.0000	2.1133
11.5.88	31.3500	2.0780	21.0000	2.5461
12.5.88	31.1500	2.0247	17.0000	2.5461

Lysimeter No. : ly5
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
27.3.88	30.0000	3.1708	13.9999	2.0369
28.3.88	30.2500	4.6441	17.0000	2.6989
29.3.88	30.3000	5.2312	18.0000	3.3100
13.4.88	29.9500	1.7615	19.0000	3.0554
14.4.88	29.9500	2.4555	15.0000	2.5461
15.4.88	30.1000	3.6298	16.0000	3.0554
16.4.88	30.0500	2.5622	17.0000	2.8008
17.4.88	30.1500	2.6690	17.0000	2.5461
18.4.88	30.1500	1.6548	17.0000	2.5461
19.4.88	30.1500	1.7082	17.0000	2.5461
20.4.88	30.2500	2.7758	17.0000	2.8008
21.4.88	30.3000	2.9893	16.0000	2.5461
7.5.88	29.7000	2.5089	14.0000	3.3100
8.5.88	29.7500	3.1494	17.0000	2.8008
9.5.88	29.7500	1.7615	17.0000	2.8008
10.5.88	29.3000	2.2953	10.0000	1.6550
11.5.88	29.6000	1.5480	13.9999	2.0624
12.5.88	29.2500	1.6014	7.0000	2.5461

Lysimeter No. : ly9
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
27.3.88	30.7000	4.0421	20.0000	2.0369
28.3.88	31.0000	4.0421	23.9999	2.9026
29.3.88	31.1500	5.3185	29.0000	3.3100
13.4.88	30.6500	2.8720	23.0000	3.0554
14.4.88	30.7500	2.3933	21.0001	3.8192
15.4.88	30.8000	4.1484	26.0000	3.5646
16.4.88	30.9000	2.6061	24.0000	3.3100
17.4.88	30.7000	2.1806	28.0000	3.0554
18.4.88	30.5000	1.5956	20.0000	2.1642
19.4.88	30.7500	2.3401	25.0000	2.2406
20.4.88	30.8000	2.4465	22.0000	2.8008
21.4.88	30.8500	3.6166	23.0000	2.8008
7.5.88	30.8500	2.8720	23.0000	4.3285
8.5.88	30.9500	3.2975	27.0000	3.0554
9.5.88	30.8500	2.0210	23.0000	2.8008
10.5.88	30.5500	2.3401	17.0000	2.1388
11.5.88	30.7500	1.7019	23.0000	2.3272
12.5.88	30.6000	2.2870	18.0000	2.5461

Lysimeter No. : ly17
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
27.3.88	32.1500	3.0591	23.0000	3.0554
28.3.88	32.3500	4.2540	27.0000	3.5646
29.3.88	32.4000	4.9710	30.0000	4.3285
13.4.88	32.4000	2.2465	26.0000	3.3100
14.4.88	32.2000	2.2943	22.0000	3.0146
15.4.88	32.3000	3.2503	30.0000	3.9211
16.4.88	32.3000	2.3899	28.0000	3.7327
17.4.88	32.3000	2.0075	26.0000	3.5137
18.4.88	32.2500	1.3861	25.0000	3.0554
19.4.88	32.4500	2.0075	25.0000	3.3100
20.4.88	32.5000	2.1031	26.0001	3.4475
21.4.88	32.3500	3.1069	23.0000	3.1318
7.5.88	30.8500	3.2025	21.0000	4.3285
8.5.88	30.9500	3.3459	23.0000	3.0554
9.5.88	31.1500	1.9119	23.0000	3.3100
10.5.88	30.7000	2.0553	14.0000	2.5461
11.5.88	30.7500	1.8641	23.0000	2.5461
12.5.88	30.6000	1.6729	16.0000	2.5461

Lysimeter No. : ly19
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
27.3.88	31.5500	3.8717	27.0000	3.0554
28.3.88	31.6500	4.3496	29.0000	3.3100
29.3.88	32.0000	5.2578	36.0001	4.3285
13.4.88	30.9500	2.3899	29.0000	5.0923
14.4.88	30.5500	3.4415	25.0000	3.7174
15.4.88	31.0500	4.7798	31.0000	3.9720
16.4.88	30.8500	1.5773	27.0000	3.2693
17.4.88	31.0000	1.9119	30.0000	3.0401
18.4.88	30.8500	1.3861	27.0000	3.0554
19.4.88	30.9000	2.3899	30.0000	3.3100
20.4.88	30.9000	3.0591	28.0000	3.6665
21.4.88	30.8500	3.4893	27.0000	3.4628
7.5.88	31.1000	3.7856	28.0000	6.6200
8.5.88	31.0500	2.8679	29.0000	3.0554
9.5.88	31.3000	2.2465	32.0000	3.5646
10.5.88	30.7000	1.7685	20.0000	2.0369
11.5.88	31.0500	1.7207	27.0000	2.5461
12.5.88	30.6000	1.6729	18.0000	2.5461

Section D3

Lysimeter No. : ly7
Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
24.3.88	2.2000	1.5773	38.0000	1.8842
25.3.88	2.3500	2.7245	39.0000	3.5646
26.3.88	1.7000	0.1912	30.0000	4.5933
27.3.88	2.5000	4.4930	44.0000	1.9605
28.3.88	2.6500	4.5886	45.0000	3.1063
29.3.88	2.8000	5.6402	48.0000	4.0738
30.3.88	2.9500	3.2981	48.9999	3.8701

Lysimeter No. : ly10
Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
24.3.88	1.9000	1.9631	34.0000	2.1388
25.3.88	1.6000	2.4419	30.0000	2.6480
26.3.88	1.7500	0.6703	31.0001	1.6550
27.3.88	2.1000	4.5008	38.0000	2.5716
28.3.88	2.6000	4.1657	44.0000	3.6919
29.3.88	2.7000	4.7881	46.0000	4.0738
30.3.88	2.6500	4.1178	51.0000	1.5379

Lysimeter No. : ly12
Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
24.3.88	1.4000	1.8674	28.0000	1.4768
25.3.88	1.8000	2.5856	28.0000	2.8517
26.3.88	1.3000	0.4788	22.0000	0.3055
27.3.88	2.0000	3.3996	36.0001	1.6295
28.3.88	2.3500	3.9741	43.0000	3.2336
29.3.88	2.3500	6.5118	43.0000	3.6665
30.3.88	2.6500	2.2504	47.0000	1.1814

Lysimeter No. : ly7
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	31.1000	1.7685	32.0000	1.5888
13.4.88	31.1000	2.2465	32.0000	2.3017
14.4.88	31.0500	3.1547	27.0000	1.0032
15.4.88	31.4000	4.7798	32.0000	2.9077
16.4.88	31.2500	1.7207	29.0000	2.5207
17.4.88	31.2500	2.6767	35.0000	2.6735
18.4.88	31.1000	1.8163	32.0000	1.6805
19.4.88	31.3000	2.0075	32.0000	2.0115
20.4.88	31.2000	2.0075	28.0000	1.8842
21.4.88	30.8000	2.9635	22.0000	2.6480

Lysimeter No. : ly10
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	30.7000	1.3407	20.0000	2.0216
13.4.88	30.7000	2.0110	16.0000	2.2304
14.4.88	30.5500	2.9686	17.0000	1.5939
15.4.88	30.7500	3.4474	18.9999	2.2915
16.4.88	30.6000	1.9631	18.0000	2.1999
17.4.88	30.6000	2.0110	22.0000	2.6989
18.4.88	30.5000	1.1013	20.0000	1.7925
19.4.88	30.6500	2.2504	21.0000	2.0878
20.4.88	30.6000	2.0110	18.0000	1.8434
21.4.88	30.7000	2.9208	16.0000	2.1133

Lysimeter No. : ly12
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	27.9000	1.6280	22.0000	1.2833
13.4.88	28.2500	2.1547	23.0000	1.9605
14.4.88	28.0500	2.2025	23.0000	0.8046
15.4.88	28.2500	3.4953	27.0000	2.5461
16.4.88	28.2500	2.4419	27.0000	2.3934
17.4.88	28.4000	2.1068	28.0000	2.4443
18.4.88	28.2500	1.2928	27.0000	1.6295
19.4.88	28.4500	2.0589	27.0000	1.6805
20.4.88	28.4000	2.3941	28.0000	1.5022
21.4.88	28.3000	3.3517	26.0000	2.4952

Lysimeter No. : ly7
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	60.4000	3.1069	16.0000	0.2241
8.5.88	60.6500	2.9635	19.0000	1.8689
9.5.88	60.7000	1.5773	22.0000	1.6092
10.5.88	60.3500	2.2943	13.0000	1.0337
11.5.88	60.3000	1.6251	14.0000	0.9013
12.5.88	60.2500	1.6729	13.0000	1.6143
13.5.88	60.2000	1.3861	14.0000	0.1782
14.5.88	60.2500	2.1509	13.0000	-0.4430
19.5.88	60.2000	1.6251	12.0000	-0.3157
20.5.88	60.2500	2.7723	17.0000	0.0102
27.5.88	60.6500	3.0591	17.0000	1.2782
28.5.88	60.7000	3.3459	18.0000	1.1458
29.5.88	60.6000	4.1584	20.0000	2.6225
30.5.88	60.3500	1.2428	17.0000	1.9249
31.5.88	60.3000	1.1472	12.0000	0.0000

Lysimeter No. : ly10
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	60.0000	2.7292	18.0000	0.5449
8.5.88	60.2000	3.0644	22.0000	1.2985
9.5.88	60.7000	1.5801	30.0000	1.7568
10.5.88	60.2000	1.9152	16.0000	1.2018
11.5.88	60.4000	1.4364	24.0000	2.5461
12.5.88	60.1000	1.4843	20.0000	1.1560
13.5.88	60.1000	1.2449	18.0000	0.9828
14.5.88	59.6000	2.2504	10.0000	0.6620
19.5.88	60.3000	1.2928	24.0000	1.2527
20.5.88	60.0000	2.4898	20.0000	0.9777
27.5.88	60.6500	2.9208	29.0000	1.8638
28.5.88	60.6000	3.2080	28.0000	1.8485
29.5.88	60.3500	3.6390	25.0000	1.4768
30.5.88	60.7000	1.3407	34.0000	1.9860
31.5.88	60.6500	1.1013	29.0000	1.5532

Lysimeter No. : ly12
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	60.2000	3.1602	14.0000	0.8759
8.5.88	60.3000	3.0165	16.0000	1.9147
9.5.88	60.4000	1.3407	18.0000	1.8740
10.5.88	60.1000	1.7237	10.0000	1.2833
11.5.88	60.2000	1.4843	16.0000	1.6194
12.5.88	59.9500	1.8195	11.0000	1.1560
13.5.88	59.9500	1.1491	11.0000	0.8148
14.5.88	59.8500	2.0110	13.0000	0.3055
19.5.88	59.7500	1.6280	9.0000	3.8498
20.5.88	59.8500	2.3941	13.0000	0.6009
27.5.88	60.2500	2.5856	17.0000	2.0115
28.5.88	60.3000	3.0644	18.0000	1.8943
29.5.88	60.4000	3.2080	16.0000	2.4341
30.5.88	60.1500	1.1491	15.0000	2.1897
31.5.88	59.9500	0.8619	11.0000	0.3463

Section D4

Lysimeter No. : ly2

Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
25.3.88	3.1000	2.2582	34.0000	2.6480
26.3.88	2.6000	0.9129	28.0000	1.6805
27.3.88	3.1500	5.4294	43.0000	2.8262
28.3.88	3.7500	4.4204	48.9999	3.6919
29.3.88	4.0500	4.9009	53.0000	4.0738
30.3.88	3.9000	3.3633	48.0000	3.9720

Lysimeter No. : ly8
Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
25.3.88	2.7000	2.6108	42.0000	2.7600
26.3.88	2.4000	0.5861	28.0000	1.2476
27.3.88	2.7000	5.3282	34.0000	2.4188
28.3.88	3.1500	4.7954	51.0000	3.6919
29.3.88	3.3500	5.0085	57.0000	4.0993
30.3.88	3.7500	3.3035	51.0001	3.9720

Lysimeter No. : ly18
Water Table : 0 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
25.3.88	2.2500	2.0856	51.0001	6.1108
26.3.88	1.8000	1.3904	44.0000	3.8447
27.3.88	2.2500	5.7756	45.0000	4.6340
28.3.88	2.0500	5.3478	45.0000	3.9720
29.3.88	2.3000	6.2034	50.0000	4.7358
30.3.88	2.1500	2.9413	47.0000	4.5474

Lysimeter No. : ly2
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	28.1500	1.9219	13.0000	1.6703
13.4.88	28.1000	2.8348	12.0000	2.3526
14.4.88	28.2000	2.4024	14.0000	1.3851
15.4.88	28.2000	3.3153	10.0000	2.1897
16.4.88	28.3000	2.5465	16.0000	2.1897
17.4.88	28.4500	2.0180	13.0000	2.0878
18.4.88	28.2500	1.9219	13.0000	1.5532
19.4.88	28.3500	1.9700	13.0000	1.6295
20.4.88	28.4000	2.2102	14.0000	1.5684
21.4.88	28.4000	3.1231	12.0000	2.2915

Lysimeter No. : ly8
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	31.4000	2.3977	26.0000	1.6499
13.4.88	31.4000	2.8240	24.0000	2.2915
14.4.88	31.3500	2.9838	23.0000	1.3240
15.4.88	31.6000	3.7298	26.0000	2.7600
16.4.88	31.4500	2.3977	25.0000	2.4341
17.4.88	31.6500	2.4510	29.0000	2.4698
18.4.88	31.4000	1.9182	22.0000	1.7518
19.4.88	31.5500	2.5043	27.0000	1.9605
20.4.88	31.6000	2.8240	28.0000	1.6143
21.4.88	31.6500	3.6232	23.0000	2.5716

Lysimeter No. : ly18
Water Table : 30 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
12.4.88	27.6500	2.4600	21.0000	1.8943
13.4.88	27.7500	2.5669	21.0001	2.9535
14.4.88	27.6000	3.2087	20.0000	1.6703
15.4.88	27.8000	4.1178	26.0000	3.1063
16.4.88	27.8000	3.0482	24.0000	2.9535
17.4.88	27.7500	2.7809	23.0000	2.5971
18.4.88	27.7500	1.5509	17.0000	1.7823
19.4.88	27.8000	2.4600	22.0000	2.3934
20.4.88	27.8000	3.3156	20.0000	2.3934
21.4.88	27.8000	3.3156	20.0000	2.3170

Lysimeter No. : ly2
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	60.5500	3.3633	11.0000	0.4532
8.5.88	60.7000	2.8348	12.0000	1.1560
9.5.88	60.8000	2.0180	16.0000	1.2833
11.5.88	60.6000	2.1141	12.0000	1.0337
12.5.88	60.5000	1.8739	10.0000	0.9828
13.5.88	60.5000	1.2973	8.0000	0.4074
14.5.88	60.4500	2.1621	11.0000	0.0917
15.5.88	60.5000	3.2672	12.0000	1.4258
19.5.88	60.3500	1.2492	9.0000	-0.2954
20.5.88	60.5000	2.7868	10.0000	-0.1528
27.5.88	60.6500	2.9309	11.0000	1.2833
28.5.88	60.9000	3.6516	14.0000	1.3138
29.5.88	60.9000	3.4114	12.0000	1.7823
30.5.88	60.6000	1.6336	12.0000	1.4768
31.5.88	60.6500	1.0571	9.0000	0.4583

Lysimeter No. : ly8
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	61.1500	3.4101	17.0000	1.0490
8.5.88	61.3000	3.1969	22.0000	2.0675
9.5.88	61.5000	1.5452	24.0000	2.2050
11.5.88	61.2000	2.0247	20.0000	1.1050
12.5.88	61.0000	1.8649	16.0000	1.8434
13.5.88	60.8000	1.5985	13.9999	1.8434
14.5.88	60.8500	1.5985	13.0000	0.6926
14.5.88	60.9000	2.2911	14.0000	0.4583
15.5.88	61.1000	3.5166	22.0000	2.4137
19.5.88	60.9500	1.7050	13.0000	0.7129
20.5.88	60.9500	3.1437	15.0000	0.6009
27.5.88	61.3000	2.5043	20.0000	2.3323
28.5.88	61.3000	3.7830	20.0000	2.0013
29.5.88	61.3000	3.5166	20.0000	2.7244
30.5.88	61.2000	1.5985	20.0000	2.6225
31.5.88	61.1000	1.1722	16.0000	0.9675

