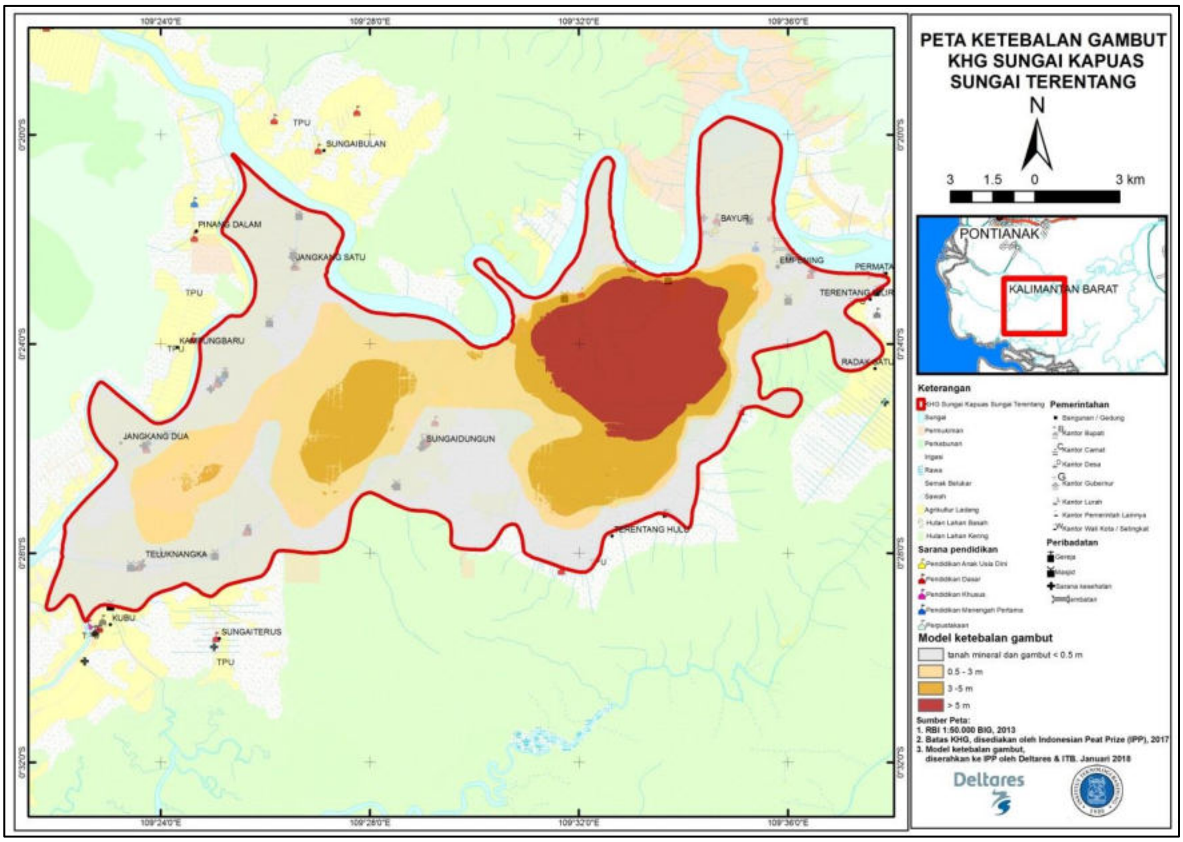
Peatland mapping for Kubu Raya, West Kalimantan, using limited LiDAR data and peat thickness field measurements



Submission by Deltares and ITB (Team Deltares)
to
Indonesian Peat Prize

Indonesian Peat Prize – Final Phase

Final Report, January 2018

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Scientific Abstract

For two study areas of 54,133 and 23,681 ha respectively in Bengkalis (Riau Province) and Kubu Raya (West Kalimantan Province), peat extent and peat thickness (PT) models are created from limited LiDAR data along separate parallel flight lines (30.2% and 29.9% area coverage, respectively) and field PT measurements collected for the study area. High R^2 values of 0.84 and 0.90 respectively were found between surface elevation and PT, with regression relations approaching unity (1:1) confirming that the peat bottom is relatively flat and close to Sea level as is often the case in coastal peatlands, where peat development started from river floodplains and mangroves some 5,000 years ago. Surface elevation DTMs were created from the LiDAR data, and PT measurements were subtracted to derive a peat bottom (PB) elevation model applying and comparing three different methods. The result of the simplest model, assuming a flat PB at 0.61 and 0.27 m +MSL respectively for the two areas, was found to be as accurate as the results of more complex approaches, while requiring less survey and analysis effort with as few measurements as ~40 (1 per 640 hectare) being sufficient. The accuracy of the peat thickness map for Kubu Raya was validated using an independent dataset of 65 field measurements. The difference between peat map and validation data was on average 0.15 +/- 0.55 m, with 64.6 and 93.8 % of validation points being within 0.5 and 1 m respectively from the model. From this and other studies we conclude that this simple method will allow sufficiently accurate peat thickness maps for 75 to 90 % of peatlands in Sumatra and Kalimantan; maps for most of East Sumatra are being produced on this basis at present. In 10 to 25% of peatlands, peat bottom is more complex and denser field surveys are required, which can be developed in a stepwise approach. It was determined that the peat bottom is below 2 m +MSL (current coastal high tide level i.e. minimum flood level) in 94.7 and 100 % of the areas respectively, and below MSL in 56.5 and 9.8 %, indicating that most if not all of these peatland areas may be subject to frequent or permanent future flooding if peat loss due to drainage continues. Total cost of LiDAR and field data collection and analysis for both the Bengkalis and Kubu Raya study areas has been near 1 US$ per ha of actual peatland area, indicating that all peatland in Sumatra and Kalimantan (or around 15 Mha in total) could be mapped for around 15 Million US$. It is demonstrated that the LiDAR data can also be used to determine canal water table depth (CWD) below the land surface, which provides useful data for water management aiming to reduce peat loss and subsidence; it is found that CWD in the study areas is more than 0.5 m below the peat surface along 84.1% and 64.1% respectively of canals during the LiDAR survey in the wet seasons of 2016 and 2017, and would therefore be expected to be >1 m in the dry season, which will cause excessive peat loss and fire risk.

Summary and Conclusions

In this report, the application to a study area in Kubu Raya (West Kalimantan) of the method for peatland mapping as applied by Deltares and ITB is submitted to the IPP (Indonesia Peat Prize) organization. The method builds on past work by Deltares and others in research and advisory projects that required peat mapping in Indonesia (since 2007), with the aim of not only yielding a sufficiently accurate result but also of doing this quickly and economically. In our experience, this requires three main elements:

- the use of elevation models (DTMs), applying LiDAR data where possible,
- peat thickness (PT) field surveys that are limited in scope where possible but meet the highest quality standards,
- and an understanding of peatland genesis and morphology that allows insightful interpretation of the data.

Airborne LiDAR data provides the fastest and most accurate way to creating DTMs over large areas, while also providing useful information on vegetation and canal water depth. In our experience however, LiDAR data can often not economically be collected at full coverage as this would cost tens of millions of dollars if applied to all peatland in Indonesia (maybe hundreds of millions if repeat measurements are required for monitoring, as we propose) and years of data collection and processing. The funding and the time required for repeated full coverage LiDAR data collection are likely not available in time for preserving remaining peatland resources (carbon and forest) in Indonesia, as peatland degradation proceeds year by year and peatland related policies evolve rapidly. Therefore in our projects we apply a method that allows generation of elevation models from LiDAR data collected along ‘flight strips’ that cover only 10 to 30 % of the area, and manual support of interpolation, as explained in Section 2.1.4. Combined with competitive bidding for LiDAR data collection at the very large scale, this can result in a reduction of cost and data collection time by a factor 10 to 25 compared to full coverage collection over small areas, while also speeding up the process by months to even years. As the Kubu Raya study area was found to be unusually small and quite complex in morphology, a relatively high LiDAR coverage of 29.9 % was applied in this case.

LiDAR data following this method has in 2014, 2015, 2016 and 2017 been collected over most of East Sumatra lowland and parts of West Kalimantan lowland (Section 1.2; Figure 1), resulting in coverage of 5.1 Mha of LiDAR data over a total of more than 30,000 km of flight lines. Most of this coverage is over lowland peatland. The resulting DTMs will be available in the public domain for further use in mapping initiatives.

To minimize cost and effort peat surveys in the field were optimized by conducting them [a] along transects perpendicular to coast and streams and going up the peat slopes (Figure 3), [b] starting transects near the expected peat extent boundary mapped based on existing maps and visual interpretation of satellite data (Figure 16), and [c] ending surveys where PT was found to exceed some 7 m (Figure 4). Measurement quality was assured by having the peat/mineral interface in augers photographed at all locations (time and location verified) and having multiple replicates for averaging and error rejection. A total of 147 average measurements were collected of which 111 had peat over 0.5 m in depth (Table 2). The field survey report and SOP are presented in Annex 1 and 2.

Peat extent was delineated from the DTM, modified somewhat to match available measurements of peat presence and absence as well as existing peat maps and clear indications of peat presence/absence in Landsat satellite images. It was found that the four data sources are in close agreement.

PT models were derived by subtracting peat bottom (PB) models from the DTM (Section 2.5). The first method ('Method 1') of PB model creation was to interpolate a surface model between measurement points. 'Method 2' assumes a flat horizontal PB surface determined from the average of available data. 'Method 3' applies a regression equation between DTM and available PT data.

A very close relation (R^2=0.90) was found between PT measurements and LiDAR based DTM (Figure 14). PB points are 0.27 m +MSL on average with a standard deviation of 0.54 m and with 92.8 % of 111 points being between +1 and -1 m +MSL (Table 2). This all confirms that the peat bottom in the study area is very flat indeed as we find to be the case in most coastal peatlands in Indonesia. As a consequence, the result of the three methods is nearly identical. The simple 'Method 2' assuming a flat peat bottom will therefore suffice in this area as in many areas, including large uniform peat domes that tend to be still partly forested so peat thickness data are often scarce and hard to obtain. It is recognized however that there are exceptions, with some 10 to 25 % of peatlands having irregular peat bottoms; in such areas a greater density of field surveys will be needed and the peat bottom should be determined from 'Method 1' if maximum accuracy is required.

However we discuss that, where the peat bottom is below permanent water level, the bottom peat will never be available for oxidation (Section 5.1). In such areas, it may be considered whether it is always necessary to know the exact peat thickness within 0.5 metre or whether accuracy requirements can be somewhat reduced – especially when it involves large peat domes that are largely covered by protected forest. The same applies to peat thickness over 7 m, the bottom peat of which will not be available for fire or oxidation for well over a century. We therefore suggest that the accuracy requirement for peat thickness mapping may be adjusted according to peat thickness and likely position of the peat bottom, as well as land use and planning requirements. Field efforts may be reduced in large inaccessible peatland areas where peat is clearly very deep. In our experience this can greatly reduce the time and effort required for peat mapping as efforts can be focused on those areas where urgency and requirements are greatest.

We demonstrate that the peat thickness model for Kubu Raya could have been achieved with far less field measurements than were collected in our study for validation and research purposes. Any collecting of some 40 data points along well selected transects would have yielded a peat bottom within 0.1 m difference. We therefore submit to IPP the result of an effort using 37 data points, compared with a larger dataset of 147 data points (Figure 20).

The accuracy of the resulting peat thickness map was assessed using an independent validation dataset of 65 field measurements collected at the same time as the measurements used to create the peat thickness map (Figure 22). The resulting difference between peat map and validation data was 0.15 on average with a standard deviation of 0.55 m, with 64.6 % of validation points being within 0.5 m from the model and 93.8% of the measurements within 1 m.

We find that peat covers 45.7 % of the Kubu Raya study area. PT exceeds 3 m for 53.3 %, 54.2 % and 56.0 % of the peat area respectively according to the three different methods (Table 4).

The DTM resulting from LiDAR data shows that 26.9 % of the study area (including mineral soil areas) is now below 2 m +MSL (approximately high tide level) and 70.9 % below 4 m +MSL (approximately the highest possible flood level). It is therefore a very low-lying area, with the lowest areas already being prone to flooding. In future, if peat continues to be lost (following drainage) and as Sea level rises, almost the entire area will be severely flood prone or may even be lost to the Sea permanently after peat is fully removed, with the peat bottom everywhere below 2 m + MSL and with 9.8% of it being below current Mean Sea Level (Section 3.10).

It is demonstrated that canal water table depth (CWD) relative to the surrounding land surface can be mapped from LiDAR data. During the measurement on 5 October 2017, CWD in LiDAR strip coverage over peat in the study area is in the ranges of 0-0.5 m, 0.5-1 m and >1 m below the peat surface in 35.9 %, 41.5 % and 22.7 % of cases respectively. The substantial area with canal water table depth well over 0.5 m in wet season conditions suggests that water levels will drop well below 1 m in the dry season in much if not most of the area, enhancing peat loss and fire risk. In such areas, water management improvements are required. We propose that regular repeat LiDAR surveys over selected flight lines can offer a robust monitoring mechanism alongside ground measurements.

Airborne LiDAR data were collected within 1 day of flying. Survey duration for 37 points was 4 days at an overall survey average of 10 measurements per day (including replicates) with 2 survey teams. The time required for design, training, mobilization and demobilization is not included in these time estimates, as this would not be relevant if the work had been done as part of a comprehensive large scale mapping effort as is the ultimate goal.

The cost of peatland mapping over the Kubu Raya study area of 23,691 ha has been 7,100 US$ for collecting LiDAR data (excluding mobilization costs) and 1,389 US$ for field surveys (37 data points). The cost of data processing, analysis and reporting is hard to determine as this will be much reduced when applying this method at the large scale, but this will be below 50 % of the cost of data collection (LiDAR + field) in a normal assignment (without the scientific analyses and cross checks applied in this study for IPP). An estimate of 25 % is reasonable in our experience. The total cost of mapping of the study area is therefore 10,611 US$, or 0.45 US$ per hectare (0.99 US$ per hectare of actual peatland; Table 7).

1 Introduction

1.1 The need for improved peat extent and thickness maps for Indonesia

It is well documented that Indonesia has extensive peatland cover, especially in the coastal lowlands of Sumatra, Kalimantan and Papua. Peat maps for some areas have existed for more than 100 years, and the first comprehensive and consistent nationwide map was produced by the Regional Physical Planning Programme for Transmigration (RePPProT) project (RePPProT, 1990). A map by Puslitanak (Ministry of Agriculture) was published by Wetlands International in 2003-2006 (Wahyunto *et al.*, 2003, 2004, 2006), followed by a derived map published in 2011 by BBSDLP (Ministry of Agriculture; Ritung *et al.*, 2011).

An assessment of the accuracy of the latter 2 maps (Puslitanak and BBSDLP), funded by Netherlands Government, was published by Deltares in 2013 (Hooijer and Vernimmen, 2013). It was found that while peat thickness information provided by existing maps is very poor, peat extent in most areas is actually quite well known, actually no worse than in other regions with major peatland extent including Russia and Canada. The location and extent of all major peat areas in Sumatra and Kalimantan is indicated on existing maps, but questions do exist on exact boundaries, of the peat and especially of deep peat. The 3 m peat thickness boundary, that has legal implications and is often considered as the 'deep peat boundary', is particularly poorly known.

The existence of fairly accurate maps of peat extent, by international standards, presents an advantage to efforts to better map peat thickness. Existing peat boundaries can be used as a starting point for map improvement.

When improving peatland maps for Indonesia, it is important to understand priorities and deal with highest priorities first. The first priority is to generate maps that allow land use zoning at the landscape scale, distinguishing agri/silvicultural production areas (plantations and smallholders) and remaining conservation/restoration areas for natural peat swamp forest. These maps will also support redesign of water management systems at the landscape (i.e. meso-) scale. In our view this meso-scale mapping needs to be done very rapidly in support of current Government initiatives to reduce fire risk and carbon emissions, yet it does not require the highest level of detail and accuracy that may take years to achieve. After the initial overall mapping for zoning purposes is done, it will be easier to create more detailed maps where needed for detailed planning and design purposes. By creating separate products that are 'fit for purpose', rather than aiming to achieve perfection in a first edition product, the process can be speeded up and resources can be applied where they are most needed to meet priorities.

1.2 Background to Deltares peatland mapping method

Deltares, with partners, has been involved in large scale peat mapping in SE Asia since 2007, starting with the mapping of the Ex Mega Rice Project (EMRP) area in the CKPP project (2005-2008), with Wetlands International, which relied mostly on field surveys along 1,350 km of transects (Silvius *et al.*, 2007). It was found that field surveys alone are not the most suitable approach to peatland mapping because of the vast scale and poor accessibility of the areas involved, difficulties in making field teams follow strict protocol under difficult conditions, and high financial and time requirements. Mapping results based on field surveys alone are often poor in our experience.

Since 2007, Deltares has been pioneering the use of LiDAR data in peat mapping. In the KFCP project (2010-2014) full LiDAR coverage over much of the EMRP area was collected in 2011[1] at very considerable cost and time investment (Figure 1). It was then found that for most purposes, including peat mapping and water management, such full coverage data is neither affordable nor required. Instead, it was found to be possible to collect data along parallel flight lines and create elevation models and derived models though interpolation. A first application of this method in 2014, with Wetlands International and UGM, has been for the Kampar Peninsula in Sumatra (Hooijer *et al.*, 2015b).

LiDAR data has from 2014 to 2017 been collected over most of East Sumatra lowland and parts of West Kalimantan lowland (Figure 1), following the 'strip' method described in this report, mostly funded by Asian Pulp and Paper (APP, over its *Acacia* plantations and surrounding landscapes) and by UKCCU (over much of South Sumatra) with other organizations (funding smaller areas of specific interest). First data over these areas was collected in June 2014 (Hooijer *et al*. 2015b), followed by April-May 2015[2], October 2016 - March 2017 and October 2017, the latter also covering the Kubu Raya study area (Figure 2). By the end of 2017 this has resulted in coverage of 2.0 Mha of LiDAR data over a total of more than 30,000 km of flight lines. Most of this coverage is over lowland peatland.

1 http://www.forda-mof.org/files/4._LIDAR.pdf
2 https://www.deltares.nl/en/projects/lidar-data-large-scale-peatland-management-flood-risk-assessment/

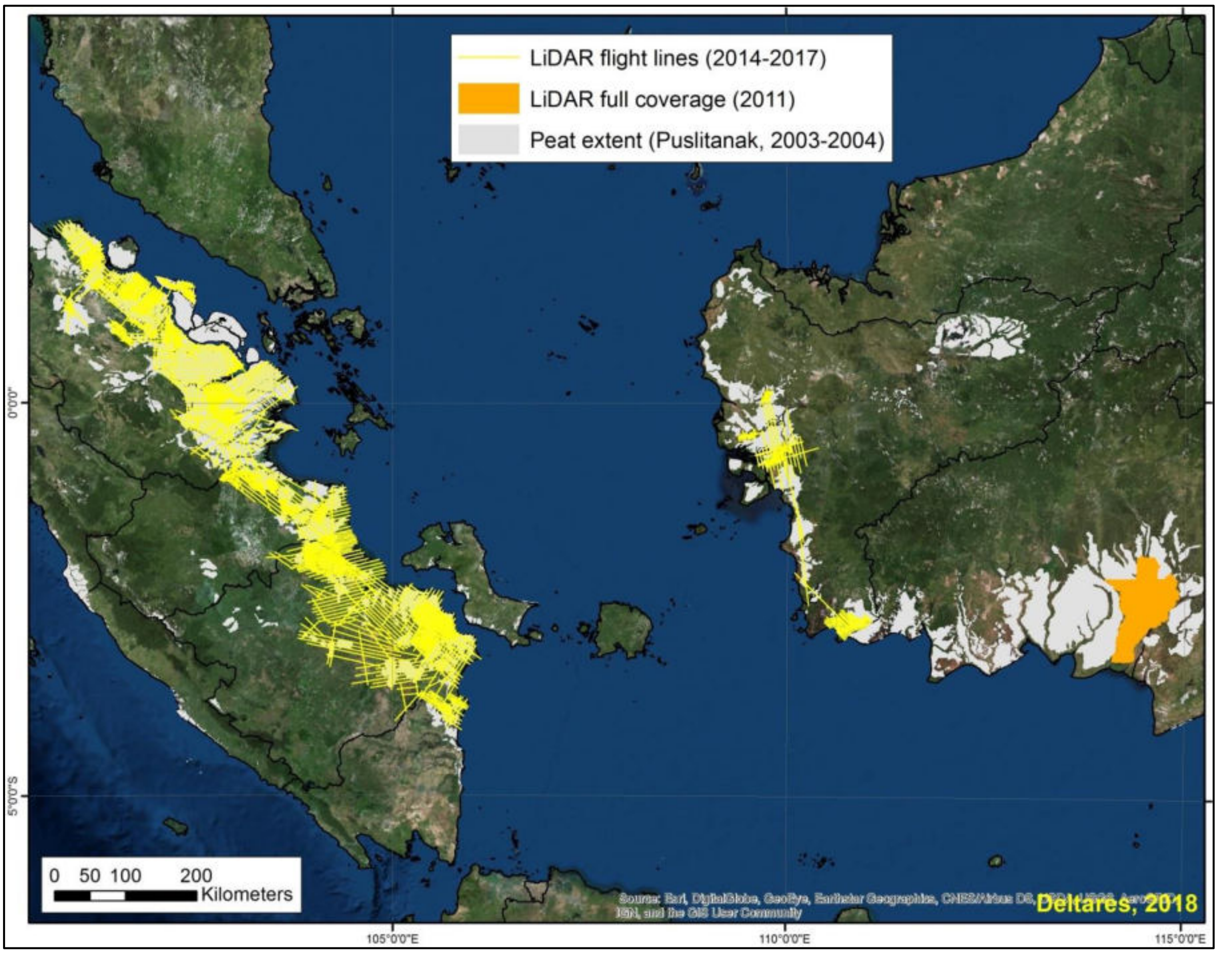


Figure 1 LiDAR flight line coverage over East Sumatra and Kalimantan lowland acquired in 2011 and 2014-2017, in projects that Deltares and partners were involved in. More coverage is available from other projects.

By collecting selective LiDAR data over large areas, and by allowing competitive tendering by multiple different provider companies, the cost of LiDAR data collection is reduced by between 10 and 25 times compared to full coverage data over small areas.

The method proposed in this IPP submission and applied in ongoing management support projects is an iterative process. The first stage is rapid data collection and rapid production of maps with relatively limited data. The resulting maps are considered sufficiently accurate for most purposes in most areas, but possibly not for all detailed design purposes in all areas. The second stage focusses on refining the results for areas of specific interest where necessary. In several smaller areas in East Sumatra, LiDAR data have been collected at denser and even full coverage to answer specific client questions, following a first round of mapping with limited data.

Through this two-stage approach, obtaining a big picture first and generating a spatial framework in which to later place detailed studies where this is found ‘fit for purpose’, major reductions in time and resource requirements can be achieved compared to an approach that requires uniform high data coverage in all areas even if the result far exceeds the 'fit for purpose' requirement.

The LiDAR data are used in generation of DTMs, that are applied in lowland flood risk assessments and peat thickness mapping, as well as assessments of subsidence and canal water depth (from repeated data collection) and vegetation characteristics and used as base models for drainage and irrigation design (from DTMs). Of particular interest is that some of the data over peatland was collected over the same strips before and after the 2015 fires, allowing accurate assessment of fire impacts including loss of peat and carbon.

Accounting for all land that is within 2.5 km from a LiDAR strip, current LiDAR coverage of peatlands in East Sumatra and Kalimantan by projects involving Deltares now suffices to produce elevation models over some ~5 Mha of peatland from ~2 Mha of actual LiDAR coverage. Most of these elevation models equal the accuracy achieved over the Kubu Raya and Bengkalis IPP study areas. Where sufficient validation peat thickness field measurements are available, peat thickness mapping will therefore also equal that in these study areas. In some areas however, peat thickness mapping is complicated by irregularities in the peat bottom or sudden changes in peat surface elevation; in such areas, additional LIDAR and/or field data can be collected later to refine models.

The LiDAR based DTMs produced by Deltares will be available in the public domain for further use in mapping initiatives. We invite others to use this framework as a starting point for further improvement of maps, collecting additional data (LiDAR and field measurements) where necessary.

1.3 Using a LiDAR based DTM for peat thickness mapping

The fundamental assumption of the LiDAR-based peat mapping method applied by Deltares and ITB is that the bottom of the peat deposit, i.e. the top of the underlying mineral soil (usually clay or sand), is relatively flat compared to the top of the peat deposit. We have found this to be the case in many coastal peat locations in Indonesia, which is explained by the peat having formed on top of a mostly flat terrain of floodplains and mangroves, starting some 5,000 years ago. However, the assumption does not always hold for inland peat deposits (so-called valley peat) where the peat in some cases has formed on top of a pre-existing hilly landscape well above MSL, nor for some locations along major rivers where old river channels are filled with peat (sedimented detritus or 'gyttja') well below MSL.

1.4 Study area

The study area is located in Kubu Raya district (West Kalimantan Province) and covers an area of 23,681 ha (Figure 2).

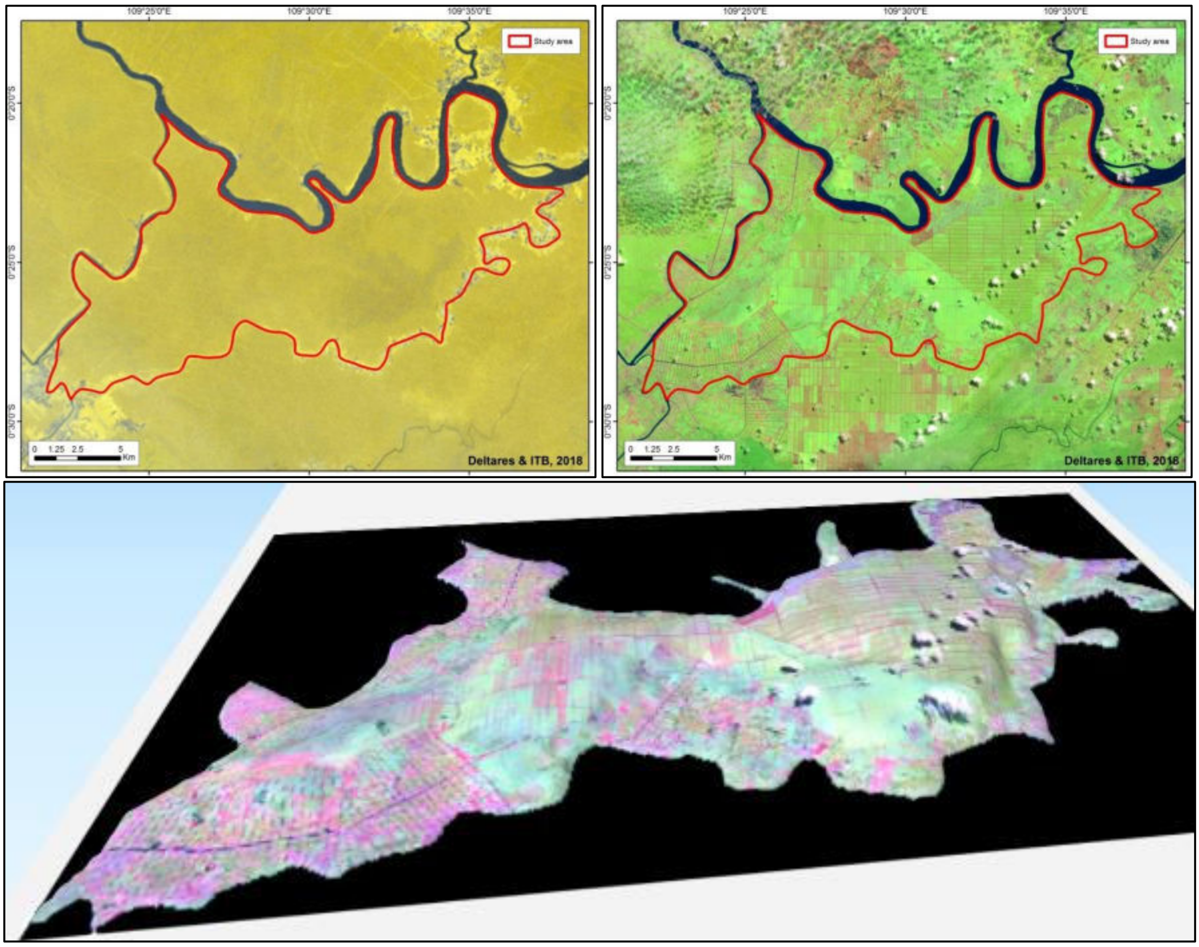


Figure 2 Study area in Kubu Raya district (West Kalimantan Province). In the background a RGB composite (TOP LEFT) Landsat-1 image of 12 September 1972 (spectral bands 7-6-5) and (TOP RIGHT) Sentinel-2 image of 22 April 2017 (spectral bands 11-8-5). (BOTTOM) A 3D representation of the DTM presented in Figure 10 with the Sentinel-2 composite image of 22 April 2017 superposed on it. It is evident that the area was entirely forested some 40 years ago, but this forest has now been cleared entirely and given way to drained agricultural landscapes.

