The Planter, Kuala Lumpur, **97** (1142): 293-313 (2021)

RSPO Tier 1 Drainability Assessment in Deep Peat of Kinabatangan River Basin-A Case Study

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A case study of peat drainability assessment based on the tier 1 method of roundtable on sustainable palm oil (RSPO) was conducted in three estates covering over 1 421 hectares of oil palm planted in contiguous deep peat. The objective of the study was to understand whether the land can be replanted with oil palm for future cultivation as per RSPO principle 7, criterion 7.7 and indicator 7.7.5. The factors surveyed and measured were the peat land area cultivated, its elevation, thickness, subsidence, determination of drainage base, daily measuring of mean water level at outlet to nearest waterbody, depth to the drainage base and finally the drainage limit time (DLT) for replanting and cultivation of oil palm. Based on the evaluation in 1 421 hectares, it was measured and observed that the depth to the drainage base was higher than the peat thickness in 526 hectares (37%). In such condition if organic matter is fully subsided, the land is suitable to be cultivated with oil palm on the underlying gleyic alluvium soil. In the rest of the fields of 895 hectares (63%) the peat thickness or depth was higher than the depth to the drainage base while the balance of 204 hectares of land have the DLT of less than 40 years (calculated at 5 cm default value of subsidence). The balance of 690 hectares with DLT more than 40 years can be replanted and cultivated with oil palm, provided that stringent water management programmes are implemented in place to reduce the subsidence of peat for prolonged cultivation.

Keywords: *Peat subsidence, peat drainage assessment, drainage limit time drainage base.*

Malaysian peat soil is defined as the organic soil with organic content cumulated in a thickness more than 50 cm within the depth of top 1 m of the soil profile and contains organic matter of more than 65 per cent determined through loss of ignition or organic carbon of more than 35 per cent (Dachnowski-Stokes, 1930; 1935; Leamy & Panton, 1966; Paramanathan, 2016; Parish *et al.*, 2019). For the last one-and-a-half decades, there have been tussles and controversies over planting oil palm on peatland. Many plantation companies including IOI entered into the sustainability programme of pledging on "no new planting" of oil palm in peatland due to the pressure from non-governmental organisations [Roundtable on Sustainable Palm Oil (RSPO) 2018]. Currently, about 1.06 million hectares of peatland is under oil palm cultivation in Malaysia including Peninsular, Sarawak and Sabah (Miettinen *et al.*, 2016). Some of the peatland have undergone two or three cycles of cultivation of oil palm.

Annual subsidence of peat due to oxidation of organic matter and shrinkage is a general phenomenon in any agricultural crop cultivation.

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Cultivation of oil palm in peat is not an exception for such annual subsidence (Wösten *et al.,* 1997; Tie, 2004; Paramananthan, 2016). Continuous draining of water in peatland by natural gravity results in the subsidence of peat and the quantum of it varies depending on the draining and management of groundwater (Singh *et al.,* 1986; Wösten *et al.,* 1997; Tie, 2004; Mathews & Clarence, 2004; Hooijer *et al.,* 2012; Paramananthan, 2016; Parish *et al.,* 2019). As draining and subsidence continues, a situation may arise where the water level of peatland could reach to the drainage base and further drainage by natural gravity is impossible (Wösten *et al.,* 1997; Tie, 2004; Hooijer, 2012; RSPO Drainability Assessment Procedure 2019). When the peat thickness diminishes by continuous drainage, the depth to the drainage base of the land will reach to same or lower than the water level of the nearest waterbody. When peat subsidence to such extent happens, the water in the land cannot be drained further by natural gravity and this paves the way for the intrusion of tidal sea and river flood water into the cultivated peatland. The consequence of such an effect will be prolonged flooding, leading to an uncultivatable condition of the land for oil palm in future (Wösten *et al.,* 1997; Tie, 2004; Parish *et al.,* 2019). Before the permanent intrusion of water happens, the drainability assessment of existing oil palm planting in peat was included in the RSPO Principle and Criteria (P&C) in 2013 as Criteria 4.3 with a specific guidance 4.3.5 (RSPO P&C 2013). The specific guidance 4.3.5 states that "where drainability assessments have identified areas unsuitable for oil palm replanting, plans must be in place for appropriate rehabilitation or alternative use of such areas. If the assessment indicates high risk of serious flooding and/or salt water incursion within two crop cycles (40 years), the growers should consider ceasing replanting oil palm and implementing rehabilitation". Although in 2013 specific guidance was on qualitative observations, there were no appropriate methods developed at that time to quantify and estimate the drainability of peat. Qualitative measurements for drainability assessment include the frequency of flooding and the period of days of flooding resulting in stagnation of water in the field and these were considered as the assessment criteria (RSPO P&C 2013). In current RSPO P&C the drainability assessment criterion was improvised on a quantitative basis as included in principle 7, criterion 7.7, indicator 7.7.5 (RSPO P&C 2018). RSPO through Peat Land Working Group 2 (PLWG2) had engaged Wetland International to develop the methodologies in March 2017 and two methods, tiers 1 and 2 were adopted by RSPO. In tier 1, the calculation of drainage is based on theoretical default values. While in tier 2 the measurements are based on actual data of digital terrain model (DTM) measurement of subsidence using permanent pole, peat depth and regular collection of water level data in the peat outlets (RSPO Drainability Assessment Procedure 2019).

IOI group's major peat planting is in Sabah in the basin of Kinabatangan river covering three estates. The first generation of palms at this site were planted from 1993 to 1997. The palms are 24 to 28 years old and ready for replanting having taken into consideration of palm age, leaning, low yield etc. In view of the urgency for the replanting, drainability was measured and calculated according to tier 1 method (RSPO Drainability Assessment Procedure 2019). Due to insufficient data on subsidence of peat, default value of annual subsidence of 5 cm per year was incorporated in this case study. The current ground work was carried out from July 2019 to November 2019 and the results and its interpretation are discussed in this paper.

METHODOLOGY AND RESULTS

Location of case study site

Location of the peat study site as given in *Figure 1* is near the basin of the Kinabatangan river, Sukau, Kinabatangan district. By direct straight line measurement, the outlet of the Kinabatangan river to the Sulu sea from the study site is about 25 km towards the eastern part of Sabah. However, the tidal sea water effects in the site is through meandering of the Kinabatangan river, which is about 72 km from the Sulu sea to the downstream of the tributary Sipasidom. The daily effects of the high and low tides in Kinabatangan river can be seen up to the Sipasidom tributary. The natural distance of the Sipasidom tributary to the study site entrance (R1) is about 6.25 km. The total distance from the Sulu sea to the entrance of the study site R1 by waterways is 78.25 km.

There are three estates (Estates A to C) in the study site with peat soil. Estate D is generally thionic alluvium on either side of the Sipasidom river indicating the tidal water effects up to only Estate D (IOI internal soil survey report, 2004). The tidal effect of Kinabatangan river floods effects Estate D thereby affecting the outflow of monsoon rainfall water from the study site. At the study site none of the three Estates A, B or C have any thionic alluvium soils indicating that the flood formed in the study site is due to the inland rainwater. As the high tide causes water to raise in the western part of Estate D from the Kinabatangan river it prevents the outflow of inland rainwater from the site.