Lysimeter No. : ly18
Water Table : 60 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
7.5.88	59.7000	3.5295	20.0000	1.1865
8.5.88	59.7500	4.2782	21.0000	1.6652
9.5.88	60.0500	1.8717	23.0000	2.1031
11.5.88	59.5000	1.5509	14.0000	1.3342
12.5.88	59.9000	2.0322	20.0000	1.3036
13.5.88	59.6500	1.4974	17.0000	1.3749
14.5.88	59.2500	2.4065	7.0000	0.9013
15.5.88	59.5000	3.7435	14.0000	1.3342
19.5.88	59.9500	1.8182	19.0000	1.8587
20.5.88	59.6000	3.2622	10.0000	0.6875
27.5.88	59.9000	3.3691	20.0000	1.6703
28.5.88	60.0500	4.4387	21.0000	1.5532
29.5.88	59.8500	4.0643	17.0000	2.0471
30.5.88	59.8000	2.0856	16.0000	2.0115
31.5.88	59.8500	1.0161	17.0000	0.7129

Lysimeter No. : ly2
Water Table : 90 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
10.6.88	72.1500	2.5946	7.0000	0.2954
11.6.88	72.2000	2.6907	8.0000	0.4227
12.6.88	72.2000	2.9790	8.0000	0.3565
13.6.88	72.2500	3.1231	7.0000	0.4074
14.6.88	72.2000	3.0751	6.0000	0.1935
15.6.88	72.3000	3.0270	8.0000	1.0694
16.6.88	72.4000	0.9610	12.0000	0.7027
17.6.88	72.2000	2.6907	8.0000	0.4583
18.6.88	72.2000	2.5946	8.0000	0.4990
19.6.88	72.1000	2.4024	8.0000	0.3055
20.6.88	72.1500	2.9790	9.0000	0.6620
27.6.88	72.2500	2.1621	9.0000	0.5602
28.6.88	72.0000	3.0270	10.0000	0.7638
29.6.88	72.3000	0.4324	10.0000	0.9166
30.6.88	72.0500	1.6336	5.0000	0.3819
1.7.88	72.1000	1.6336	6.0000	0.3565
2.7.88	72.1500	1.8739	7.0000	0.5602
3.7.88	72.0500	2.0180	5.0000	0.5092
4.7.88	72.0500	1.1531	5.0000	0.8657
5.7.88	72.0500	0.7207	5.0000	0.2546
8.7.88	72.1000	2.4985	6.0000	0.2139
9.7.88	72.1500	2.3063	7.0000	0.6111
10.7.88	72.1500	2.0180	7.0000	0.9166
11.7.88	72.1000	0.8649	8.0000	0.7537
12.7.88	72.0500	1.6817	5.0000	0.1528
13.7.88	72.0500	2.1141	5.0000	0.1630
14.7.88	72.1500	3.1231	7.0000	0.1884

Lysimeter No. : ly8
Water Table : 90 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
10.6.88	70.2000	2.4510	12.0000	1.1305
11.6.88	70.2000	2.6641	12.0000	0.8657
12.6.88	70.1500	2.8240	11.0000	0.8148
13.6.88	70.3500	3.0904	13.0000	1.0083
14.6.88	70.2000	2.9305	14.0000	0.8148
15.6.88	70.2000	3.1437	14.0000	1.4513
16.6.88	70.4500	1.3853	17.0000	1.4258
17.6.88	70.3000	2.7174	12.0000	0.9675
18.6.88	70.1500	2.3444	11.0000	1.0948
19.6.88	70.1500	3.1969	11.0000	0.8402
20.6.88	70.4000	3.0371	14.0000	1.1458
27.6.88	70.4500	1.8116	19.0000	1.3749

28.6.88	70.2000	2.8772	14.0000	1.3749
29.6.88	70.5500	0.6927	15.0000	1.3902
30.6.88	70.3000	1.5985	10.0000	0.6875
1.7.88	70.2500	1.7583	9.0000	0.7740
2.7.88	70.3500	2.1846	9.0000	1.0439
3.7.88	70.2500	2.1313	9.0000	1.1356
4.7.88	70.3000	1.4386	12.0000	1.2222
5.7.88	70.3500	0.6927	11.0000	0.8148
8.7.88	70.3000	2.8240	12.0000	0.9930
9.7.88	70.3000	2.7174	10.0000	1.1101
10.7.88	70.3500	1.9182	11.0000	1.2731
11.7.88	70.6000	0.7460	14.0000	1.4157
12.7.88	70.2000	2.0780	8.0000	0.7231
13.7.88	70.2000	1.9714	8.0000	0.6314
14.7.88	70.3000	2.9838	10.0000	1.0083

Lysimeter No. : ly18
Water Table : 90 cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
10.6.88	68.6000	2.5135	10.0000	0.8148
11.6.88	68.5500	2.8878	9.0000	0.7129
12.6.88	68.4000	3.4761	10.0000	0.5500
13.6.88	68.6500	3.4761	13.0000	0.6111
14.6.88	68.7500	3.3691	15.0000	0.4481
15.6.88	68.5500	3.8504	11.0000	1.2069
16.6.88	68.7000	1.0696	14.0000	0.8402
17.6.88	68.4500	3.2622	9.0000	0.5703
18.6.88	68.2500	2.6739	5.0000	0.6365
19.6.88	68.3500	2.7809	7.0000	0.4685
20.6.88	68.5000	3.9574	12.0000	0.7638
27.6.88	68.8000	1.5509	14.0000	0.9574
28.6.88	68.3500	3.4226	7.0000	0.9879
29.6.88	68.4000	0.5348	10.0000	0.9675
30.6.88	68.3000	2.0322	6.0000	0.3310
1.7.88	68.3000	2.0322	8.0000	0.4583
2.7.88	68.5000	2.2995	10.0000	0.8046
3.7.88	68.3500	2.4065	9.0000	0.6314
4.7.88	68.3500	1.7113	9.0000	1.0592
5.7.88	68.3000	0.7487	6.0000	0.2546
8.7.88	68.4000	3.3156	8.0000	0.5092
9.7.88	68.4000	3.1017	8.0000	0.7638
10.7.88	68.4500	2.0856	11.0000	1.1203
11.7.88	68.3500	0.9626	9.0000	0.7129
12.7.88	68.1500	2.2461	5.0000	0.2444
13.7.88	68.3000	2.5669	8.0000	0.1782
14.7.88	68.4000	3.7435	10.0000	0.5602

Section D5

Lysimeter No. : ly11

Water Table : w cm

Date	Actual Water Table (cm)	Rate of Water Loss Petri Dish (mm)	Side Column (mm)	Replenish (mm)
24.3.88	0.0000	0.0000	5.0000	3.3355
25.3.88	0.0000	0.0000	5.0000	4.5576
26.3.88	0.0000	0.0000	0.0000	-2.4443
27.3.88	0.0000	0.0000	8.9999	4.8377
28.3.88	0.0000	0.0000	9.0001	5.0159
29.3.88	0.0000	0.0000	9.0001	5.2960
30.3.88	0.0000	0.0000	8.0000	5.3215
12.4.88	0.0000	0.0000	5.0000	1.6906
13.4.88	0.0000	0.0000	6.0001	-0.3463
14.4.88	0.0000	0.0000	7.0000	4.6187
15.4.88	0.0000	0.0000	8.9999	5.3978
16.4.88	0.0000	0.0000	8.0000	3.4729
17.4.88	0.0000	0.0000	8.9999	3.7683
18.4.88	0.0000	0.0000	6.0001	0.9421
19.4.88	0.0000	0.0000	8.0000	2.6633
20.4.88	0.0000	0.0000	8.9999	3.2845
21.4.88	0.0000	0.0000	10.0000	5.8561
7.5.88	0.0000	0.0000	8.9999	4.6391
8.5.88	0.0000	0.0000	8.9999	4.2775
9.5.88	0.0000	0.0000	8.0000	3.3864
10.5.88	0.0000	0.0000	5.0000	2.9433
11.5.88	0.0000	0.0000	5.9999	10.1846
12.5.88	0.0000	0.0000	5.9999	3.4220
13.5.88	0.0000	0.0000	3.9999	4.4303
14.5.88	0.0000	0.0000	3.9999	6.8237
15.5.88	0.0000	0.0000	8.9999	5.9325
16.5.88	0.0000	0.0000	5.9999	7.2158
19.5.88	0.0000	0.0000	3.9999	-0.5143
20.5.88	0.0000	0.0000	7.0000	3.5391
27.5.88	0.0000	0.0000	8.0000	3.6715
28.5.88	0.0000	0.0000	7.0000	4.1349
29.5.88	0.0000	0.0000	7.0000	6.1362
30.5.88	0.0000	0.0000	3.9999	1.7925
31.5.88	0.0000	0.0000	3.9999	0.8148
8.6.88	0.0000	0.0000	8.9999	3.5901
9.6.88	0.0000	0.0000	8.9999	4.1248
10.6.88	0.0000	0.0000	8.0000	3.5646
11.6.88	0.0000	0.0000	8.0000	3.4373
12.6.88	0.0000	0.0000	8.0000	3.6155
13.6.88	0.0000	0.0000	8.9999	3.7174
14.6.88	0.0000	0.0000	7.0000	4.0229
15.6.88	0.0000	0.0000	8.9999	6.3756
16.6.88	0.0000	0.0000	8.0000	4.1349
17.6.88	0.0000	0.0000	7.0000	3.3100
18.6.88	0.0000	0.0000	7.0000	3.9975

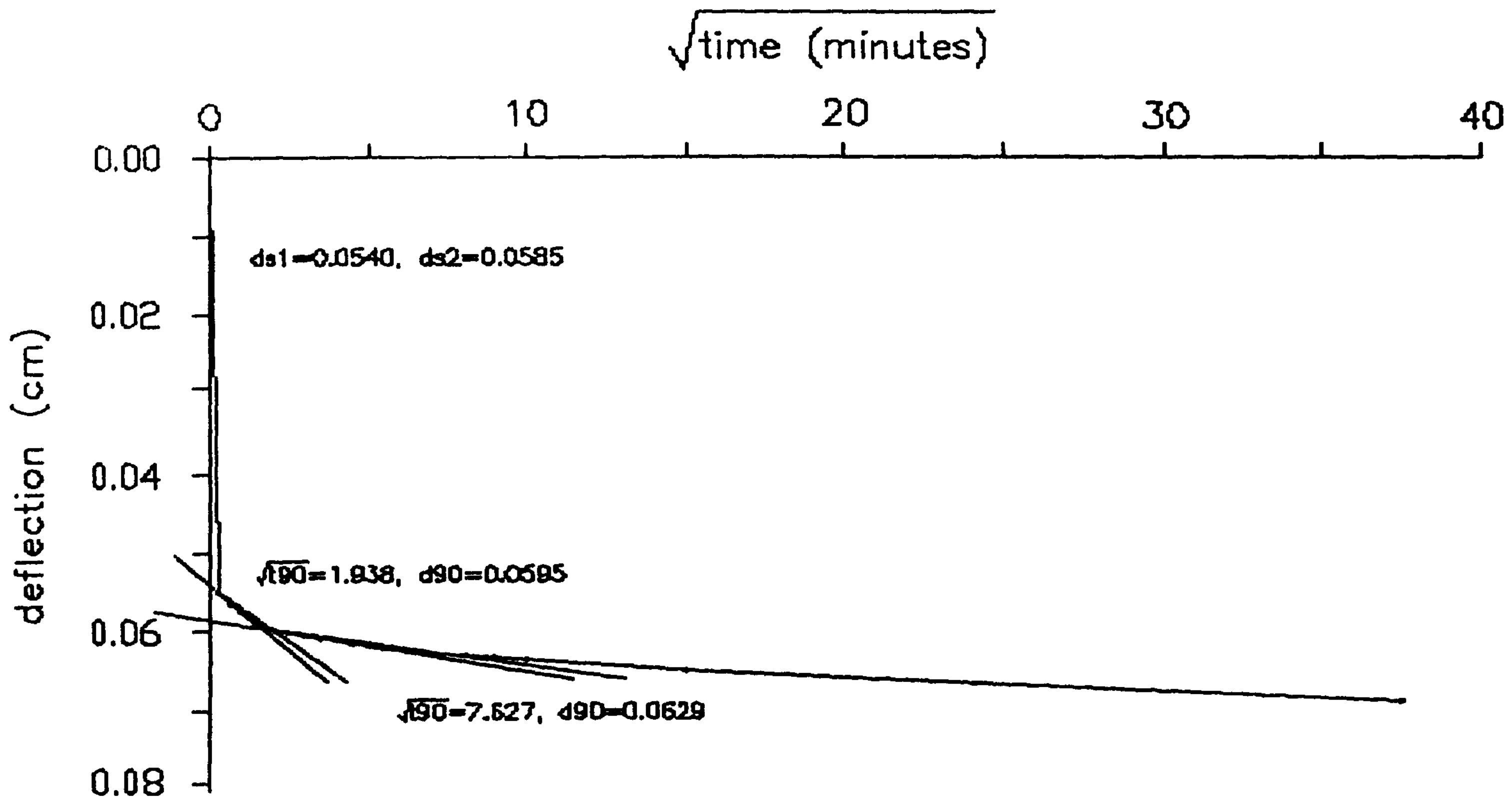
19.6.88	0.0000	0.0000	3.9999	2.4443
20.6.88	0.0000	0.0000	7.0000	3.6155
21.6.88	0.0000	0.0000	7.0000	2.9535
2.7.88	0.0000	0.0000	6.0001	2.2661
3.7.88	0.0000	0.0000	5.0000	2.2813
4.7.88	0.0000	0.0000	5.0000	3.0808
5.7.88	0.0000	0.0000	2.0000	-0.8912
6.7.88	0.0000	0.0000	6.0001	1.6499
7.7.88	0.0000	0.0000	7.0000	2.2406
8.7.88	0.0000	0.0000	7.0000	0.0000
9.7.88	0.0000	0.0000	7.0000	0.0000
10.7.88	0.0000	0.0000	6.0001	4.8122
11.7.88	0.0000	0.0000	2.0000	-0.6467
12.7.88	0.0000	0.0000	5.0000	2.3425
13.7.88	0.0000	0.0000	5.0000	1.9962
14.7.88	0.0000	0.0000	7.0000	3.3253
31.7.88	0.0000	0.0000	8.0000	4.5067
1.8.88	0.0000	0.0000	8.0000	4.2521
2.8.88	0.0000	0.0000	5.0000	1.5786
3.8.88	0.0000	0.0000	7.0000	2.9943
4.8.88	0.0000	0.0000	7.0000	4.7613
5.8.88	0.0000	0.0000	12.0000	9.3953
8.8.88	0.0000	0.0000	6.0001	0.7027
9.8.88	0.0000	0.0000	8.9999	5.1178
10.8.88	0.0000	0.0000	7.0000	3.6512
11.8.88	0.0000	0.0000	6.0001	1.5277
12.8.88	0.0000	0.0000	7.0000	1.7416
13.8.88	0.0000	0.0000	8.0000	5.6677
14.8.88	0.0000	0.0000	3.9999	5.6525
15.8.88	0.0000	0.0000	6.0001	3.3100
16.8.88	0.0000	0.0000	5.0000	1.5277
25.8.88	0.0000	0.0000	4.0001	6.9001
26.8.88	0.0000	0.0000	6.0001	2.9128
27.8.88	0.0000	0.0000	1294.9990	2.2915
28.8.88	0.0000	0.0000	6.0001	2.5971
29.8.88	0.0000	0.0000	7.0000	3.1419
30.8.88	0.0000	0.0000	12.0000	7.8014
3.9.88	0.0000	0.0000	8.0000	2.3934
4.9.88	0.0000	0.0000	8.9999	2.3425
5.9.88	0.0000	0.0000	8.9999	5.0159
6.9.88	0.0000	0.0000	8.0000	1.8078
7.9.88	0.0000	0.0000	7.0000	4.2266
8.9.88	0.0000	0.0000	6.0001	1.0286
9.9.88	0.0000	0.0000	6.0001	2.9535
10.9.88	0.0000	0.0000	7.0000	4.2775