1.5 This report

This report consists of 2 parts. The main report is in the format similar to a scientific paper, aiming to be concise and relatively brief. Annexes 1 to 4 provide a detailed report of the peat thickness field survey carried out during this study including the SOP used and provides the resulting field data. In Annex 5 and 6 the peat map resulting from this study is provided at 1:50,000 scale.

2 Methods and materials

2.1 LiDAR data and DTM generation

2.1.1 LiDAR data collection partner

The company contracted to collect LiDAR data (PT. Surtech) was selected in a competitive bidding process to which four companies were invited, on the basis of quality of proposal, proven experience and cost. The work was offered as part of a much larger package of LiDAR data collection over Sumatra and Kalimantan over 2015-2017, allowing bidders to lower unit cost and increase efficiency.

2.1.2 LiDAR data collection design

Peat extent was first visually identified from Landsat images, showing drainage and vegetation patterns that in our experience are likely to indicate peat, as well as from existing peat maps. LiDAR flight lines were then designed to cross peat boundaries and rivers at perpendicular angles (Figure 3) to extract the maximum of information from a minimum of coverage and cost. As the Kubu Raya study area consists of a relatively small peat dome with steep sides, strips were placed at 2.5 km intervals[3] where the presence of peat was expected.

LiDAR data over the study area were collected on 5 October 2017. Overall LiDAR coverage over the study area is 71 km^2 or 29.9 % of the study area. Cost of LiDAR data collection over the study area was 7,100 $US (excluding mobilization costs) at a unit cost of 1.00 US$/ha.

[3] Strip intervals are measured between the centre lines of flight lines. In other areas with larger and simpler peat domes, LiDAR strip intervals of 5 km suffice in our experience, for peatland mapping at the landscape scale.

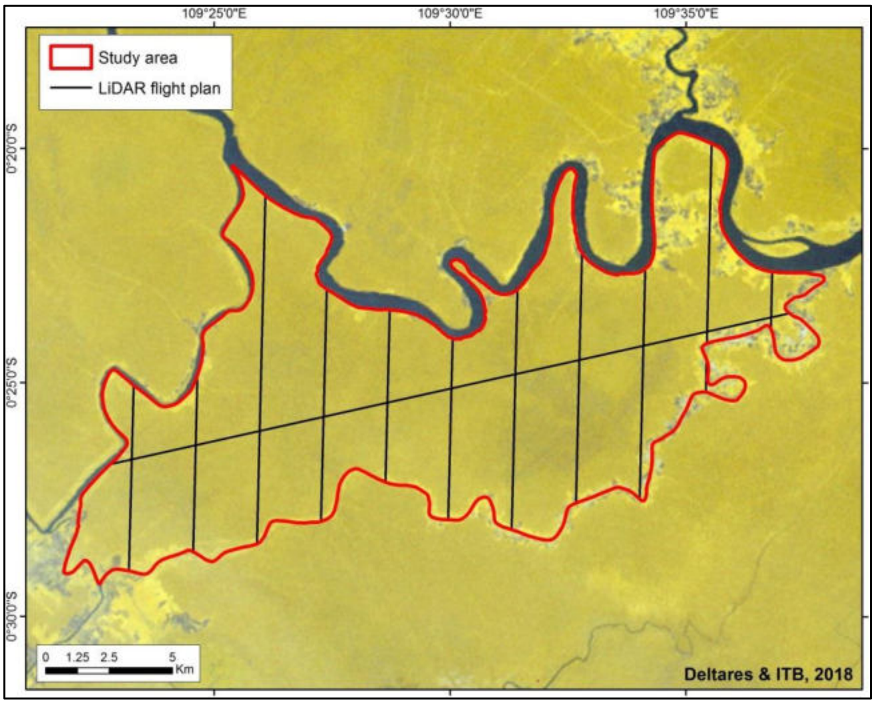


Figure 3 LiDAR flight plan over Kubu Raya study area as designed using existing peat extent maps, historical Landsat imagery (using vegetation patterns indicating presence of peat) and location of rivers. In the background the RGB composite Landsat-1 image of 12 September 1972 (spectral bands 7-6-5) used. LiDAR flight line spacing, as measured between centre lines is mostly at 2.5 km in this study. The East-West line is required to connect the North-South lines.

2.1.3 LiDAR data filtering

LiDAR data were filtered applying the well-established progressive morphological filter algorithm (Zhang *et al.*, 2003) implemented in Julia programming language[4] by Deltares, removing vegetation signal to create a layer that presents the soil surface. The applied filtering method will be published scientifically in coming months. However, it should be noted that the accuracy of the filtering method applied here does not differ substantially from those used in other initiatives, including the TerraScan commercial software[5] that is most widely used.

2.1.4 Creating a DTM from LiDAR data along strips

Contour lines of soil surface elevation at 0.5 m intervals were drawn manually between filtered LiDAR strips. In areas with elevation below 2.5 m +MSL additional contour lines were drawn at 0.25 m intervals. A recent (April 2017) composite Sentinel-2 image was used to extract further information on likely peat dome morphology, guiding the location of contour lines in some locations. A DTM (Digital Terrain Model i.e. surface elevation model) was created by Inverse Distance interpolation between LiDAR strip data and contour lines.

4 https://julialang.org/
5 https://www.terrasolid.com/products/terrascanpage.php

2.2 Field data collection of peat thickness

A detailed report on the peat survey and budget is included in Annex 1.

2.2.1 Field survey design

Survey transects were designed to cross the peat dome at perpendicular angles to extract the maximum of information from a minimum of data points. Transects started where no peat was expected to be found and along easy access points such as roads or canals, and extended up the dome to where peat was expected to be deep according to the DTM (Figure 4). At the edge of the dome, measurements were generally taken at 200 m intervals to accurately capture the steeper slopes of the dome, whereas going up the dome where slopes are much smoother, measurements were taken at 500 m intervals. In Figure 5 the survey design is presented.

The peat thickness field survey was conducted in the period 1 to 24 November 2017 (preceded by training and trials), by 2 field teams working in parallel supervised by experts from Deltares and ITB.

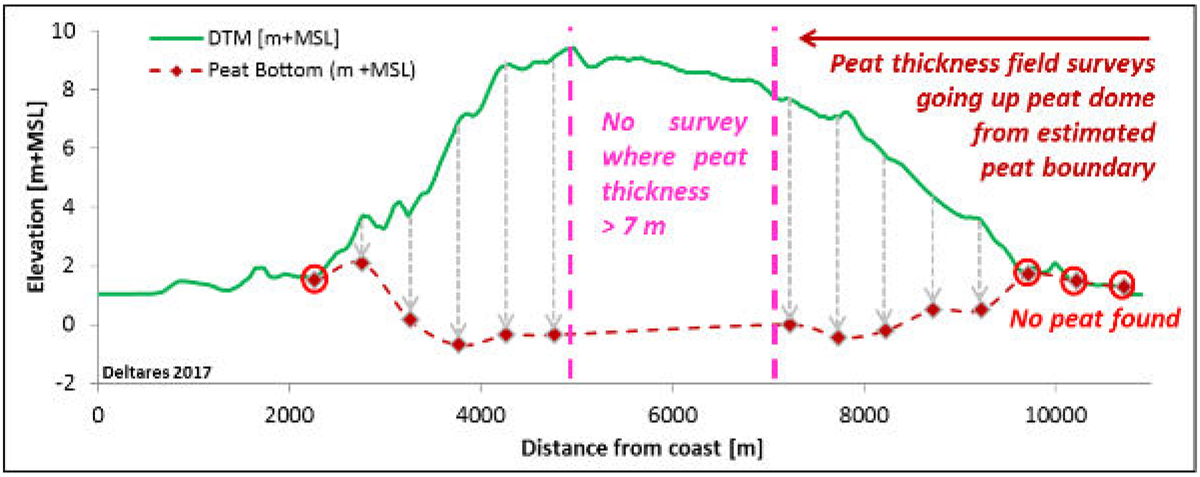


Figure 4 General schematic set-up of an effective and cost-efficient peat thickness survey. Surveys are planned perpendicular to coastlines and river as much as possible, which often matched the steepest slope of the peat dome. To reduce the number of sampling points in areas without peat, surveys start at a 'likely peat boundary' that is identified from satellite images. To reduce the number of measurements in areas where very deep peat is known to be present without further survey, surveys along transects end when a certain peat thickness limit is reached (in this schematic illustration 7 m, but sometimes a 5 m limit can be applied, depending whether the peat domes are small and steep or large with more gradual slopes).

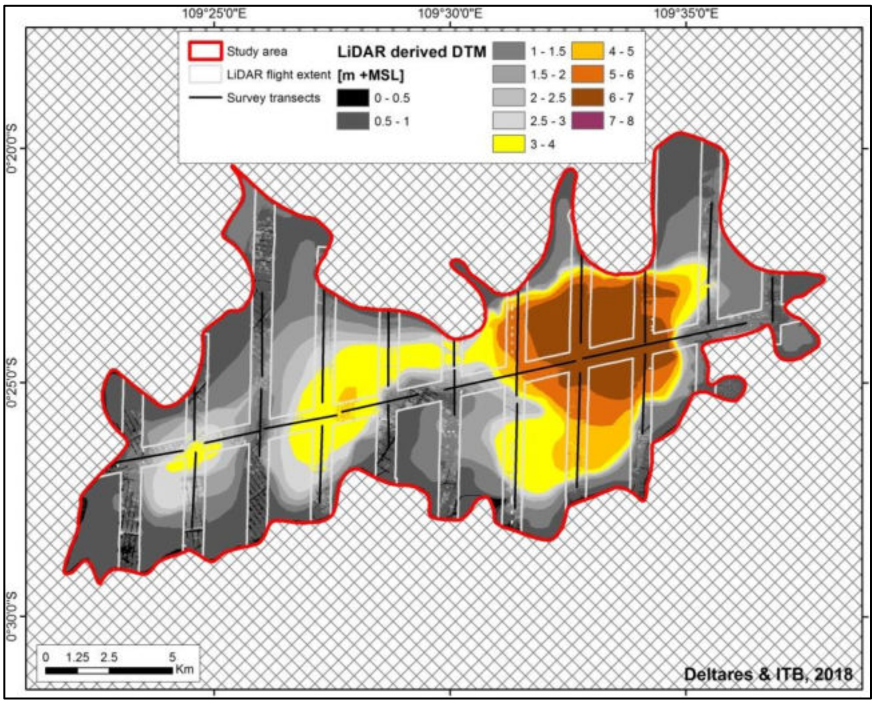


Figure 5 Peat thickness survey design along 25 transects, starting at areas where no peat was expected going perpendicular up the dome. In the background DTM generated from the LiDAR strip data (Figure 10).

2.2.2 Survey protocol

The peat thickness field survey was carried out following a field protocol (SOP; Annex 2). Peat thickness was measured using an Edelman type auger. Replicate measurements were taken at every sample location within 1 to 5 m of each other, to be able to investigate variation and error sources. The peat thickness measurement used for analysis was the average of the replicate measurements.

Vegetation cover and land use was documented at each survey location and photographed in four directions. The mineral subsoil that was trapped in the auger was photographed as well as evidence that the peat bottom had been reached.

2.3 Comparing LiDAR DTM and peat thickness measurements

The surface elevation above Mean Sea Level was derived from the LiDAR derived DTM, for all peat thickness measurement locations. DTM values were then plotted against peat thickness measurements and the regression was determined. The coefficient of determination (R^2) was calculated as a measure of how well peat surface elevation can be used as a proxy for peat thickness.

2.4 Mapping peat extent

Where we usually find historical remote sensing imagery useful for visual interpretation of the peat extent from vegetation patterns, we found this not to be the case in this area as extensive areas were still forested in 1972 (Figure 2) but peat boundaries do not come out clearly (Figure 12). Instead, we mapped likely peat extent by applying the 2 m +MSL contour line determined from the LiDAR derived DTM (Section 2.1). In some areas the resulting extent was manually corrected using the collected peat (and no peat) thickness measurements (Section 2.2).

2.5 Creating a peat bottom elevation model

As input to the peat thickness model, and to gain understanding of the future flood risk in a scenario where all peat is removed from the area due to oxidation and fires (both inevitable consequences of peatland drainage), a model was constructed of the elevation of the peat bottom, i.e. the top of the mineral substrate below the peat, relative to Mean Sea Level and tidal range. Three types of peat bottom models were constructed. The first method creates a non-uniform peat bottom layer by subtracting actual field peat thickness measurements from the LiDAR based DTM (Figure 13) after which a peat bottom map is created by inverse distance interpolation between the resulting peat bottom elevation points. The second method applies a constant horizontal peat bottom elevation surface near Mean Sea Level based on the average peat bottom elevation determined from peat thickness measurement locations. The third method applies a linear regression relationship between peat surface elevation and peat thickness measurements.

2.6 Creating a peat thickness model

Peat thickness models were created using the LiDAR based peat surface DTM (Section 2.1) and the peat bottom maps (Section 2.5). Peat thickness is determined as the difference between peat surface and peat bottom as illustrated in Figure 6.

As three peat bottom maps were created, this results in three peat thickness maps.

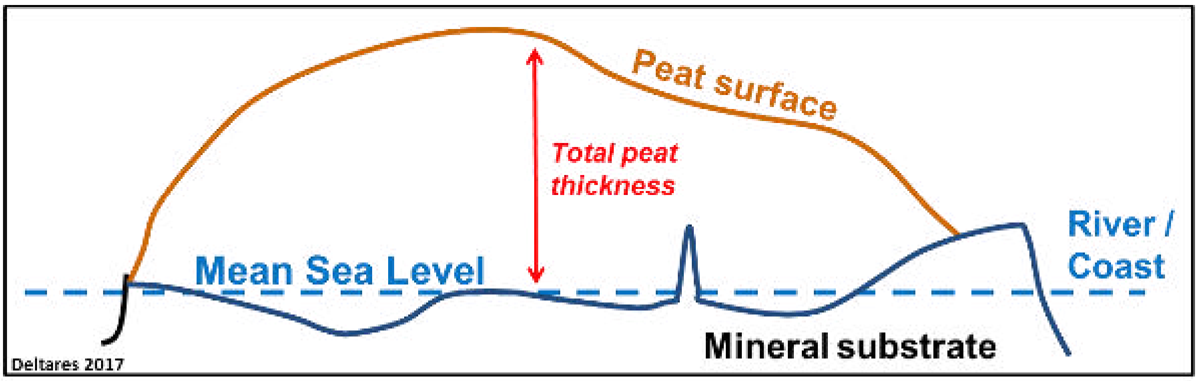


Figure 6 Illustration of how peat thickness is determined as the difference from the peat surface and depth of the peat bottom (interface with the mineral substrate).

2.7 Peat thickness map validation

A separate peat thickness field dataset was collected during the same period as data collection for the map creation (1-24 November 2017) to allow validation of the map result.

2.8 Assessment of current and future flood risk

In the absence of accurate and recent water level data for the area, and in the limited scope of this assignment, it is not possible to produce a detailed flood risk assessment here. This will be done when this study is published. However, it is possible to predict how much of the area would be flooded in future if peat surface subsidence and Sea Level Rise continue. The principles applied have been published before, detailed descriptions can be found in Hooijer *et al.* (2015ab).

Current flood risk is assessed for the amount of land which is currently (2017) below 2 m +MSL, which corresponds to highest tide along the coast, and will therefore be frequently flooded by river water. Extreme flooding (by a combination of tidal levels and high discharges from upland areas) occurring less often are determined from river levee levels which are determined from two LiDAR flight lines which crossed the Kapuas River bordering the Kubu Raya study area in the North. As river levees are deposited by sedimentation of sand from flood waters, they provide an indication of minimal flood levels. Actual peak flood levels typically exceed levee levels by 0.5 to 1 metres.

2.9 Measuring canal water table depth from LiDAR data

The purpose of peatland mapping is to allow improved land use zoning and water management, in order to reduce loss of peat and peat swamp forest through fire and oxidation. To define appropriate peatland water management interventions, not only accurate peat maps but also accurate water level data are required. Given the large scale and often poor accessibility of most peatland areas in Indonesia, data sources other than field monitoring are required. We have developed a simple and rapid method that applies LiDAR data to determine canal water table depth (CWD) relative to the ground surface. The method is already being used in plantations for rapid assessments of areas most in need of improved water level control, and will be published in a peer reviewed scientific journal in 2018.

2.9.1 Method of determining

CWD is determined from a LiDAR based DTM (Digital Terrain Model) at 100 m resolution as the difference between the median of all 5 m cells in a 100 *100 m cell which represents the ground surface elevation, and the minimum water level that represents water table elevation (Figure 7). A grid cell size of 100 m was found to best represent the actual land surface adjacent to canals, with surface elevation in smaller cells being too much dominated by embankments formed by material excavated from canals (resulting in an overestimation of CWD) and in larger cells by landscape surface slopes.

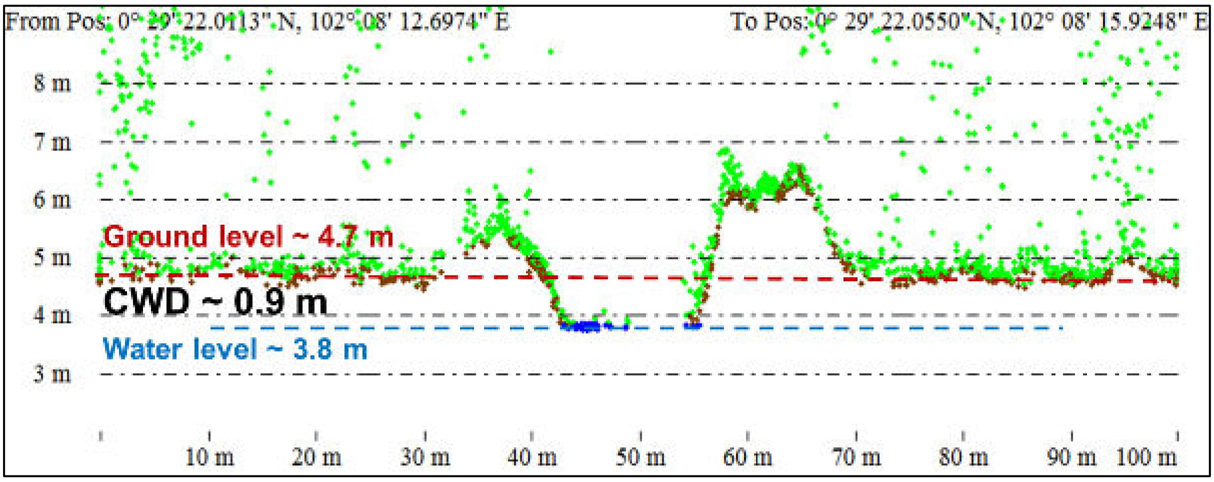


Figure 7 Demonstration of estimation of Canal Water Depth (CWD) from LiDAR based measurements of ground level and canal water level. In this case, CWD is 0.9 m (ground level at 4.7 m – water level at 3.8 m).

2.9.2 Validation of LiDAR derived CWD against field measurements

The accuracy of CWD determined from LiDAR was validated against field measurements on the same day or the day after, in plantation canals in East Sumatra. Field measurements followed a strict protocol as shown in Figure 8, involving 5 ground surface measurements on both sides of the canal, which is more accurate than the standard approach of measuring ground surface at one random location.

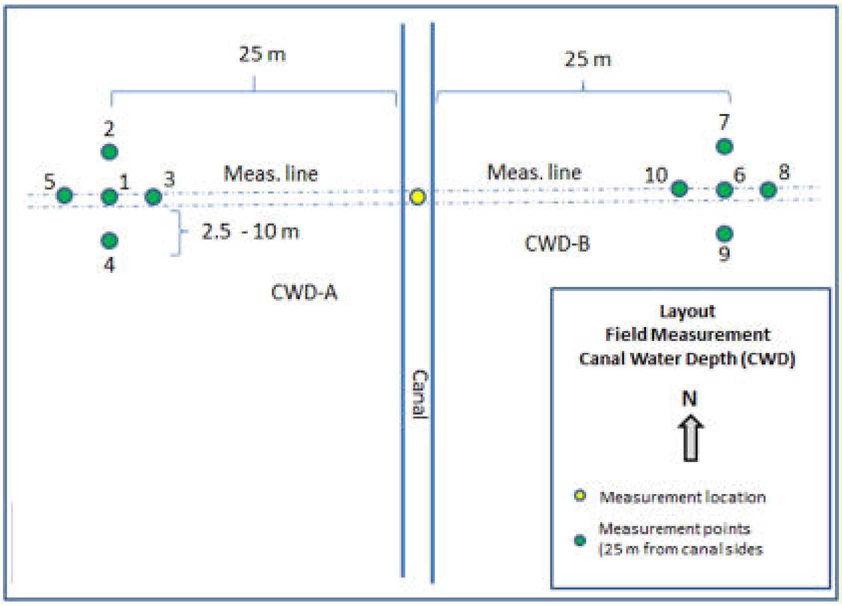


Figure 8 Protocol for field measurements of CWD, for validation of LiDAR based measurements.

The R^2 between the two independent measurements was found to be 0.81 (Figure 9). It should be noted that this fit can not be expected to be very close to 1 because field measurements were done at a random point within the corresponding 100 m grid cell within which considerable variation in soil surface elevation (and therefore CWD) will exist, whereas the LiDAR measurement presents a median value that we consider most representative of actual conditions. Moreover, some field measurements were done 1 day after LiDAR data collection by which time canal water level may have risen or dropped, and any field measurement should always be expected to involve some amount of human error. Therefore, we interpret the deviation in R^2 value as mostly the result of imperfections in the field validation data, and less in shortcomings of the LiDAR based CWD value.

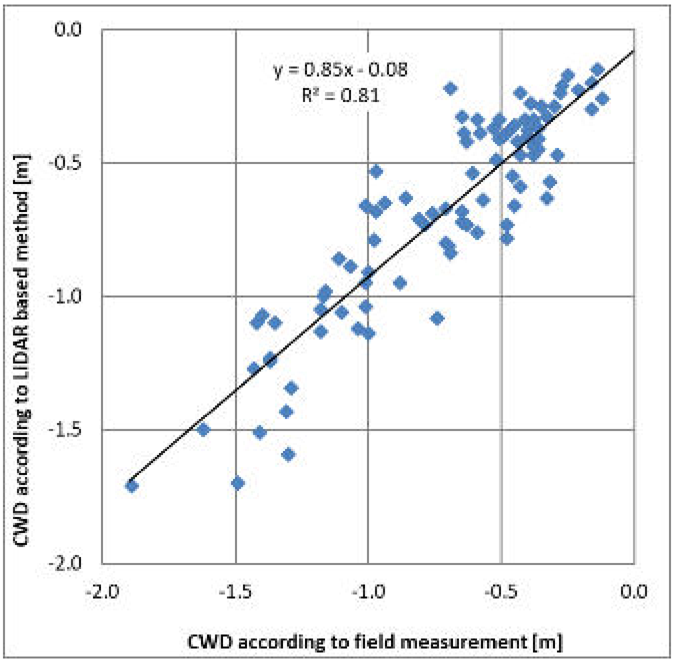


Figure 9 LiDAR derived CWD versus field measurement of CWD, for 103 measurements in East Sumatra and West Kalimantan plantation canals.

2.9.3 Estimating ground water depth from CWD

The condition of peat and peat swamp forest is not affected directly by canal water levels, but by groundwater levels. However, groundwater levels are much harder to measure then canal water levels. And especially in areas of deeper (>3 m) peat that have dense drainage systems, we find that groundwater levels are close to canal water levels during most of the year, being substantially higher (>20 cm) only during relatively short periods after intense rainfall. As a rule of thumb, in plantations on deep peat, we find that ground water level is 0.1 m above canal water level on average throughout the year. Therefore, in our experience, if CWD is known, ground water depth (GWD) can in many areas be estimated with sufficient accuracy to support water management decisions.

Situations where CWD is not suitable to estimate GWD further away (>50 m) from canals include areas of shallow or dense peat (where lower transmissivity (i.e. peat thickness * peat hydraulic conductivity) impedes rapid outflow of groundwater to canals after rainfall, resulting in substantially higher groundwater levels than canal water levels), and peatlands that are not intensely drained by canals (i.e. much peatland outside plantations).

3 Results and Discussion

3.1 LiDAR data and DTM generation

The DTM that was generated from filtered LiDAR data and contour lines (Figure 10) shows one distinct peat dome in the East of the study area, extending to the West into a much lower lying peat area.

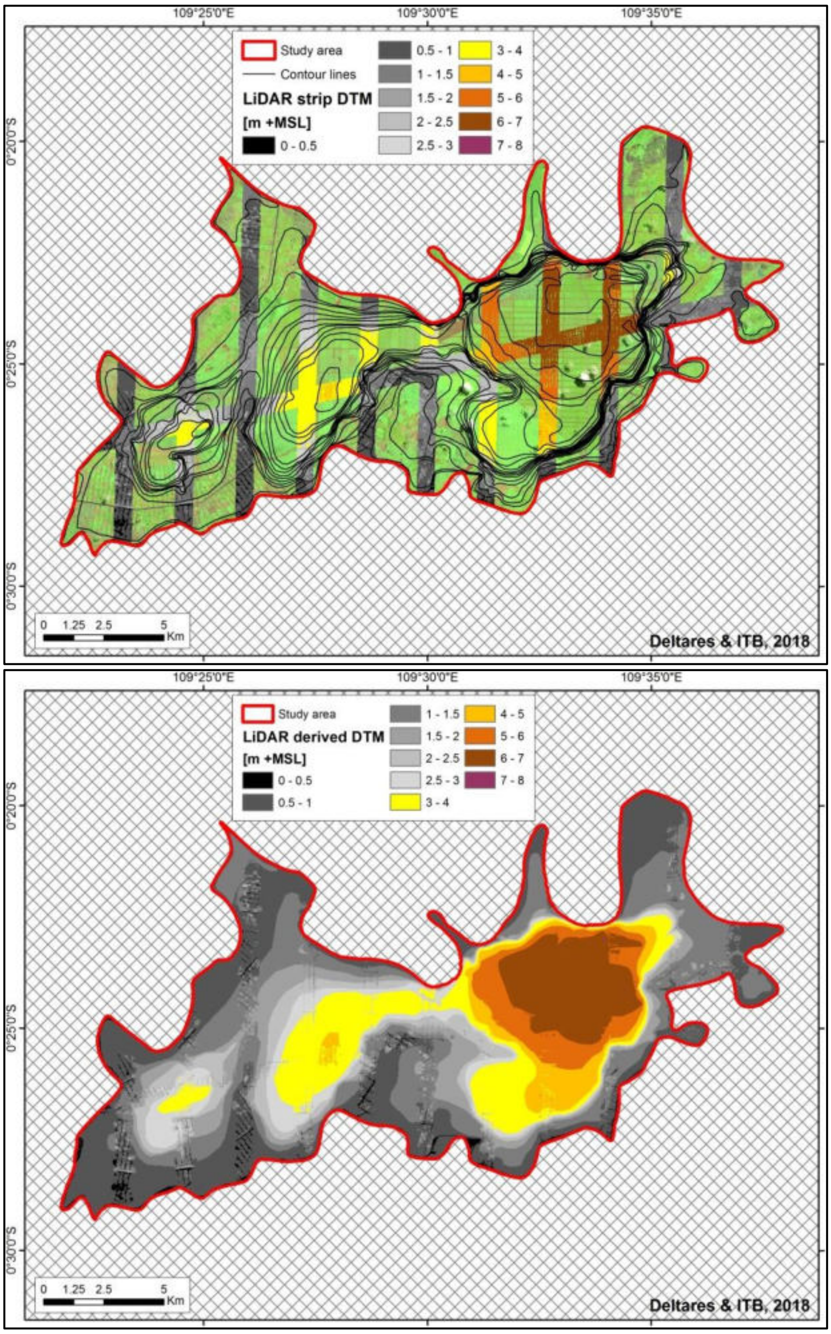


Figure 10 (TOP) LiDAR strip + manually drawn contour lines and (BOTTOM) LiDAR derived DTM (25 m spatial resolution) for the study area (interpolated using LIDAR strip and contour lines).