The method adopted for the study was tier 1 of RSPO Drainability Assessment Procedure 2019. The measurement of peat depth was initiated in July 2019 and completed in August 2019. The land for peat was resurveyed at the same time with demarcation of peat within the cultivation area. Peat terrain was measured from August 2019 to November 2019. The water level heights of river are measured daily initiated from July 2019. The fundamental work of measurements for drainability valuation were carried out or implemented from July 2019 to November 2019. The level of river water near outlet R1 is still being measured daily for future references.

Peat survey map

Peatland planted with oil palm was resurveyed and measured as given in the map [Timbalai 1948 Malaysia Borneo RSO (metre)] of *Figure 2*. The breakdown of area of oil palm planted in peat soil in three estates is given in *Table 1*

The total peatland re-surveyed in all three estates was 1 421 hectares. Estate A has 93 per cent of the peat planting, while Estates B and C have 4 per cent and 3 per cent, respectively of peat areas planted with oil palm. Although the area in hectares of peat in Estates B and C are relatively low, it is contiguous peat catchment and an essential part of the study. The peat planted area is surrounded by hills at the northern and eastern parts of the study area, indicating that the peat is a basin peat (*Figure 1*).

There are two watercourses passing through Estate A, which are considered to be the rivulets of Sipasidom, a tributary of the main Kinabatangan river of the surveyed land. Till now, there are no names for these two rivulets in Estate A. For easy references for this case study, the central north rivulet is called “north Sipasidom rivulet “ and southern rivulet is called “south Sipasidom rivulet”. Both rivulets originate from the eastern hill ranges of Estates

Figure 1 Location of oil palm planted on peat site for drainability assessment on Google map

TABLE 1
AREA OF CONTIGUOUS PEAT UNDER ESTATES A, B AND C

Estates	*Area (ha)*
Estate A	1318
Estate B	62
Estate C	41
Total	1421

B and C and flow towards the western part of the Estate and merge as a part of the tributary of Sipasidom at the boundary of Estates A and D (*Figure 1*). The north Sipasidom rivulet originates from Estate B and is considered as the lowest level of land elevation in the surveyed land and can be considered as main drainage of the cultivated land. The south Sipasodom rivulet originates from Estate C on the higher ground and passes partially through alluvium soil and merge at the boundary of Estates A and D.

The Estate D (*Figure 1*) adjacent to Estate A has alluvium soils of Koyah and Metah series, both thionic in nature and could have geographically been developed by the sedimentation of alluvium plain from the upstream or tidal water movement of the Kinabatangan river or continual erosion and sedimentation from the surrounding hills for many years. These soils cannot be classified as peat although organic matter could be seen below 1 m depth of the soil profile. The organic matter seen at the underlying soil profile of more than 1 m in Estate D could be an extension of the peat to Kinabatangan river from Estate A. Basically, most of the water from peat planted estates flow towards the north rivulet Sipasidom river. There is a topographical gradient in the river from east to west direction for both the rivers, where the eastern part is higher than the west. The palms in the three Estates A, B, and C were planted in 1993, 1996 and 1997. As the palm age is over 24 to 26 years, replanting will have to start from 2020/2021 and 2021/2022 financial years.

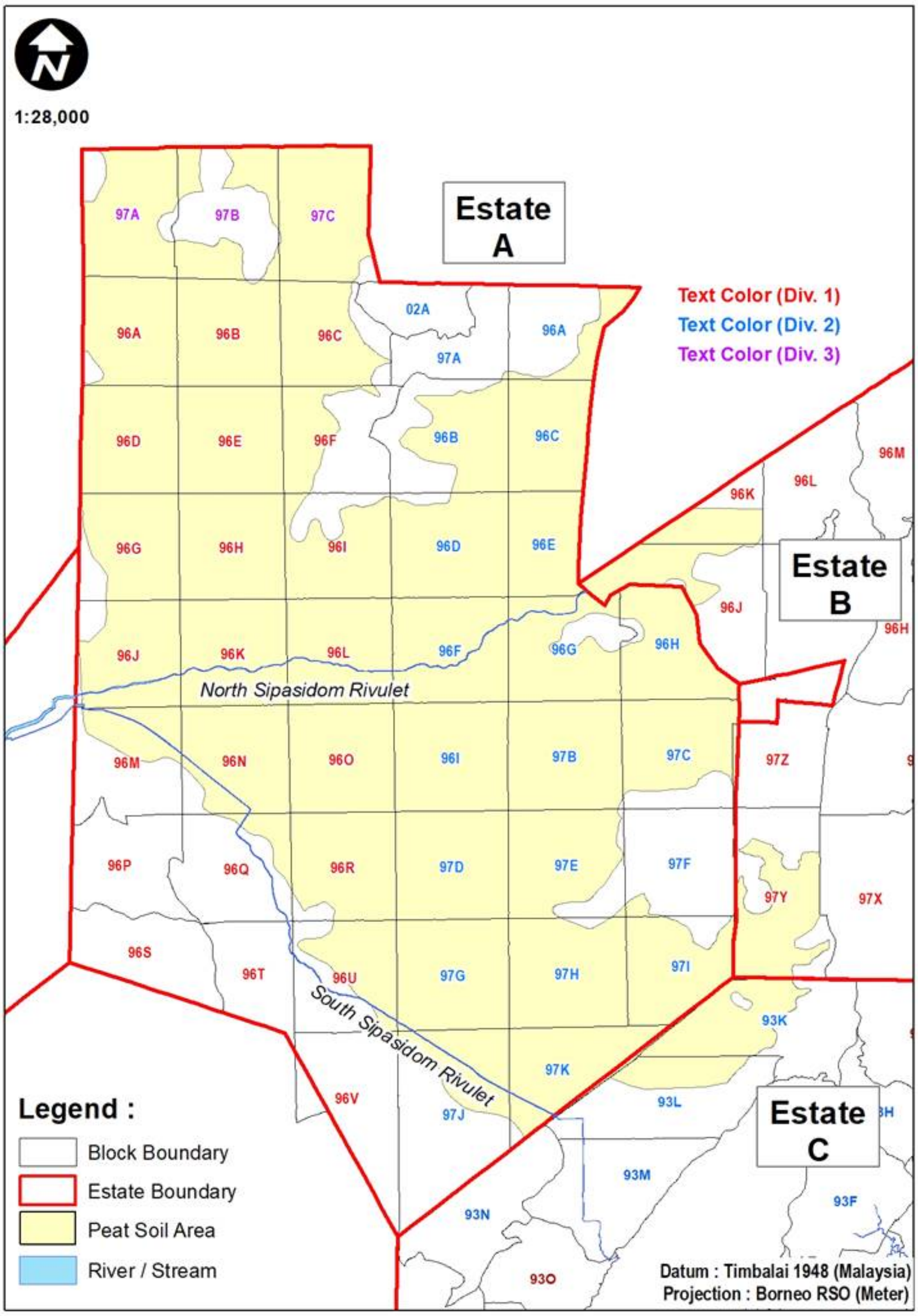

Figure 2   Surveyed oil palm planting in peat Estates A, B and C

Peat depth (D_P)

Peat depth or thickness of each oil palm planted field in peat which is on a basin have been measured. The depth of peat was measured at about 20-30 m from the collection road at the south and north directions of each field. A total of 88 points were measured using stainless steel Eijkelkamp peat sampler augur with variable extension rods. The mean peat depth for each field is shown in *Appendices 1* to *3*.