APPENDIX E

Consolidation Tests

consol 2: ef5sepR. dwg

APPENDIX 5.2 3i

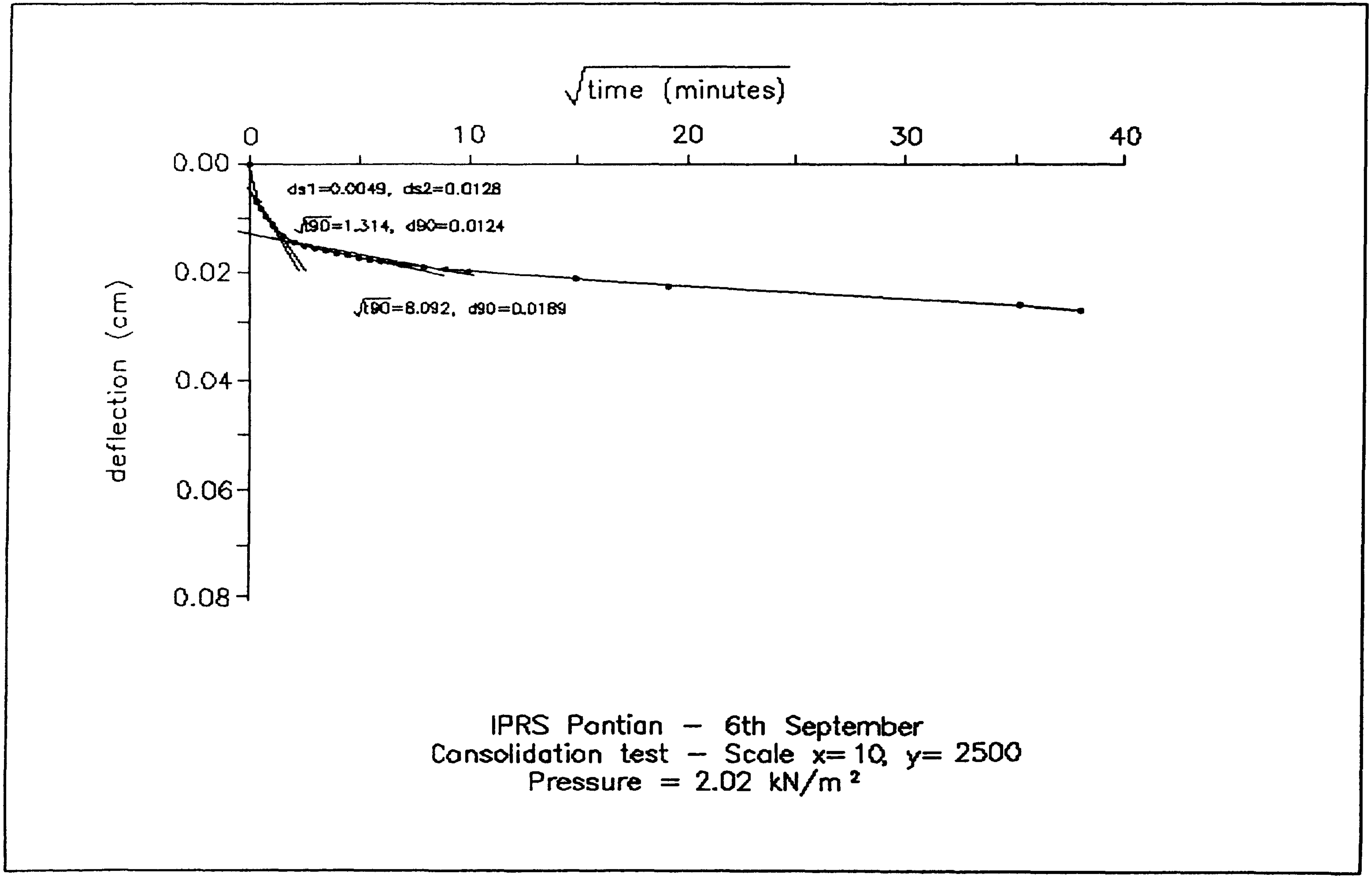


IPRS Pontian - 5th Sept 1988
Consolidation test - Scale x=10, y=2500
Pressure = 1.01 kN/m²

E1

ef6sepr.dwg

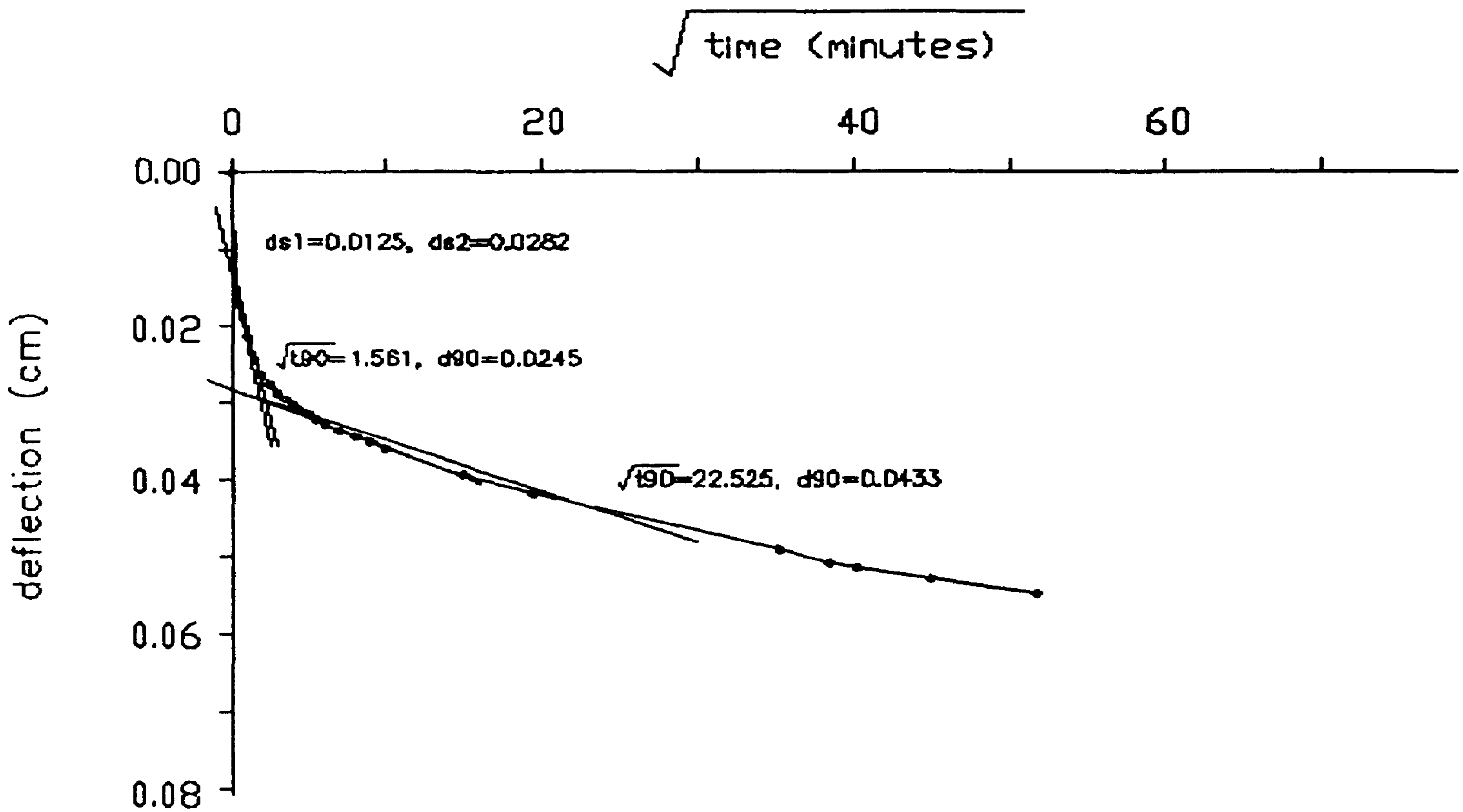
APPENDIX 5.2.3 ii



E2

ef 7 sepr.dwg

APPENDIX 5.2.3 iii

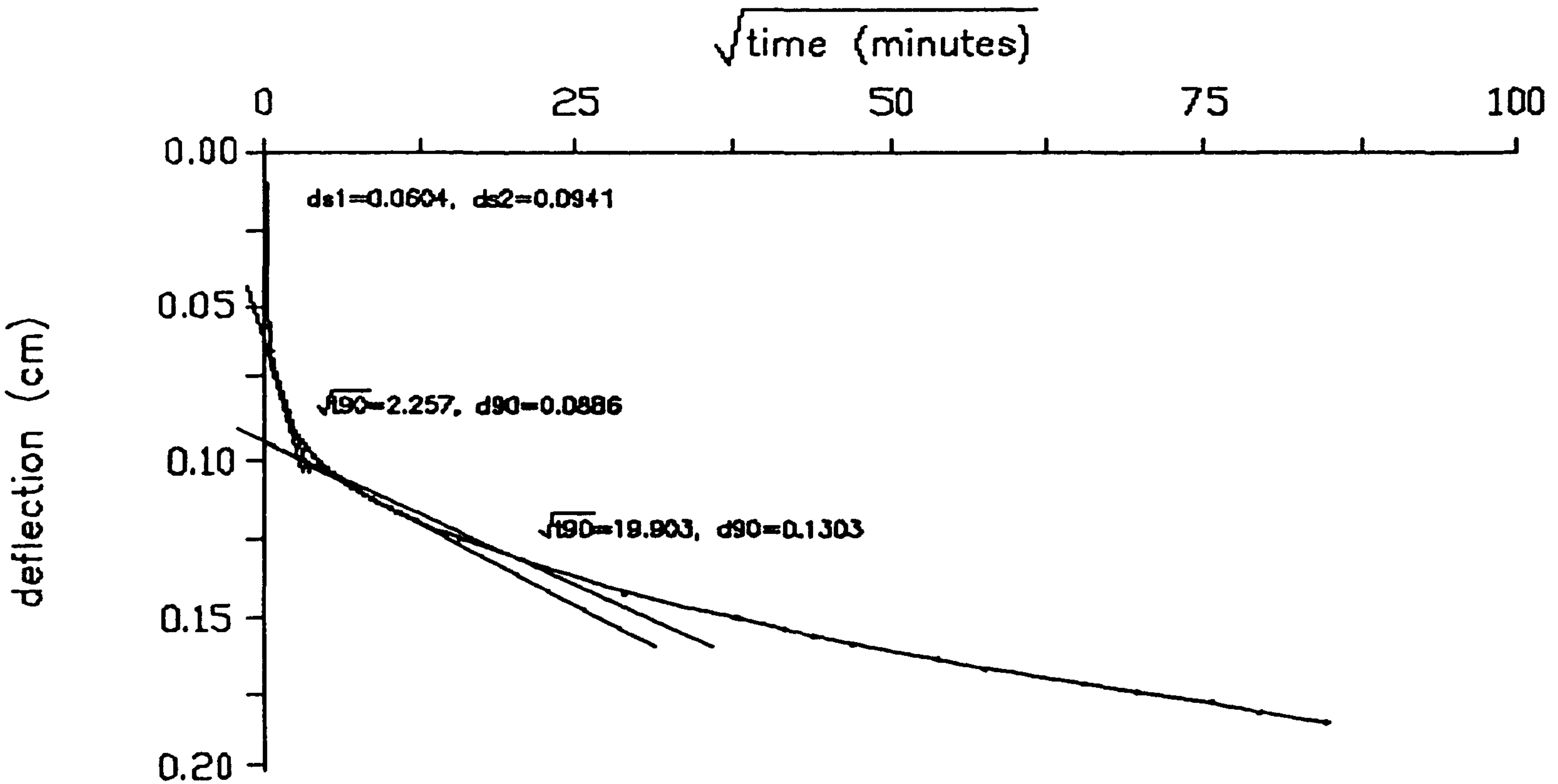


IPRS Pontian – 7th to 8th Sept 1988
Consolidation test – Scale x=5 , y=2500
Pressure = 4.01 kN/m²

E3

APPENDIX 5.2.3 iv

efgsepr.dwg

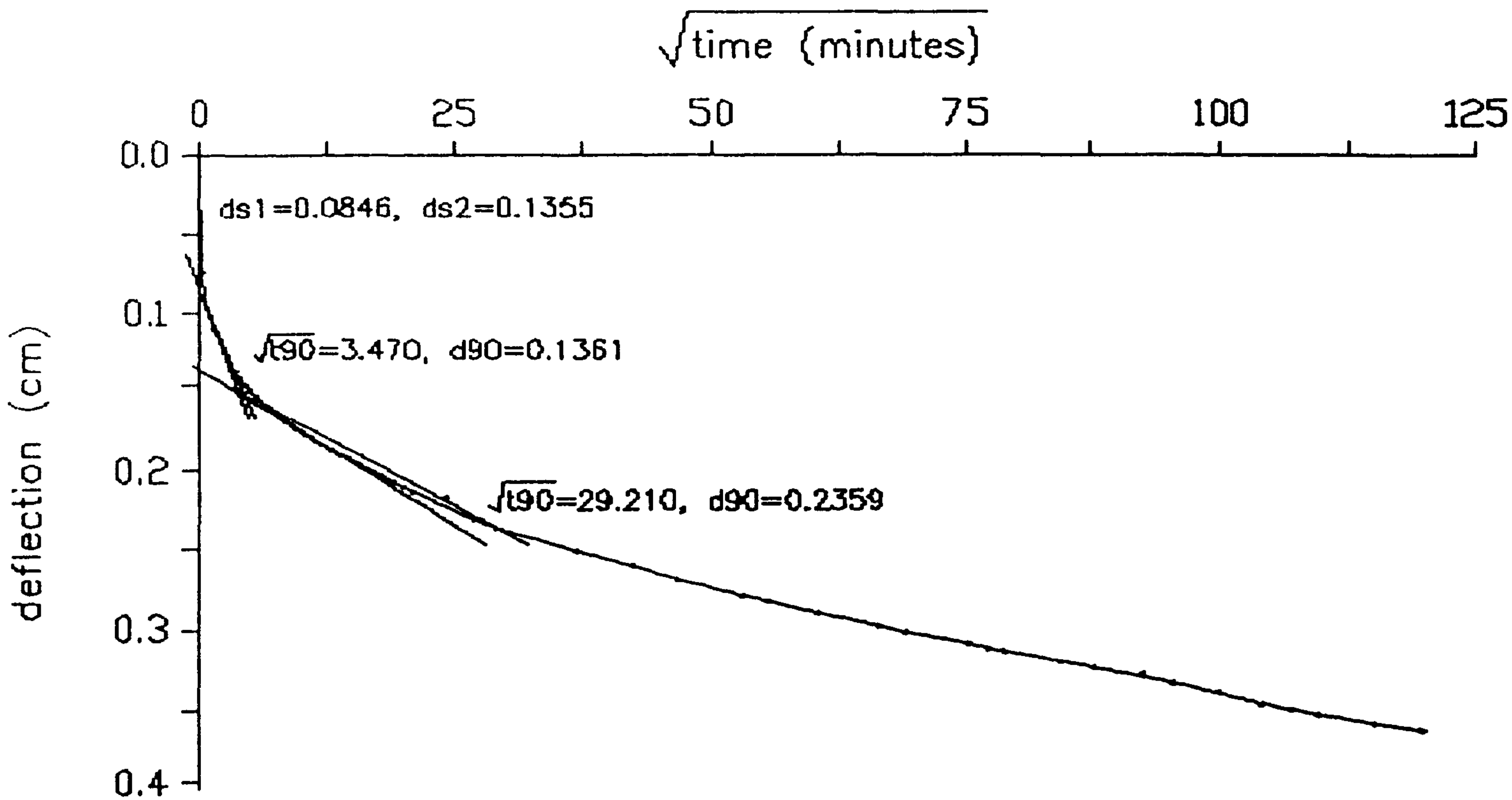


IPRS Pontian - 9th to 13th Sept 1988
Consolidation test - Scale x= 4, y=1000
Pressure = 10.002kN/m²