The average elevation of the LiDAR strip data after filtering (removal of vegetation signal) was 2.42 m +MSL with a standard deviation of 1.85 m. Figure 11 presents the elevation distribution in the study area determined from the LiDAR DTM shown in Figure 10. The DTM derived from the filtered LiDAR data and contour lines shows that 63 km^2 or 26.9 % of the study area surface is below 2 m +MSL, 137.9 km^2 or 58.2% below 3 m +MSL, and 31 km^2 or 13.2 % is more than 6 m +MSL For the peat area, these numbers are 0.1 km^2 or 0.1%, 9.4 km^2 or 8.9% and 30.6 km^2 or 29.8 % (Table 1).

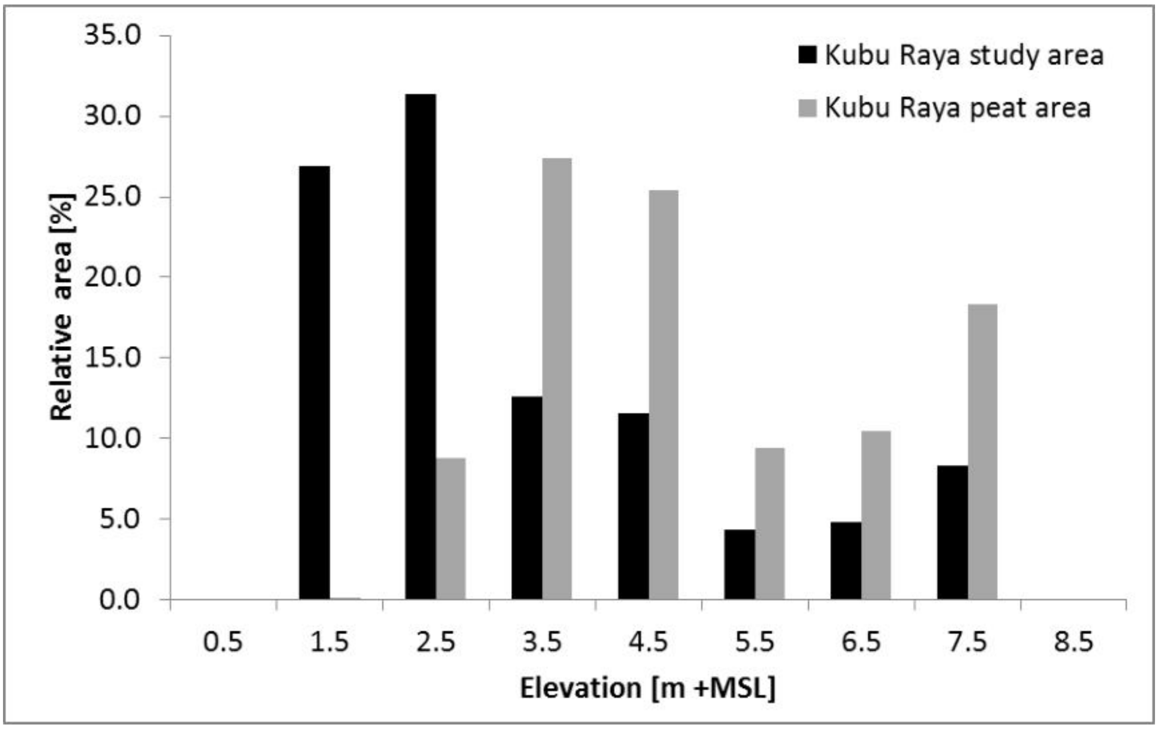


Figure 11 Relative distribution of surface elevation in the LiDAR-derived DTM, for the Kubu Raya study area, as well as for the peat area (using the delineated likely peat extent, Section 2.4; Figure 16).

Elevation characteristics	Whole study area	Peat area
Area [ha]	23681	10617
Mean [m]	2.32	3.88
% <2 m +MSL	26.9	0.1
% <3 m +MSL	58.2	8.9
% <4 m +MSL	70.9	36.3
% <6 m +MSL	86.8	71.2
% <8 m +MSL	100.0	100.0

Table 1 Elevation characteristics of LiDAR-derived DTM for the Kubu Raya study area.

3.2 Peat thickness field data

Of the 147 survey locations, 111 (75.5%) found the presence of peat i.e. an organic top soil horizon of over 0.5 m thickness. Of these 111 locations, 94.6% found a peat thickness of over 1 m and 51.4% over 3 m. Average peat thickness of the 111 locations is 3.37 m with a standard deviation of 1.66 m (Table 2).

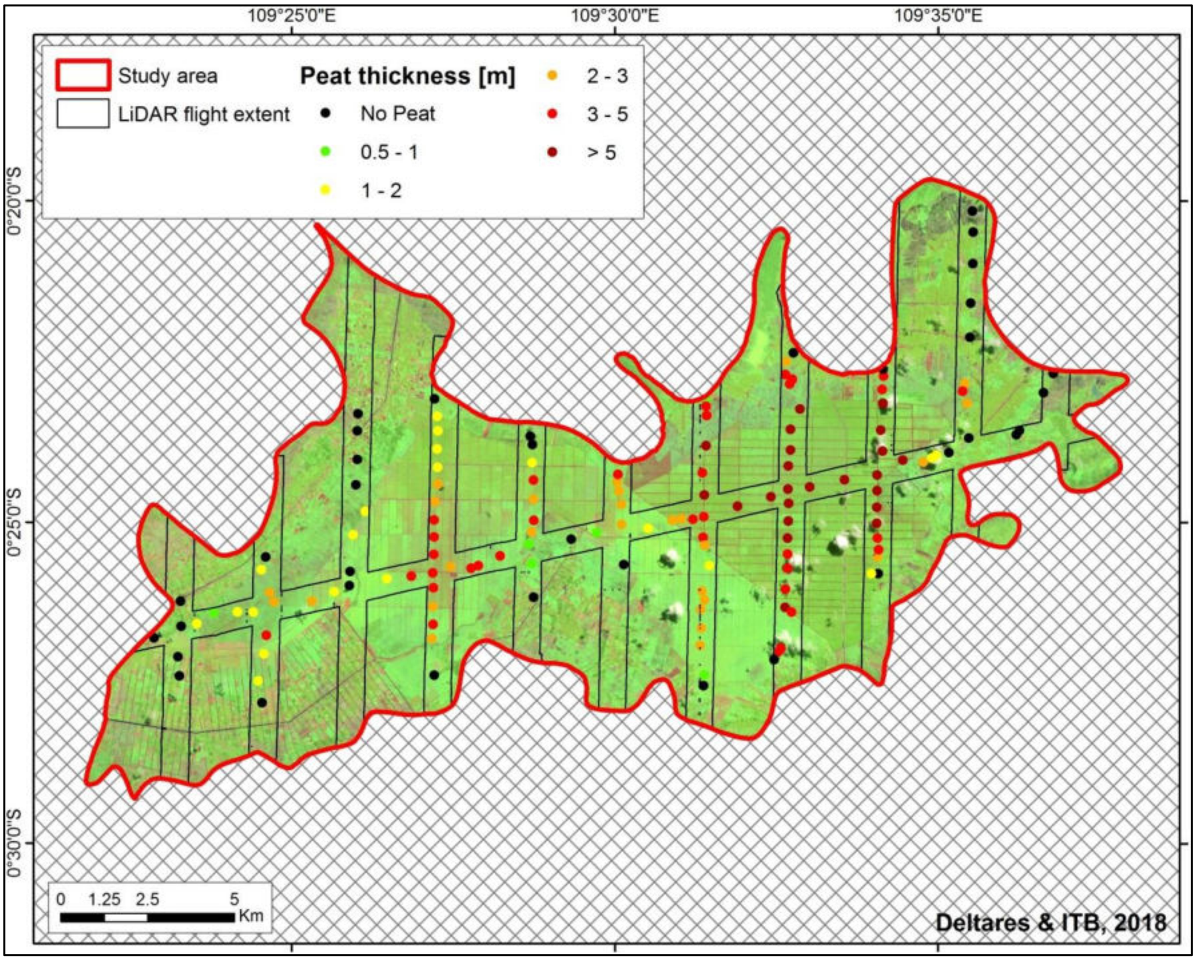


Figure 12 Peat thickness measurements in the study area as surveyed between 1 and 24 November 2017. Also shown is the extent of the LiDAR strip data (Figure 10).

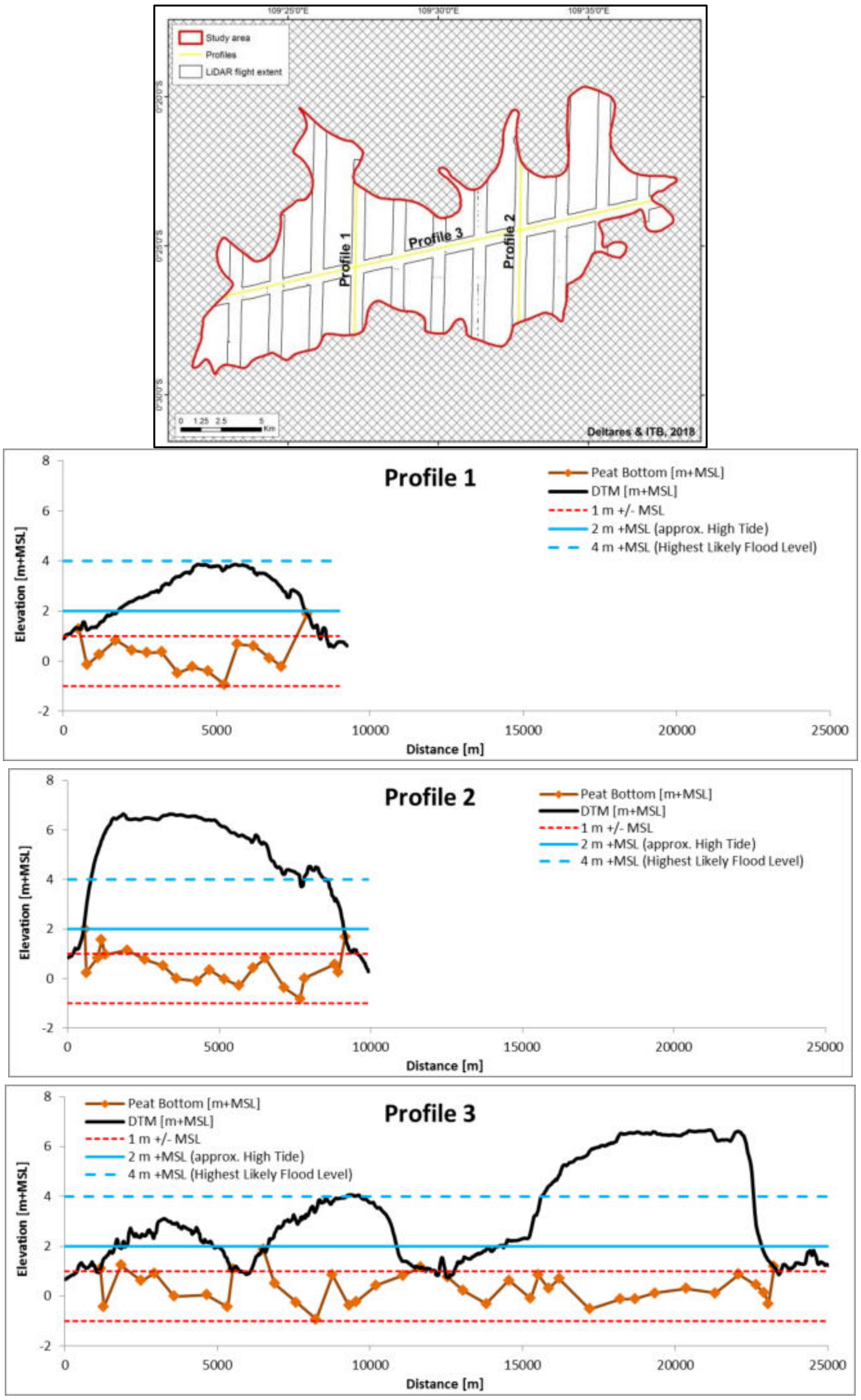


Figure 13 Three cross sections over the Kubu Raya peat dome along LiDAR flight lines (top two North-South, bottom one West-East), showing LiDAR derived surface elevation (DTM) and the peat bottom as derived from field measurements. The North or West side is on the left in the profiles. Approximate high tide and highest likely flood levels are also shown. *Notes:*

- *The peat bottom (i.e. the top of the mineral substrate) is quite flat with variations mostly limited to within 1 metre (Table 2).*
- *The peat bottom is usually around Mean Sea level, and always below the estimated High Tide level of 2 m +MSL below which drainage will probably not be possible in the longer term.*

3.3 LiDAR strip DTM compared with peat thickness measurements

A very close fit was found between surface elevation above Mean Sea Level as derived from the LiDAR DTM (Figure 10) and peat thickness measurements (Figure 12), with an R^2 value of 0.88 for all data combined if 'no peat' measurements are excluded (Figure 14). This confirms that the peat bottom is relatively flat, as found in most coastal peatlands in Indonesia, and that a surface DTM can be used for peat thickness mapping. This was most recently also demonstrated for Bengkalis (Vernimmen *et al.*, 2017) where the correlation between peat surface elevation and 156 peat thickness field measurements was 0.86 (Figure 15).

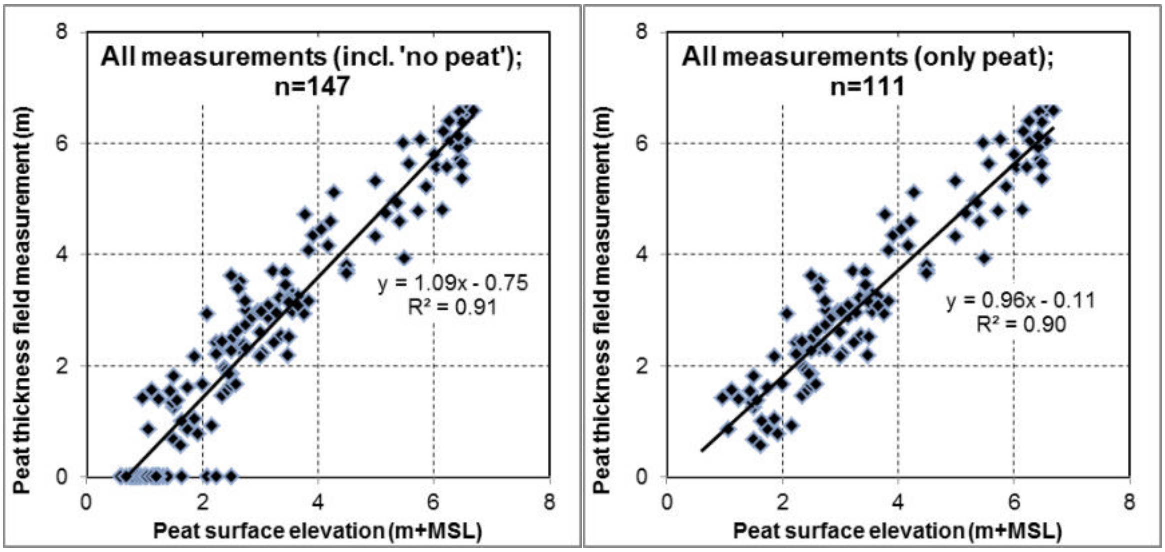


Figure 14 Peat thickness measurements plotted against elevation as determined from LiDAR strip DTM for the Kubu Raya study area. (LEFT) including all (incl. 'no peat') measurements, (RIGHT) including only peat measurements.

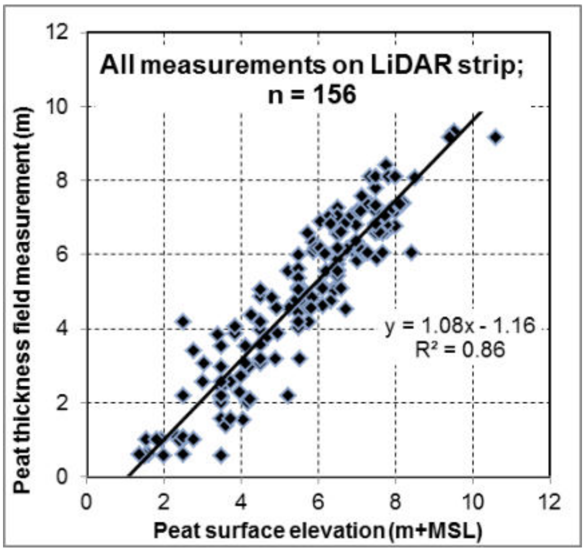


Figure 15 Peat thickness measurements plotted against elevation as determined from LiDAR strip DTM in Bengkalis (Vernimmen *et al.*, 2017).

Based on the good correlations found as shown in Figure 14, we conclude that peat thickness field measurements match the peat surface DTM very well. This confirms that the DTM should allow generation of an accurate peat thickness model.

Table 2 Peat thickness (PT) measurement statistics. PB = Peat bottom.

Peat thickness class	All		
	n	[%]	[%] (excl. no peat)
no peat	36	24.5	n.a.
0.5 - 1 m	6	4.1	5.4
1 - 2 m	20	13.6	18.0
2 - 3 m	28	19.0	25.2
3 - 5 m	34	23.1	30.6
5 - 8 m	23	15.6	20.7
total	**147**	**100**	**100**
average PT (excl. no peat) [m]	3.37		
standard deviation PT (excl. no peat) [m]	1.66		
maximum PT [m]	6.58		
average PB (excl. no peat) [m +MSL]	0.27		
standard deviation PB (excl. no peat) [m +MSL]	0.54		
minimum PB [m +MSL]	-1.12		
maximum PB [m +MSL]	1.56		
measurements with PB within +/- 0.5 m +MSL [%]	58.6		
measurements with PB within +/- 1.0 m +MSL [%]	92.8		

3.4 Peat extent

It was found that peat (>0.5 m) was present in sampling locations with ground surface above 1.5 m +MSL. On that basis, the likely peat extent boundary (Figure 16) was mapped by applying the 2 m +MSL contour line determined from the LiDAR derived DTM (Figure 10). In some areas the resulting extent was manually corrected based on field measurements of peat presence and absence measurements (Figure 12).

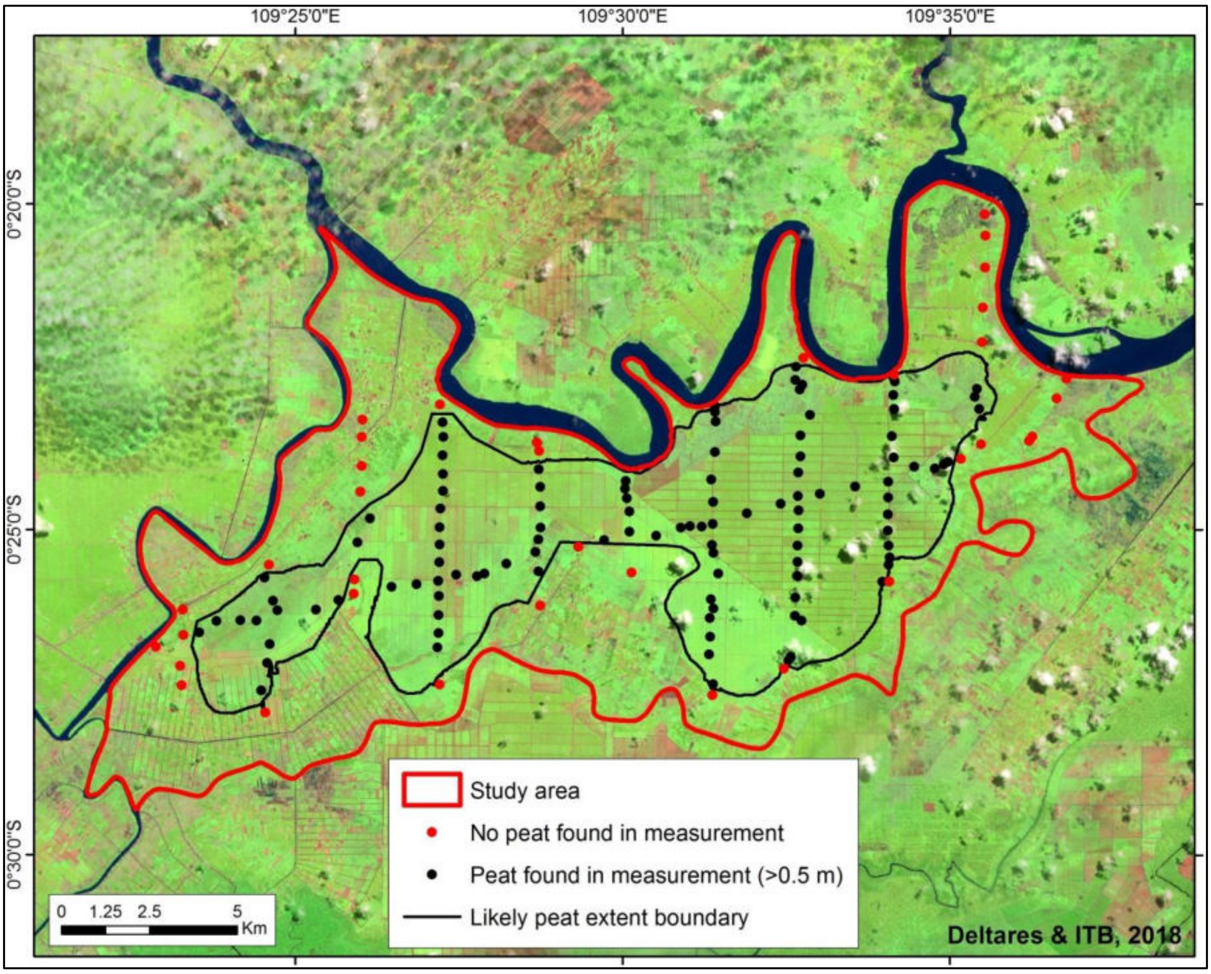


Figure 16 Likely peat extent boundary in the study area delineated based on the 2 m +MSL contour lines determined from the LiDAR derived DTM (Figure 10) and peat thickness measurements (black and red dots). In the background the Sentinel-2 RGB image of 22 April 2017 (spectral bands 11-8-5).

3.5 Peat bottom elevation model

From Figure 13 it is evident that the peat bottom is quite smooth in most of the area and near Mean Sea Level, with variations mostly within plus or minus 1 metre +MSL (92.8% of the measurements used for the model creation; Table 2).

This uniform peat bottom elevation is expected given the peat formation history in this area, with peat formation starting some 5,000 years ago on a relatively flat pre-existing landscape of coastal river floodplains and mangroves (Cameron *et al.*, 1989). In fact, this principle of the peat bottom being more or less horizontal and near Mean Sea Level has in the past been used to determine surface elevation above Sea level from peat thickness measurements, as described for Padang Island in Riau by van Doorn (1959) (Figure 17). In the case of some other older publications that show greater variation in peat bottom elevation, such as Supardi *et al.* (1993) for Bengkalis Island (although that still shows limited variations with plus and minus 2 metres +MSL), we suspect that this is largely due to the lack of an accurate surface elevation model (land based peat elevation surveys as applied in that study are notoriously inaccurate and often wrong by several metres in our experience, especially in forested areas).

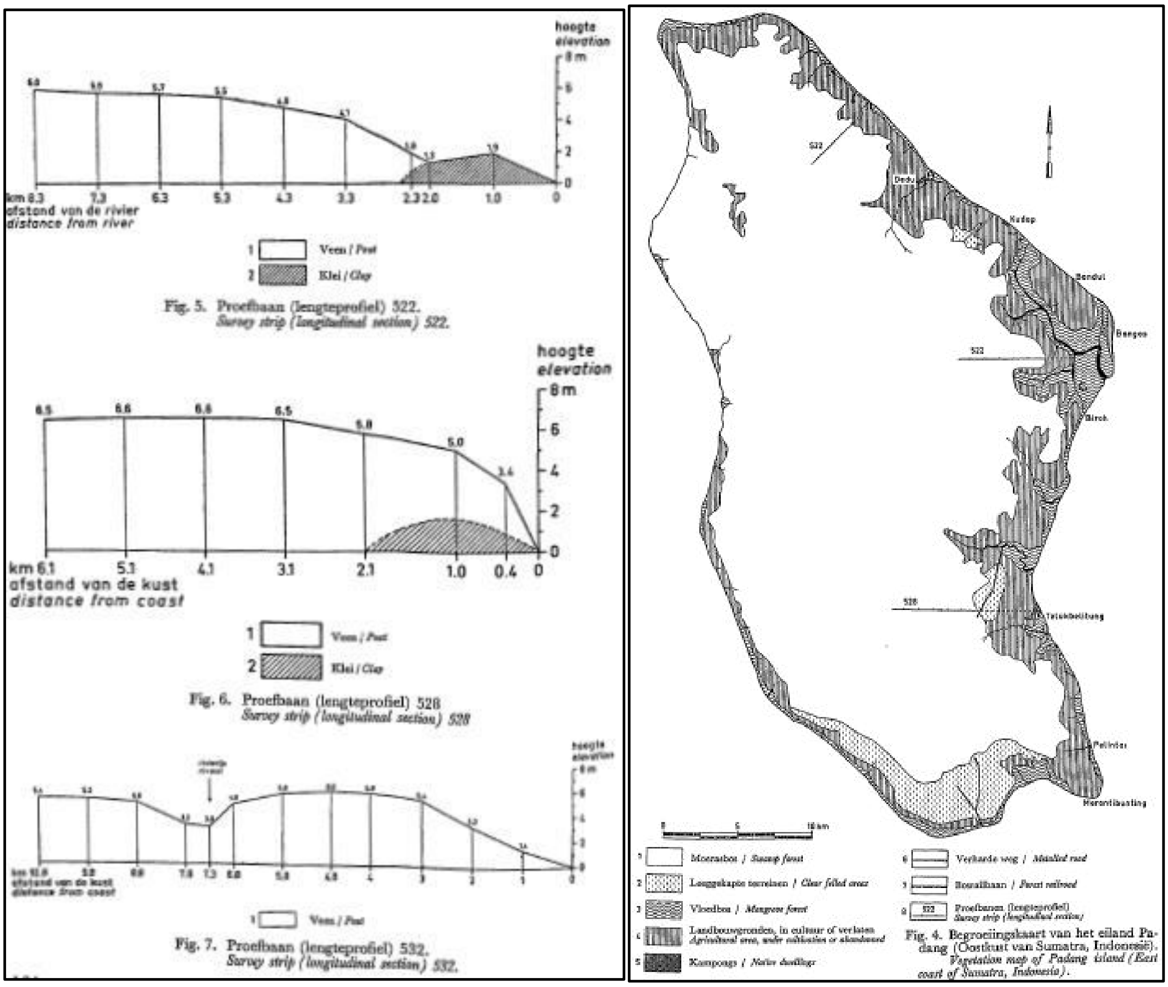


Figure 17 Cross sections through coastal peatland on Pulau Padang, adjoining Bengkalis Island, as published by van Doorn in 1959. This study applied the principle that the peat bottom in such areas is relatively flat compared to the peat surface.