In general, the depth of peat is more than 3 m and considered deep in the surveyed area. The peat is sapric up to 30 cm to 50 cm at the top and the rest is mixture of sapric and hemic with woody materials underneath the peat layer. The underlying material is alluvium Eutric gleysol. In 2002, the peat was classified under Gondang series with plenty of soft and hard undecomposed wooden material underneath it (Mathews & Clarence, 2004). The peat was classified according to the Malaysian Unified Soil Taxonomic Classification of 2002 (Paramananthan, 2002). In 2002, Gondang series was classified as deep hemic peat with the combination of many hard and soft undecomposed wooden materials deep peat profile. With the advancement of Malaysian soil taxonomic classification after 15 years, the peat in this region is further mainly classified under Karap series - a very deep peat with sapric material of decomposed and undecomposed woods in the peat profile (IOI Internal Soil Survey Report, 2017).

Topography of peat planting or land elevation (Z_S) (August 2019 to November 2019)

Ground reference station verification for topography measurement

Prior to measuring elevation of peatland, establishing the ground reference points is an essential procedure. The objective of the reference or bench mark point is for the correction of elevation data collected at ground level. Information and data related to reference point or bench mark near to survey area were gathered before site elevation verification. The overall flow of collection of information of ground reference points or geological bench mark are shown in *Figure 3*.

The first reference point (TBM2) nearest to the study site was verified from a government road survey plan in Kampung Sukau, which has coordinates of 2952805.88 East and 5611961.21 North at known land elevation of 14.84 m - mean sea level (msl). This first ground reference point (TBM2) was again crossed referred to an established land survey department reference point G02909-93 in Kampung Sukau at GPS coordination 2953808.73 East and 5611869.37 North and considered as the second reference point with known measured land elevation at 18.41 m-msl along Kinabatangan river. From the second reference point the team again cross referred to the temporary bench mark (TBM A) in field 96S of Estate A with measured and corrected elevation of 62.59 m-msl. This became the final reference point for topography measurement of the study site. However, an additional reference point TBM B was marked at 2967303.22 East and 5616375.10 North to speed up the work in the eastern part of the study site of Estates A, B and C with an elevation measure of 64.49 m-msl.

Peat topography

After establishing the ground reference points for elevation in Estate A, the peatland topography planted with oil palm were measured initially with theodolite, which was a very tedious method and later changed to

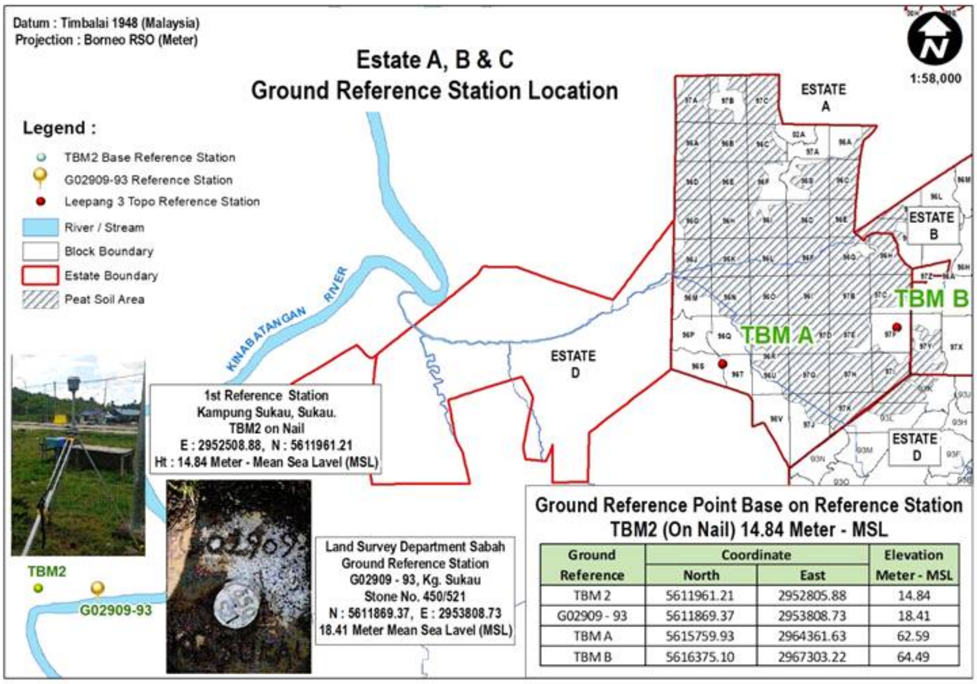

Figure 3 Developing of GPS bench mark points (or reference points)

dumpy levelling with the support of real time kinematic (RTK). Overall, the dumpy levelling too was intensive and took about 150 man-days to complete the information collection of land elevation in 1 421 hectares of peat. With this RTK information and corrections from the reference points, the error of elevation can be reduced to less than 5 cm. The topo to raster interpolation of the data collected was developed into digital terrain model (DTM) map and later a contour map was derived at 0.5 interval as given in *Figures 4* and *5*, respectively. It could be seen from the topo to raster map (*Figure 4*) that the upper part of the central north Sipasidom rivulet has the elevation from high to low levels in a north-south direction, while in south Sipasidom rivulet the elevation is from high to low in the south to west direction; i.e the area is more a basin.

The north Sipasidom rivulet has the lowest elevation of land of the whole catchment, where the measured elevation at R1 was 2.70 m above msl at the entry of Sipasidom tributary in the west in field 96J. The north and south of the peatland is elevated up to 8.0 m above the msl from the north and south Sipasidom rivulets. The detailed elevation of topography for each field is given in the final calculation of drainability assessment in *Appendices 1* to *3*.