E4

ef14sept.dwg

APPENDIX 5.2.3V

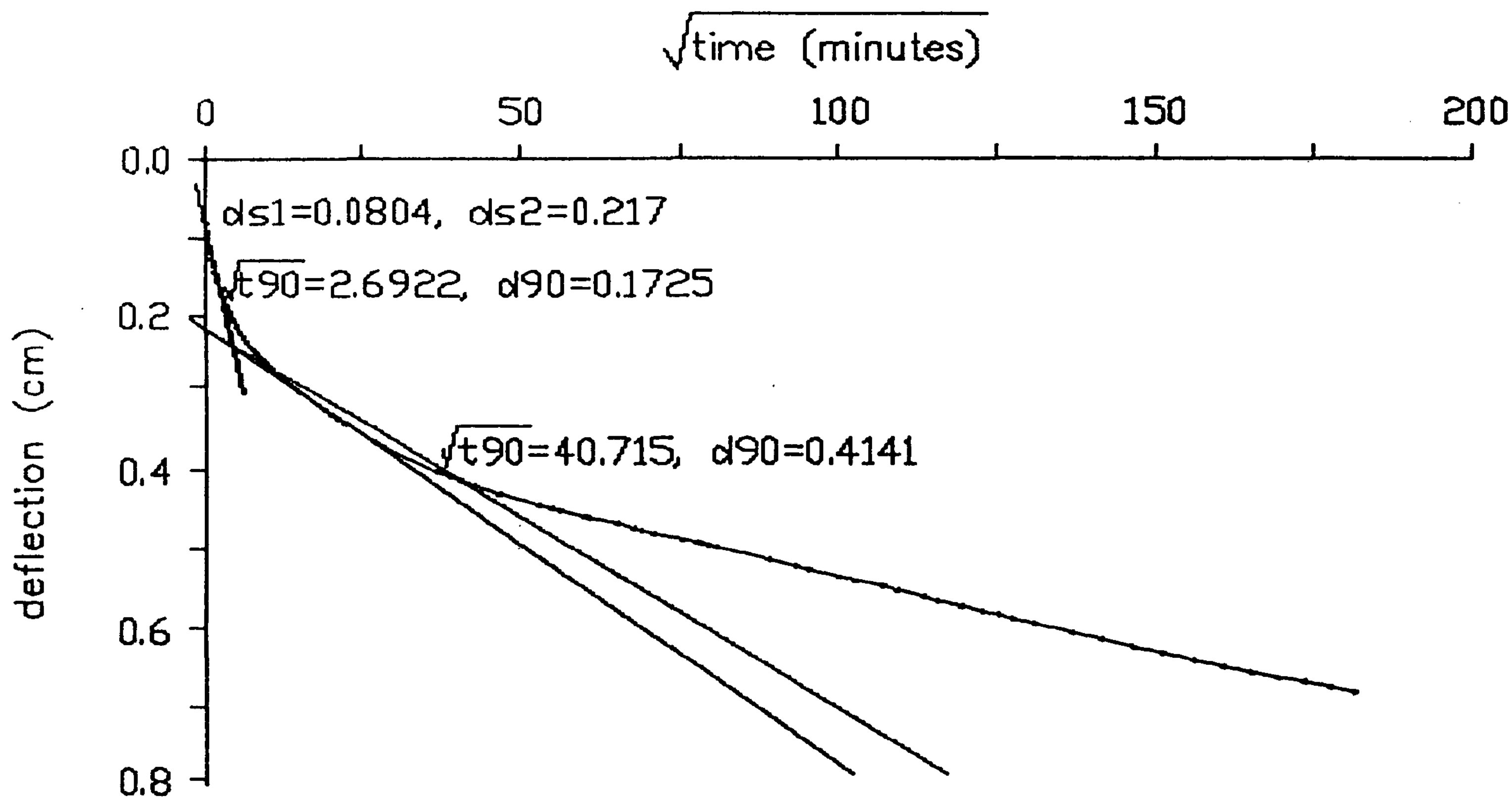


IPRS Pontian – 14th to 24th Sept 1988
Consolidation test – Scale x=3.2, y=500
Pressure =19.974kN/m²

E5

APPENDIX 5.2.3 vi

ef24sepr.dwg

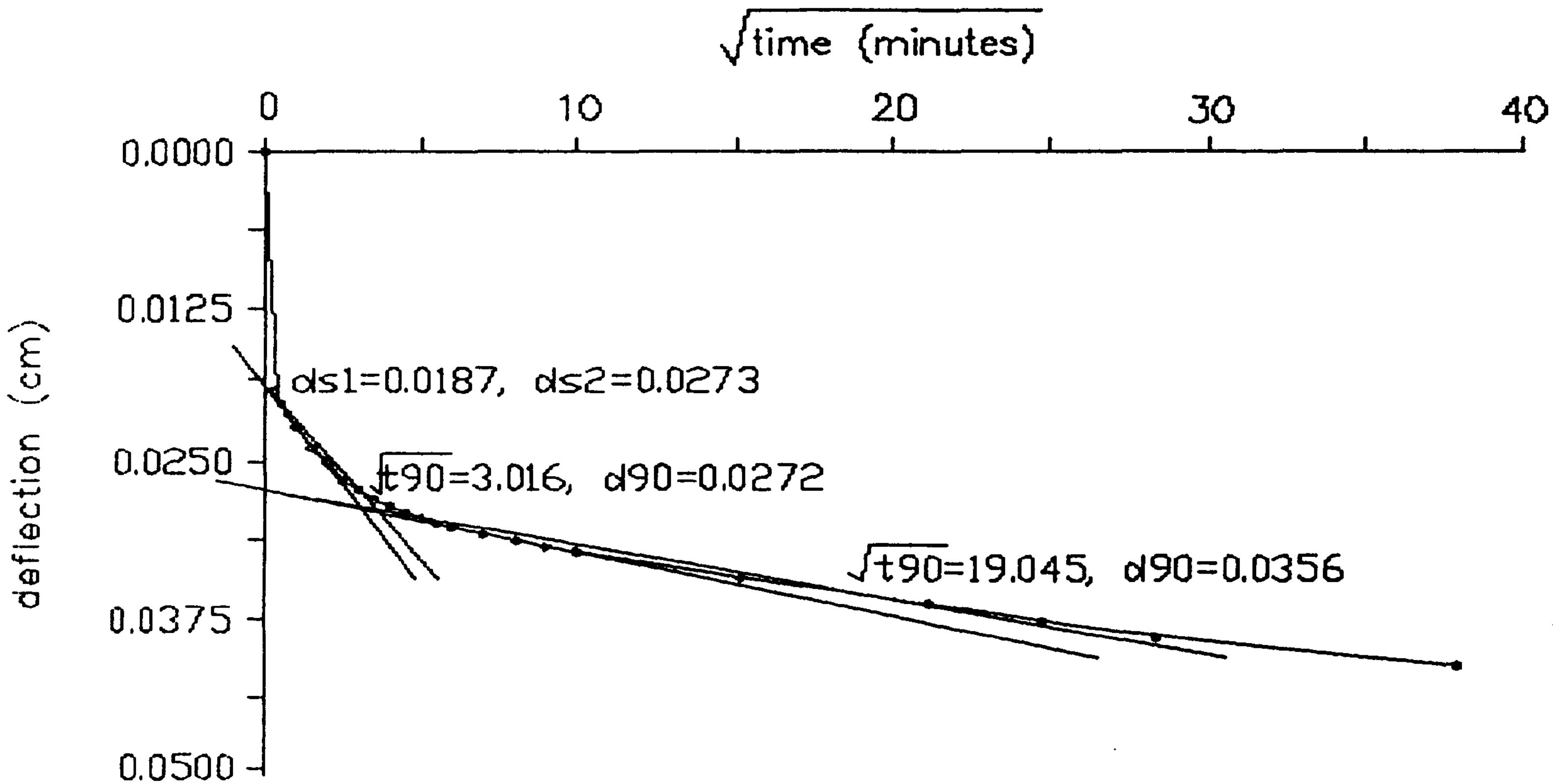


IPRS Pontian – 24th Sept to 17th Oct 1988
Consolidation test – Scale x= 2 , y= 250
Pressure =39.874kN/m²

E6

APPENDIX 5.2.3 vii

ef17octr.dwg

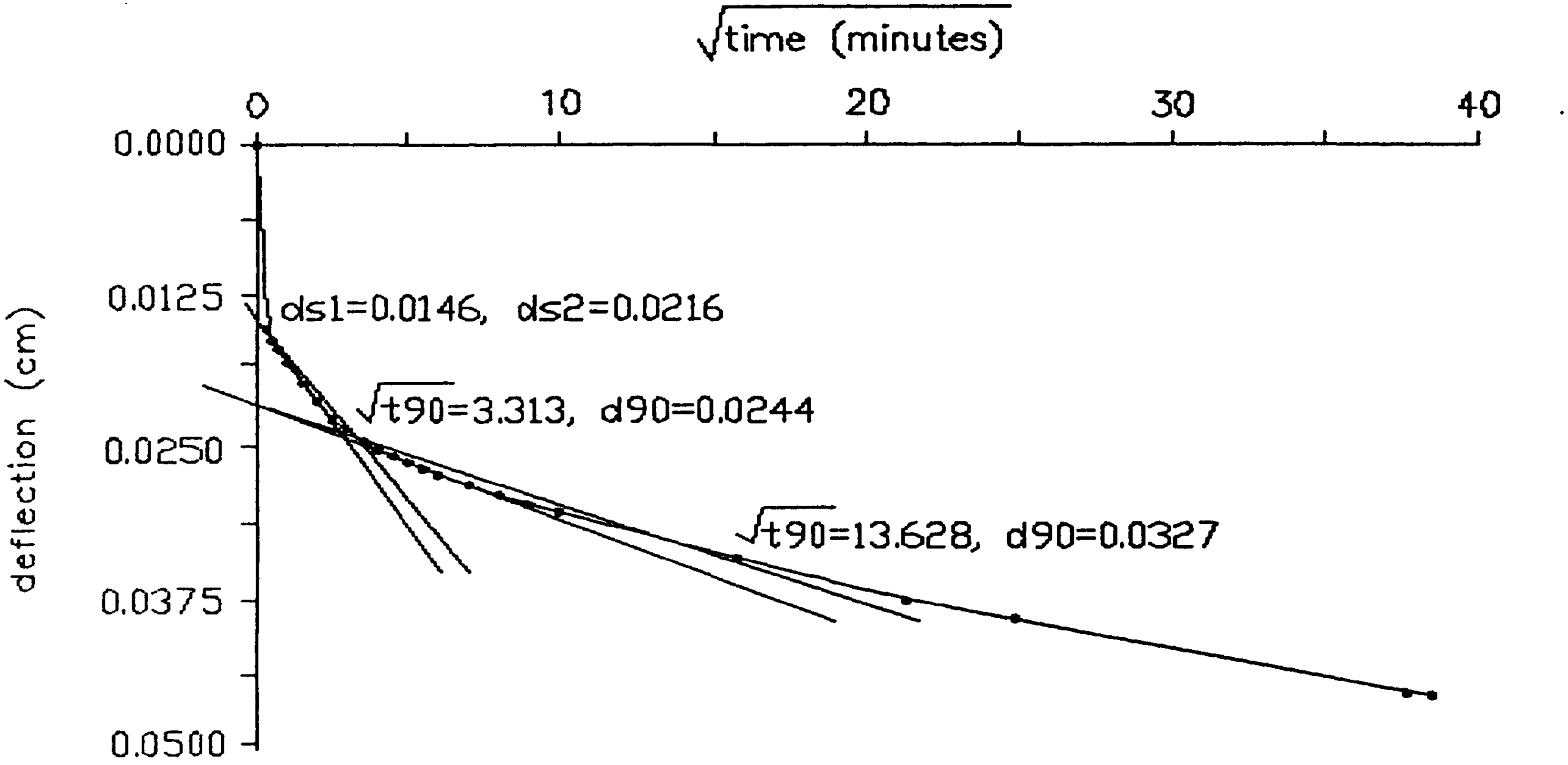


IPRS Pontian - 17th Oct 1988
Consolidation test - Scale x=10, y=4000
Pressure =19.974kN/m²

E7

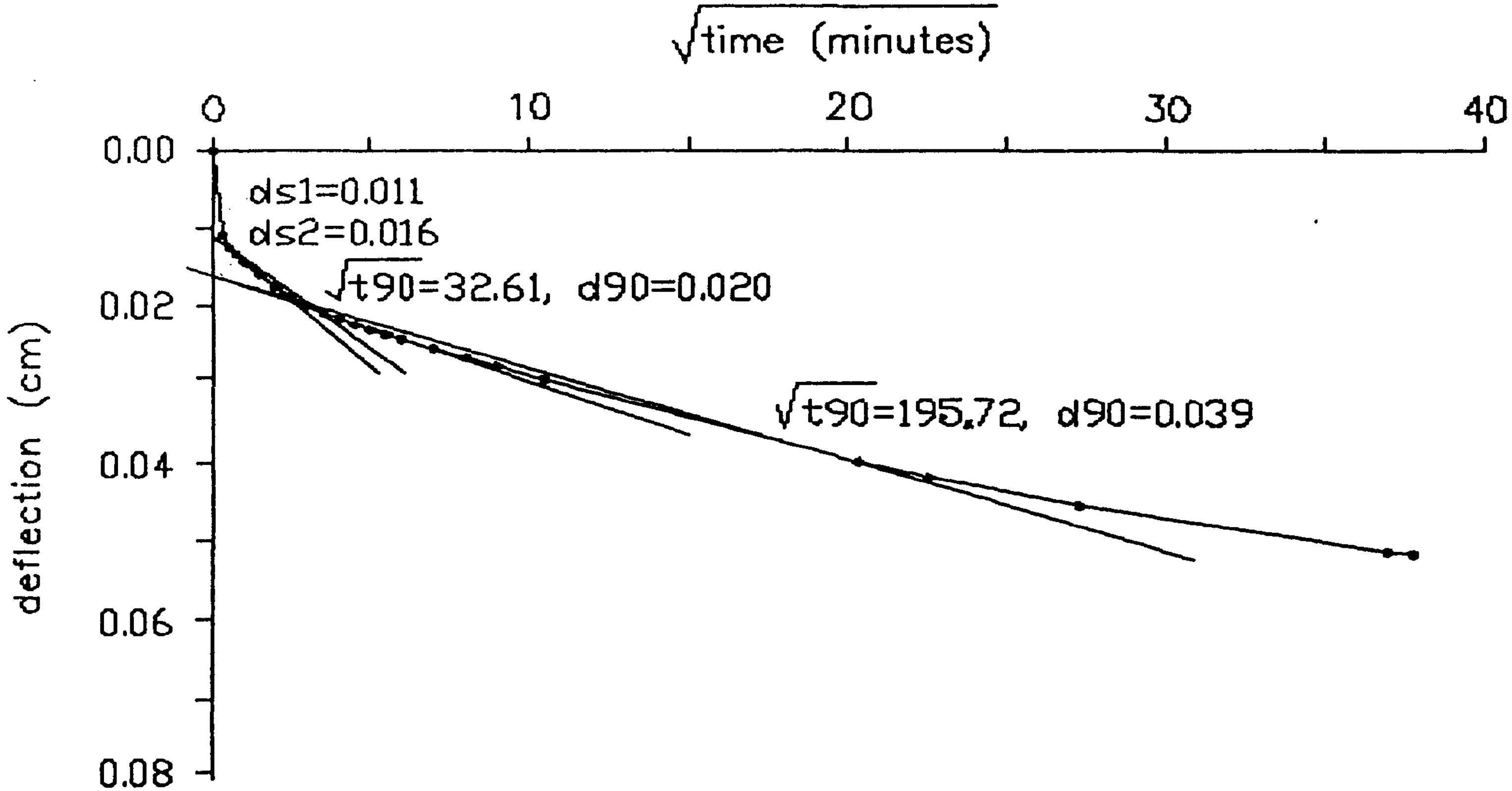
APPENDIX 5.2.3 viii

ef18OctR.dwg



IPRS Pontian - 18th Oct 1988
Consolidation test - Scale x=10 , y=4000
Pressure = 10.002 kN/m²