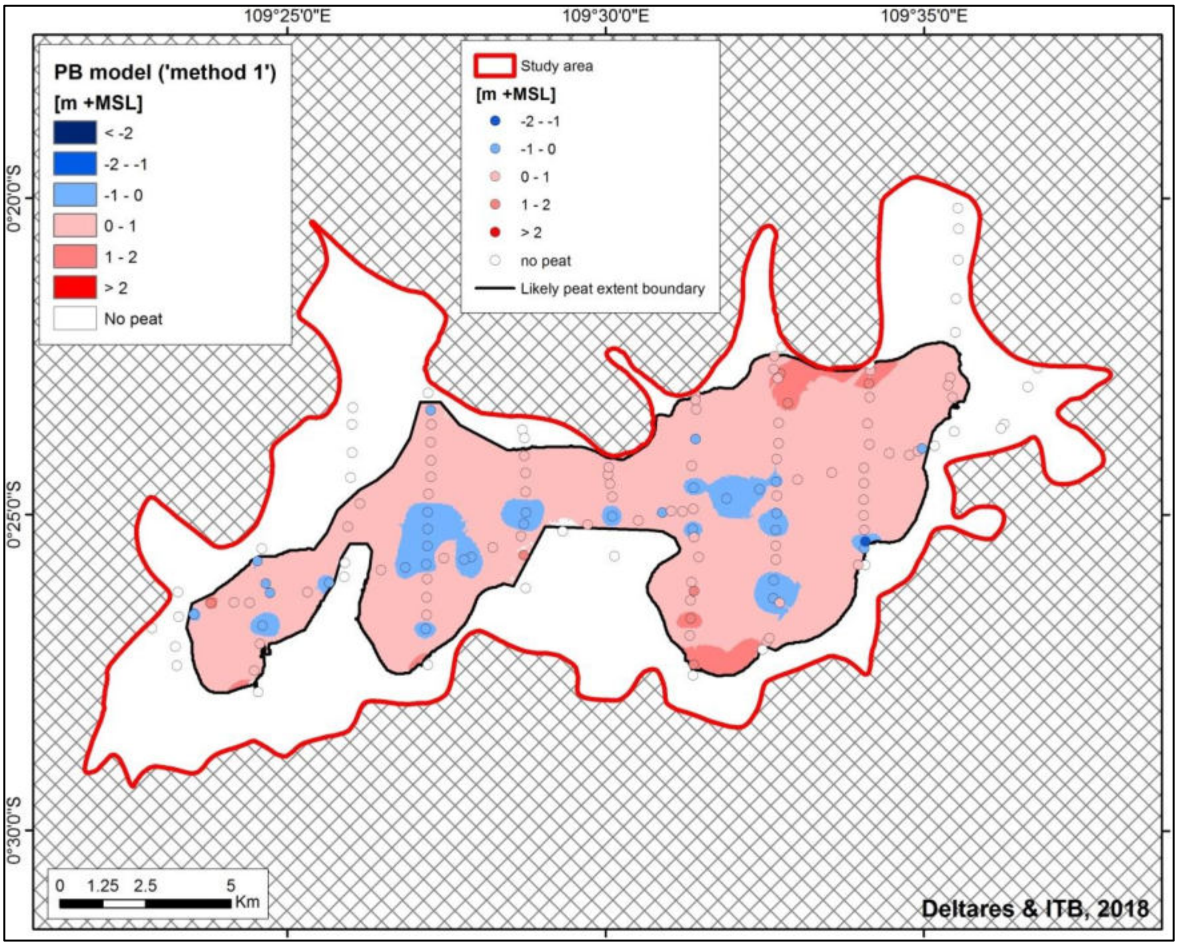


Figure 18 Peat bottom model as derived from subtracting field peat thickness measurements (Figure 12) and the LiDAR based DTM (Figure 10). The peat bottom map is created through inverse distance interpolation between the peat bottom measurements ('Method 1').

In Figure 18 the peat bottom model is shown resulting from the interpolation between peat thickness measurements subtracted from the LiDAR derived DTM ('Method 1'). It should be noted that the peat bottom model shown in Figure 18 already accounts for the 'no peat' area as shown in Figure 19 resulting from the difference between the LiDAR derived DTM and the 'full' peat bottom model. Overall peat bottom elevation above MSL in this model is 0.36 m with a standard deviation of 0.33 m. The peat bottom is below MSL over 9.8% of the peat area, and below 1 m +MSL over 95.7 % of the area. This finding is comparable to the recent Bengkalis study where it was found that average peat bottom elevation is 0.50 +/- 0.77 (standard deviation) m +MSL (Vernimmen *et al.*, 2017) with 76.3 % below 1 m +MSL. We find similar conditions in most other areas where we map coastal peatlands in Sumatra and Kalimantan.

3.6 Peat thickness and extent models

The first peat thickness model created (Figure 19), utilizing both LiDAR based DTM and field measurements of peat thickness collected in this study and applying the likely peat extent boundary (Figure 16), has an average peat thickness of 3.49 m with a standard deviation of 1.63 m (Table 3).

The second peat thickness and extent model (Figure 19), applying a constant peat bottom elevation (Table 2) and the likely peat extent boundary (Figure 16), has an average peat thickness of 3.56 m with a standard deviation of 1.60 m (Table 3).

A third peat thickness and extent model (Figure 19) was created by applying the regression equation between the LiDAR derived DTM and peat thickness measurements used to create the first peat thickness model (Figure 14) and the likely peat extent boundary (Figure 16), has an average peat thickness of 3.59 m with a standard deviation of 1.54 m (Table 3).

Table 3 Statistics of modeled peat thickness (PT) and peat bottom (PB).

	PT models		
	'method 1'	'method 2'	'method 3'
only 'no peat'			
average PB	0.36	0.27	0.26
standard deviation PB	0.33	0.00	0.06
average PT	3.49	3.56	3.59
standard deviation PT	1.63	1.6	1.54

The three methods yield very similar results, with average differences of only up to 0.10 m. The same was found for the earlier Bengkalis study and other peat mapping efforts in Sumatra. Because of these almost identical results of the different methods, the simple 'method 2' model (with constant peat bottom) is preferred, as it requires least effort and data.

With method 2, in case only the 37 peat thickness measurements (of which 4 were 'no peat') along profiles 1 and 2 (see Figure 13) would have been available this would have resulted in an identical map because the average peat bottom for these 37 measurements was only 3 cm lower than when all measurements would have been used. Similarly, if only the 40 peat thickness measurements (of which 8 were 'no peat') along profile 3 (see Figure 13) would have been available the average peat bottom would have been 8 cm lower compared to using all measurements, i.e. the difference is negligible in both situations. This finding illustrates that in case a relatively flat peat bottom is found from limited field measurements and an accurate DTM is available an accurate peat thickness model can be created.

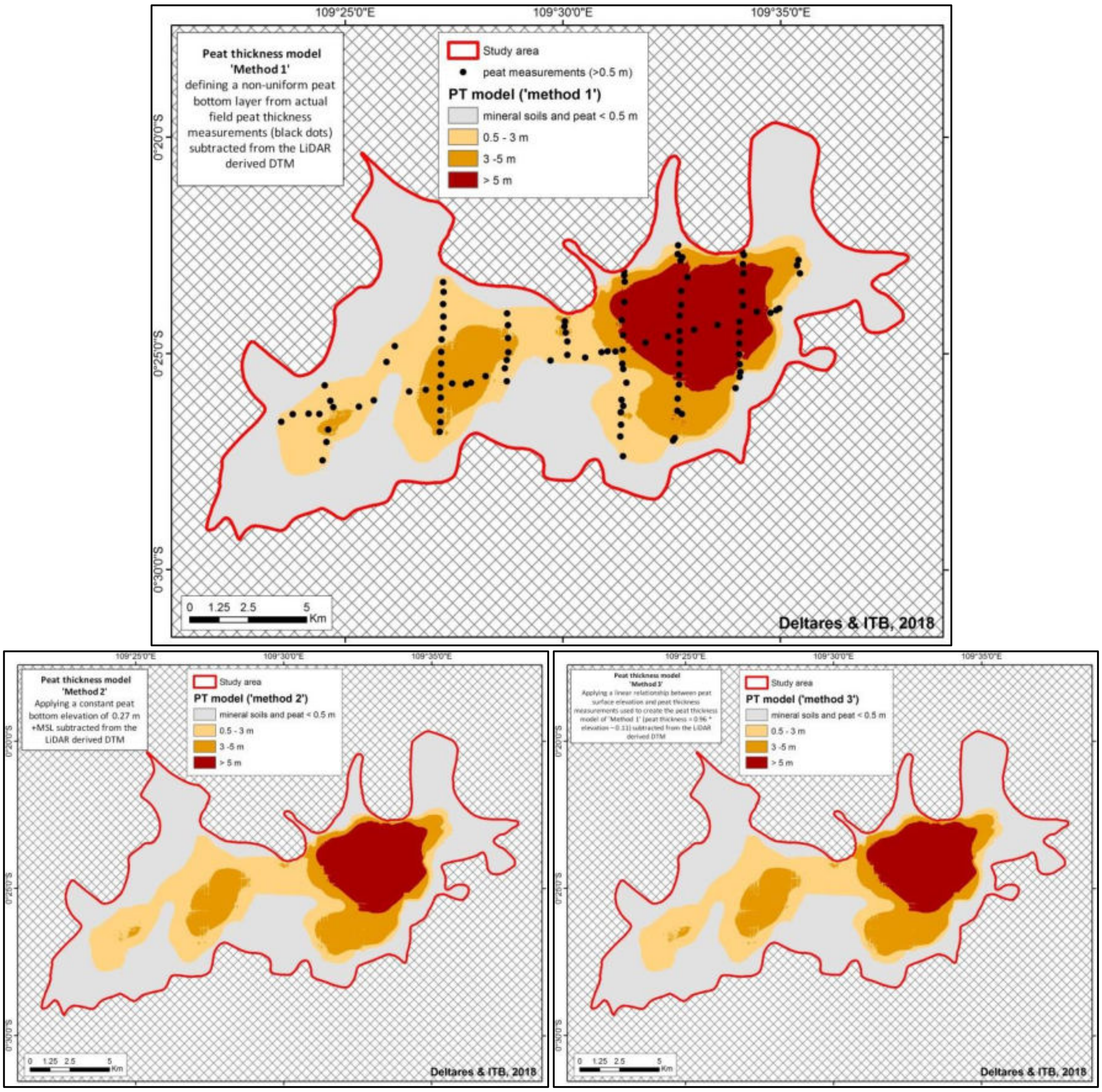


Figure 19 Peat thickness models as derived from LiDAR based DTM (25 m spatial resolution), applying three different methods:

- Method 1: Defining a non-uniform peat bottom layer from actual field peat thickness measurements (black dots; Figure 12).
- Method 2: Applying a constant peat bottom elevation of 0.27 m +MSL (Table 2).
- Method 3: Applying a linear relationship between peat surface elevation and peat thickness measurements used to create the first peat thickness model (peat thickness = 0.96 * elevation – 0.11) (Figure 14).

The peat thickness area distribution for each of the 4 classes of the peat thickness research models (Figure 19) is provided in Table 4 and shows that peat covers 45.5 % of the study area, with 53.3 % of peat being deeper than 3 m according to peat thickness model using 'Method 1'. These values are 45.7 % and 54.2 % for 'Method 2' and 45.7 % and 56.0 % for 'Method 3', respectively.

Table 4 Peat thickness area (ha) distribution for the three different peat thickness research models (Figure 19).

Peat thickness class	Method 1			Method 2			Method 3		
	[ha]	[%]	[%] (excl. 'no peat')	[ha]	[%]	[%] (excl. 'no peat')	[ha]	[%]	[%] (excl. 'no peat')
no peat	12815	54.5	-	12779	54.3	-	12777	54.3	-
0.5 - 3 m	5000	21.3	46.7	4918	20.9	45.8	4728	20.1	44.0
3 - 5 m	2998	12.7	28.0	2988	12.7	27.8	3217	13.7	29.9
>5 m	2708	11.5	25.3	2835	12.1	26.4	2798	11.9	26.0
Total	23520	100	100	23520	100	100	23520	100	100

3.7 Peat thickness model submitted to IPP

Because the flat peat bottom from field measurements could already be determined from 37 peat thickness measurements with negligible differences compared to the full field dataset (see previous Section), the peat thickness model we submit is the 'Method 2' version applying a flat peat bottom at 0.24 m, based on 37 measurements along 2 transects as shown in Figure 20.

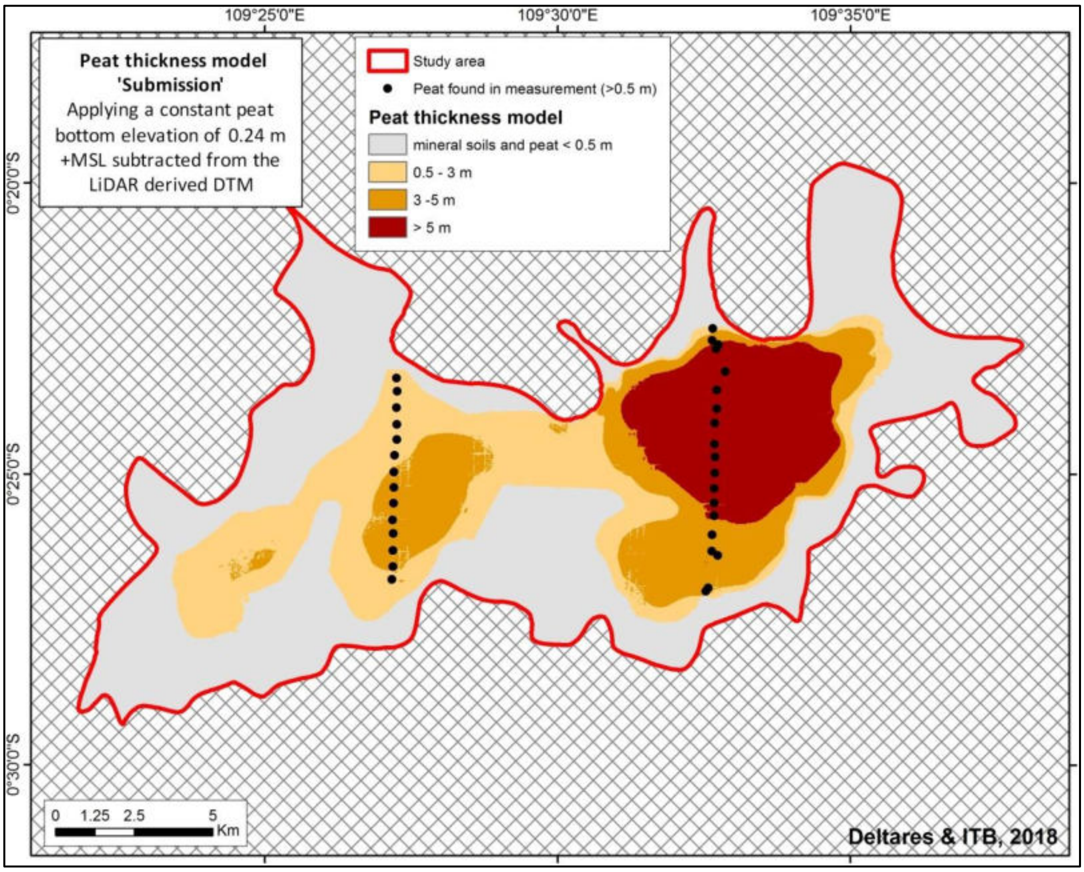


Figure 20 IPP submission version of the peat thickness model as derived from LiDAR based DTM (25 m spatial resolution), applying a constant peat bottom of 0.24 m +MSL using 37 field measurements collected along 2 transects (black dots). In Annex 5 and 6 the map is provided at 1:50,000 scale.

3.8 Peat thickness map validation

The PT model submitted to IPP ('Method 2'; Figure 20) was validated using an additional independent dataset of 65 peat thickness measurements (outside LiDAR strips) that was collected at the same time as the other data but not used in comparison of methods or in map creation.

Overall a good correlation was found with an R^2 of 0.86 (Figure 21) and an average difference between peat thickness model and validation data of 0.15 m with a standard deviation of 0.55 m. The accuracy of the model is further demonstrated by the fact that 64.4% of the validation points was within 0.5 m from model depth, and 93.8% within 1 m (Figure 22).

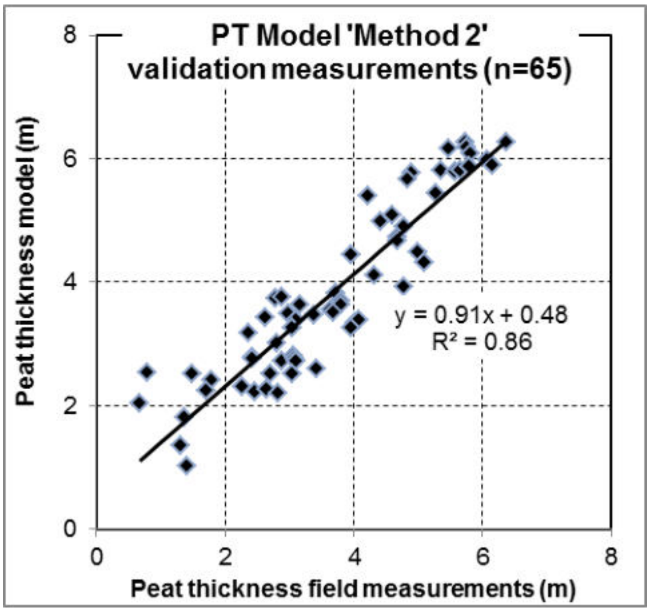


Figure 21 Peat thickness measurements plotted against modelled PT (Figure 22).

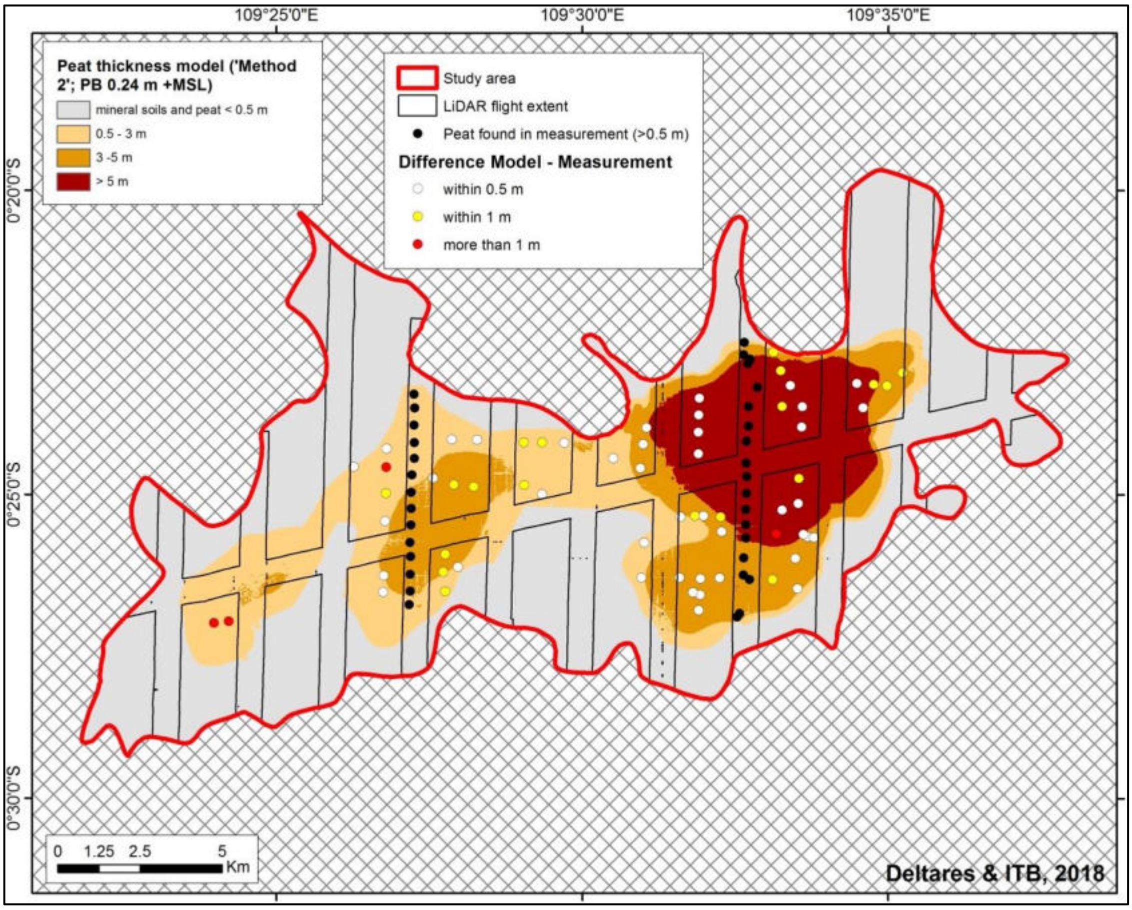


Figure 22 Peat thickness difference as calculated from the validation measurements and the PT model. The peat thickness measurements used in the creation of the 'Method 2' peat thickness model with constant peat bottom at 0.24 m +MSL (black dots) are also shown. The full validation dataset is provided in Annex 4. In the background the PT model (Figure 20). Also shown is the extent of the LiDAR strip data.

3.9 Comparing DTM based peat thickness map with existing maps

Three widely known peat extent maps exist for Indonesia, namely RePPProT (1990), Puslitanak (published by Wetlands International, Wahyunto *et al.*, 2004) and BBSDLP (Ritung *et al.*, 2011). For the Kubu Raya study area these maps are shown in Figure 23.

The 2003 and 2011 maps both present a similar peat extent which is comparable to the peat extent found in this study. However, both these maps indicate peat thickness is between 1-2 m only, while our map shows that the study area is partly covered by peat >3 m (Table 5). It is clear that the peat extent and thickness map presented by Deltares and ITB is a major improvement on existing maps.

Table 5 Areas of peat as determined from different peat thickness maps: (1) Puslitanak (Wahyunto et al., 2004), (2) BBSDLP (Ritung et al., 2011) and (3) this study (Figure 20).

Source	Peat thickness class	Area [ha]
Puslitanak (2003)	0 - 1 m	11664
BBSDLP (2011)	0 - 1 m	11162
This study (submission)	0.5 - 3 m	4727
	> 3 m	6015

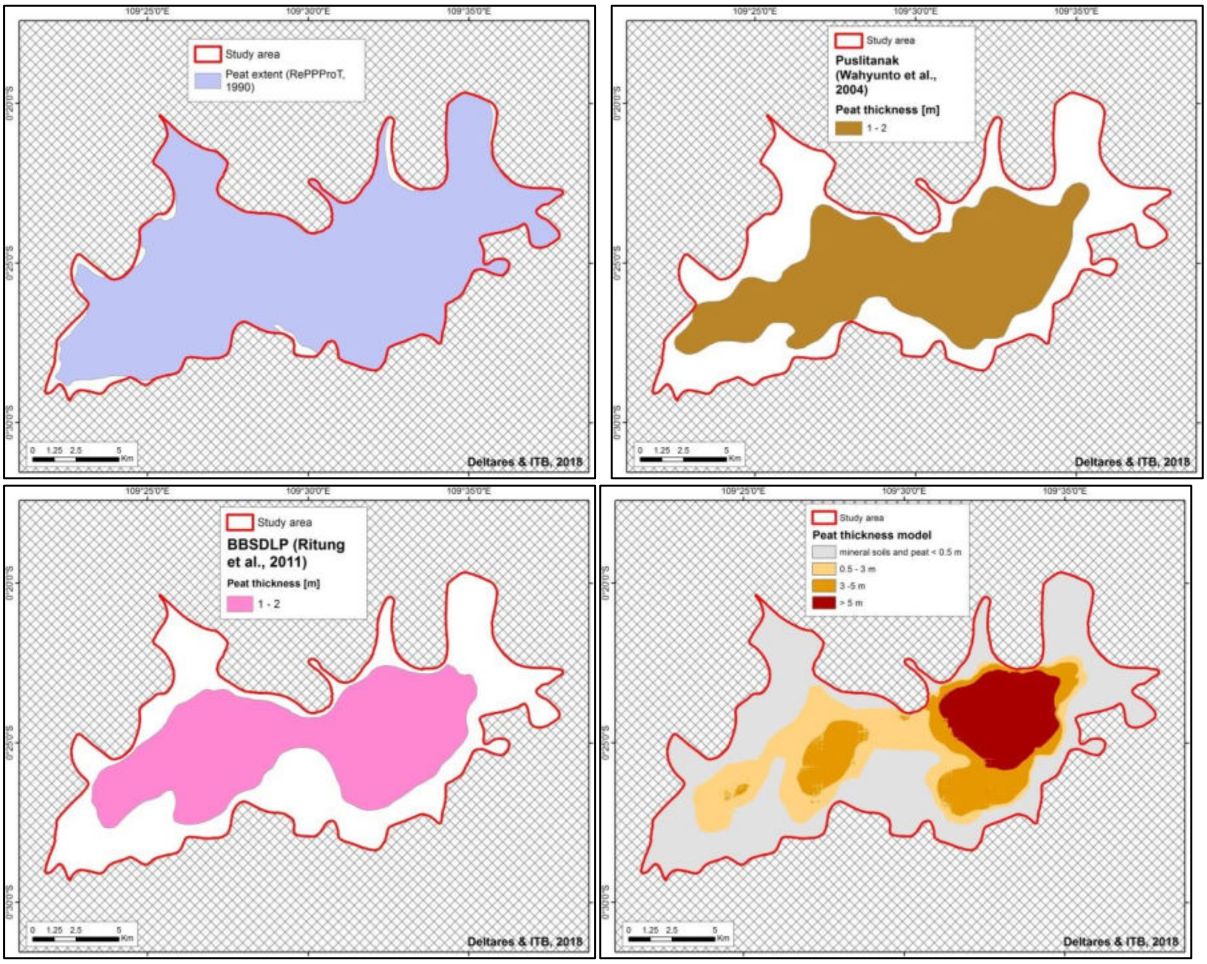


Figure 23 Three existing peat extent (and thickness for Puslitanak and BBSDLP) maps for the Bengkalis study area. (TOP LEFT) RePPProT (1990), (TOF RIGHT) Puslitanak (Wahyunto *et al.*, 2004) and (BOTTOM LEFT) BBSDLP (Ritung *et al.*, 2011). For comparison our ‘submission’ peat thickness model (Figure 20) is also shown (BOTTOM RIGHT).