Peat subsidence (S) (default value)

The annual subsidence of peat is an important factor to include in the calculation of drainability assessment. Subsidence is the result of consolidation, oxidation and shrinkage of the organic peat and is related to groundwater table

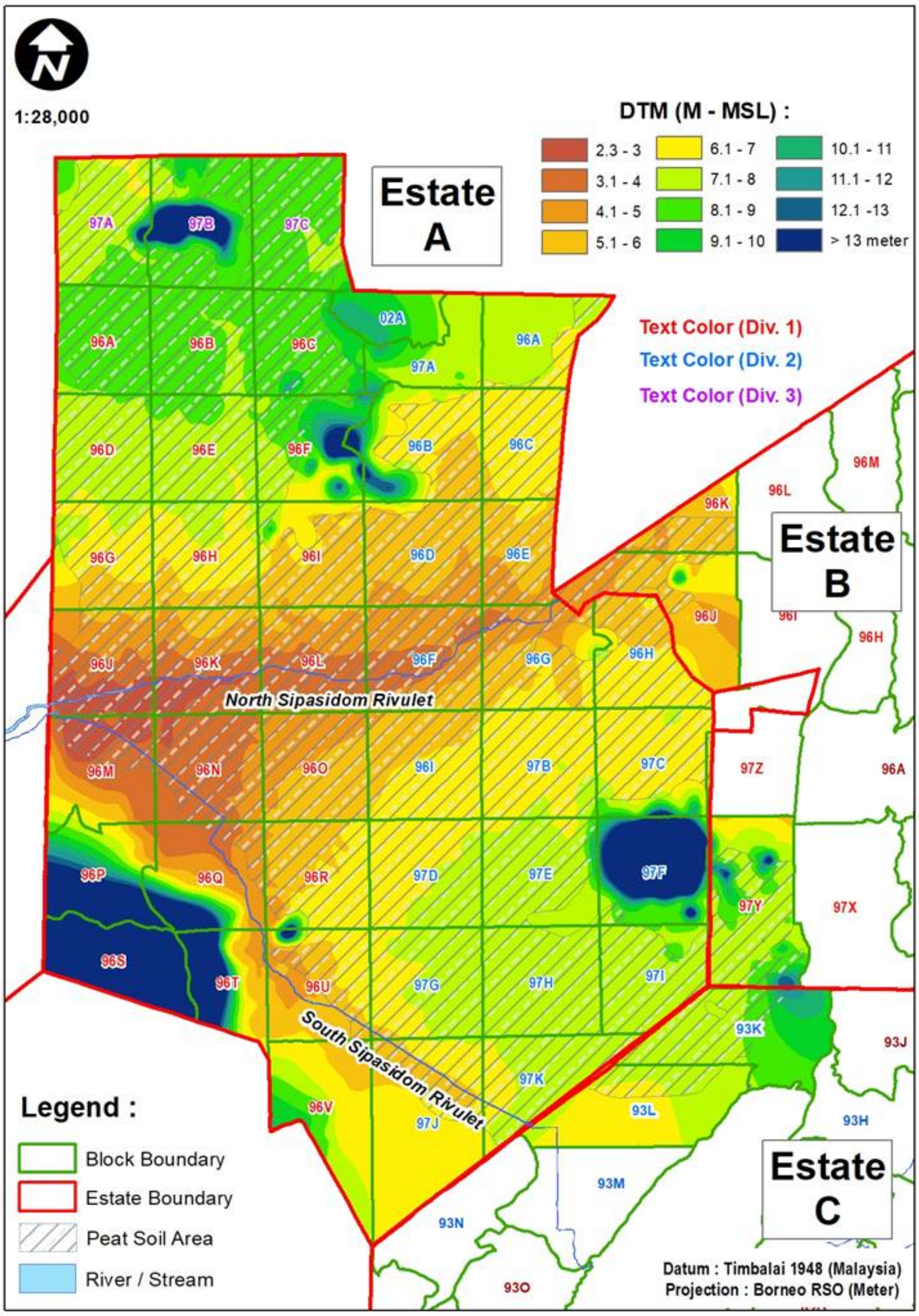

Figure 4 Digital terrain model of the study site

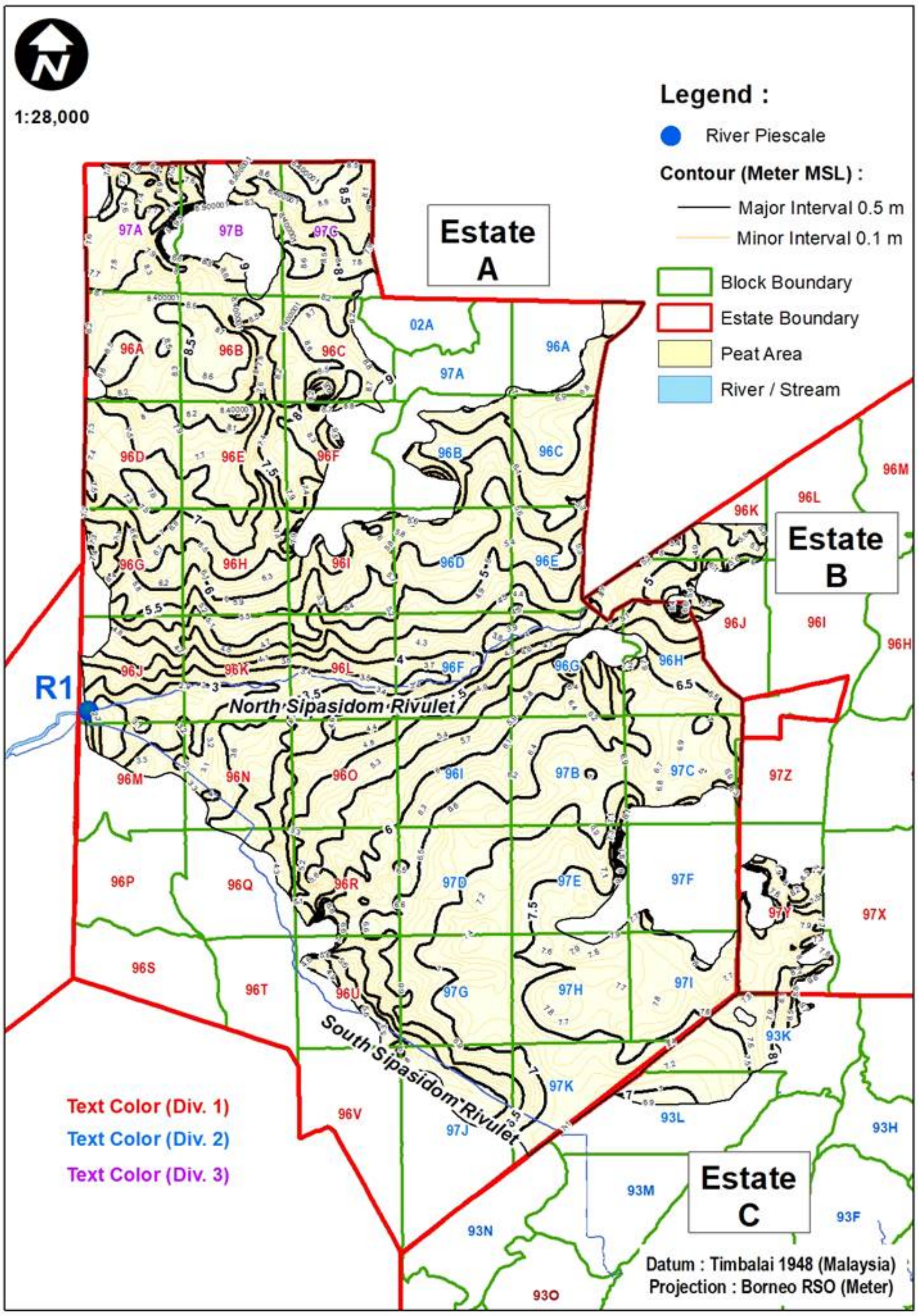

Figure 5   Contour map derived from the topography measurement

management. Hooijer *et al*. (2012) averaged 5 cm of subsidence after 5 years of drainage. Based on the available literature reviewed by Carlson *et al*. (2015), RSPO drainability assessment opted to default value of 5 cm per year of subsidence for tier 1 assessment. If there is an actual data collection of subsidence for a period of 2 years through an installed subsidence pole in the peat planting, then the actual data collected from such measurement can be used in the drainability assessment. In the present site, the recording of subsidence was only initiated in July 2019 and a total of seven stations of monitoring system were placed in peat of 1 421 hectares that represents a mean of 203 hectares per station. The subsidence of peat is measured on a 6-monthly basis. At this juncture, for early replanting purpose due to insufficient actual data on subsidence, a default value of 5 cm subsidence was used for the drainability assessment of peat in this location.