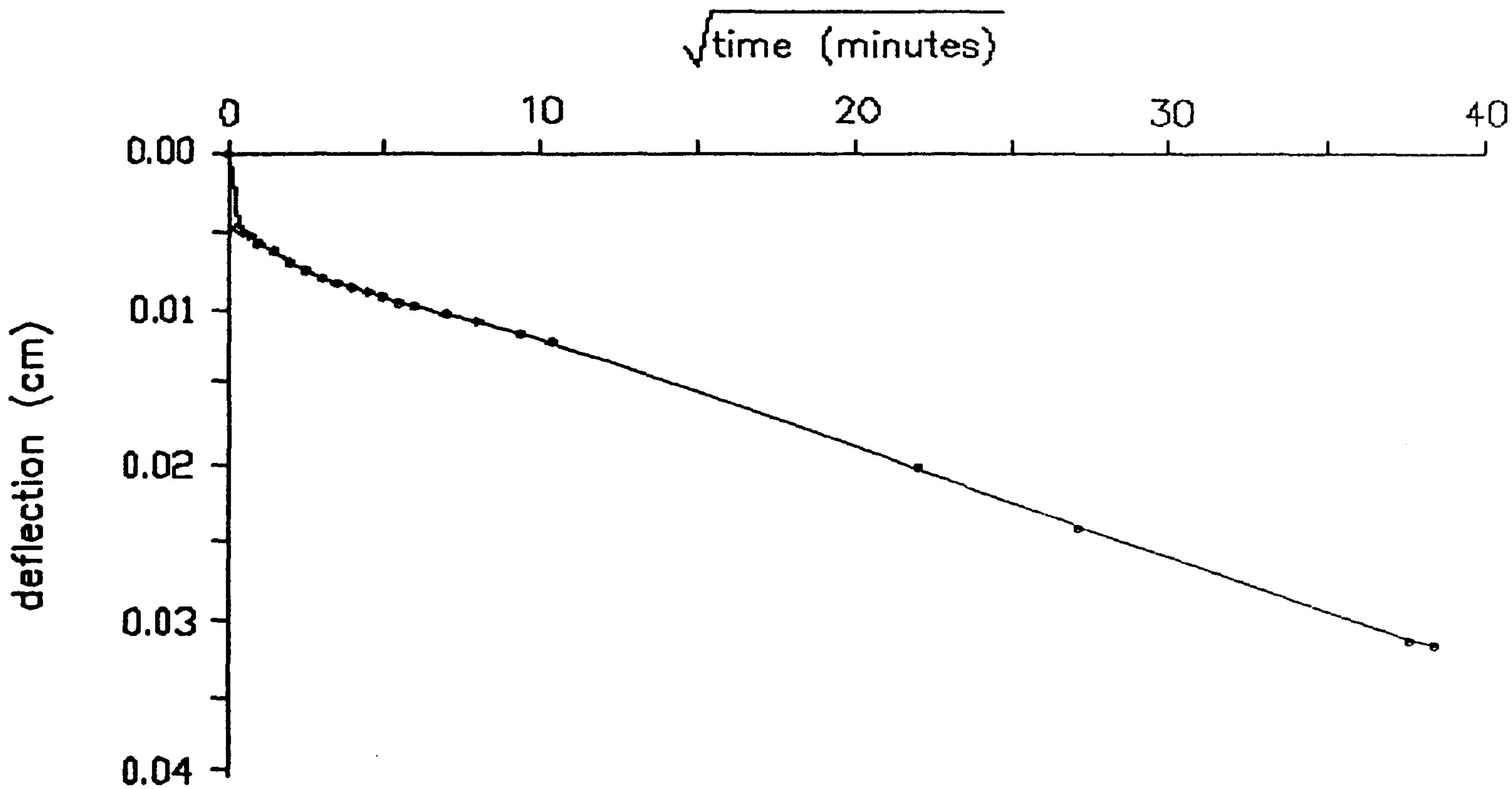
APPENDIX 5.2.3 ix ef19 Oct R.dwg



IPRS Pontian – 19th Oct 1988
Consolidation test – Scale x=10, y= 2500
Pressure = 4.01 kN/m²

APPENDIX 5.2.3X

ef 20 Oct. dwg

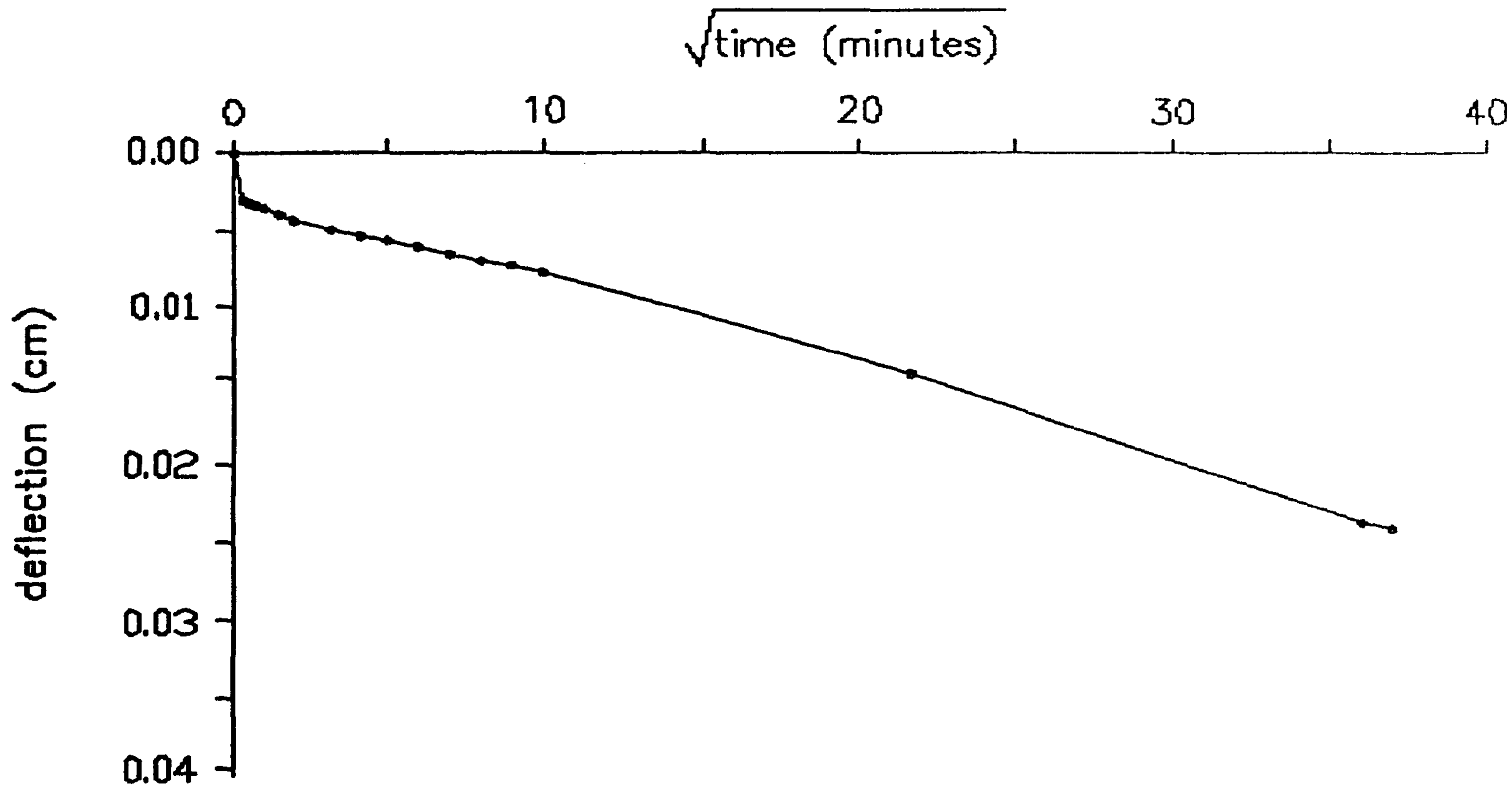


IPRS Pontian – 20th Oct 1988
Consolidation test – Scale x=10, y=5000
Pressure = 2.02 kN/m²

E10

APPENDIX 5.2 3 xi

ef21octr.dwg

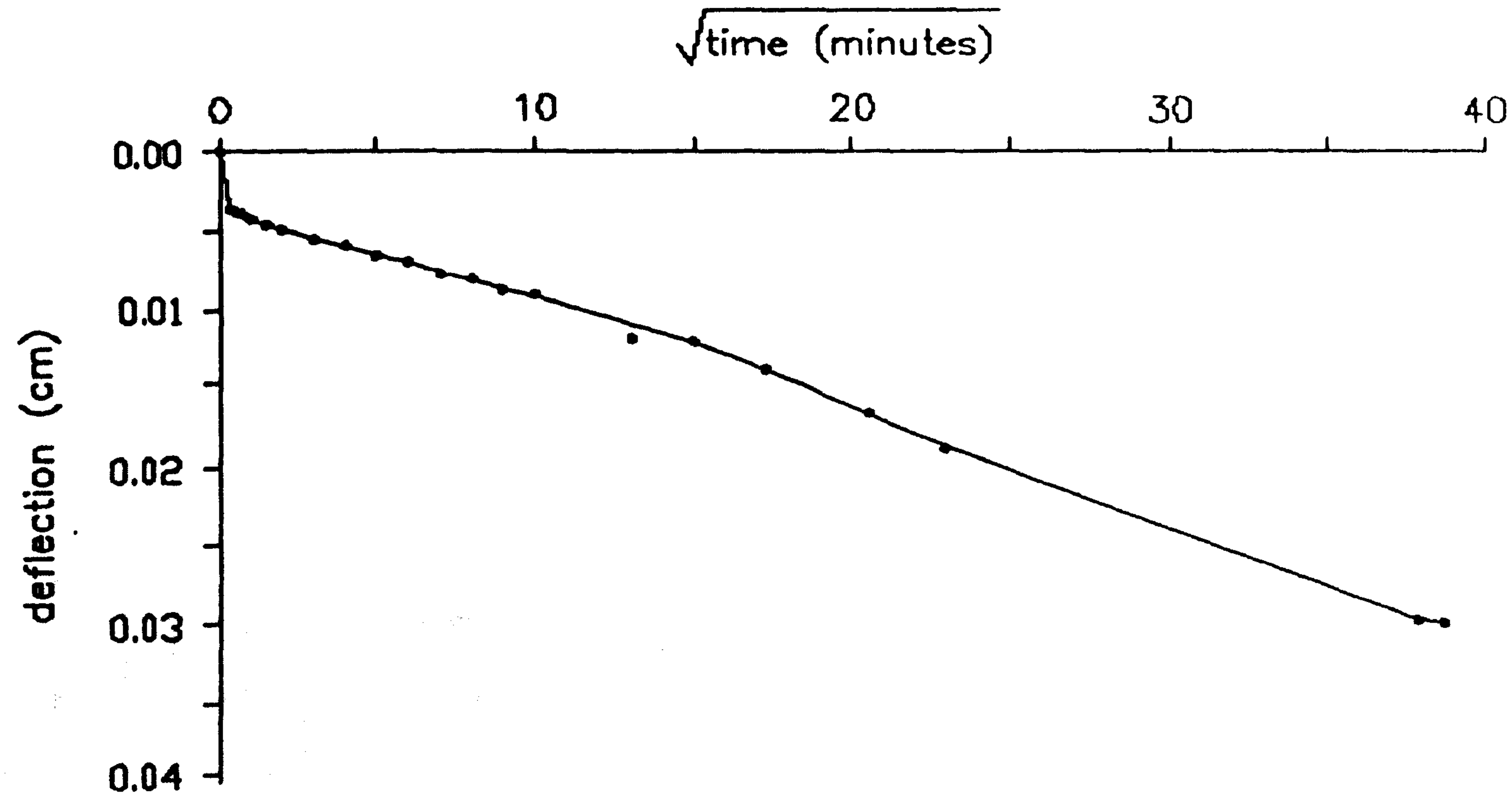


IPRS Pontian - 21st Oct 1988
Consolidation test - Scale x=10, y=5000
Pressure = 1.01 kN/m²

E11

APPENDIX 5.2.3 xii

ef22octr.dwg

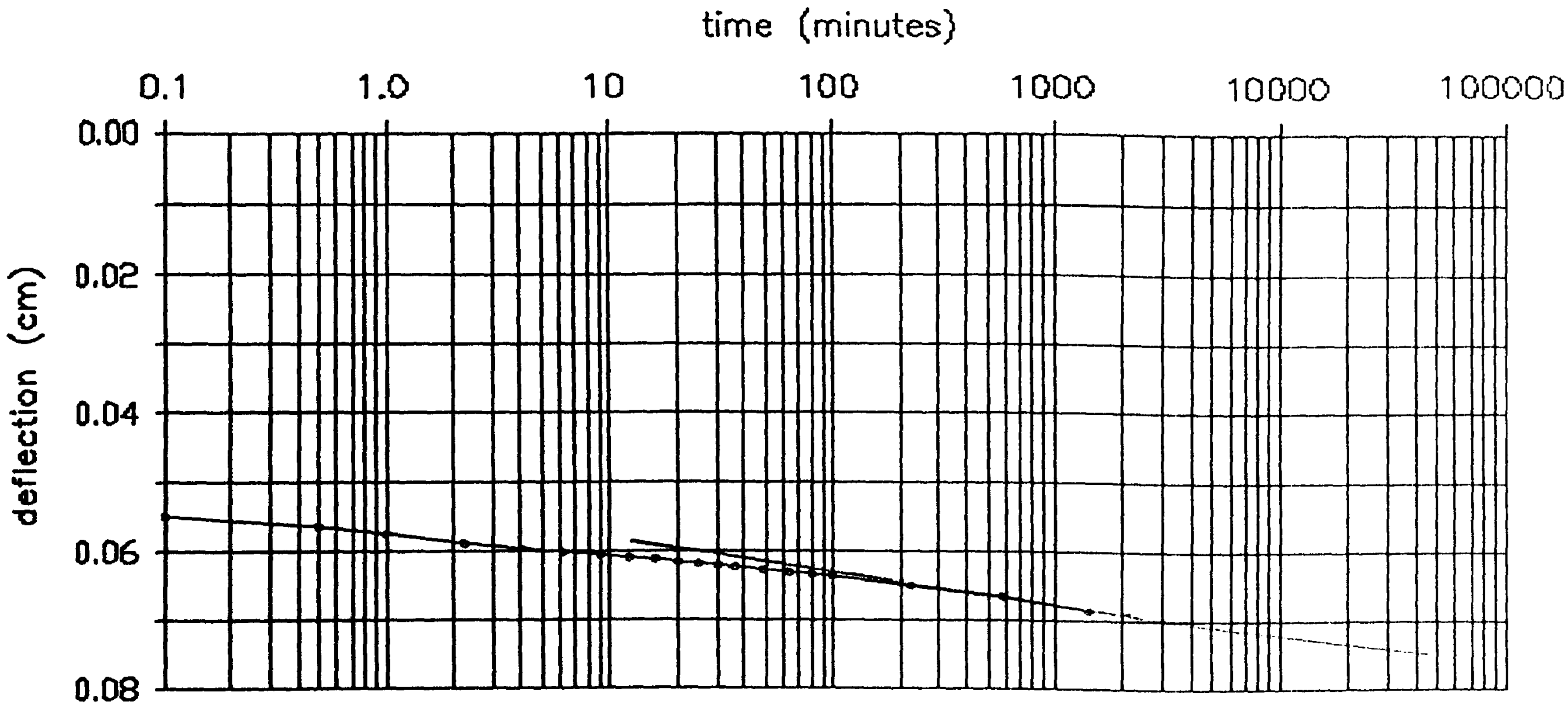


IPRS Pontian - 22nd Oct 1988
Consolidation test - Scale x=10, y= 5000
Pressure = 0 kN/m²