3.10 Current and future flood risk

The DTM resulting from LiDAR data shows that 26.9 % of the study area (including mineral soil areas) is currently (2017) below 2 m +MSL (Table 1), which corresponds to highest tide along the coast, and will therefore be frequently flooded by river water. As much as 70.9 % of the area is below 4 m + MSL (Table 1) which corresponds to 0.5 m above river levees along the Kapuas River bordering the Kubu Raya study area in the North (as determined from LiDAR elevation profiles for flight lines crossing the river); to which level extreme floods can extend. Therefore, it appears that much if not most land in the Kubu Raya study area is already too flood prone for crops that are not flood tolerant, such as oil palm. This is confirmed by the very poor condition of much oil palm plantation in the area, including large areas that have no or very low standing crops (Figure 24).

Figure 24 Median canopy height as determined from LiDAR. Indicated as well the boundaries of two large industrial oil palm plantations (PT Bumi Perkasa Gemilang (BPG) and PT Rezeki Kencana (RK)) as digitized based on the presence of canals (Figure 26)) which for 90.4 % of their area are located on peat and which together cover 70.8 % of the peatland area. A large part of the area has a very low standing crop, less than 2 m which is also illustrated by the two orthophotos taken at the time of the LiDAR flights, locations of the orthophotos is indicated on the map (1 = left, 2 = right orthophoto).

In peatlands, we find that 94.5 % (10,152 ha) has a peat bottom below 1 m +MSL and 9.8 % (1,050 ha) a peat bottom below 0 m +MSL, while all peat has a peat bottom below 2 m +MSL (Figure 25). In future, if peat continues to be lost (following drainage) and Sea level rises, the entire area will be severely flood prone or may even be lost to the Sea permanently after peat is fully removed, which is not unlikely considering the peatland area is now almost entirely drained for oil palm (Figure 24). In case the land use doesn't change, using a subsidence rate around 3.5 cm yr^{-1} as applied in other studies, most of this land loss could take place well within 100 years, much of it within 50 years.

The position below Sea and River level of the mineral soil substrate in most of the Kubu Raya study area also implies that peat below this flood limit can never burn or be oxidized as it will always remain inundated, and should in our view therefore not be included in calculations of future carbon emissions or total carbon stock available to emission. It may therefore be asked what the actual requirement is for highly detailed peat thickness maps in areas where the peat bottom is below the (future) flood limit.

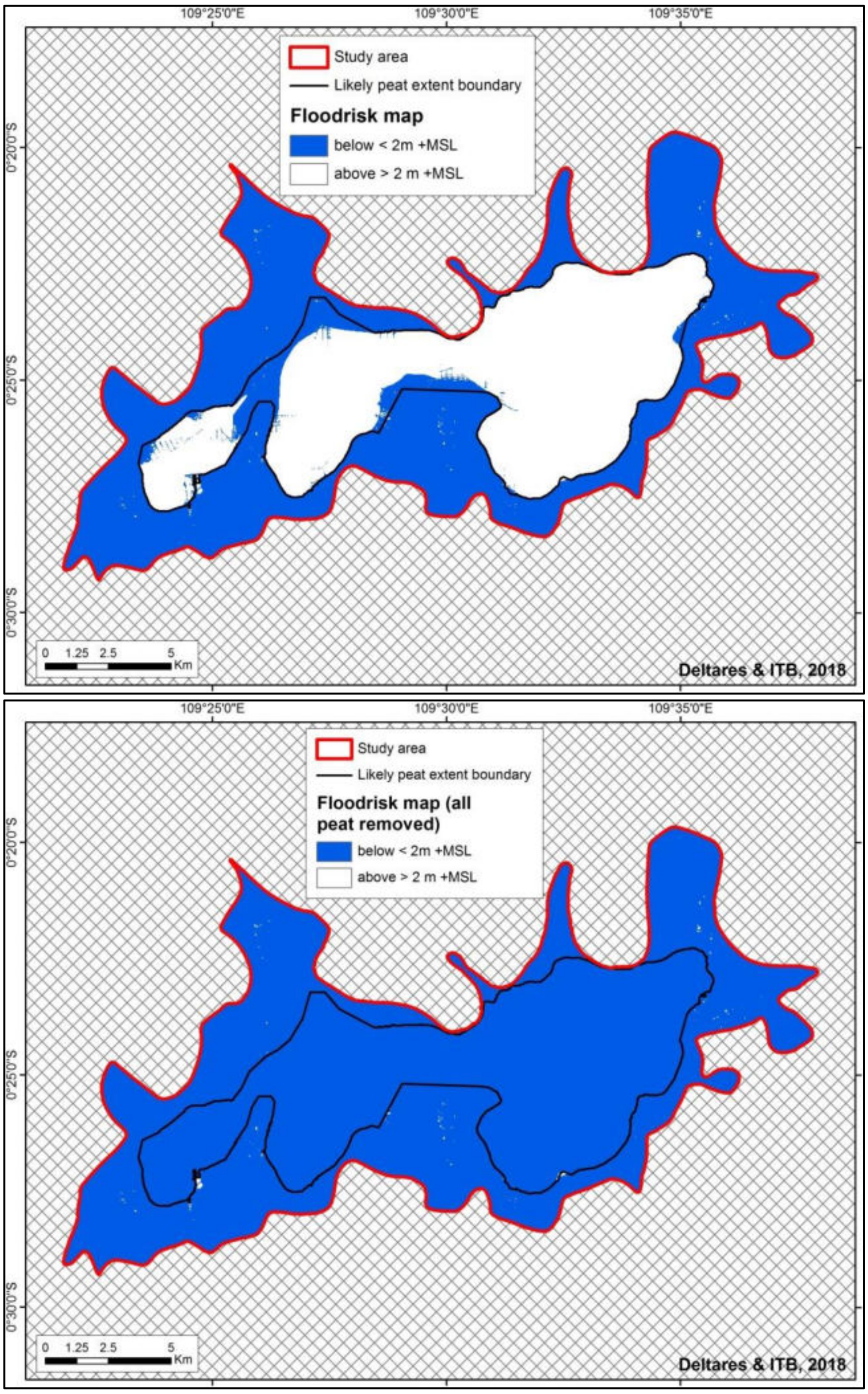


Figure 25 Land surface below 2 m +MSL in 2017 (TOP), as determined from the LiDAR based DTM, and (BOTTOM) after removal of all peat following drainage.

3.11 Measuring canal water table depth from LiDAR data

Canal water depth was determined in the Kubu Raya study area, using the available LiDAR data along strips at 2.5 km intervals and the location of the canals as they were digitized using recent Sentinel-2 imagery (Figure 26). It should be noted that this assessment represents a snapshot of conditions on a single date, 5 October 2017. This is usually the transition period from dry season to wet season, however 2017 had extremely high rainfall in what is normally the dry season (Figure 27; Figure 28), so water tables will have been much higher than normal in October and may be considered representative for the wet season.

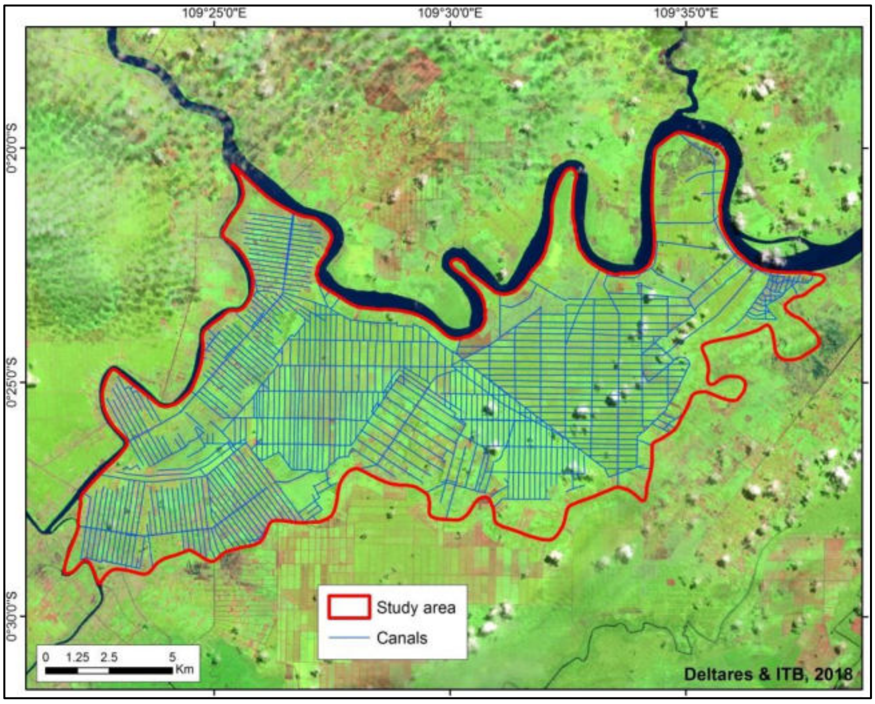


Figure 26 Canals in the Kubu Raya study area as manually digitized from Sentinel-2 image of 22 April 2017 (spectral bands 11-8-5).

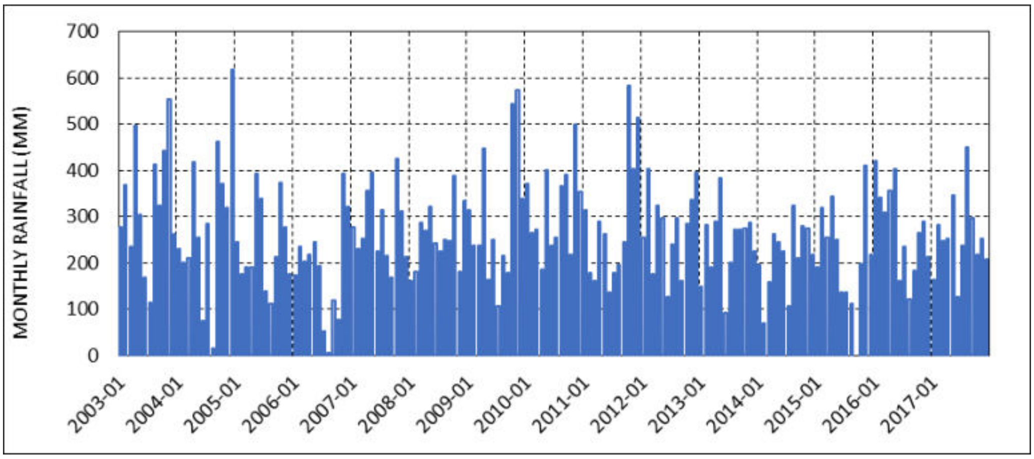


Figure 27 Bias corrected TRMM 3B42RT monthly rainfall from 2003 to 2017 (15 years) in the Kubu Raya study area. For details on the bias correction see Vernimmen *et al.* (2012).

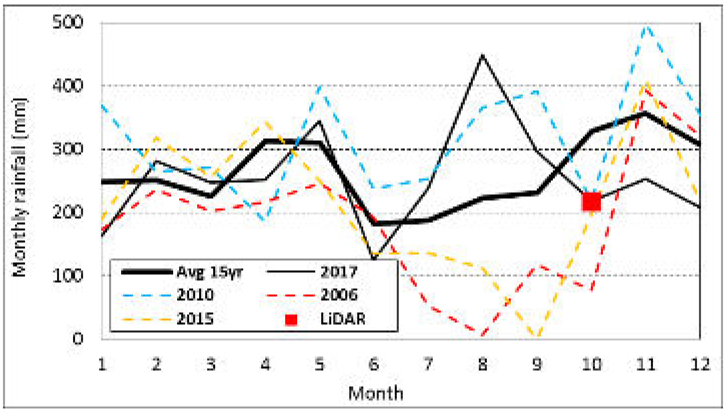


Figure 28 Bias corrected TRMM 3B42RT monthly rainfall in 2017 in the Kubu Raya study area, compared with the 15-year average (2003-2017) and with some years with extreme rainfall in the dry season (June-September). 2017 had the highest dry season rainfall (1,112 mm) after 2010 (1,250 mm). 2006 and 2015 had the lowest dry season rainfall, at 371 and 383 mm respectively. Rainfall in month of LiDAR data collection also indicated.

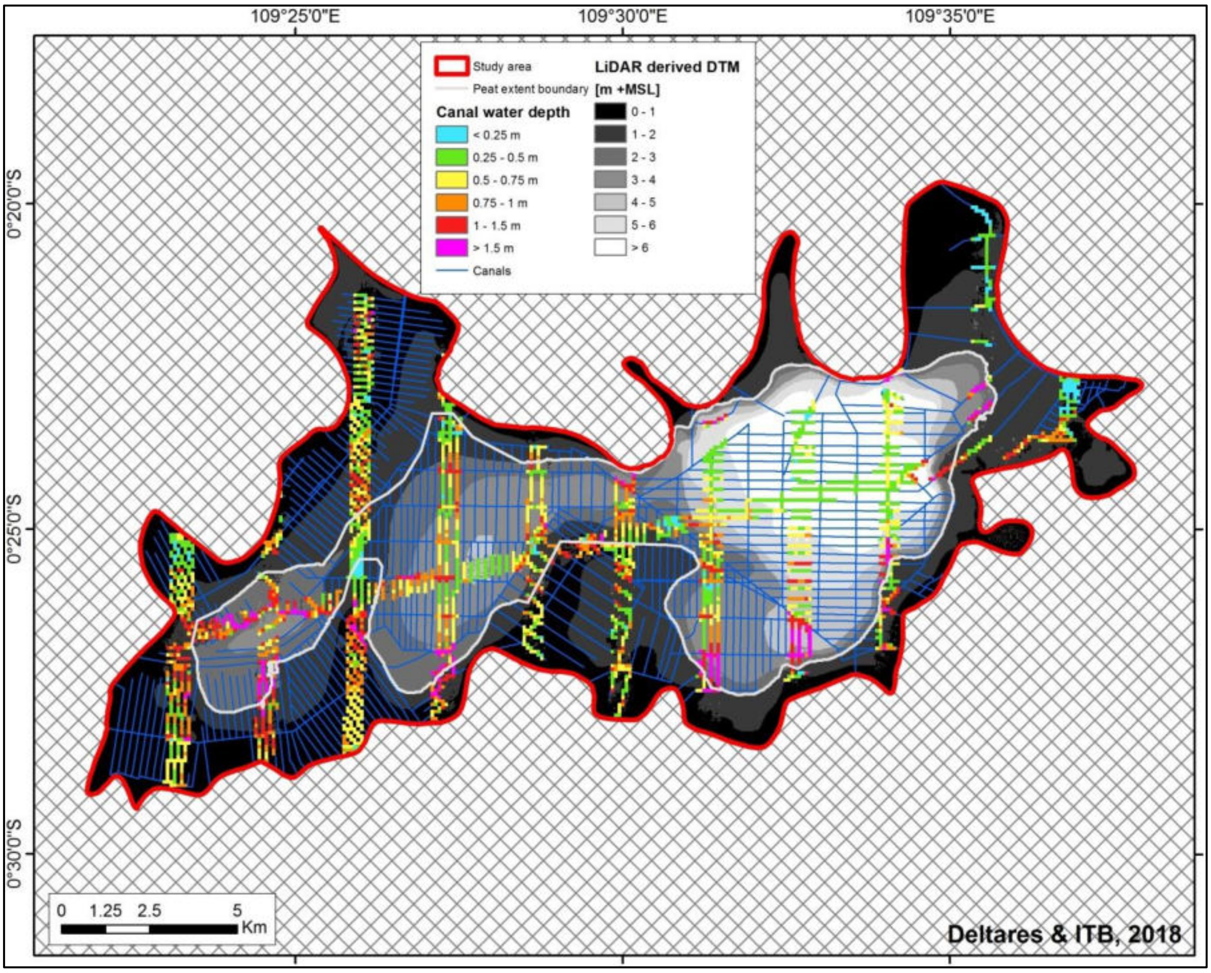


Figure 29 Canal water depth below the surrounding land surface for 5 October 2017 as determined from LiDAR data with DTM in the background. Distinct spatial patterns are visible: some areas near rivers have CWD < 0.25 m, i.e. water levels very close to the surface. However, much larger areas have CWD > 0.5 m and most of that > 1 m (Table 6).

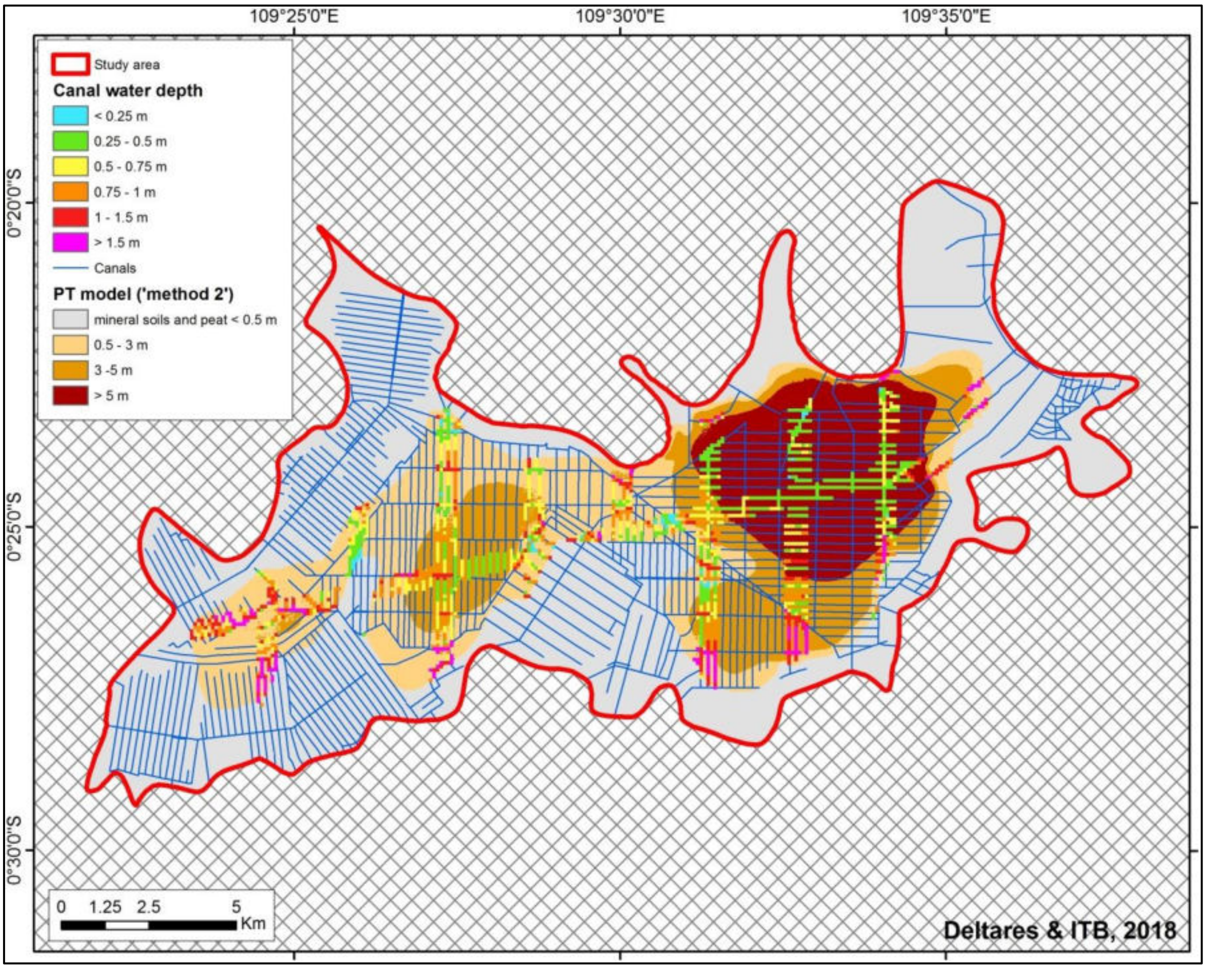


Figure 30 LiDAR based CWD values on peatland for 5 October 2017 with canals and peat thickness ('Method 2') in the background.

Table 6 Canal water depth statistics for the peat area within the Kubu Raya study area.

Peat thickness class	CWD		CWD class [m]					
	Mean [m]	Std [m]	0 - 0.25 [%]	0.25 - 0.50 [%]	0.50 - 0.75 [%]	0.75 - 1.00 [%]	1.00 - 1.50 [%]	> 1.50 [%]
all peat	0.78	0.48	2.5	33.4	25.6	15.8	13.9	8.7
0.5 - 3 m	0.89	0.51	4.1	19.3	23.3	22.5	18.6	12.2
3 - 5 m	0.84	0.48	0.0	26.0	32.2	14.9	16.2	10.6
> 5 m	0.47	0.18	1.6	68.0	24.5	3.2	2.5	0.2

From Figure 30 it is clear that canal water table depth (CWD) relative to the surrounding land surface, as mapped using LiDAR, presents consistent and plausible CWD values over long stretches of canals and that these are higher in deep peat areas compared to shallow peat areas (Table 6). On average, CWD in the peat area on 5 October 2017 was 0.78 m. On the deep peat (> 5 m) average CWD was 0.47 m, with 30.5% having a CWD deeper than 0.5 m. For the 0.5-3 m and 3-5 m classes these values were 76.6% and 74.0% respectively The relative abundance of lower water table depths, in a period that was relatively 'wet' with high rainfall and therefore high water tables, indicates that major improvements in water management are required. Canal water tables will drop by 0.5 to 1 m in the dry season, in a normal year, so will be below 1 m in most peatland canals in the study area for part of the year.

4 Duration and cost of peatland mapping

Airborne LiDAR data were collected within 1 day of flying. Survey duration for 37 points was 4 days at an overall survey average of 10 measurements per day (including replicates) with 2 survey teams. The time required for design, training, mobilization and demobilization is not included in these time estimates, as this would not be relevant if the work had been done as part of a comprehensive large scale mapping effort as is the ultimate goal.

The cost of LiDAR data collection at 2.5 km intervals, resulting in 29.9 % coverage (7,092 ha) of the Kubu Raya study area, has been 7,100 US$ (excluding mobilization costs). The relatively low unit cost by SE Asia standards (but similar to other regions) is explained by the large volume of work (hundreds of thousands of hectares across Sumatra and Kalimantan) and a competitive bidding process.

The cost of the Kubu Raya field survey activity for the collection of 147 measurements has been 5,517 US$ (Table 10) (this excludes the duration and cost of collection of 65 validation data points). The cost of 37 measurements along 2 transects alone (Figure 20), or 1 measurement per 640 hectare of study area, which we show to suffice for mapping in this area, is 1,389 US$. The latter cost for 37 measurements will be used in further calculation of overall mapping cost, as this would have been the cost had the Kubu Raya area been surveyed as part of a survey over a much larger area, as is the purpose of comprehensive peatland mapping.

Total combined cost to create the peat thickness map presented in this study is 23,748 US$: 7,100 US$ for LiDAR data collection (including orthophotos) and 1,389 US$ for field surveys (37 points). For 10,741 hectare of peatland (Table 5), this is 0.99 US$ per hectare of peat. The canal water depth map and flood map (and other products like a canopy height map that can also be produced from LiDAR data, and orthophotos) are produced in the same process without additional data requirements. The cost of data processing, analysis and reporting is hard to determine as this will be much reduced when applying this method at the large scale, but this will be below 50 % of the cost of data collection (LiDAR + field) in a normal assignment (without the scientific analyses and cross checks applied in this study for IPP). An estimate of 25 % is reasonable in our experience. The total cost of mapping of the study area is therefore 10,611 US$, or 0.45 US$ per hectare (0.99 US$ per hectare of actual peatland) (Table 7).

Table 7 Overview of mapping costs for the Kubu Raya study area.

Description	USD
LiDAR survey (excl. mobilization costs)	7100
Field survey	1389
Subtotal	**8489**
Data processing, analysis, reporting (est. 25% of survey costs)	2122
Total	**10611**
Total (USD/ha)	0.45
Total (USD/ha peat)	0.99

In many areas, including possibly Kubu Raya, LiDAR cost can be lowered by almost 50% as flights at 5 km intervals suffice for large domes. On the other hand, in some areas we find that the peat bottom is more complex and requires more field measurements of peat thickness. Overall, we consider the cost presented here to be valid for large scale application.

However, in practice this cost can be lowered further for future mapping in areas where LiDAR data and/or field peat thickness are already available, as is already the case for most Sumatra peatlands and some in Kalimantan (Figure 1).

5 Discussion and recommendations

5.1 Peat thickness mapping

The three different methods applied to calculate peat thickness for the Kubu Raya study area using a LiDAR derived elevation model and peat thickness field measurements, yield very similar results, with average differences of only up to 0.10 m. Because of these almost identical results of the different methods, the simple ‘method 2’ model (with constant peat bottom) is preferred, as it requires least effort and data.

It was further demonstrated that only limited peat thickness field measurements would be required to determine that the peat bottom is relatively flat in the Kubu Raya study area and that this constant peat bottom was within 10 cm compared to using all field measurements collected irrespective of which transects were chosen to determine the position of the peat bottom. Our submission to the IPP is therefore the peat thickness model based on a constant peat bottom at 0.24 m +MSL as determined from 2 peat thickness transects consisting of a total of 37 measurements (Figure 20).

The accuracy of the resulting peat thickness map was assessed using an independent validation dataset of 65 field measurements collected at the same time as the measurements used to create the peat thickness map (Figure 22). The resulting difference between peat map and validation data was 0.15 on average with a standard deviation of 0.55 m, with 64.6 % of validation points being within 0.5 m from the model and 93.8% of the measurements within 1 m.

The studies in Kubu Raya and Bengkalis have demonstrated that it is possible to create peat thickness maps of sufficient detail and accuracy for purposes of land use zoning, at the landscape level, using a cost effective combination of limited LiDAR and field data. A few areas in transition zones between peat and mineral soil areas are left where it may be helpful to have more detailed peat thickness maps for the purpose of precise land use planning; such gaps are easily filled in by additional targeted field mapping if and where required.

We conclude that the peat bottom elevation in many coastal peatland areas in Indonesia is sufficiently uniform to allow creation of a peat thickness map from a DTM even if only few peat thickness measurements would be available, applying only an estimate of uniform peat bottom elevation based on scarce data.

It is recognized though that in some areas the peat bottom elevation may be more variable, which can be explained by the existence of a pre-existing landscape with greater morphology around early Holocene river channels and estuaries, and hills. It is also found in a few areas along the Sumatra coastline that the peat bottom has been moved up or down by tectonics, sometimes by several metres. However, whether the peat bottom is uniform and near Sea level can be determined from a relatively limited number of field measurements, and the mapping approach can be adjusted accordingly.

Our recommendation is therefore to conduct peat thickness mapping in 2 phases, to ensure speed and cost effectiveness:

- Phase 1 consists of a rapid landscape scale assessment utilizing strip-based LiDAR and limited field surveys, as demonstrated in this study. This will provide clarity on areas of deep peat in the short term and at limited cost, and allow creation of landscape scale models of where peat protection is required. National and Provincial management plans can be developed on this basis.
- Phase 2 can zoom in on areas where the presence or thickness of peat is not sufficiently clear after Phase 1, and where detailed planning at the village or plantation level requires such information. This phase will consist mostly of detailed field investigations, for instance using a sampling grid, and may in some areas take years to complete.

The Phase 1 approach is currently being applied by Deltares for most of East Sumatra and parts of West and Central Kalimantan, following the method applied to the Kubu Raya and Bengkalis study areas, with results planned to be released in the public domain by 2018. This data is available to be the basis of Phase 2 type detailed mapping by other organizations. We would recommend other organizations to also bring relevant LiDAR and peat thickness data in the public domain in support of such efforts.