Distance between nearest water body and centroid measurement (ΔX_{NWB})

From the centre of the oil palm peat planted field (centroid) to the nearest or lowest outlet (R1) of waterways was measured from the map (scale 1:28 000) and tabulated in the drainage base calculation in *Appendices 1* to *3*. The distance calculated (in metres) from all the fields are merged to the outlet in R1 the lowest point of north Sipasidom rivulet.

Water elevation measurement or gauging of rivulet water level (ΔZ_{NWB})

The water level in north Sipasidom rivulet outlet at point R1 was measured since July 2019. This is the major watercourse that receives water from the north and south of peat fields and discharges at R1. The north Sipasidom rivulet in the estate periodically floods during monsoon season. The ground level zero of gauge at location R1 is about 2.70 m-msl. Flooding could be due to the tidal effect of the Kinabatangan river together with the monsoon rainwater from the upstream of the Kinabatangan river and also the high inland water due to rain from the hills of Estates A and B. The influence of tidal water is daily seen up to the entrance of the Estate A through Estate D (*Figures 1* and *4*). Once the Kinabatangan river subsides, the water from the peatland too will subside through the tributary Sipasidom. The measurement of rivulet water level was carried out daily. The 12 months data for the water fluctuation at R1 is shown in *Table 2*.

Drainage base (Z_{DB})

The drainage base or otherwise natural drainage limit is the level, where it is no longer possible to drain the water by its natural gravity flow (RSPO Drainability Assessment Procedure 2019). The drainage base is calculated using the following formula of tier 1 method.

$$Z_{DB} = (\Delta Z_{NWB} + (0.0002 x \Delta X_{NWB}))$$

ΔZ_{NWB} is the average monthly fluctuation of water level of the river measured with a permanently placed pie scale daily (*Table 2*). The constant 0.0002 is the theoretical assumption conveyance gradient that at every 1 km, there is an elevation of land at 20 cm from the nearest water body (Tie, 2004; Hooijer *et al*., 2012b). ΔX_{NWB} is the distance to natural gravity water flow to the outlet R1 of north Sipasidom rivulet from the centroid of the peat planted field. The distance to outlet R1 from each centroid of the field is given in *Appendices 1* to *3*.

TABLE 2
MEAN MONTHLY FLUCTUATION OF WATER LEVEL (M-MSL) AT NORTH SIPASIDOM RIVULET (R1) OUTLET FROM JULY 2019 TO JUNE 2020

Months	*Monthly mean of north Sipasidom rivulet water level below/above peat ground level (in cm)*	*North Sipasidom rivulet water level from reference ground level of 2.70 m-msl (ΔZ_{NWB})*
July 2019	38 (below)	2.32
August 2019	91 (below)	1.79
September 2019	86 (below)	1.84
October 2019	45 (below)	2.25
November 2019	22 (below)	2.48
December 2019	44 (above & flooded)	3.14
January 2020	23 (below)	2.47
February 2020	37 (below)	2.33
March 2020	83 (below)	1.87
April 2020	98 (below)	1.72
May 2020	95 (below)	1.75
June 2020	26 (below)	2.44
Mean	50 (below)	2.20

Depth to the drainage base (D_{DB})

The depth to the drainage base is the vertical depth differences between measured elevation of peatland presently under cultivation (in m-msl) and the elevation of the drainage base. The calculation is as follows:

Depth to the drainage base D_{DB}= Peatland elevation (Z_S) – Drainage base (Z_{DB})

The calculated depth to the drainage base is shown in *Appendices 1* to *3*. The area of fields (in hectares) where the depth to the drainage base is higher than peat depth and peat depth higher than depth to drainage base is summarised in *Table 3*.

Depending on the terrain, the calculated depth to the drainage base can be higher than the peat depth or lower than the peat depth. If the depth to the drainage base is higher than peat depth, then the underlying mineral soil may not be subjected to floods or incursion of saline water. Such condition is found in 526 hectares (37%) of the study site, where it is possible to cultivate oil palm, even though the whole peat layer is oxidised. The only factor to consider here is the time taken for complete subsidence of peat and the quantity of greenhouse gas emitted at the time of subsidence. If the peat depth is higher than the depth to the drainage base, there is a likelihood that a time will be reached for peat subsidence, where the water may not be drained by natural gravity. Such area of coverage is about 895 (63%) hectares in the present study site.

Drainage limit time (DLT)

The calculated DLT is shown in *Appendices 1* to *3*. The DLT is the timeframe in years for future replanting and cultivation of oil palm quantified through drainability evaluation and to keep a buffer of peat thickness for 40 years before the organic matter reaches the drainage

TABLE 3
DEPTH TO DRAINAGE BASE (D_{DB}) AND ITS RELATION TO PEAT DEPTH (D_p)

Estate/Division	*Peat depth (D_p) ≥ Depth to drainage (D_{DB}) (ha)*	*Depth to drainage base (D_{DB}) ≥ Peat depth (D_P) (ha)*	*Total area (ha)*
Estate A/ Division 1	372	208	580
Estate A/ Division 2	464	166	630
Estate A/ Division 3	0	108	108
Estate B/ Division 1	28	13	41
Estate C /Division 2	31	31	62
Total	895	526	1 421

base through subsidence of peat. In the present study most of the fields had peat depth higher than the depth of drainage subjected to DLT evaluation. These are the areas that in future can be affected by long-term drainage of water and subsidence of peat resulting in a situation where water cannot be drained by natural gravity. The fields with depth to drainage base higher than peat depth comprises 526 hectares. Even when the peat has subsided fully the alluvium plain beneath is unlikely to be flooded by the intrusion of river water and hence it is not necessary to calculate the DLT. Only the 895 hectares of fields, where the peat depth is higher than depth to the drainage base needs to be included in the DLT calculation. The area covered in the study site with 40 years or less than 40 years of DLT is shown in *Table 4* and the area covered is depicted in the map as shown in *Figure 6*.

An area of 159 hectares of Estate A (division 1) and 45 hectares in Estate A (division 2), totalling 204 hectares have DLT less than 40 years. This is about 14 per cent of the total land of 1 421 hectares planted and under evaluation. The fields are located near to the banks of the north Sipasidom rivulet. The rest of the fields (691 hectares) calculated with DLT values higher than 40 years is recommended for the replanting programme in 2021.