E12

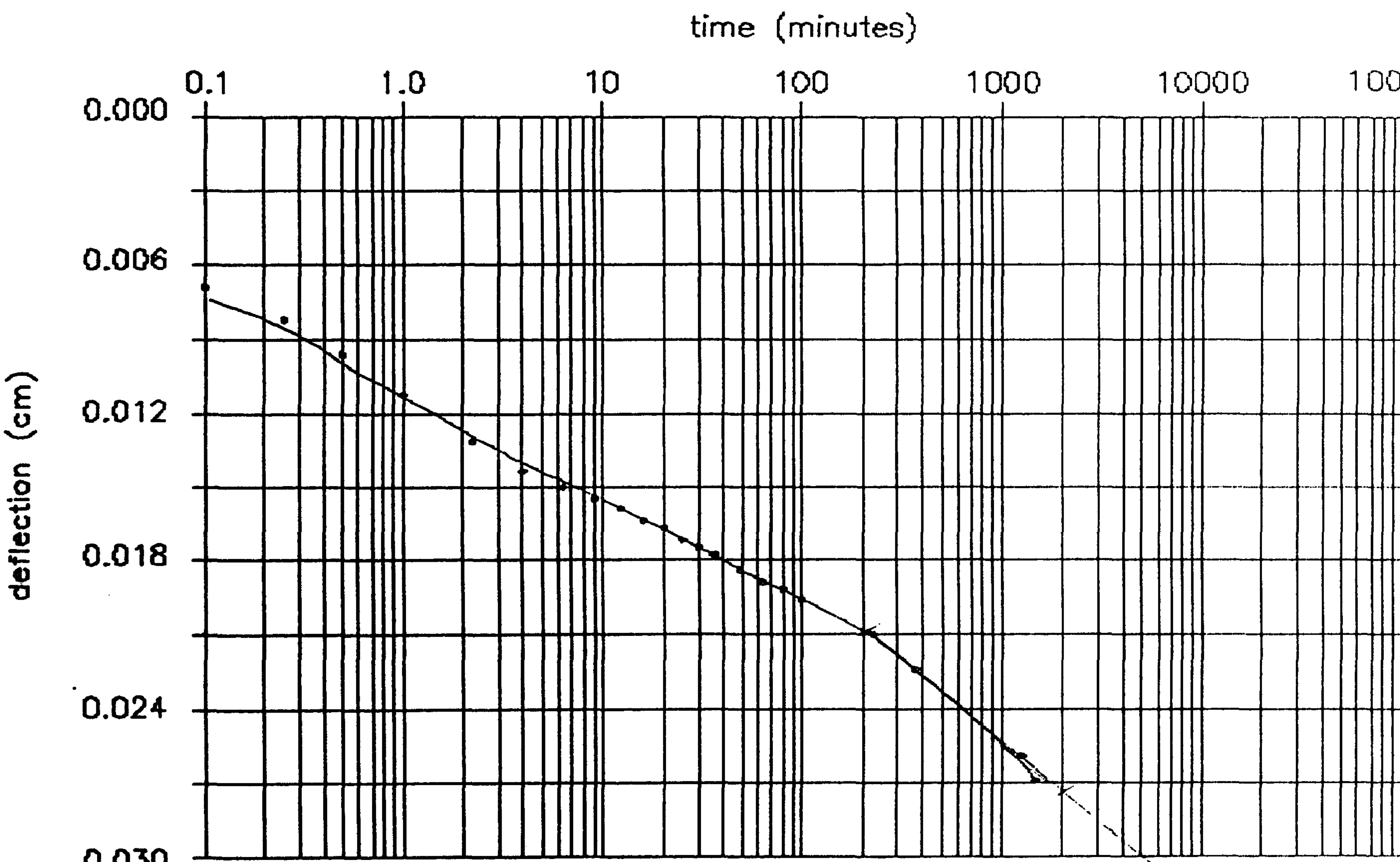
APPENDIX 5.2.3 xiii

Consd 2: ef5sep1.dwg

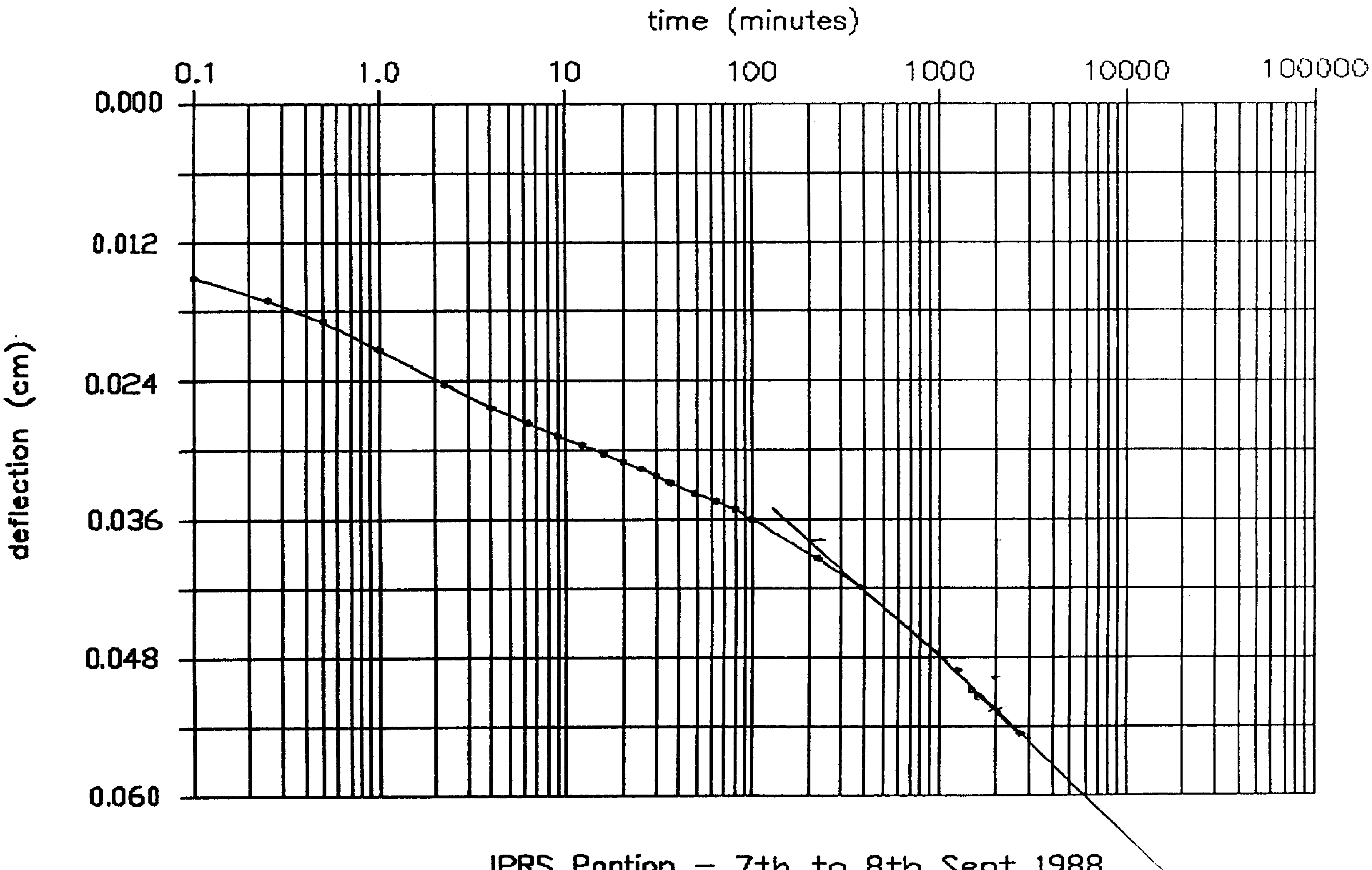


IPRS Pontion - 5th Sep 1988
Consolidation test - Scale x=80, y= 3750
Pressure = 1.01 kN/m²

E13

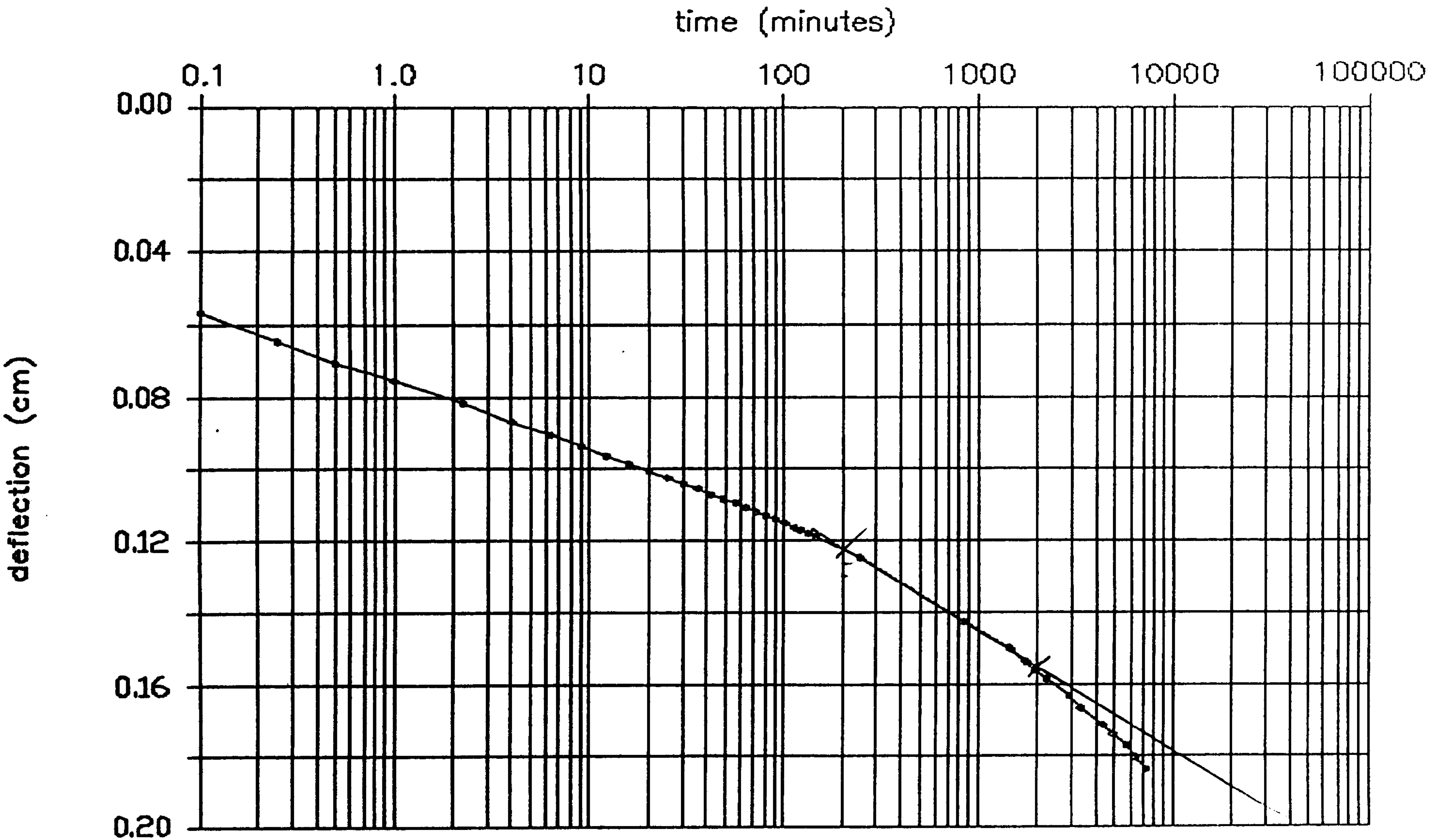


IPRS Pontion – 6th Sept 1988
Consolidation test – Scale x=80, y= 10000
Pressure = 2.02 kN/m²



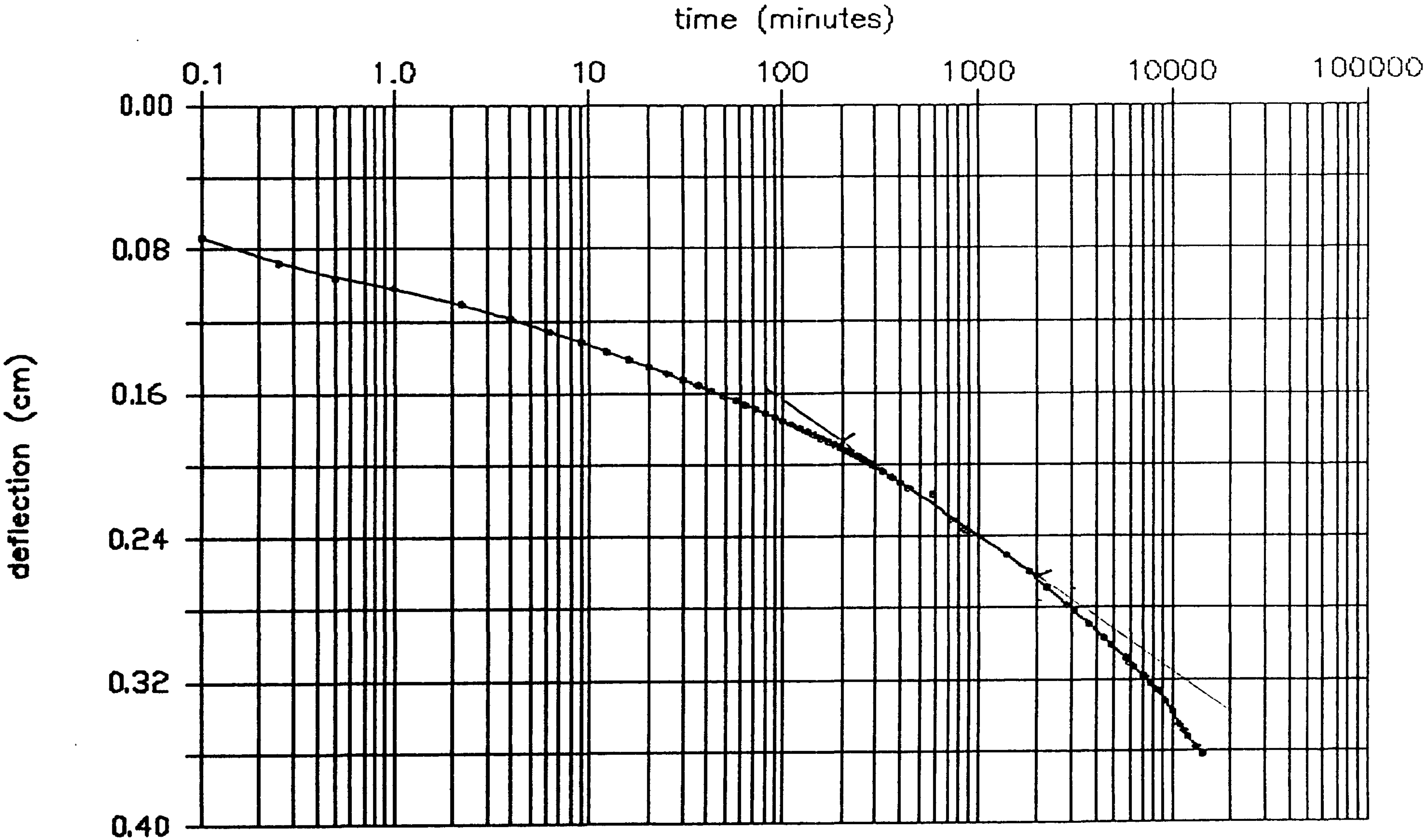
IPRS Pontion – 7th to 8th Sept 1988
Consolidation test – Scale x=80, y= 5000
Pressure = 4.01 kN/m²