It should also be considered that only part of a peat deposit may be available for oxidation including fires. Peat that is below the permanent water table will always be water saturated and can therefore never decompose or burn (although it may be eroded by waves in coastal settings). The position of the permanent water table depends on Sea / River level, which changes with Sea Level Rise, and also on distance to Sea or River as a conveyance gradient is required to remove water from the peat surface (DID, 2001; Hooijer *et al.*, 2015b). Thus, it should be considered that a substantial amount of peat may be excluded from carbon stock calculations, and that knowing the depth of peat below the permanent water table may be less relevant for many purposes. Likewise, for land suitability assessments for agriculture, it is often not relevant to know the depth of peat below the permanent water table.

This principle may be used to reduce accuracy and intensity requirements for peat thickness surveys and mapping in peatlands where the peat bottom is known to be below the permanent water table over large areas. The reduction in effort and cost required for peatland mapping may be substantial especially in extensive, inaccessible and data scarce areas like the Kampar Peninsula in Riau (Hooijer *et al.*, 2015b) or the EMRP area in Central Kalimantan (Sumarga *et al.*, 2016).

5.2 Flood risk mapping

The DTM resulting from LiDAR data shows that 26.9 % of the study area (including mineral soil areas) is currently (2017) below 2 m +MSL which is the top range of current tidal fluctuations, and 70.9% below 4 m which is the estimated recent highest flood level (as determined from levee morphology in the area).

The results of the flood risk mapping for Kubu Raya and Bengkalis are in agreement with those of earlier assessments of this nature (Hooijer *et al.*, 2015ab; Sumarga *et al.*, 2016) and confirm that most coastal lowland peatland in SE Asia will flood in future if peatland drainage and subsidence are allowed to continue. Ending drainage will require either full restoration to natural forest, or conversion to alternative crop species that tolerate high water levels (sometimes referred to as 'paludiculture'). Such crops are also required for areas that are already prone to flooding.

5.3 Canal water table depth measurements from LiDAR

We demonstrate that it is possible to estimate ground water depth in plantations on deep peat from LiDAR derived CWD measurements. Since plantations on deep peat are numerous, and amongst the areas most requiring water management improvements, this is a useful tool in improving overall peatland water management.

However, collection of airborne LiDAR data at present can be difficult and expensive. It is rare to be able to collect such data more than once a year, maybe twice at most, over large areas. Therefore, we are developing a method that uses both LiDAR measurements to create full maps of CWD for specific moments, and field measurements that have less spatial coverage but higher temporal frequency. By combining the two sources, in suitable areas, monthly CWD maps can be created that are accurate within 0.25 m for over 75% of the area, which is helpful for water management and zoning decisions.

Moreover, to reduce cost and time requirements, techniques are applied to interpolate CWD between LiDAR strips, in areas where no full coverage LiDAR is available.

Plantation companies are trialing such hybrid solutions, because a fully field based monitoring system that measures actual ground water levels at high frequency (e.g. monthly) and high spatial resolution (e.g. every compartment) is unlikely to be not feasible in practice, certainly in the long term. Attempts to pursue such systems in all plantations may result in delayed and incomplete data at a high cost, or even in flawed data, which is not beneficial to true improvements in peatland management.

6 Acknowledgements

We thank Asia Pulp and Paper for funding the data collection in the study area.

7 References

Cameron CC, I, Esterle JS, Curtis AP, 1989. The geology, botany and chemistry of selected peat-forming environments from temperate and tropical latitudes. International Journal of Coal Geology, 12 (1989) 105-156.

DID Sarawak, 2001. Water management guidelines for agricultural development in lowland peat swamps of Sarawak (Report of the Department of Irrigation and Drainage, Sarawak, Malaysia, 78 pp.

van Doorn Z, 1959. Enkele waarnemingen aan oorspronkelijke Indonesische veenmoerassen ter vergelijking met de Hollands-Utrechtse venen (in Dutch). Some Observations on Original Peat Bogs in Indonesia for Comparison with the Holland-Utrecht Peat Area. Boor en Spade 10:156-170.

Hooijer A, Vernimmen R, 2013. Peatland maps for Indonesia. Including accuracy assessment and recommendations for improvement, elevation mapping and evaluation of future flood risk. Quick Assessment and Nationwide Screening (QANS) of Peat and Lowland Resources and Action Planning for the Implementation of a National Lowland Strategy - PVW3A10002. Agentschap NL 6201068 QANS Lowland Development, for Government of Indonesia and Partners for Water (Netherlands). https://www.deltares.nl/app/uploads/2015/03/QANS-Peat-mapping-report-final-with-cover.pdf

Hooijer A, Vernimmen R, Visser M, Mawdsley N, 2015a. Flooding projections from elevation and subsidence models for oil palm plantations in the Rajang Delta peatlands, Sarawak, Malaysia. Deltares report 1207384, 76 pp. https://www.deltares.nl/app/uploads/2015/06/Rajang-Delta-Peatland-Subsidence-Flooding-Deltares-2015.pdf

Hooijer A, Vernimmen R, Mawdsley N, Page S, Mulyadi D, Visser M, 2015b. Assessment of impacts of plantation drainage on the Kampar Peninsula peatland, Riau. Deltares Report 1207384 to Wetlands International, CLUA and Norad. https://www.deltares.nl/app/uploads/2015/12/Plantation-Impacts-Kampar-Peatland-DELTARES-2015.pdf

RePPProT, 1990. The Land Resources of Indonesia: a national overview. Government of the Republic of Indonesia: Ministry of Transmigration, Directorate General of Settlement Preparation, and BAKOSURTANAL. Land Resources Department NRI, Overseas Development Administration, Foreign and Commonwealth Office UK. Peat classification according to interpretation of databasin.org (version 2), available for download from http://databasin.org/datasets/eb74fe29b6fb49d0a6831498b0121c99, last accessed 10 February 2016.

Ritung S, Wahyunto, Nugroho K, Sukarman, Hikmatullah, Suparto, Tafakresnanto C, 2011. Peta lahan gambut Indonesia. Skala 1:250.000. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian.

Silvius M, Hooijer A, Vernimmen R, 2007. Central Kalimantan Peatland Project CKPP; Final report of the project expansion component under CKPP Activity 8: Improved policies and coordination between government departments: Peat soil and drainage mapping for the Ex-Mega Rice Project area in Central Kalimantan Implemented by Wetlands International with Delft Hydraulics. Annex 12 - Land-based elevation surveys.

Sumarga E, Hein L, Hooijer A, Vernimmen R, 2016. Hydrological and economic effects of oil palm cultivation in Indonesian peatlands. Ecology and Society 21(2):52. http://dx.doi.org/10.5751/ES-08490-210252

Supardi, Subekty AD, Neuzil SG, 1993. General geology and peat resources of the Siak Kanan and Bengkalis Island peat deposits, Sumatra, Indonesia. In Cobb JC, Cecil CB, eds. Modern and Ancient Coal-Forming Environments. Boulder, Colorado, Geological Society of America Special Paper 286.

Vernimmen RRE, Hooijer A, Mamenun, Aldrian E, van Dijk AIJM, 2012 Evaluation and bias correction of satellite rainfall data for drought monitoring in Indonesia, Hydrol. Earth Syst. Sci., 16, 133-146, doi:10.5194/hess-16-133-2012.

Vernimmen R, Hooijer A, Akmalia R, Mulyadi D, Syahrozi O, Anugrah I, Visser M, Yuherdha A, Andreas H, 2017. Peatland mapping for Bengkalis Island, Riau, using limited LiDAR data and peat thickness field measurements. Team Deltares report to the Indonesian Peat Prize - Solution Development Phase.

Wahyunto, Ritung S, Subagjo H, 2003. Peta luas sebaran lahan gambut dan kandungan karbon di pulau Sumatera / Map of area of peatland distribution and carbon content in Sumatera, 1990-2002. Wetlands International - Indonesia Programme and Wildlife Habitat Canada (WHC), Bogor, Indonesia.

Wahyunto, Ritung S, Subagjo H, 2004. Peta Sebaran Lahan Gambut, Luas dan Kandungan Karbon di Kalimantan / Map of Peatland Distribution Area and Carbon Content in Kalimantan, 2000-2002. Wetlands International - Indonesia Programme & Wildlife Habitat Canada (WHC), Bogor, Indonesia.

Wahyunto, Bambang Heryanto, Hasyim Bekti dan Fitri Widiastuti, 2006. Peta-Peta Sebaran Lahan Gambut, Luas dan Kandungan Karbon di Papua / Maps of Peatland Distribution, Area and Carbon Content in Papua, 2000 - 2001. Wetlands International – Indonesia Programme & Wildlife Habitat Canada (WHC).

Zhang K, Chen S-C, Whitman D, Shyu ML, Yan J, Zhang C, 2003. A progressive morphological filter for removing nonground measurements from airborne LiDAR Data. IEEE Transactions on Geoscience and Remote Sensing, Vol. 41, No. 4: 872–882. doi:10.1109/TGRS.2003.810682.

Annex 1 – Peat thickness field survey

As part of the effort to create a peat map for the IPP study area in Kubu Raya district, a total of 147 locations were surveyed by two separate field teams consisting of Deltares and ITB staff with support staff recruited from local communities. The peat thickness field survey was conducted in the period 1 to 24 November 2017 (preceded by training and trials), by 2 field teams working in parallel supervised by 2 experts from Deltares and ITB.

A1 Introduction

The peat thickness survey was carried out in Kubu Raya district (Figure 31). The team accessed the study area on 31 October 2017 from Pontianak within 1 hour using a speedboat taxi from Sei Durian to Teluk Empening Village. Prior to survey execution, approval to carry out the survey was secured through a letter issued by BIG (Figure 32). In Teluk Empening village, this letter was presented to the head village to introduce the team members and explain the purpose of the survey.

Figure 31 Area location of Kubu Raya District.

BADAN INFORMASI GEOSPASIAL
(B I G)
Jl. Raya Jakarta-Bogor KM. 46, Cibinong 16911
Telepon. (021) 875 2062-2063, Faksimile. (021) 875 2064 PO. Box. 46 CBI
Website: http://www.big.go.id

Nomor : B-20.5 /DIGT/IGT/10/2017 — 20 Oktober 2017
Sifat : Biasa
Lampiran : Daftar Anggota Tim
Perihal : Informasi Pelaksanaan Survei *Indonesian Peat Prize*

Kepada Yth.
1. Bupati Kubu Raya
2. Kepala Badan Pembangunan Daerah Kabupaten Kubu Raya
3. Kepala Badan Lingkungan Hidup Kabupaten Kubu Raya
4. Kepala Badan Kesatuan Bangsa dan Politik Kabupaten Kubu Raya
5. Camat Terentang

di tempat

Bersama ini diinformasikan bahwa Badan Informasi Geospasial (BIG) sedang melaksanakan kegiatan *Indonesian Peat Prize*, suatu kompetisi yang bertujuan untuk mengidentifikasi metode pemetaan gambut yang akurat, cepat, dan terjangkau. Pada tahapan kompetisi ini, BIG telah mengumumkan 5 tim yang maju ke Tahap 3 untuk melakukan uji coba lapangan. Lebih lanjut, BIG telah menetapkan Kawasan Hidrologis Gambut Sungai Kapuas – Sungai Terentang, Provinsi Kalimantan Barat sebagai lokasi uji coba Tahap 3 yang akan dilaksanakan pada kurun waktu bulan Agustus hingga Desember 2017.

Salah satu tim yaitu tim dari Deltares dan Institut Teknologi Bandung akan melaksanakan kegiatan survei pengumpulan data di Kawasan Hidrologis Gambut Sungai Kapuas – Sungai Terentang, Provinsi Kalimantan Barat. Kegiatan tersebut mencakup survei untuk permukaan tanah, pengukuran dan analisa kedalaman tanah gambut, dan identifikasi tutupan lahan terutama di lahan gambut.

Sehubungan hal tersebut, kami sampaikan informasi pendahuluan agar koordinasi yang dibutuhkan di lapangan berupa pemberian informasi kepada pihak terkait, termasuk Kepala Desa setempat di wilayah Kecamatan Terentang, atas adanya rencana kegiatan ini dapat dilakukan sebelumnya. Pelaksanaan survei lapangan tersebut akan dilaksanakan pada tanggal **23 Oktober sampai dengan 30 November 2017**.

Demikian disampaikan, atas perhatian dan bantuan Saudara/i diucapkan terima kasih.

Deputi Bidang Informasi
Geospasial Tematik,

Nurwadjedi

Tembusan:
1. Kepala Badan Informasi Geospasial
2. Sekretaris Utama Badan Informasi Geospasial
3. Direktur Pengendalian Kerusakan Gambut, Kementerian Lingkungan Hidup dan Kehutanan.

Figure 32 Letter from BIG informing local government about the peat thickness survey carried out by Deltares and ITB team.

A2 Reconnaissance survey

The reconnaissance survey was carried out a day before the actual measurement by Deltares team to determine the survey requirements and approval from the local stake holders. Prior to the reconnaissance survey in the field, the Deltares team prepared a survey plan based on the spatial data (canals, roads, and KHG boundary) which were provided by the IPP committee combined with the location of LiDAR flight lines.

The survey locations were determined not only based on transects (as described in transect design) but also considering the road access to get a more efficient survey. On the first day of the reconnaissance survey, the team visited Teluk Empening village office to meet the village head and his staff. The letter from BIG together with the map of survey locations were presented to them. Unlike the first study in Bengkalis where none of the village heads were aware, the village head in Teluk Empening village was fully aware of the peat prize competition.

During the first day visit in Teluk Empening, the village's staff helped Deltares team to find local workers and to settle in at the first basecamp. Ideally, the basecamp is located in the center of the study area so the team can easily reach the whole area from there. However, since most of the study area consists of oil palm plantations, the only possibility is to stay at the closest villages located in the Northeast (Teluk Empening) and West part (Teluk Nangka) of the study area.

To get an idea on the actual field conditions in the whole area, the second day of the reconnaissance was used to reach the West part of the study area. During this survey, the team found out that the existing roads in the field that can be accessed were actually only a few compared with the existing roads in the provided shapefile. Only short roads were paved (cement), while the majority of the roads were unpaved. The condition of the roads worsened during and after rain. An overview of good and bad roads is provided in Figure 33. Photos of road conditions are provided in Figure 34.

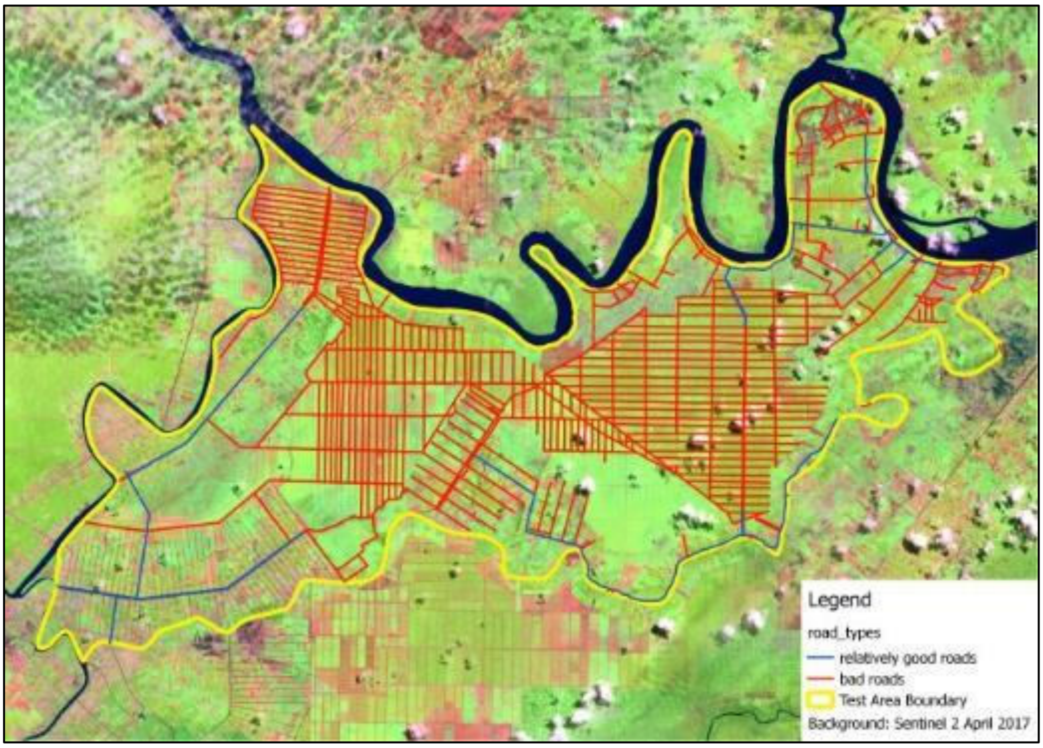


Figure 33 Overview of good and bad roads.

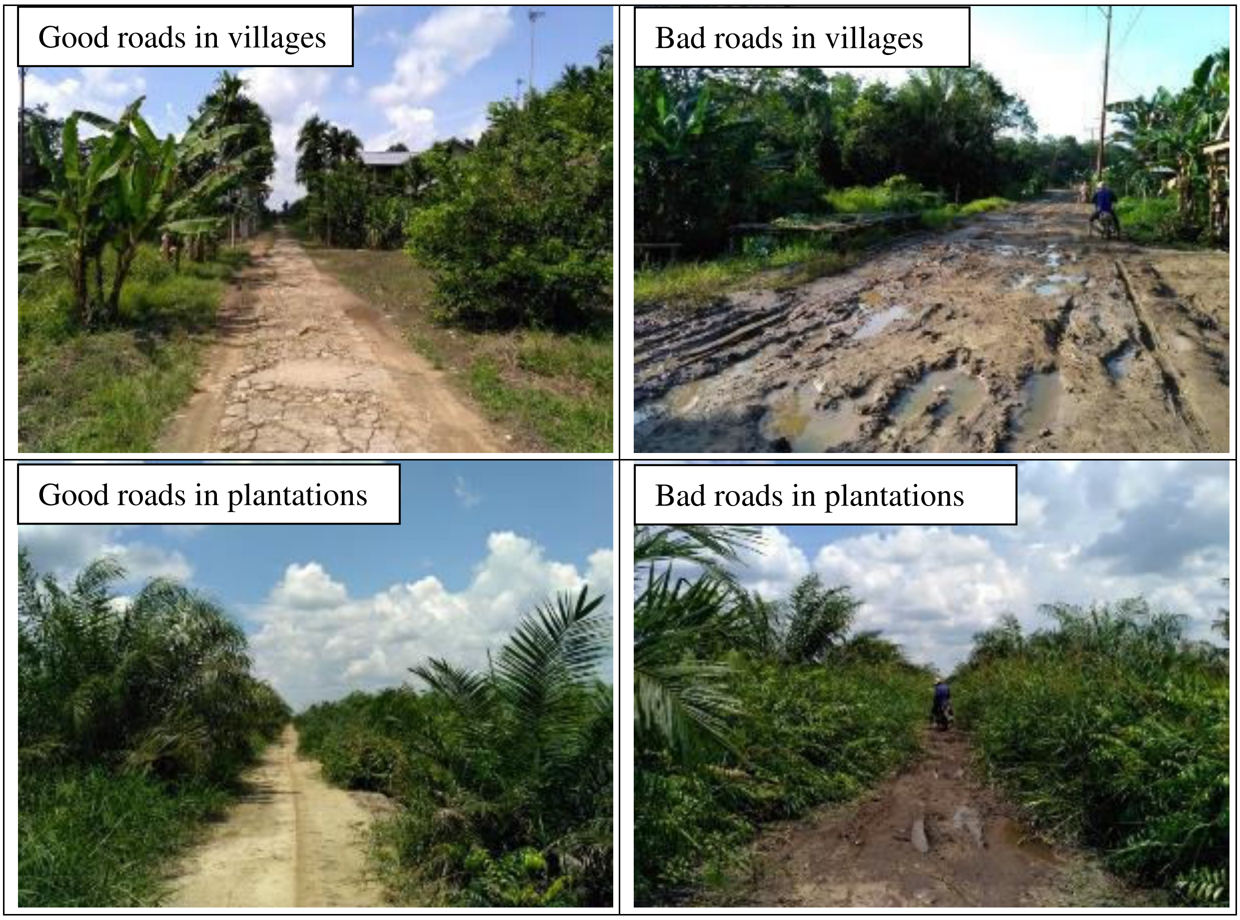


Figure 34 Road condition in the field.

The survey area was divided into two sectors: East (Terentang sub-district) and West (Kubu Raya sub-district). This division was based on field conditions. The middle part of the study area is covered by two large oil palm plantations, PT Bumi Perkasa Gemilang (BPG) and PT Rezeki Kencana (RK), while villages were located in the East and West. Total travel time by motorcycle from the Teluk Empening village (in the East) to the Teluk Nangka village (in the West) was 3.5 hours. Based on road accessibility and accommodation availability, the team decided to survey the West part of the study area from the Teluk Nangka village (second basecamp). The location of both basecamps and the villages is shown in Figure 35. The name of the villages in the Kubu Raya study area is provided in Table 8 while the location of the villages is shown in Figure 36.

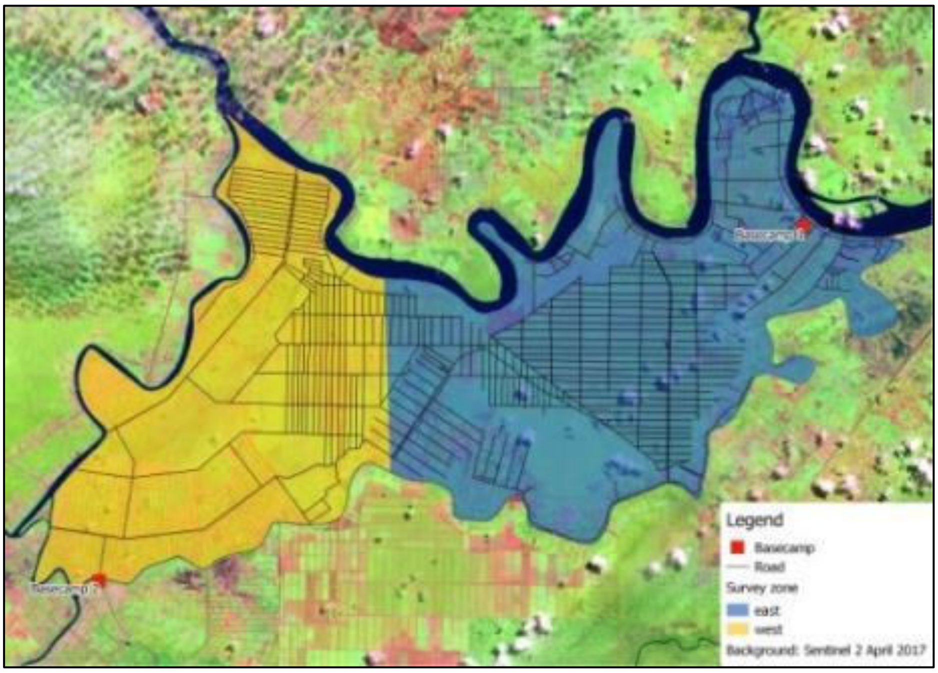


Figure 35 Location of survey zones and basecamps.

Table 8 List of villages in the Kubu Raya study area. The location is shown in Figure 36.

Sub-District	***Village Name***
Terentang	Teluk Empening
	Teluk Bayur
	Teluk Simpur
	Terentang Hulu
	Terentang Hilir
	Dungun
Kubu	Teluk Nangka
	Jangkang Baru
	Jangkang Satu
	Jangkang Dua

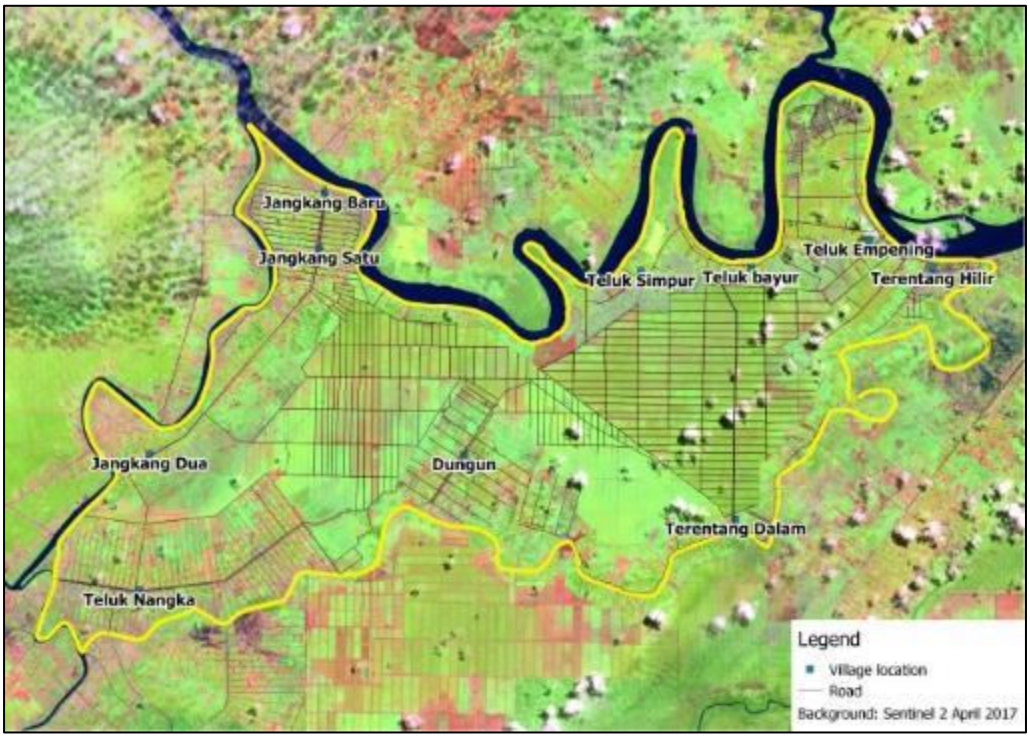


Figure 36 Location of villages in the Kubu Raya study area.

Much of the survey points were located in the concessions of the two oil palm plantations, BPG and RK. The team could access both the BPG and RK oil palm plantations after obtaining permission with the help of the local workers and the letter from BIG. There were also no problems to enter neighboring villages although the team has never met the village's head formally. The local workers usually helped to talk to the villager when the team needed to conduct the survey inside a smallholder's plantation.

One factor affecting the number of team members was the land cover and accessibility of survey locations (illustrated in Figure 37). For areas which could not be easily reached and required 'rintisan', additional local workers were hired. In general, each of the two field teams consisted of one team leader (from ITB) and 2 to 3 local workers, supervised by Mr. Fitranatanegara and Mrs. Rizka Akmalia of Deltares. The main field team (present during the whole survey) consisted of 2 team leaders from ITB (Mr. Esa Rizky and Mr. Tezar Febriyanto) and 4 local workers from Desa Teluk Empening (Pak Indra, Pak Jaiz, Pak Gipon, and Pak Herman).

Figure 37 Different types of land cover needed to be crossed to reach the survey location.

A3 Field survey

The field survey was carried out following a field protocol (SOP) using an Edelman type auger (details can be found in Annex 2). An overview of all equipment used during the survey is provided in Table 9.

Table 9 List of survey equipment.

Equipments	Specification
Auger	Edelman/Belgy type
	stainless steel
	6 cm diameter
	23 cm long
	12 x 1 m extensions
	(see Annex 2, Fig 1)
Handheld GPS	GARMIN GPSMAP 64S
	3-axis tilt-compensated compass
	sunlight readable screen
	accuracy 3-15 meters
Camera	Digital Nikon CoolPix A10
	AA battery
	16.1 MP
Measuring tape	2 m long

Different auger types are readily available on the market in Indonesia. A modified Edelman type stainless steel auger was used in this survey with 12 one meter extension rods (Figure 38). As auger head we chose the Edelman/Belgy type with a head diameter of 6 cm and 23 cm body length. Using experience from our previous survey in Bengkalis, modifications were made to the auger head to ensure more soil was trapped.