DISCUSSIONS

Wösten *et al.* (2006) modelled the water management of a huge landscape of Air Hitam Laut catchment in Jambi province, Indonesia. In their hydrological model, the data inputs were digital elevation model (DEM) using shuttle radar topography mission (SRTM) radar image, drainage pattern, calibrated and validated groundwater levels monitored at several sites, measured water discharges and flooding pattern from sensed radar images. Their study provides a generalised prediction of three zones comprising of possible areas for expansion of oil palm cultivation in upstream, expansion of agriculture downstream and continuing fire damage. They also indicated the possible exposure of underlying acid sulphate soils due to continuous drainage of peat at downstream based on their model of water management. Hooijer *et al.* (2010) indicated that major CO_2 emission is expected from the deforested drained lowland tropical peat. The present and future emissions from such drained peat have to be quantified in peatland area through, peat

TABLE 4
FIELDS AND AREA WITH DRAINAGE LIMIT TIME (DLT)

Estate/Division	*Peat depth (D_P)≥Depth to drainage (D_{DB}) (ha)*	*DLT ≤40 years (ha)*
Estate A/ Division 1	372	159
Estate A/ Division 2	464	45
Estate A/ Division 3	0	0
Estate B/ Division 1	28	0
Estate C /Division 2	31	0
Total	895	204

thickness, projected and presently available land use, water management practices and peat decomposition rate. Hooijer *et al*. (2012b) postulated that 30 per cent to 69 per cent of the coastal peatland in South East Asia may cease to be under agricultural production in 50 years due to temperature dependent oxidation process leading to subsidence of 5 cm per year with the water table at 70 cm from ground level and with a 0.5 factor of annual rise of sea level for 100 years. They estimated that the land used under agricultural production in Johore covering 950 hectares has a drainage period of about 40 years and thereafter it was predicted that the gravity drainage of water will stop the agricultural food production.

Members of the Peatland Working Group 1 (PLWG 1) of RSPO were encouraged by the studies by Wösten *et al.* (2006), Hooijer *et al.* (2010) and Hooijer *et al.* (2012b) and incorporated drainability assessment of peat by qualitative means as the tool in RSPO P&C in 2013. This was later refined to quantitative evaluation in RSPO P&C in 2018. Two tiers of methods of evaluation were later proposed by the peatland working group of RSPO (RSPO Drainability Assessment Procedure 2019) and tier 1 method was tested in this current case study of peat drainability assessment in Sabah. Based on the assessment as indicated in criteria 7.7, indicator 7.7.5 a time frame is to be set for future oil palm replanting and phasing out of its cultivation in peat, after the DLT for 40 years or two cycles of replanting, whichever comes first. When oil palm cultivation is phased out, the land should be converted for paludiculture or rehabilitated for natural vegetation (RSPO P&C 2018). In the present study, 895 hectares (63%) of the planted land showed peat depth is higher than depth to drainage base and 526 hectares (37%) of the land where depth to drainage base is higher than peat depth, which in the latter 37 per cent land when the peat is fully oxidised the underlying alluvium soil can be cultivated with oil palm. The essence to consider in such situation of subsidence is the quantity of greenhouse gas emissions due to oxidation and shrinkage of organic matter in the form of CO_2, which is translated to 0.91 tonne CO_2 per hectare per year per centimetre (Hooijer *et al.*, 2010). Further, if one adds N_2O and CH_4 after converting to global warming potential (GWP) emission, then 35 tonnes to 80 tonnes of CO_2 per hectare per year is expected depending on the type of peat, temperature, groundwater level etc. (Parish *et al.*, 2019). Out of 895 hectares of planted land, 204 hectares show the DLT of less than 40 years, which is about 14 per cent of the total land of 1 421 hectares evaluated. There

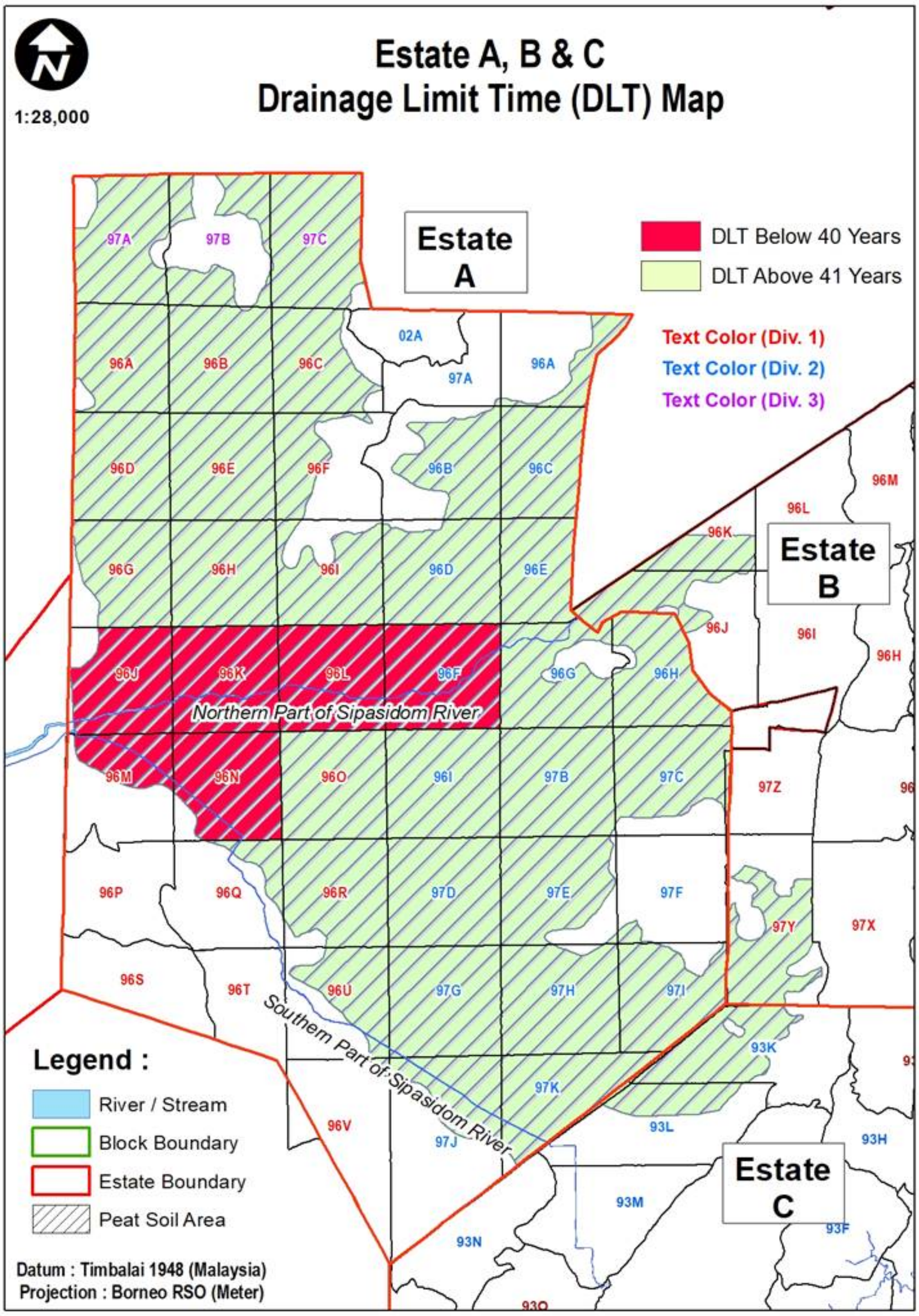

Figure 6 DLT of study site, fields showing less than 40 years for cultivation

were no actual subsidence data in the present study hence a default value at 5 cm was used for the calculation of DLT of the site. Two new subsidence poles have been placed within the vicinity of the land with DLT less than 40 years to evaluate the actual subsidence with necessary and appropriate water management programmes. The replanting for the 204 hectares has been put on abeyance to 2022 until further actual data is collected on subsidence.