E15



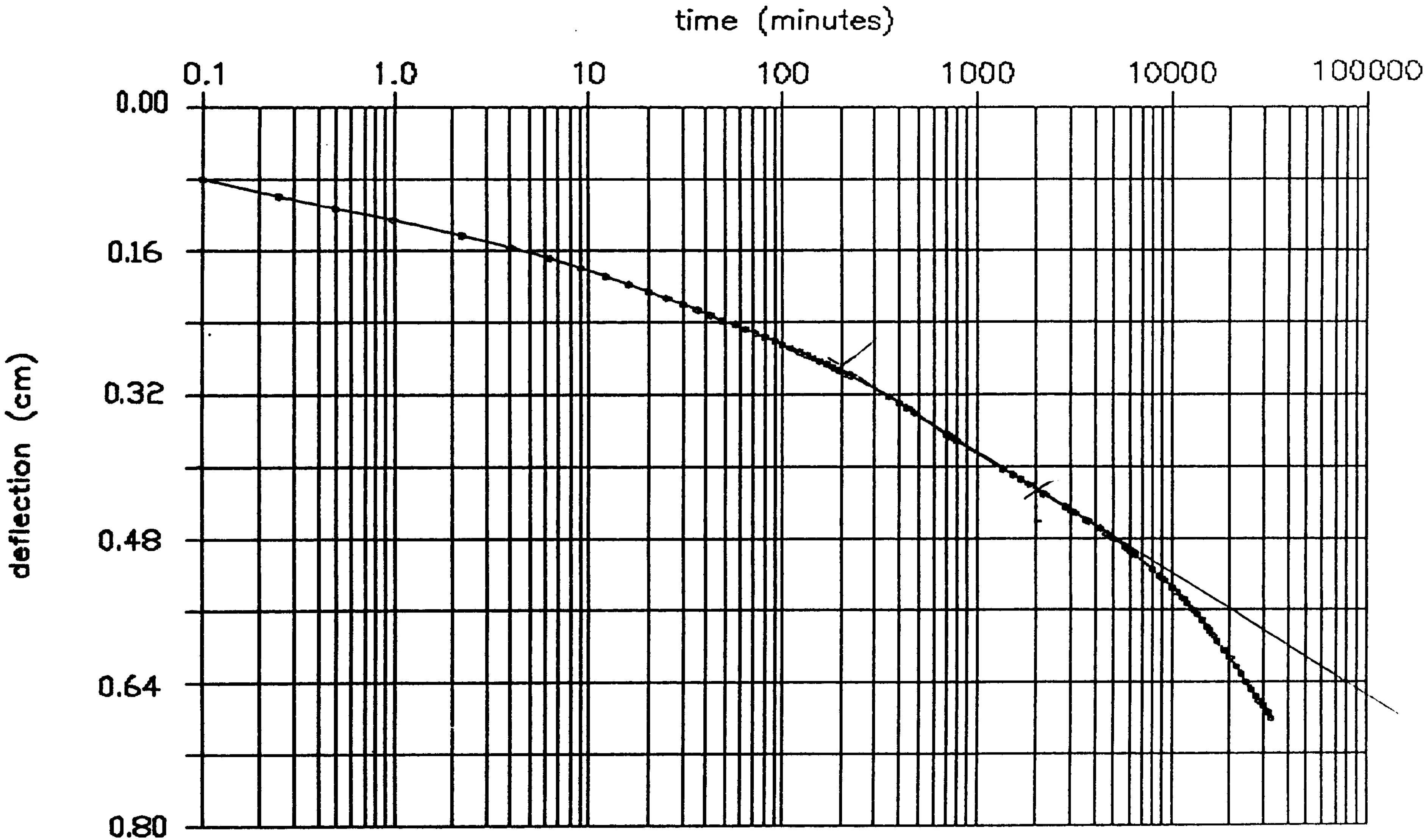
IPRS Pontion – 9th to 13 Sept 1988
Consolidation test – Scale x=80, y= 1500
Pressure = 10.002 kN/m²

APPENDIX 5.2



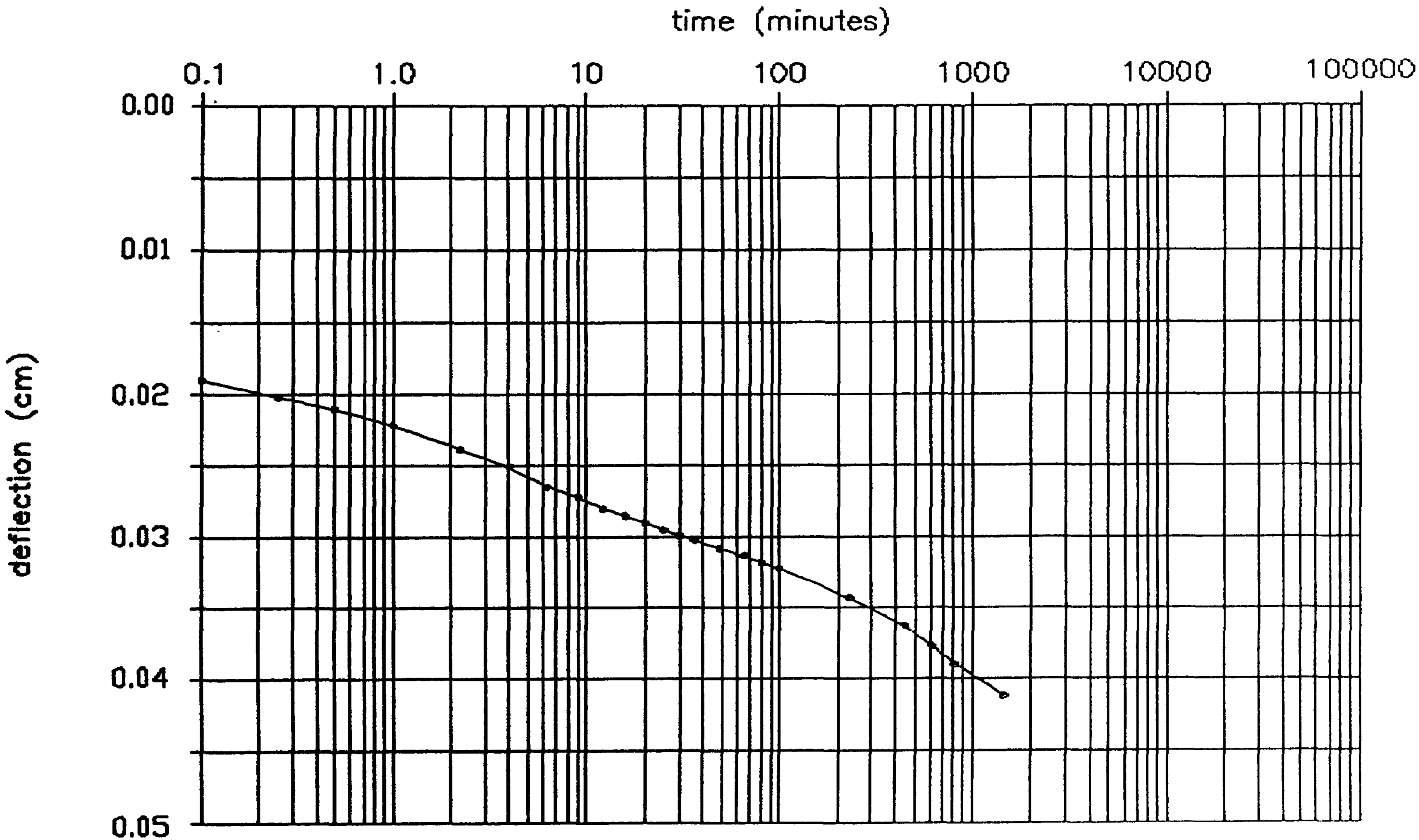
IPRS Pontion – 14th to 24th Sept 1988
Consolidation test – Scale x=80, y= 750
Pressure = 19.974 kN/m²

E17

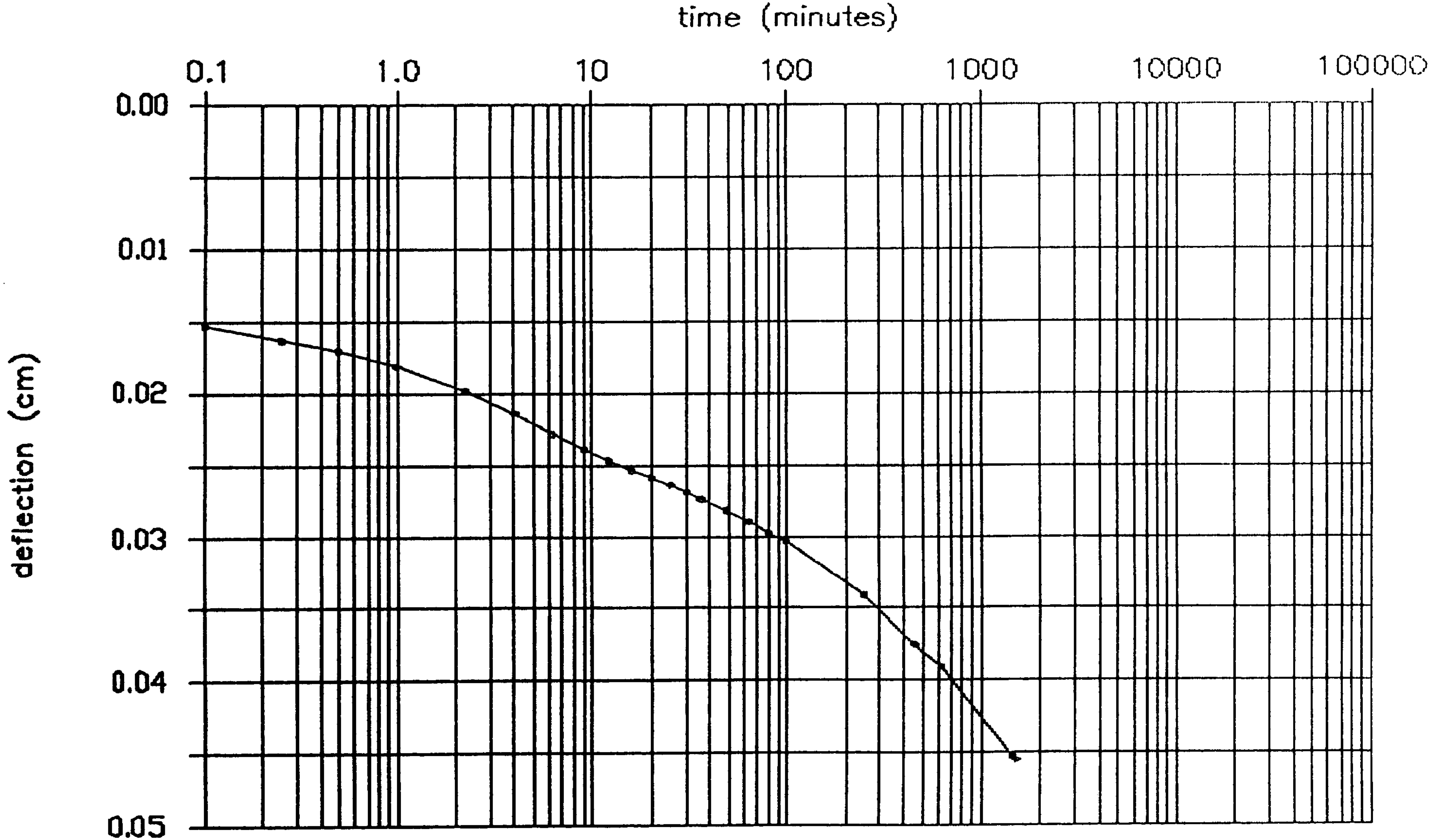


IPRS Pontion – 24th Sept to 17 Oct 1988
Consolidation test – Scale x=80, y= 375
Pressure = 39.874 kN/m²

E18



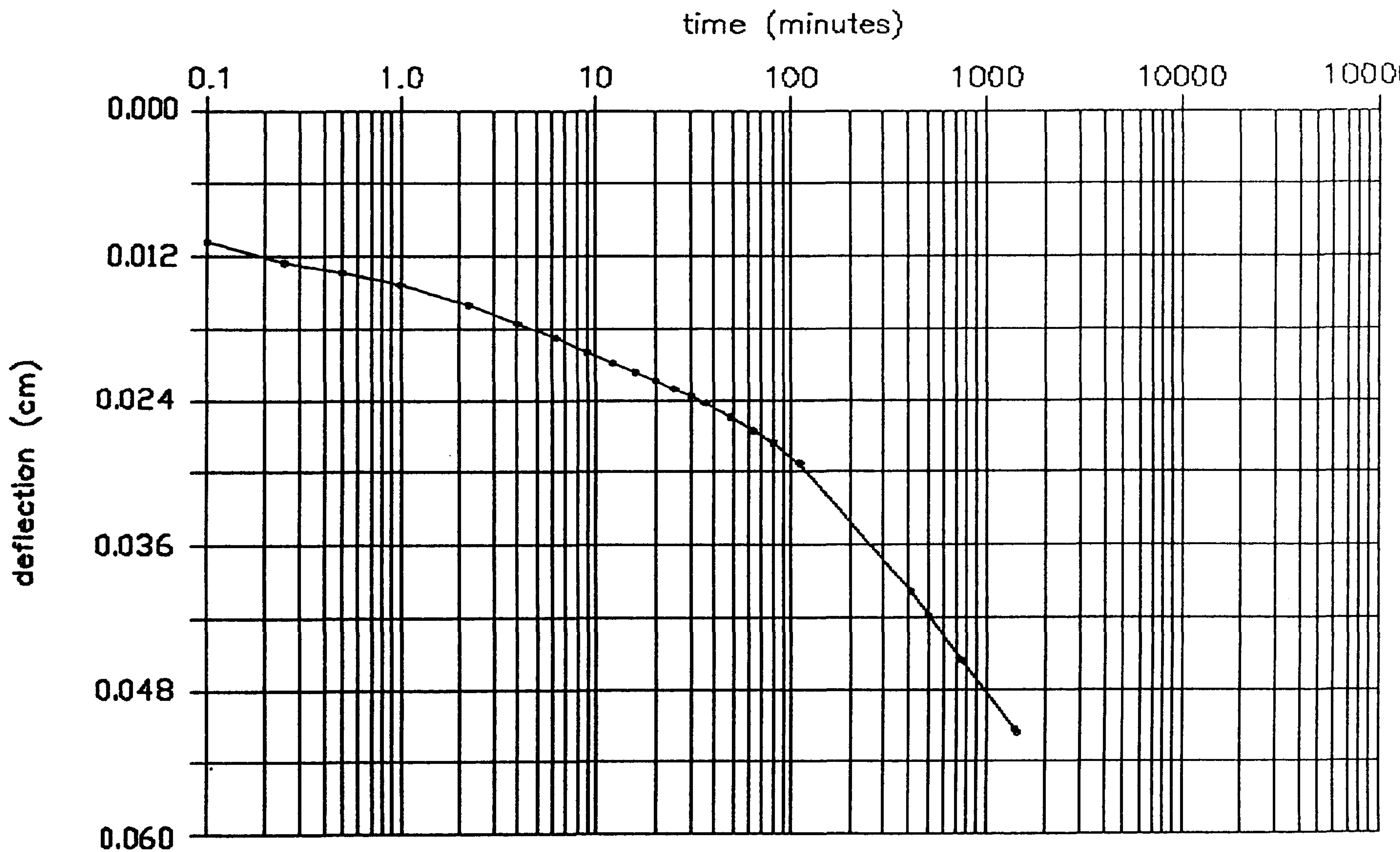
IPRS Pontion – 17th Oct 1988
Consolidation test – Scale x=80, y= 6000
Pressure = 19.974 kN/m²



IPRS Pontion – 18th Oct 1988
Consolidation test – Scale x=80, y= 6000
Pressure = 10.002 kN/m²