Ng and Tan (1974) reported oil palm cultivation in peat in 1960s. However, their studies were focused on the complexities with regard to the foliar deficiency symptoms, nutrition and yield rather than the water management and subsidence of peat. Singh *et al.* (1986) had described the advancement and management practices of oil palm cultivation, where importance of water management of peat in oil palm cultivation had been emphasised through installing water gates and weirs at strategic locations of main and collection drains. Subsidence of peat layer is the major factor for the study of drainability assessment of peat currently being cultivated with oil palm. Wösten *et al.* (1997) in their study at Western Johore Integrated Agricultural Development Project (IADP) on ombrogenous peat showed that the analyses of peat subsidence in the initial years of measurement from 1974 was about 4.6 cm per year (standard deviation 3.0 cm per year) and subsequent measurements from 1988 was 2 cm per year (standard deviation 1.5 cm per year). These subsidence were related to groundwater management and came to the conclusion that with higher water table in peat, the subsidence can be reduced. Tie (2004) indicated a subsidence of 60 cm with water table of 75 cm to 105 cm in the first two years after opening of land for oil palm cultivation and in the subsequent years 6 cm of subsidence per annum. He also mentioned that there are continual records of subsidence at 2.5 cm per year in the subsequent years. Melling *et al.* (2005) indicated seasonal carbon flux due to climate, soil moisture and bulk density. However, such carbon flux or soil respiration in oil palm cultivated field was dominantly influenced by the higher percentage of soil water filled pore space (WFPS). Othman (2009) from his study of peat at Sessang station in Sarawak for 9 years indicated a subsidence of peat to about 29 cm in the first year due to drainage and compaction of peat in the land preparation. In the second year, the subsidence reduced to 17 cm and in the subsequent years the rate of subsidence was 5-6 cm from years three to nine. Thereafter, the subsidence rate was further reduced to 2 cm to 4 cm per year due to proper water management practices. Hooijer *et al.* (2012) studied the conversion of tropical peatlands to crop cultivation results to land subsidence and was considered as substitute measurement for the carbon dioxide emissions to the atmosphere. Their studies in *Acacia* and oil palm plantations in Indonesia mentioned that the first year of draining water in peat resulted in 75 cm of subsidence and the subsequent 4 years average subsidence rate was 16.75 cm per year. In the same study sites with a water table of 70 cm in the drains the average subsidence after the first 5 years was stabilised at 5 cm per year indicating again water management in oil palm cultivation is a vital management aspect to reduce subsidence of peat (Hooijer *et al.*, 2012a). In the RSPO Drainability Assessment Procedure for tier 1 method subsidence default value was fixed at 5 cm per year based on the study by Hooijer *et al.* (2012a), which was later reviewed by Carlson *et al.* (2015). However, with good water management it is possible to reduce the subsidence rate further from the default value. In 2018, during RSPO peatland working group workshop and field visit to an oil palm plantation in Miri had shown 10-year- old palms standing without leaning in more than 5 m deep peat with efficient water management. Ten-year-old palms standing without leaning in peat cultivation is a sign of very low subsidence. In this plantation, the drains were constructed according to contour and slopes and the structure of wooden logs were placed as weirs in a cascading manner (RSPO Workshop of PLWG 2018).

The four major subsidence were due to consolidation of peat by heavy machineries to improve bearing capacity of soil, oxidation of organic matter by decomposition process, shrinkage and by burning (Wösten *et al.*, 1997; Tie, 2004; Paramananthan, 2016). In agriculture and any crop production in peat soil, the draining of peatland water is inevitable due to high water table (Tie, 2004). Maintaining water table at 40-60 cm from ground level in the main and collection drains through installation of suitable structures made of wooden log or sand bag reduces the subsidence rate of peat. A cascading system of control structures weirs placed at 20 cm drop of terrain helps to maintain water. Such maintenance of water regularly has to be monitored through piezometer installed at strategic locations of the fields (Parish *et al.*, 2019). It again shows the need to install control infra structures like weirs at 20 cm drop of elevation. Accurate topography map is essential to understand the direction of water flow. It was estimated, that on days without rain, the water level of peat may drop to 0.5 cm to 1 cm per day which translates to 15 cm to 30 cm fall in water level in a month without rain (Parish *et al.*, 2019). The essence of this whole drainability assessment provides the growers a hint of cultivating existing oil palm in peat with no choice of maintaining high groundwater table in the collection and main drains without affecting the growth and yield of palms. Structures of graduated scales and piezometers have to be placed strategically in the fields for daily monitoring of water. Daily inspection and repairs of the structures holding water in drains become a daily routine work for oil palm growers. Dedicated water management team with their plans must be in place to monitor the maintenance of water in peat. Without these water management commitments, the growers cannot expect a long-term cultivation of oil palm on peat.

One of the weaknesses of the drainability assessment is the manipulation of the measurement itself. The whole assessment is based on the calculation using numbers. There is a possibility that the numbers of the terrain and peat depth may be adjusted to favour cultivation, thus showing that the depth to drainage base is always higher than peat depth even to the nearest waterbody. It is important to evaluate drainability on individual oil palm planted field rather than averaging and estimating the entire contiguous peatland. If the values are averaged for the entire contiguous peatland, the values of low drainage base will be hidden within the average figures. The coefficient variation between the fields in *Appendix 3* explains the same. It is unsure how RSPO is going to handle, review and verify such reports and make the study more genuine.

CONCLUSIONS

Growers who follow RSPO and are undergoing replanting of oil palm in existing peat areas have to evaluate the long-term drainability. Drainability assessment will become an important tool for growers to prepare themselves for the long-term management of oil palm cultivation on peat through prudent water management programmes. In the present study, about 1 217 hectares or 85.6 per cent of the land planted from 1993-1997 can undergo replanting in 2021 and 2022. About 204 hectares of the planted peat area need further evaluation on subsidence and is on abeyance in replanting for the time being. Topographical and peat depth surveys were more accurate in this case study. This allows the grower to plan more efficient water management programmes of peat at the time of replanting. Growers should plan the peat water management plans in such a way that subsidence is greatly reduced and the life span of oil palm cultivation on peat is extended. Thus coupled with best management practices to improve palm growth and yields in peat can be enhanced further.

ACKNOWLEDGEMENT

The authors wish to thank IOI Group for giving permission to publish this paper. The authors are thankful to the Plantation Director for having been supportive throughout the work. Work contribution from the staff of GIS/GPS and agronomy departments are also kindly acknowledged.

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APPENDIX 1

ESTIMATED DRAINAGE LIMIT TIME (DLT) OF PEAT FIELDS IN ESTATE A, DIVISION 1

Estate/ division	*Field no.*	*Peat planted area (ha)*	*Peatland elevation m-msl (Z_S)*	*Average peat depth (m) (D_P)*	*Distance (m) between waterbody outlet and oil palm planted peat centroid (ΔX_{NWB})*	*Drainage base in m-msl (Z_{DB}) = (ΔZ_{NWB} +(0.0002 x ΔX_{NWB})) (ΔZ_{NWB} in Table 2 R1= 2.7 m-msl)*	*Depth to the drainage base (D_{DB})= (Z_S-Z_{DB})*	*Drainage limit time (DLT) in year if $D_P \geq D_{DB}$= D_{DB}/S Subsidence (S=5 cm/year)*	*Years to complete subsidence of peat surface if $D_{DB} \geq D_P$= D_P /S Subsidence (S = 5 cm/year)*	*No. of years of peat layer to remain after deducting threshold of 40 years*
A /1	96A	36	8.37	5.00	2 234	2.65	5.72		100	
	96B	41	8.45	4.00	2 377	2.68	5.77		80	
	96C	32	8.72	5.20	2 647	2.73	5.99		104	
	96D	39	7.60	5.05	1 580	2.52	5.08		101	
	96E	42	7.89	4.45	1 793	2.56	5.33		89	
	96F	18	8.31	4.00	2 118	2.62	5.69		80	
	96G	34	6.60	4.75	941	2.39	4.21	84		44
	96H	42	6.41	4.05	1 277	2.46	3.95	79		39
	96I	33	5.87	4.30	1 793	2.56	3.31	66		26
	96J	36	3.55	4.50	367	2.27	1.28	26		-14
	96K	42	4.07	3.55	947	2.39	1.68	34		-6
	96L	41	4.13	2.70	160	2.23	1.90	38		-2
	96N	40	3.70	2.80	1 004	2.40	1.30	26		-14
	96O	42	5.08	3.65	1 617	2.52	2.56	51		11
	96R	39	5.87	4.25	1 896	2.58	3.29	66		26
	96U	23	5.74	4.00	2 341	2.67	3.07	61		21
Total/ mean		580	6.27	4.14	1 568	2.51	3.76	52	92	13

APPENDIX 2

ESTIMATED DRAINAGE LIMIT TIME (DLT) OF PEAT FIELDS IN ESTATE A, DIVISION 2

Estate/ division	*Field no.*	*Peat planted area (ha)*	*Peatland elevation m-msl (Z_S)*	*Average peat depth (m) (D_P)*	*Distance (m) between waterbody outlet and oil palm planted peat centroid (ΔX_{NWB})*	*Drainage base in m-msl (Z_{DB}) = (ΔZ_{NWB} +(0.0002 x ΔX_{NWB})) (ΔZ_{NWB} in Table 2 R1= 2.7 m-msl)*	*Depth to the drainage base (D_{DB})= (Z_S-Z_{DB})*	*Drainage limit time (DLT) in year if $D_P \geq D_{DB}$= D_{DB}/S Subsidence (S =5 cm/year)*	*Years to complete subsidence of peat surface if $D_{DB} \geq D_P$= D_P /S Subsidence (S = 5 cm/year)*	*No. of years of peat layer to remain after deducting threshold of 40 years*
A /2	96B	30	5.35	3.10	2 720	2.74	2.61	52		12
	96C	33	6.45	4.75	3 244	2.85	3.60	72		32
	96D	44	5.25	3.65	2 407	2.68	2.57	51		11
	96E	28	5.27	4.05	2 951	2.79	2.48	50		10
	96F	45	4.38	3.40	2 248	2.65	1.73	35		-5
	96G	37	5.56	3.90	2 937	2.79	2.77	55		15
	96H	35	6.35	4.50	3 559	2.91	3.44	69		29
	96I	46	5.98	4.10	2 268	2.65	3.33	67		27
	97B	46	6.67	4.50	2 953	2.79	3.88	78		38
	97C	37	6.83	4.70	3 646	2.93	3.90	78		38
	97D	45	6.87	4.20	2 471	2.69	4.18	84		44
	97E	39	7.41	4.05	3 114	2.82	4.59		81	
	97G	46	6.91	3.85	2 821	2.76	4.15		77	
	97H	47	7.56	3.90	3 399	2.88	4.68		78	
	97I	34	7.70	3.85	3 966	2.99	4.71		77	
	97K	38	7.21	4.20	4 638	3.13	4.08	82		
Total/mean		630	6.27	4.14	1 568	2.51	3.76	64	78	23
A/3	97A	39	7.90	4.40	2 958	2.79	5.11		88	
	97B	24	8.36	4.05	2 880	2.78	5.58		81	
	97C	45	8.41	5.30	3 278	2.86	5.55		106	
Total/mean		108	8.22	4.58	3 039	2.81	5.42		92	
Total/mean of Estate A (Appendices 1 and 2)		1 318	6.95	4.26	2 564	2.71	4.24	58	87	18

APPENDIX 3

ESTIMATED DRAINAGE LIMIT TIME (DLT) OF PEAT FIELDS IN ESTATE B, DIVISION 2 AND ESTATE C, DIVISION 1 AND OVERALL MEAN FOR ALL THE THREE ESTATES A,B, AND C

Estate/ division	*Field no.*	*Peat planted area (ha)*	*Peatland elevation m-msl (Z_S)*	*Average peat depth (m) (D_P)*	*Distance (m) between waterbody outlet and oil palm planted peat centroid (ΔX_{NWB})*	*Drainage base in m-msl (Z_{DB}) = (ΔZ_{NWB} +(0.0002 x ΔX_{NWB})) (ΔZ_{NWB} in Table 2 R1= 2.7 m-msl)*	*Depth to the drainage base (D_{DB})= (Z_S-Z_{DB})*	*Drainage limit time (DLT) in year if $D_P \geq D_{DB}$= D_{DB}/S Subsidence (S =5 cm/year)*	*Years to complete subsidence of peat surface if $D_{DB} \geq D_P$= D_P /S Subsidence (S = 5 cm/year)*	*No. of years of peat layer to remain after deducting threshold of 40 years*
B/1	96J	18	5.14	3.80	3 824	2.96	2.18	44		4
	96K	13	5.24	4.50	4 033	3.01	2.24	45		3
	97Y	31	7.93	3.63	4 406	3.08	4.84		73	
Total/mean		62	6.10	3.98	4 088	3.02	3.09	45	73	4
C /2	93K	28	7.86	4.85	4 638	3.13	4.73	95		55
	93L	13	7.51	4.20	4 252	3.05	4.46		84	
Total/mean		41	7.68	4.53	4 445	3.09	4.59	95	84	55
Grand total/mean of the entire site study		1 421	6.51	4.14	2 618	2.72	3.79	59	87	19
Standard deviation of the entire site study			1.43	0.58	1 112	0.22	1.34	19	10	19
Coefficient of variation (CV)%			22	14	42	8	35	32	11	100