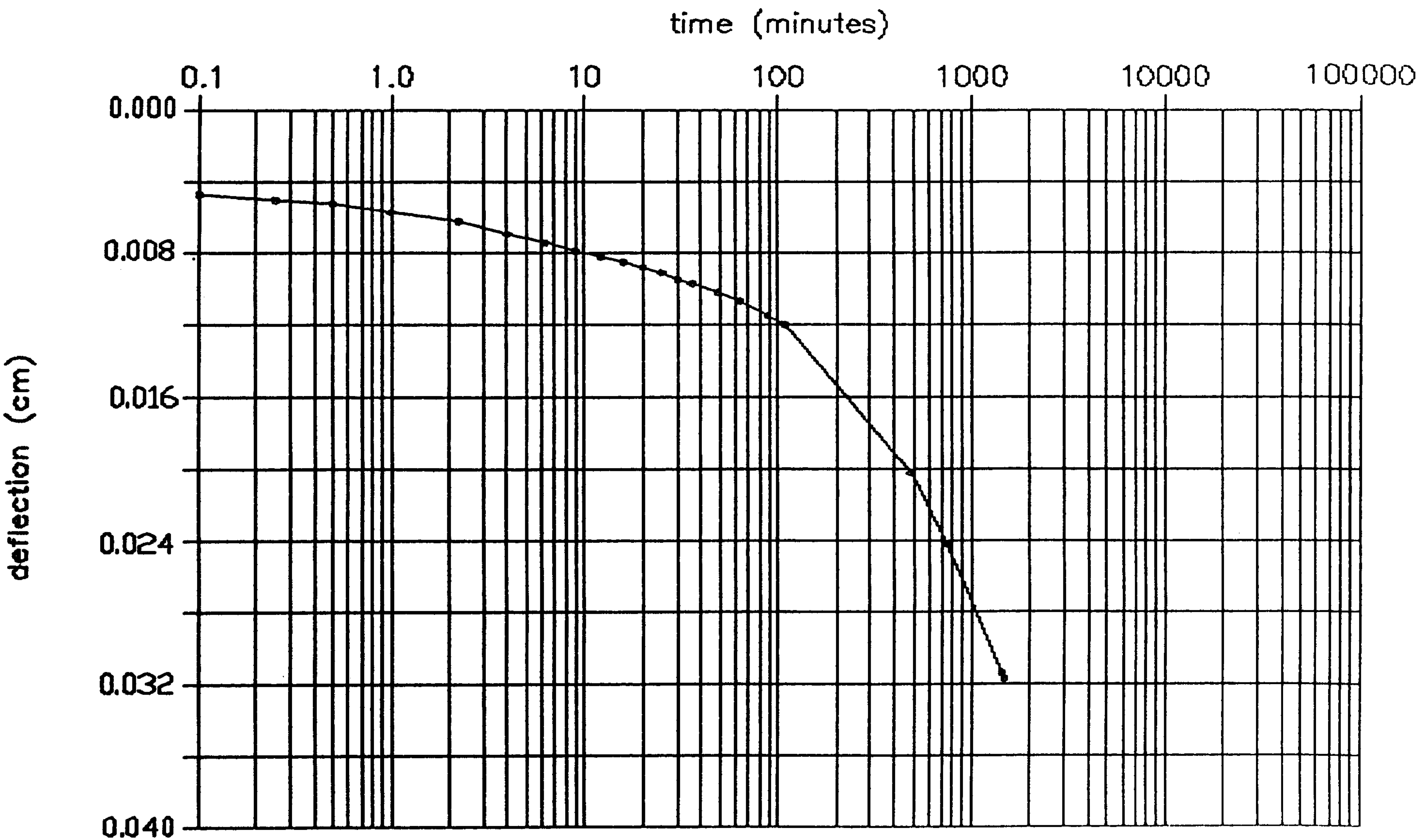
E20

APPENDIX 5.3.1 ef19ocre.dwg

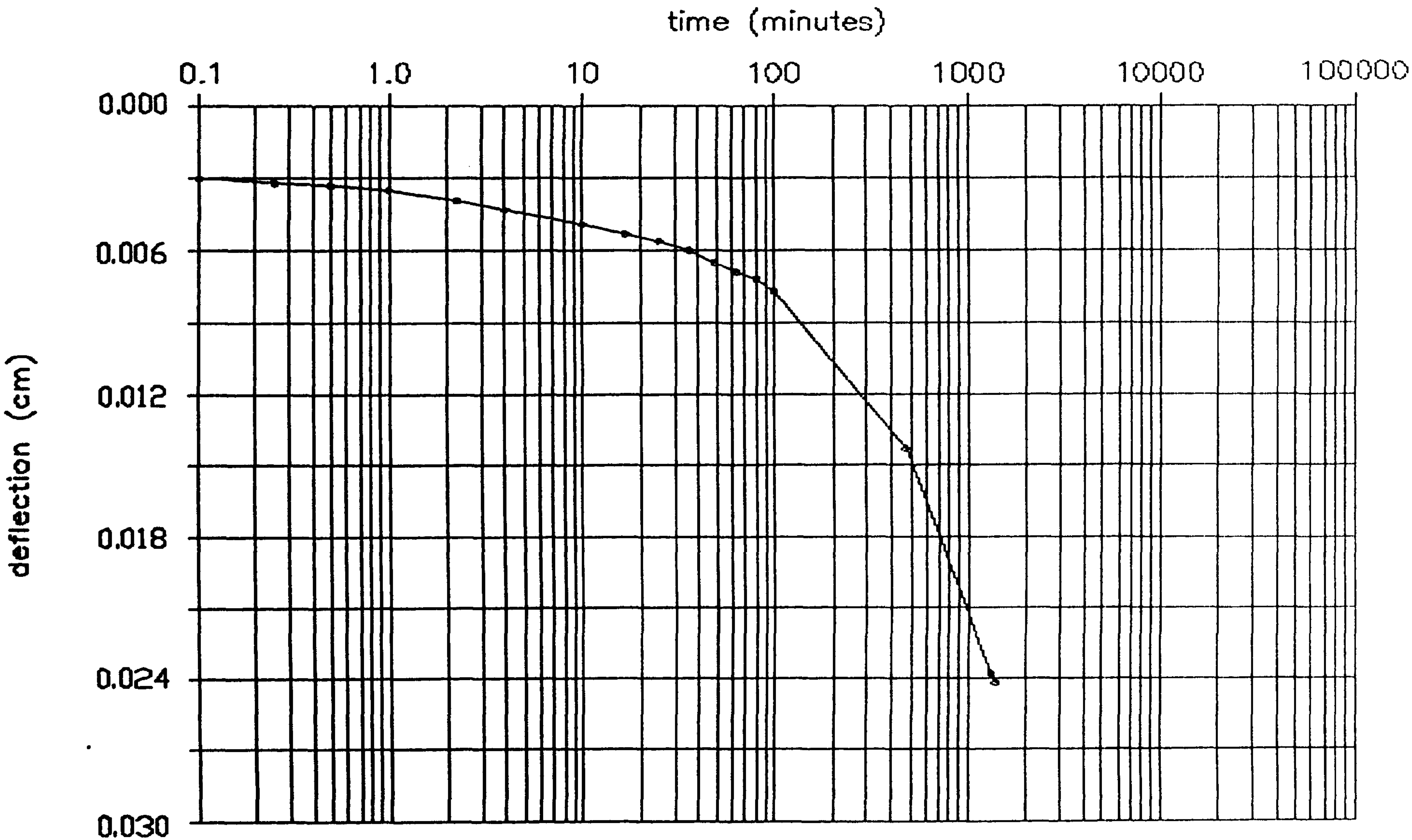


IPRS Pontion – 19th Oct 1988
Consolidation test – Scale x=80, y= 5000
Pressure = 4.01 kN/m²

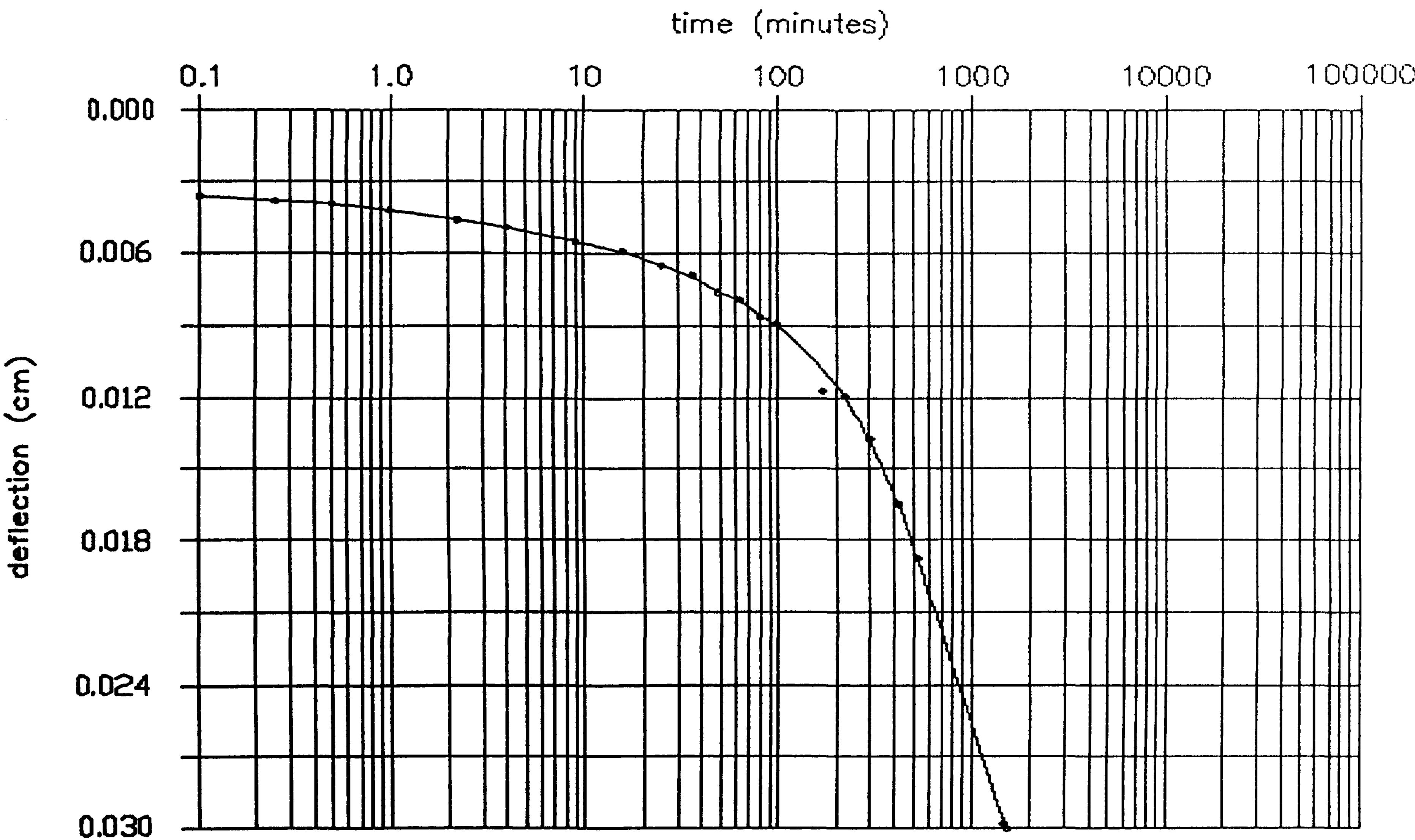
E21



IPRS Pontion – 20th Oct 1988
Consolidation test – Scale x=80, y= 7500
Pressure = 2.02 kN/m²

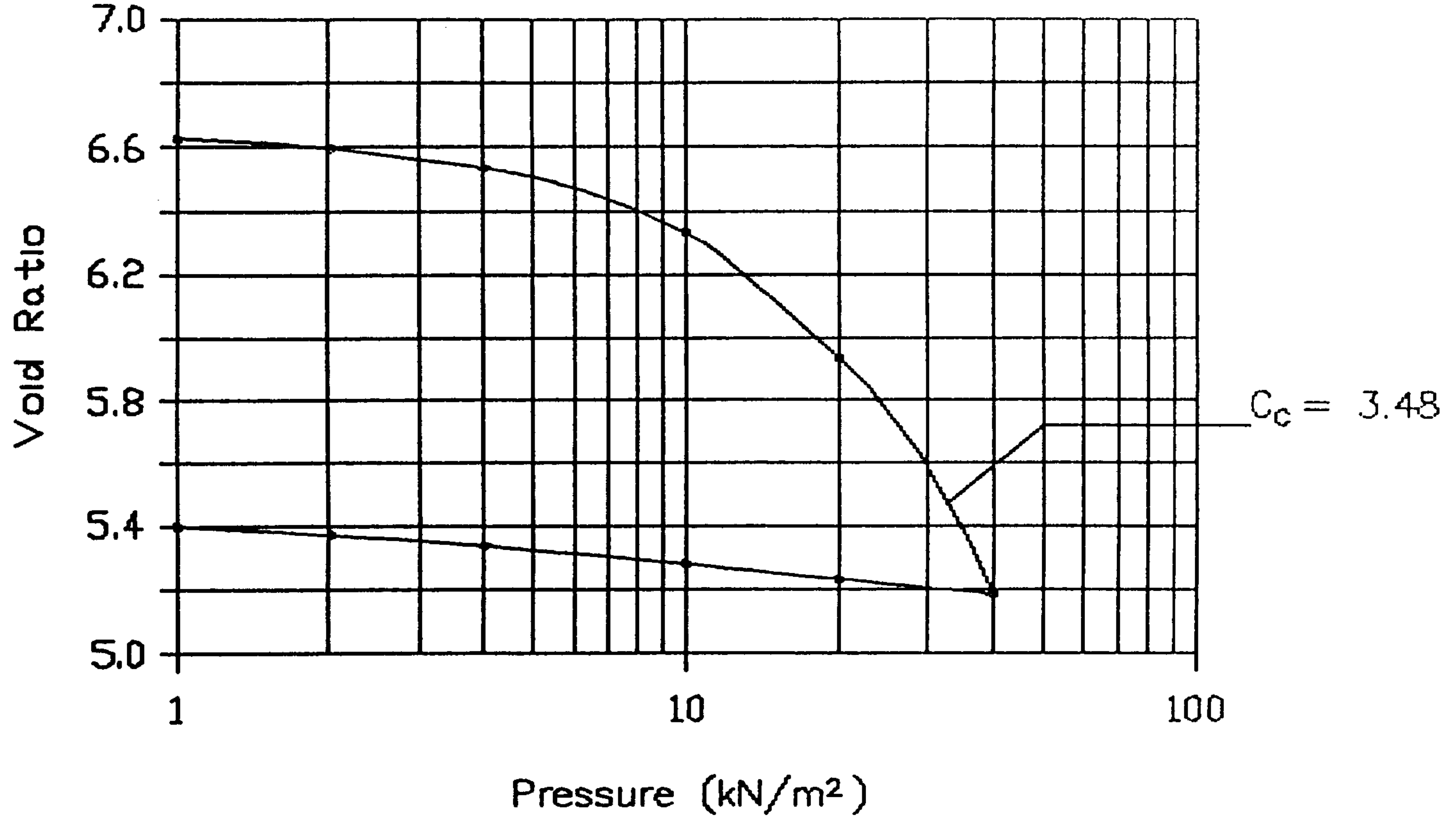


IPRS Pontion - 21st Oct 1988
Consolidation test - Scale x=80, y= 10000
Pressure = 1.01 kN/m²



IPRS Pontian – 22nd Oct 1988
Consolidation test – Scale x=80, y= 10000
Pressure = 0.0 kN/m²

consol 2: efpnesep.dwg



IPRS Pontian – 5th Sept to 22nd Oct 1988
Consolidation test – Scale x = 160, Scale y = 100

E25

Sample : 27 Acres - 0 to 15cm depth
Date : 5th to 22nd Oct 1988

Measured thickness of specimen	= 7.00 cm
Mass of ring and wet specimen	= 5590.00 g
Mass of ring and dry specimen	= 3148.00 g
Mass of ring	= 2550.00 g
Mass of dry specimen	= 598.00 g
Mass of moisture	= 2442.00 g
Moisture content	= 408.36 %
Bulk density	= 0.88 g/cc
Dry density	= 0.17 g/cc
Degree of saturation	= 81.66 %
Specific gravity	= 1.34
Height of soil particles	= 0.91 cm

Applied pressure KN/m²	Deflection cm	Total deflection cm	Thickness of specimen cm	Percentage thickness %	Height of voids cm	Voids ratio cm
					6.09	6.69
1.010	0.0686	0.0686	6.9314	99.02	6.0224	6.63
2.020	0.0269	0.0955	6.9045	98.64	5.9955	6.60
4.010	0.0546	0.1501	6.8499	97.86	5.9409	6.54
10.000	0.1838	0.3339	6.6661	95.23	5.7571	6.33
19.970	0.3619	0.6958	6.3042	90.06	5.3952	5.94
39.870	0.6808	1.3766	5.6234	80.33	4.7144	5.19
19.970	0.0412	1.3354	5.6646	80.92	4.7556	5.23
10.000	0.0455	1.2899	5.7101	81.57	4.8011	5.28
4.010	0.0516	1.2383	5.7617	82.31	4.8527	5.34
2.020	0.0317	1.2066	5.7934	82.76	4.8844	5.37
1.010	0.0242	1.1824	5.8176	83.11	4.9086	5.40
0.000	0.0300	1.1524	5.8476	83.54	4.9386	5.43

$$C_c = \frac{dy/100}{dx/160}$$ @ the steepest gradient

$$= \frac{dy}{dx} \times 1.6 = \frac{-1.8754}{0.7805} \times \frac{1.6}{1} = 3.84$$