Figure 38 (LEFT) Edelman type auger heads used in this peat survey. (RIGHT) team preparing the auger at the survey location.

An additional consideration when choosing the proper auger is the type of connector used to connect separate extensions rods. At least 3 different connection types are commonly used; nut-bolt, button-hex, and C-clip (Figure 39). Using the nut-bolt type connection, the different extension rods would be securely fastened. However, the button-hex connection was preferred since this allows connecting and disconnecting parts with less hassle than the nut-bolt type.

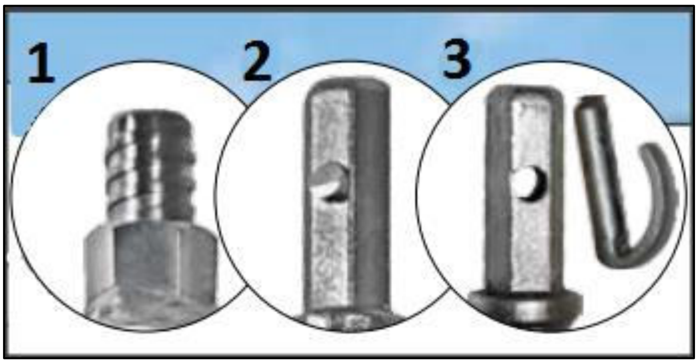


Figure 39 Different types of connector: (1) nut-bolt, (2) button-hex, (3) C-clip ((source: www.precisionagrilab.com/Documents/AMSSoilProbes.pdf).

Despite some modifications introduced to both the auger head and connector during the previous survey in Bengkalis and cautious drilling, it couldn't be prevented some auger heads were lost during the survey as these got trapped in the peat and couldn't be retrieved.

A handheld Garmin GPSMap 64S (3 - 15 m horizontal accuracy) was used to find sample locations based on the survey map and to log geographical positions of each survey point. To reach the survey locations, motorcycles were used during the survey. Some roads that exist on the map were sometimes actually canals, as can be seen in Figure 40. At some locations, the team also needs to cross the canal as can be seen in Figure 41.

Figure 40 Team members following existing roads on the map which actually are inaccessible in the field. (Left) Road condition to reach point 157 in oil palm plantation that already has been covered by bushes. (Right) Road condition to reach point 211 in an ex-burnt plantation area.

Figure 41 Team members tried to cross the perimeter canal of the plantation area to reach point 55 (left) and point 211 (right).

Vegetation cover and land use was documented at each survey location and photographed in four directions (Figure 42). The augering process in the field is shown in Figure 43. Mineral subsoil that was trapped in the auger was photographed as evidence that the peat bottom was reached (Figure 44).

Figure 42 Vegetation cover as observed in four directions at sampling point 190. (LEFT) North, (RIGHT TOP) East, (LEFT BOTTOM) South and (BOTTOM RIGHT) West.

Figure 43 (LEFT) Augering process at point 57. (RIGHT) Taking pictures of the mineral soil caught by the auger head.

Figure 44 (ABOVE) Mineral soil found below the peat at point 147 and (BELOW) clear boundaries between clay and peat caught in the auger head at point 255.

A4 Survey results / statistics used in map assessment and creation

Of the 147 survey locations, 111 (75.5%) found the presence of peat i.e. an organic top soil horizon of over 0.5 m thickness. Of these 111 locations, 94.6% found a peat thickness of over 1 m and 51.4% over 3 m. Average peat thickness of the 111 locations is 3.37 m with a standard deviation of 1.66 m.

The peat thickness survey within the study area covered 6 land cover types (1) forest, (2) scrubland/bush/ferns, (3) oil palm plantation, (4) rubber plantation, (5) sawah and (6) settlement area (see Annex 3). The majority of the locations on peat were taken in oil palm plantations (62.6 %) and shrubland (22.4%), whereas only 4.8% of the survey locations (7 measurements) were located in forest. This is a representative reflection of the actual land cover in the area, that is dominated by plantations with hardly any forest left.

A5 Survey costs for data collection used in map assessment and creation

Survey costs amounted Rp 74 million (US$ 5,517), of which Rp 12.7 million (17.0 %) was for mobilization costs, Rp 12.1 million (16.3 %) for local transportation and lodging, and Rp 49.7 million (66.7%) for wages local field staff and supervisors. All expenses are listed in Table 10.

Table 10 Survey cost overview for the field data collection used in map assessment and creation.

Specification	Unit cost (IDR/day)	IDR (in million)	US$*	% of Total
Travel to location (mobilisation)	-	12.7	937	16.0
Local transport and accommodation	-	12.1	899	15.3
Local field staff	200000	18.6	1378	23.5
Supervision (Deltares + ITB)	650000	35.8	2648	45.2
Total		**79**	**5862**	**100**
* US$ 1 = IDR 13,500				

A6 Lessons learned and recommendations for future surveys

A reconnaissance survey prior to the actual peat thickness survey is recommended as it will help efficient planning of the survey. It is important to know the field conditions both in terms of technical aspects (such as soil condition, land cover) as well as practical aspects (such as road access, availability of accommodation and local workers), prior to fully mobilizing large teams. An accurate estimation of the speed and cost of work is only possible once these aspects are known.

A proper auger (incl. sufficient extension rods) does not need to be expensive. They are available on the Indonesian market for less than 5 million IDR (approx. 375 US$). A local workshop could duplicate the auger at even lower price. Existing road lines on the map did not always really exist in the field. Even when the road existed, it cannot be accessed by a vehicle. In Kubu Raya, most of the roads were not of concrete/asphalt and therefore will be affected during and after rain shower.

Hiring local workers that knew the area well was also a key to speed up the survey. The local workers usually helped the team to speak to villagers and explain the purpose of the survey and allowed the team to easily access plantation areas.

Annex 2 – Standard Operating Procedure (SOP)

This SOP provides guidelines for measuring peat thickness using a manual auger.

Material

The following equipment should be available for measuring peat thickness in the field:

- Hand auger set (preferably Edelman type auger, see Figure 1)
  The Edelman auger body consists of two blades in conical shape with a screw-like shape in the bottom to help in entering and digging the soil. A broader auger body permits a good hold of soil sampling. This auger head should be connected to a handle. Extension rods for deeper digging are also needed.
- Survey plan and maps with survey site information
- Handheld GPS
- Measuring tape
- Pocket camera
- Gloves
- Stationery set

Method

1) Before going to the field, a good survey plan should be made in order to identify which locations are suitable to carry out the peat thickness measurement. Transects are in general designed perpendicular to coastlines or rivers (where peat thickness is shallow) going up the peat dome (where peat thickness is generally thicker). Survey points along a transect are generally at 500 m intervals. At each location a minimum of 2 replicates are to be measured. See schematic setup of an effective and cost-efficient peat thickness survey in Figure 2.
2) GPS is required for navigation and registering the actual survey location.
3) Identify a suitable location for drilling; try to drill in a relatively flat area.
4) Prior to drilling, check for cables, tubes, pipes, wood, or any other obstacles.
5) If needed, clear the area of vegetation before starting the drilling. Only clear vegetation which is hampering the drilling process.
6) Connect the handle and the auger head.
7) Place the auger on the peat surface and turn the handle clockwise. The auger must be perpendicular to the peat surface at the drilling point. To avoid slippery conditions during drilling (wet peat), the surveyor could wear gloves (see Figure 3).
8) The peat soil is collected gradually during drilling (0.3-0.5 m intervals depending on the auger head length).
9) If auger head is full, withdraw the auger. Upon withdrawal, lay the auger head on the ground and check whether mineral soil is already captured in the auger head. In case mineral soil is indeed reached document this by taking a clear picture of the mineral soil trapped in the auger head (see Figure 4).

10) For deeper drilling, one or more extension rods should be used. Connect the extension rod between the auger head and the handle. Add the extension rods as needed gradually.
11) Drilling can be carried out by two persons especially when connecting or removing the extension rods, one to hold the lower part of the auger to prevent it from falling into the borehole, while the other releasing the top parts of auger (see Figure 5).
12) Drilling is carried out until the auger head reaches the mineral soils underneath the peat layer (see Figure 4).
13) Using the measurement tape, measure the length of the mineral soil trapped in the auger. Ideally the mineral soil fills the complete auger head.
14) Before removing the auger, measured the length of the auger protruding from the peat surface.
15) Calculate the peat thickness as: (total length of auger) – (mineral soil layer trapped in the auger head) – (length of auger above the peat surface).
16) Record the coordinate of measurement point in GPS
17) Observe the surrounding vegetation and land cover of the sample location and write this down. Take photographs of the sample location in 4 wind directions to document the surrounding area. Be consistent at each location by taking pictures each time in the same direction (e.g. always clockwise, first picture to the North, second East etc.).
18) Repeat the process by taking one or two replicate samples located within 5 to 10 m from the first measurement location.

Figure 1 Edelman Auger set.

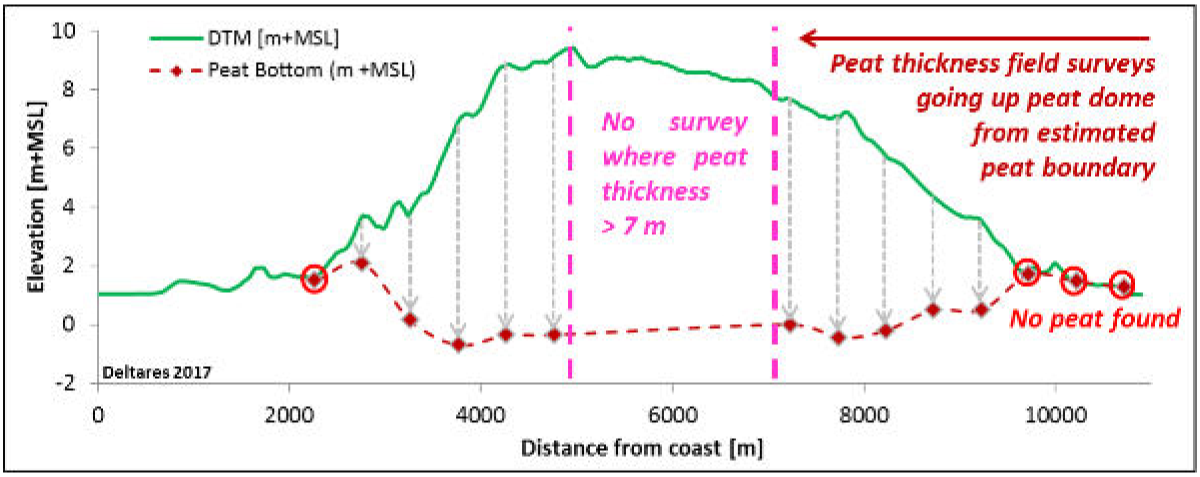


Figure 2 General schematic set-up of an effective and cost-efficient peat thickness survey. Surveys are planned perpendicular to coastlines and river as much as possible, which often matched the steepest slope of the peat dome. To reduce the number of sampling points in areas without peat, surveys start at a 'likely peat boundary' that is identified from satellite images. To reduce the number of measurements in areas where very deep peat is known to be present without further survey, surveys along transects end when a certain peat thickness limit is reached (in this schematic illustration 7 m, but sometimes a 5 m limit can be applied, depending whether the peat domes are small and steep or large with more gradual slopes).

Figure 3 The initial stage of peat drilling. The wooden planks are not required if purpose is only to determine peat thickness. These planks are only required in case the bore hole is also used for dipwell installation (to measure groundwater table and/or subsidence) as to minimize disturbance.

Figure 4 Photographic evidence of mineral soil trapped in the auger head.

Figure 5 The process of removing and connecting the extension rods and continue drilling.

Annex 3 – Peat thickness measurements

The detailed peat thickness field survey results are presented in following tables.

LocationId	TotalReplicates	Date	X-UTM49S	Y-UTM49S	Peat Thickness	Mineral Soil	LULC	Location	Field Team
KR_006-R1	1	19-Nov-17	325695	9957041	No Peat	Clay	Rubber Plantation	Desa Jangkang	Deltares, ITB
KR_007-R1	1	19-Nov-17	325672	9956548	No Peat	Clay	Rice Field	Desa Jangkang	Deltares, ITB
KR_008-R1	1	19-Nov-17	325666	9955728	No Peat	Clay	Op Plantation Mix Ferns	Desa Jangkang	Deltares, ITB
KR_009-R1	1	13-Nov-17	330631	9956396	No Peat	Clay	forest	Desa Dungun	Deltares, ITB
KR_010-R1	1	13-Nov-17	330698	9956155	No Peat	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_011-R1	3	13-Nov-17	330690	9955638	1.42	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_011-R2	3	13-Nov-17	330677	9955637	1.50	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_011-R3	3	13-Nov-17	330673	9955637	1.45	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_012-R1	3	13-Nov-17	330738	9955140	2.88	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_012-R2	3	13-Nov-17	330728	9955136	3.04	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_012-R3	3	13-Nov-17	330713	9955139	3.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_013-R1	3	13-Nov-17	330732	9954592	2.97	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_013-R2	3	13-Nov-17	330730	9954587	2.79	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_013-R3	3	13-Nov-17	330720	9954590	2.84	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_014-R1	3	12-Nov-17	330738	9953991	3.61	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_014-R2	3	12-Nov-17	330733	9953990	3.65	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_014-R3	3	12-Nov-17	330740	9953987	3.29	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_015-R1	3	12-Nov-17	330678	9953651	2.87	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_015-R2	3	12-Nov-17	330676	9953649	2.96	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_015-R3	3	12-Nov-17	330669	9953652	2.94	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_016-R1	3	13-Nov-17	330594	9953298	0.56	Clay	Rice field	Desa Dungun	Deltares, ITB
KR_016-R2	3	13-Nov-17	330594	9953294	0.84	Clay	Rice field	Desa Dungun	Deltares, ITB
KR_016-R3	3	13-Nov-17	330602	9953291	0.61	Clay	Rice field	Desa Dungun	Deltares, ITB
KR_017-R1	3	13-Nov-17	330672	9952745	0.71	Clay	ferns	Desa Dungun	Deltares, ITB
KR_017-R2	3	13-Nov-17	330676	9952745	0.50	Clay	ferns	Desa Dungun	Deltares, ITB
KR_017-R3	3	13-Nov-17	330677	9952755	0.48	Clay	ferns	Desa Dungun	Deltares, ITB
KR_019-R1	1	10-Nov-17	330729	9951781	No Peat	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_022-R1	1	19-Nov-17	327887	9957468	No Peat	Clay	Op Plantation Mix Ferns	Desa Jangkang	Deltares, ITB
KR_023-R1	3	19-Nov-17	327986	9956977	1.35	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_023-R2	3	19-Nov-17	327958	9956961	1.39	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_023-R3	3	19-Nov-17	327931	9956960	1.44	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_024-R1	3	19-Nov-17	327985	9956550	1.50	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_024-R2	3	19-Nov-17	327980	9956553	1.10	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_024-R3	3	19-Nov-17	327974	9956555	1.13	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_025-R1	3	19-Nov-17	327954	9956037	1.03	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_025-R2	3	19-Nov-17	327960	9956034	1.06	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_025-R3	3	19-Nov-17	327967	9956036	1.03	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_026-R1	3	18-Nov-17	327965	9955505	1.87	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_026-R2	3	18-Nov-17	327974	9955505	2.06	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_026-R3	3	18-Nov-17	327976	9955506	1.92	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_027-R1	3	18-Nov-17	327965	9955022	2.40	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_027-R2	3	18-Nov-17	327971	9955020	2.44	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_027-R3	3	18-Nov-17	327980	9955022	2.06	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_028-R1	3	18-Nov-17	327908	9954524	2.30	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_028-R2	3	18-Nov-17	327902	9954523	2.35	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_028-R3	3	18-Nov-17	327896	9954521	2.44	Clay Mix Peat	Op Plantation	Desa Jangkang	Deltares, ITB
KR_029-R1	3	18-Nov-17	327887	9953991	3.78	Sandy Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_029-R2	3	18-Nov-17	327881	9953993	3.54	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_029-R3	3	18-Nov-17	327873	9953989	3.75	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_030-R1	3	18-Nov-17	327883	9953503	3.61	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_030-R2	3	18-Nov-17	327882	9953502	3.66	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_030-R3	3	18-Nov-17	327874	9953505	3.74	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_031-R1	3	18-Nov-17	327869	9953005	4.16	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_031-R2	3	18-Nov-17	327862	9953004	4.36	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_031-R3	3	18-Nov-17	327858	9953005	4.51	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_032-R1	3	18-Nov-17	327846	9952469	4.58	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_032-R2	3	18-Nov-17	327838	9952469	4.73	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_032-R3	3	18-Nov-17	327841	9952476	4.82	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_033-R1	3	18-Nov-17	327862	9952049	3.19	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_033-R2	3	18-Nov-17	327860	9952050	3.06	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_033-R3	3	18-Nov-17	327854	9952051	3.25	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_034-R1	3	18-Nov-17	327852	9951508	2.96	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_034-R2	3	18-Nov-17	327852	9951505	2.94	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_034-R3	3	18-Nov-17	327848	9951509	2.99	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_035-R1	3	18-Nov-17	327850	9950998	3.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_035-R2	3	18-Nov-17	327846	9950996	3.20	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_035-R3	3	18-Nov-17	327843	9950999	3.40	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_036-R1	3	18-Nov-17	327819	9950591	3.09	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_036-R2	3	18-Nov-17	327819	9950587	2.88	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_036-R3	3	18-Nov-17	327821	9950590	3.00	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_037-R1	2	20-Nov-17	327883	9949538	No Peat	Clay	Forest	Desa Dungun	Deltares, ITB
KR_037-R2	2	20-Nov-17	327880	9949536	No Peat	Clay	Forest	Desa Dungun	Deltares, ITB
KR_039-R1	3	12-Nov-17	333141	9955095	2.90	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_039-R2	3	12-Nov-17	333132	9955094	3.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_039-R3	3	12-Nov-17	333124	9955093	2.61	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_040-R1	4	08-Nov-17	333257	9954398	2.64	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_040-R2	4	08-Nov-17	333248	9954397	2.26	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_040-R3	4	22-Nov-17	333262	9954492	2.30	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_040-R4	4	22-Nov-17	333259	9954488	2.66	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_041-R1	4	08-Nov-17	333258	9953867	2.69	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_041-R2	4	08-Nov-17	333257	9953868	2.26	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_041-R3	4	22-Nov-17	333258	9953869	1.80	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_041-R4	4	22-Nov-17	333256	9953869	1.92	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_042-R1	1	08-Nov-17	333318	9952717	No Peat	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_046-R1	3	09-Nov-17	335661	9957417	0.85	Clay	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_046-R2	3	09-Nov-17	335698	9957426	0.85	Clay	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_046-R3	3	09-Nov-17	335671	9957417	0.85	Clay	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_047-R1	3	09-Nov-17	335706	9957004	3.63	Clay	ferns	Desa Teluk Simpur	Deltares, ITB
KR_047-R2	3	09-Nov-17	335699	9957000	3.36	Clay	ferns	Desa Teluk Simpur	Deltares, ITB
KR_047-R3	3	09-Nov-17	335669	9956983	4.14	Clay	ferns	Desa Teluk Simpur	Deltares, ITB
KR_048-R1	3	08-Nov-17	335664	9956135	5.62	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_048-R2	3	08-Nov-17	335667	9956107	5.90	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_048-R3	3	08-Nov-17	335696	9956147	5.34	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_049-R1	3	08-Nov-17	335572	9955366	4.86	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_049-R2	3	08-Nov-17	335567	9955350	4.67	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_049-R3	3	08-Nov-17	335564	9955340	5.33	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_050-R1	3	07-Nov-17	335591	9954730	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_050-R2	3	07-Nov-17	335608	9954709	4.77	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB

LocationId	TotalReplicates	Date	X-UTM49S	Y-UTM49S	Peat Thickness	Mineral Soil	LULC	Location	Field Team
KR_050-R3	3	07-Nov-17	335674	9954704	5.35	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_051-R1	4	07-Nov-17	335607	9954085	3.65	Silty Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_051-R2	4	07-Nov-17	335615	9954079	3.89	Silty Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_051-R3	4	14-Nov-17	335610	9954110	3.63	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_051-R4	4	14-Nov-17	335624	9954110	4.02	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_052-R1	2	07-Nov-17	335597	9953500	3.29	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_052-R2	2	07-Nov-17	335597	9953501	3.04	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_053-R1	2	07-Nov-17	335629	9953261	2.26	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_053-R2	2	07-Nov-17	335647	9953278	2.26	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_054-R1	3	10-Nov-17	335785	9952690	1.40	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_054-R2	3	10-Nov-17	335770	9952692	1.68	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_054-R3	3	10-Nov-17	335774	9952699	1.63	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_055-R1	3	09-Nov-17	335568	9951964	2.41	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_055-R2	3	09-Nov-17	335567	9951964	2.67	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_055-R3	3	09-Nov-17	335549	9951962	2.52	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_056-R1	3	09-Nov-17	335537	9951425	2.98	Clay Mix Peat	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_056-R2	3	09-Nov-17	335538	9951426	2.95	Clay Mix Peat	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_056-R3	3	09-Nov-17	335518	9951427	2.94	Clay Mix Peat	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_057-R1	3	09-Nov-17	335548	9950898	2.42	Silty Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_057-R2	3	09-Nov-17	335528	9950890	2.06	Silty Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_057-R3	3	09-Nov-17	335547	9950898	2.07	Silty Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_058-R1	3	09-Nov-17	335524	9950400	2.18	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_058-R2	3	09-Nov-17	335510	9950404	2.36	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_058-R3	3	09-Nov-17	335503	9950407	2.16	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_059-R1	3	11-Nov-17	335628	9949559	0.73	Clay	bushes/shrub	Desa Terentang Dalam	Deltares, ITB
KR_059-R2	3	11-Nov-17	335636	9949562	0.70	Clay	bushes/shrub	Desa Terentang Dalam	Deltares, ITB
KR_059-R3	3	11-Nov-17	335637	9949557	0.87	Clay	bushes/shrub	Desa Terentang Dalam	Deltares, ITB
KR_060-R1	1	11-Nov-17	335610	9949251	No Peat	Clay	bushes/shrub	Desa Terentang Dalam	Deltares, ITB
KR_062-R1	2	06-Nov-17	337967	9958546	2.26	Clay Mix Peat	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_062-R2	2	06-Nov-17	337978	9958540	2.26	Clay Mix Peat	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_063-R1	2	06-Nov-17	338156	9958033	3.74	Clay	forest	Desa Teluk Simpur	Deltares, ITB
KR_063-R2	2	06-Nov-17	338150	9958038	4.13	Clay	forest	Desa Teluk Simpur	Deltares, ITB
KR_064-R1	2	06-Nov-17	338079	9957906	4.77	Clay	bushes/shrub	Desa Teluk Simpur	Deltares, ITB
KR_064-R2	2	06-Nov-17	338072	9957906	4.77	Clay	bushes/shrub	Desa Teluk Simpur	Deltares, ITB
KR_065-R1	2	05-Nov-17	338369	9957200	5.35	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_065-R2	2	05-Nov-17	338368	9957179	5.35	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_066-R1	4	02-Nov-17	338070	9956609	6.19	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_066-R2	4	02-Nov-17	338069	9956554	6.19	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_066-R3	4	24-Nov-17	338128	9956627	5.28	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_066-R4	4	24-Nov-17	338128	9956620	5.15	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_067-R1	4	02-Nov-17	338093	9955956	6.19	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_067-R2	4	02-Nov-17	338086	9956021	6.38	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_067-R3	4	24-Nov-17	338114	9956030	5.92	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_067-R4	4	24-Nov-17	338118	9956025	5.71	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_068-R1	4	02-Nov-17	338007	9955553	6.19	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_068-R2	4	02-Nov-17	338012	9955622	6.84	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_068-R3	4	23-Nov-17	338068	9955517	6.45	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_068-R4	4	23-Nov-17	338066	9955508	6.84	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_069-R1	4	02-Nov-17	337995	9954726	6.38	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_069-R2	4	02-Nov-17	337993	9954763	6.38	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_069-R3	4	23-Nov-17	338057	9955023	6.70	Sandy Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_069-R4	4	23-Nov-17	338057	9955019	6.76	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_070-R1	2	02-Nov-17	338049	9954469	6.04	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_070-R2	2	02-Nov-17	338053	9954486	6.04	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_071-R1	2	02-Nov-17	338045	9953983	6.04	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_071-R2	2	02-Nov-17	338041	9953968	6.38	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_072-R1	2	02-Nov-17	338016	9953488	6.06	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_072-R2	2	02-Nov-17	338015	9953476	6.06	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_073-R1	2	02-Nov-17	338016	9953010	5.01	Silty Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_073-R2	2	02-Nov-17	338018	9953036	4.84	Silty Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_074-R1	4	02-Nov-17	337992	9952532	4.86	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_074-R2	4	02-Nov-17	337990	9952536	4.32	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_074-R3	4	14-Nov-17	338044	9952710	4.65	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_074-R4	4	14-Nov-17	338037	9952706	4.56	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_075-R1	2	02-Nov-17	337961	9952002	4.32	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_075-R2	2	02-Nov-17	337961	9952019	4.87	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_076-R1	2	05-Nov-17	337955	9951494	5.03	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_076-R2	2	05-Nov-17	337943	9951502	5.17	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_077-R1	2	06-Nov-17	337770	9950226	3.29	Clay	Ferns	Desa Terentang Dalam	Deltares, ITB
KR_077-R2	2	06-Nov-17	337754	9950221	3.29	Clay	Ferns	Desa Terentang Dalam	Deltares, ITB
KR_079-R1	4	03-Nov-17	340712	9958274	2.26	Clay Mix Peat	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_079-R2	4	03-Nov-17	340705	9958266	2.68	Clay Mix Peat	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_079-R3	4	14-Nov-17	340705	9958283	2.27	Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_079-R4	4	14-Nov-17	340712	9958290	2.43	Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_080-R1	2	04-Nov-17	340768	9957376	5.80	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_080-R2	2	04-Nov-17	340742	9957339	5.80	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_081-R1	2	04-Nov-17	340693	9956595	5.35	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_081-R2	2	04-Nov-17	340690	9956564	5.80	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_082-R1	2	04-Nov-17	340743	9955994	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_082-R2	2	04-Nov-17	340744	9955971	5.35	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_083-R1	2	04-Nov-17	340584	9955283	6.38	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_083-R2	2	04-Nov-17	340585	9955300	6.38	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_084-R1	2	04-Nov-17	340585	9954844	5.78	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_084-R2	2	04-Nov-17	340581	9954851	6.06	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_085-R1	2	04-Nov-17	340579	9954363	5.93	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_085-R2	2	04-Nov-17	340580	9954379	6.14	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_086-R1	2	14-Nov-17	340575	9953916	5.22	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_086-R2	2	14-Nov-17	340573	9953907	5.22	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_087-R1	4	04-Nov-17	340605	9953500	4.32	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_087-R2	4	04-Nov-17	340605	9953501	4.79	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_087-R3	4	24-Nov-17	340600	9953475	4.88	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_087-R4	4	24-Nov-17	340599	9953477	4.91	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_088-R1	4	04-Nov-17	340598	9952928	2.26	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_088-R2	4	04-Nov-17	340599	9952927	2.26	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_088-R3	4	24-Nov-17	340602	9952959	2.58	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_088-R4	4	24-Nov-17	340606	9952960	2.56	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_089-R1	2	05-Nov-17	340617	9952467	No Peat	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB

LocationId	TotalReplicates	Date	X-UTM49S	Y-UTM49S	Peat Thickness	Mineral Soil	LULC	Location	Field Team
KR_089-R2	2	05-Nov-17	340617	9952461	No Peat	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_094-R1	1	03-Nov-17	343311	9962863	No Peat	Clay	Rice field	Desa Teluk Empening	Deltares, ITB
KR_095-R1	1	03-Nov-17	343338	9962260	No Peat	Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_096-R1	1	03-Nov-17	343324	9961363	No Peat	Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_097-R1	1	03-Nov-17	343261	9960221	No Peat	Clay	Ex-Burn Area	Desa Teluk Empening	Deltares, ITB
KR_098-R1	1	03-Nov-17	343248	9959248	No Peat	Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_099-R1	2	03-Nov-17	343097	9957923	2.72	Clay Mix Peat	ferns	Desa Teluk Empening	Deltares, ITB
KR_099-R2	2	03-Nov-17	343095	9957925	2.72	Clay Mix Peat	ferns	Desa Teluk Empening	Deltares, ITB
KR_100-R1	4	03-Nov-17	343165	9957354	3.29	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_100-R2	4	03-Nov-17	343169	9957353	3.04	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_100-R3	4	23-Nov-17	343164	9957355	2.06	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_100-R4	4	23-Nov-17	343168	9957355	1.96	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_101-R1	2	03-Nov-17	343213	9956351	No Peat	Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_101-R2	2	03-Nov-17	343211	9956351	No peat	Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_102-R1	1	03-Nov-17	345637	9958209	No Peat	Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_103-R1	1	03-Nov-17	345354	9957655	No Peat	Clay	forest	Desa Teluk Empening	Deltares, ITB
KR_105-R1	1	03-Nov-17	344674	9956573	No Peat	Clay	forest	Desa Teluk Empening	Deltares, ITB
KR_106-R1	1	03-Nov-17	344576	9956450	No Peat	Clay	forest	Desa Teluk Empening	Deltares, ITB
KR_107-R1	2	03-Nov-17	342640	9955934	0.78	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_107-R2	2	03-Nov-17	342639	9955934	No Peat	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_108-R1	3	14-Nov-17	341325	9955718	5.53	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_108-R2	3	14-Nov-17	341317	9955725	5.84	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_108-R3	3	14-Nov-17	341323	9955712	5.51	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_114-R1	1	19-Nov-17	325449	9952105	No Peat	Clay Mix Peat	ferns	Desa Jangkang	Deltares, ITB
KR_115-R1	3	19-Nov-17	325466	9952509	No Peat	Clay Mix Peat	ferns	Desa Jangkang	Deltares, ITB
KR_115-R2	3	19-Nov-17	325466	9952515	No Peat	Clay Mix Peat	ferns	Desa Jangkang	Deltares, ITB
KR_115-R3	3	19-Nov-17	325471	9952514	No Peat	Clay Mix Peat	ferns	Desa Jangkang	Deltares, ITB
KR_116-R2	2	20-Nov-17	325555	9953562	1.41	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_116-R3	2	20-Nov-17	325542	9953560	1.25	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_119-R1	1	21-Nov-17	322945	9948743	No Peat	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_120-R1	3	21-Nov-17	322830	9949367	1.89	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_120-R2	3	21-Nov-17	322830	9949369	1.81	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_120-R3	3	21-Nov-17	322831	9949369	1.84	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_121-R1	3	19-Nov-17	322993	9950155	1.76	Silty Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_121-R2	3	19-Nov-17	322991	9950157	1.72	Silty Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_121-R3	3	19-Nov-17	322990	9950156	1.49	Silty Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_122-R1	3	21-Nov-17	323065	9950682	3.22	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_122-R2	3	21-Nov-17	323062	9950679	3.48	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_122-R3	3	21-Nov-17	323059	9950678	3.45	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_123-R1	3	21-Nov-17	323151	9951911	2.90	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_123-R2	3	21-Nov-17	323158	9951915	2.90	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_123-R3	3	21-Nov-17	323156	9951917	3.11	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_124-R1	3	22-Nov-17	322921	9952563	1.55	Clay	Op Plantation Mix Ferns	Desa Jangkang	Deltares, ITB
KR_124-R2	3	22-Nov-17	322916	9952562	1.57	Clay	Op Plantation Mix Ferns	Desa Jangkang	Deltares, ITB
KR_124-R3	3	22-Nov-17	322914	9952564	1.51	Clay	Op Plantation Mix Ferns	Desa Jangkang	Deltares, ITB
KR_125-R1	1	22-Nov-17	323043	9952930	No Peat	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_130-R1	1	20-Nov-17	320564	9949511	No Peat	Clay	Op Plantations	Desa Teluk Nangka	Deltares, ITB
KR_131-R1	1	20-Nov-17	320527	9950068	No Peat	Clay	Op Plantations	Desa Teluk Nangka	Deltares, ITB
KR_132-R1	2	21-Nov-17	320753	9951098	No Peat	Clay	Op Plantation	Desa Teluk Nangka	Deltares, ITB
KR_132-R2	2	21-Nov-17	320484	9950787	No Peat	Clay	Op Plantation Mix Ferns	Desa Teluk Nangka	Deltares, ITB
KR_133-R1	1	21-Nov-17	320594	9951660	No Peat	Clay	Settlement area	Desa Teluk Nangka	Deltares, ITB
KR_134-R1	1	21-Nov-17	319839	9950605	No Peat	Clay	Op Plantation	Desa Teluk Nangka	Deltares, ITB
KR_135-R1	3	21-Nov-17	321060	9951011	1.59	Clay Mix Peat	Op Plantation	Desa Teluk Nangka	Deltares, ITB
KR_135-R2	3	21-Nov-17	321074	9951013	1.52	Clay Mix Peat	Op Plantation	Desa Teluk Nangka	Deltares, ITB
KR_135-R3	3	21-Nov-17	321067	9951015	1.56	Clay Mix Peat	Op Plantation	Desa Teluk Nangka	Deltares, ITB
KR_136-R1	3	21-Nov-17	323283	9951633	2.58	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_136-R2	3	21-Nov-17	323279	9951641	2.67	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_136-R3	3	21-Nov-17	323286	9951642	2.62	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_137-R1	3	19-Nov-17	324372	9951661	2.13	Silty Clay	ferns	Desa Jangkang	Deltares, ITB
KR_137-R2	3	19-Nov-17	324369	9951663	2.06	Silty Clay	ferns	Desa Jangkang	Deltares, ITB
KR_137-R3	3	19-Nov-17	324371	9951663	2.41	Silty Clay	ferns	Desa Jangkang	Deltares, ITB
KR_138-R1	3	19-Nov-17	325007	9951930	1.46	Sandy Clay	ferns	Desa Jangkang	Deltares, ITB
KR_138-R2	3	19-Nov-17	325009	9951935	1.40	Sandy Clay	ferns	Desa Jangkang	Deltares, ITB
KR_138-R3	3	19-Nov-17	325014	9951934	1.37	Sandy Clay	ferns	Desa Jangkang	Deltares, ITB
KR_140-R1	3	19-Nov-17	326514	9952301	2.06	Clay	ferns	Desa Dungun	Deltares, ITB
KR_140-R2	3	19-Nov-17	326512	9952303	1.86	Clay	ferns	Desa Dungun	Deltares, ITB
KR_140-R3	3	19-Nov-17	326507	9952306	1.82	Clay	ferns	Desa Dungun	Deltares, ITB
KR_141-R1	3	19-Nov-17	327229	9952378	3.63	Clay	ferns	Desa Dungun	Deltares, ITB
KR_141-R2	3	19-Nov-17	327219	9952376	3.69	Clay	ferns	Desa Dungun	Deltares, ITB
KR_141-R3	3	19-Nov-17	327214	9952376	3.74	Clay	ferns	Desa Dungun	Deltares, ITB
KR_142-R1	3	13-Nov-17	328339	9952650	3.04	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_142-R2	3	13-Nov-17	328343	9952648	2.96	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_142-R3	3	13-Nov-17	328362	9952647	2.79	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_143-R1	3	13-Nov-17	329148	9952694	4.12	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_143-R2	3	13-Nov-17	329144	9952686	3.98	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_143-R3	3	13-Nov-17	329160	9952681	4.12	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_144-R1	3	12-Nov-17	329778	9952964	3.29	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_144-R2	3	12-Nov-17	329775	9952967	3.24	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_144-R3	3	12-Nov-17	329764	9952968	3.18	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_145-R1	1	10-Nov-17	331810	9953449	No Peat	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_146-R1	3	12-Nov-17	332529	9953627	0.93	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_146-R2	3	12-Nov-17	332535	9953631	0.82	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_146-R3	3	12-Nov-17	332545	9953631	0.80	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_147-R1	3	16-Nov-17	334019	9953755	1.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_147-R2	3	16-Nov-17	334016	9953753	1.03	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_147-R3	3	16-Nov-17	334014	9953755	0.89	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_148-R1	2	08-Nov-17	334712	9953990	2.59	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_148-R2	2	08-Nov-17	334707	9953994	2.26	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_149-R1	3	07-Nov-17	336583	9954435	6.38	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_149-R2	3	07-Nov-17	336582	9954376	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_149-R3	3	07-Nov-17	336582	9954361	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_150-R1	3	08-Nov-17	337537	9954683	6.18	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_150-R2	3	08-Nov-17	337538	9954663	6.53	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_150-R3	3	08-Nov-17	337539	9954652	6.50	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_151-R1	2	01-Nov-17	338659	9954936	6.77	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_151-R2	2	01-Nov-17	338654	9954964	6.38	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_152-R1	2	02-Nov-17	339649	9955140	6.08	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB

LocationId	TotalReplicates	Date	X-UTM49S	Y-UTM49S	Peat Thickness	Mineral Soil	LULC	Location	Field Team
KR_152-R2	2	02-Nov-17	339653	9955184	6.19	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_161-R1	2	06-Nov-17	337956	9958174	3.74	Clay	bushes/shrub	Desa Teluk Simpur	Deltares, ITB
KR_161-R2	2	06-Nov-17	337958	9958172	3.59	Clay	bushes/shrub	Desa Teluk Simpur	Deltares, ITB
KR_163-R1	4	03-Nov-17	343037	9957699	3.29	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_163-R2	4	03-Nov-17	343034	9957699	3.29	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_163-R3	4	23-Nov-17	343034	9957688	2.86	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_163-R4	4	23-Nov-17	343034	9957686	2.82	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_164-R1	4	03-Nov-17	341885	9955678	2.99	Clay	Ferns	Desa Teluk Empening	Deltares, ITB
KR_164-R2	4	03-Nov-17	341891	9955676	2.26	Clay	Ferns	Desa Teluk Empening	Deltares, ITB
KR_164-R3	4	24-Nov-17	341921	9955662	2.01	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_164-R4	4	24-Nov-17	341922	9955663	1.96	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_165-R1	5	03-Nov-17	342146	9955775	1.97	Clay Mix Peat	Ferns	Desa Teluk Empening	Deltares, ITB
KR_165-R2	5	03-Nov-17	342144	9955775	2.26	Clay Mix Peat	Ferns	Desa Teluk Empening	Deltares, ITB
KR_165-R3	5	24-Nov-17	342159	9955785	1.45	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_165-R4	5	24-Nov-17	342158	9955782	1.33	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_165-R5	5	24-Nov-17	342158	9955784	1.03	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_166-R1	2	03-Nov-17	342283	9955853	1.83	Clay	Ferns	Desa Teluk Empening	Deltares, ITB
KR_166-R2	2	03-Nov-17	342285	9955851	1.79	Clay	Ferns	Desa Teluk Empening	Deltares, ITB
KR_167-R1	2	04-Nov-17	340627	9953147	3.94	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_167-R2	2	04-Nov-17	340629	9953148	3.29	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_170-R1	4	05-Nov-17	340395	9952461	2.26	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_170-R2	4	05-Nov-17	340394	9952463	1.94	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_170-R3	4	24-Nov-17	340442	9952469	1.32	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_170-R4	4	24-Nov-17	340442	9952470	1.08	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_176-R1	2	08-Nov-17	334975	9954026	2.26	Silty Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_176-R2	2	08-Nov-17	334971	9954029	2.06	Silty Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_177-R1	2	08-Nov-17	335298	9954025	3.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_177-R2	2	08-Nov-17	335302	9954020	3.29	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_179-R1	3	09-Nov-17	335681	9957247	3.20	Clay	ferns	Desa Teluk Simpur	Deltares, ITB
KR_179-R2	3	09-Nov-17	335674	9957266	3.09	Clay	ferns	Desa Teluk Simpur	Deltares, ITB
KR_179-R3	3	09-Nov-17	335666	9957284	3.14	Clay	ferns	Desa Teluk Simpur	Deltares, ITB
KR_180-R1	1	06-Nov-17	338181	9958801	No Peat	Clay	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_181-R1	2	03-Nov-17	340770	9958127	4.32	Silty Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_181-R2	2	03-Nov-17	340773	9958130	4.32	Silty Clay	Rubber Plantation	Desa Teluk Empening	Deltares, ITB
KR_182-R1	3	16-Nov-17	340724	9957752	4.82	Clay Mix Peat	bushes/shrub	Desa Teluk Empening	Deltares, ITB
KR_182-R2	3	16-Nov-17	340729	9957754	4.68	Clay Mix Peat	bushes/shrub	Desa Teluk Empening	Deltares, ITB
KR_182-R3	3	16-Nov-17	340721	9957752	4.91	Clay Mix Peat	bushes/shrub	Desa Teluk Empening	Deltares, ITB
KR_183-R1	2	16-Nov-17	333155	9955313	3.33	Clay Mix Peat	bushes/shrub	Desa Dungun	Deltares, ITB
KR_183-R2	2	16-Nov-17	333154	9955314	3.56	Clay Mix Peat	bushes/shrub	Desa Dungun	Deltares, ITB
KR_184-R1	3	12-Nov-17	333169	9954822	2.44	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_184-R2	3	12-Nov-17	333183	9954825	3.37	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_184-R3	3	12-Nov-17	333186	9954822	3.09	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_189-R1	3	13-Nov-17	328926	9952610	4.62	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_189-R2	3	13-Nov-17	328936	9952607	4.12	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_189-R3	3	13-Nov-17	328944	9952614	4.59	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_190-R1	1	21-Nov-17	325629	9955000	No Peat	Clay	Op Plantation Mix Ferns	Desa Jangkang	Deltares, ITB
KR_191-R1	3	20-Nov-17	325896	9954248	1.56	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_191-R2	3	20-Nov-17	325894	9954246	1.39	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_191-R3	3	20-Nov-17	325909	9954247	1.15	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_192-R1	3	21-Nov-17	321526	9951323	1.10	Clay	forest	Desa Teluk Nangka	Deltares, ITB
KR_192-R2	3	21-Nov-17	321585	9951360	0.89	Clay	forest	Desa Teluk Nangka	Deltares, ITB
KR_192-R3	3	21-Nov-17	321542	9951329	0.77	Clay	forest	Desa Teluk Nangka	Deltares, ITB
KR_193-R1	3	22-Nov-17	322236	9951362	1.84	Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_193-R2	3	22-Nov-17	322234	9951363	1.90	Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_193-R3	3	22-Nov-17	322235	9951360	1.78	Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_194-R1	3	21-Nov-17	322691	9951352	1.71	Clay	bushes/shrub	Desa Teluk Nangka	Deltares, ITB
KR_194-R2	3	21-Nov-17	322684	9951352	1.44	Clay	bushes/shrub	Desa Teluk Nangka	Deltares, ITB
KR_194-R3	3	21-Nov-17	322684	9951352	1.85	Clay	bushes/shrub	Desa Teluk Nangka	Deltares, ITB
KR_196-R1	2	06-Nov-17	337635	9949993	No Peat	Sandy Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_196-R2	2	06-Nov-17	337641	9949994	No Peat	Sandy Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_197-R1	2	06-Nov-17	337832	9950335	2.99	Clay Mix Peat	Ferns	Desa Terentang Dalam	Deltares, ITB
KR_197-R2	2	06-Nov-17	337837	9950331	3.17	Clay Mix Peat	Ferns	Desa Terentang Dalam	Deltares, ITB
KR_250-R1	2	06-Nov-17	338132	9951357	4.00	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_250-R2	2	06-Nov-17	338131	9951359	4.32	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_309-R1	3	22-Nov-17	335645	9951698	2.45	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_309-R2	3	22-Nov-17	335641	9951702	2.48	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_309-R3	3	22-Nov-17	335635	9951700	2.59	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_402-R1	1	14-Nov-17	340750	9958333	No Peat	Clay	bushes/shrub	Desa Teluk Empening	Deltares, ITB

Annex 4 – Validation peat thickness measurements

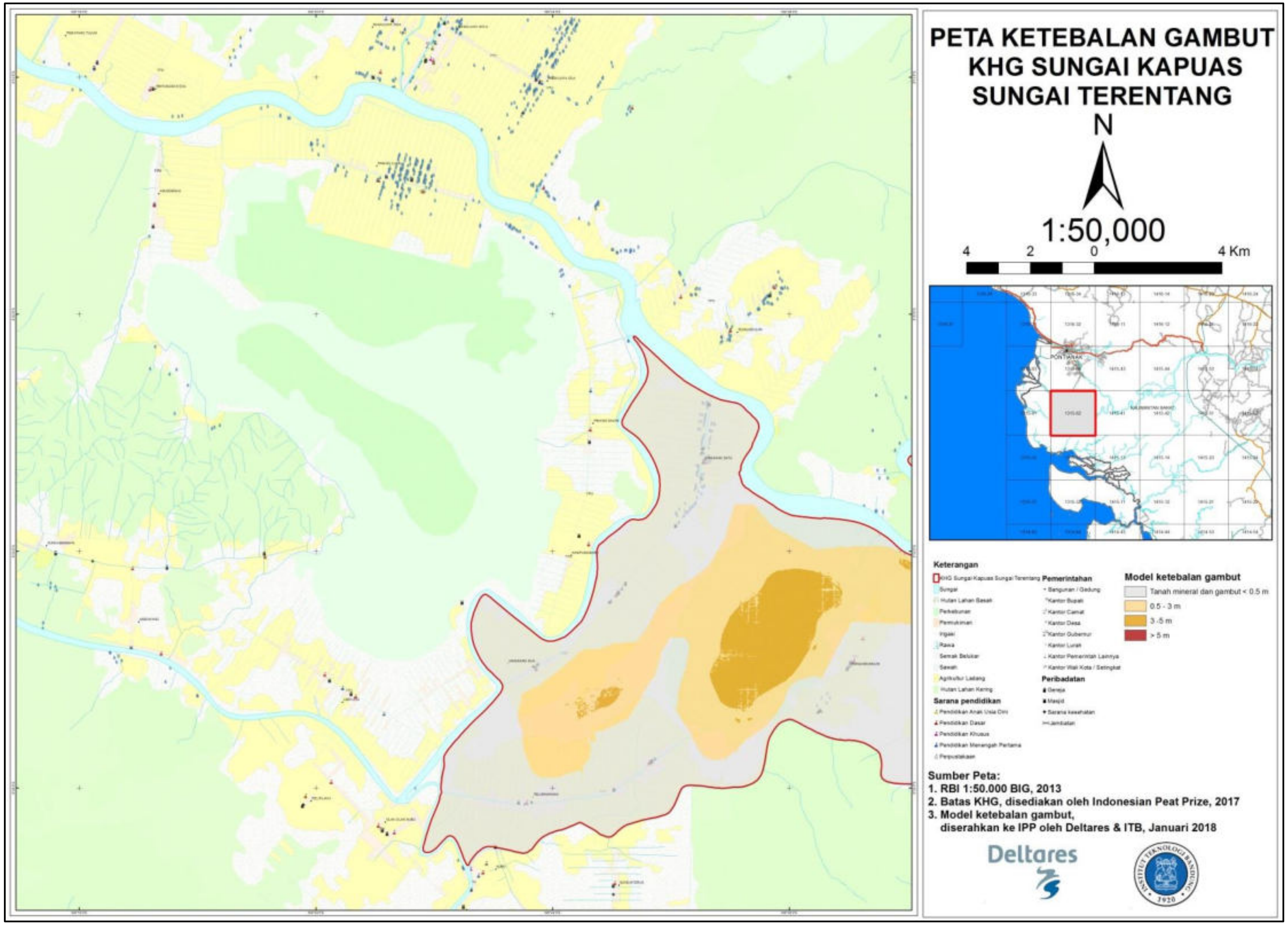
The detailed peat thickness field survey results collected for validation of the peat thickness map are presented in following tables.

LocationId	TotalReplicates	Date	X-UTM49S	Y-UTM49S	Peat Thickness	Mineral Soil	LULC	Location	Field Team
KR_155-R1	3	21-Nov-17	326119	9954756	1.03	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_155-R2	3	21-Nov-17	326124	9954762	1.40	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_155-R3	3	21-Nov-17	326127	9954765	1.48	Clay	bushes/shrub	Desa Jangkang	Deltares, ITB
KR_156-R1	3	20-Nov-17	327116	9954756	0.67	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_156-R2	3	20-Nov-17	327121	9954752	0.64	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_156-R3	3	20-Nov-17	327126	9954754	0.70	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_157-R1	3	18-Nov-17	328539	9954423	3.09	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_157-R2	3	18-Nov-17	328542	9954421	2.84	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_157-R3	3	18-Nov-17	328536	9954417	3.20	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_159-R1	3	05-Nov-17	339020	9952749	4.32	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_159-R2	3	14-Nov-17	338910	9952731	4.16	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_159-R3	3	14-Nov-17	338907	9952732	4.18	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_160-R1	3	14-Nov-17	339768	9952721	3.80	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_160-R2	3	14-Nov-17	339768	9952727	5.15	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_160-R3	3	14-Nov-17	339766	9952738	4.84	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_168-R1	2	05-Nov-17	339887	9952660	4.32	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_168-R2	2	05-Nov-17	339888	9952652	5.02	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_169-R1	4	05-Nov-17	340140	9952491	4.32	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_169-R2	4	14-Nov-17	340077	9952686	3.67	Silty Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_169-R3	4	14-Nov-17	340075	9952679	4.12	Silty Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_169-R4	4	14-Nov-17	340081	9952675	3.74	Silty Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_171-R1	2	07-Nov-17	336042	9953250	2.71	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_171-R2	2	07-Nov-17	336052	9953243	2.71	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_172-R1	2	07-Nov-17	336481	9953279	4.09	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_172-R2	2	07-Nov-17	336485	9953287	3.84	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_173-R1	2	07-Nov-17	337188	9953205	4.17	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_173-R2	2	07-Nov-17	337325	9953302	4.64	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_174-R1	2	07-Nov-17	337288	9952806	4.32	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_174-R2	2	07-Nov-17	337287	9952795	4.32	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_175-R1	2	07-Nov-17	336729	9953277	3.65	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_175-R2	2	07-Nov-17	336746	9953289	3.94	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_185-R1	3	12-Nov-17	331834	9953930	1.39	Sandy Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_185-R2	3	12-Nov-17	331838	9953939	1.36	Sandy Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_185-R3	3	12-Nov-17	331841	9953938	1.49	Sandy Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_186-R1	3	10-Nov-17	331290	9954214	2.79	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_186-R2	3	10-Nov-17	331296	9954215	2.84	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_186-R3	3	10-Nov-17	331300	9954225	2.82	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_187-R1	3	12-Nov-17	329781	9954161	4.03	Clay Mix Peat	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_187-R2	3	12-Nov-17	329778	9954159	4.12	Clay Mix Peat	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_187-R3	3	12-Nov-17	329765	9954156	3.92	Clay Mix Peat	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_188-R1	3	19-Nov-17	329177	9954224	3.94	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_188-R2	3	19-Nov-17	329157	9954223	4.18	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_188-R3	3	19-Nov-17	329171	9954222	4.12	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_206-R1	2	05-Nov-17	342301	9957228	4.77	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_206-R2	2	05-Nov-17	342301	9957235	4.77	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_207-R1	4	05-Nov-17	341925	9957259	5.35	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_207-R2	4	05-Nov-17	341922	9957249	5.14	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_207-R3	4	24-Nov-17	341853	9957270	4.52	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_207-R4	4	24-Nov-17	341876	9957287	4.36	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_208-R1	4	05-Nov-17	341378	9957318	6.19	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_208-R2	4	05-Nov-17	341378	9957274	5.66	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_208-R3	4	24-Nov-17	341402	9957317	5.76	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_208-R4	4	24-Nov-17	341382	9957305	5.68	Clay	Op Plantation	Desa Teluk Empening	Deltares, ITB
KR_211-R1	3	03-Nov-17	342768	9957621	2.62	Clay	ferns	Desa Teluk Empening	Deltares, ITB
KR_211-R2	3	15-Nov-17	342770	9957622	2.53	Clay Mix Peat	ferns	Desa Teluk Empening	Deltares, ITB
KR_211-R3	3	15-Nov-17	342772	9957624	2.75	Clay Mix Peat	ferns	Desa Teluk Empening	Deltares, ITB
KR_213-R1	3	14-Nov-17	339727	9956611	5.82	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_213-R2	3	14-Nov-17	339731	9956593	5.69	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_213-R3	3	14-Nov-17	339727	9956586	5.75	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_214-R1	5	04-Nov-17	339329	9957218	6.38	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_214-R2	5	04-Nov-17	339332	9957240	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_214-R3	5	14-Nov-17	339397	9957228	5.78	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_214-R4	5	14-Nov-17	339391	9957233	6.55	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_214-R5	5	14-Nov-17	339401	9957243	5.83	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_215-R1	4	03-Nov-17	339072	9957690	5.35	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_215-R2	4	04-Nov-17	339078	9957678	4.77	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_215-R3	4	14-Nov-17	339081	9957697	4.83	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_215-R4	4	14-Nov-17	339079	9957686	4.61	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_217-R1	3	03-Nov-17	338851	9958235	3.29	Clay	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_217-R2	3	14-Nov-17	338854	9958253	2.81	Clay	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_217-R3	3	14-Nov-17	338862	9958253	2.55	Clay	Rubber Plantation	Desa Teluk Simpur	Deltares, ITB
KR_219-R1	2	05-Nov-17	339706	9955963	6.38	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_219-R2	2	05-Nov-17	339718	9955993	6.38	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_222-R1	4	07-Nov-17	339636	9954421	5.35	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_222-R2	4	07-Nov-17	339630	9954415	5.80	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_222-R3	4	14-Nov-17	339635	9954425	5.86	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_222-R4	4	14-Nov-17	339628	9954414	5.90	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_224-R1	2	07-Nov-17	339606	9953666	6.25	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_224-R2	2	07-Nov-17	339605	9953658	6.05	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_227-R1	2	05-Nov-17	339527	9951991	5.02	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_227-R2	2	05-Nov-17	339527	9951993	4.95	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_229-R1	2	06-Nov-17	339591	9951074	3.02	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_229-R2	2	06-Nov-17	339593	9951077	3.29	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB

LocationId	TotalReplicates	Date	X-UTM49S	Y-UTM49S	Peat Thickness	Mineral Soil	LULC	Location	Field Team
KR_239-R1	2	07-Nov-17	336612	9956855	5.35	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_239-R2	2	07-Nov-17	336611	9956844	5.35	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_240-R1	4	07-Nov-17	336611	9956322	6.19	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_240-R2	4	07-Nov-17	336609	9956340	6.19	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_240-R3	4	24-Nov-17	336580	9956352	5.62	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_240-R4	4	24-Nov-17	336583	9956341	5.19	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_241-R1	2	07-Nov-17	336575	9955825	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_241-R2	2	07-Nov-17	336578	9955809	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_242-R1	3	07-Nov-17	336579	9955191	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_242-R2	3	07-Nov-17	336581	9955173	5.35	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_242-R3	3	07-Nov-17	336579	9955123	5.80	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_244-R1	3	09-Nov-17	334847	9951407	2.36	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_244-R2	3	09-Nov-17	334875	9951433	2.57	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_244-R3	3	09-Nov-17	334845	9951375	2.37	Clay	Op Plantation Mix Ferns	Desa Terentang Dalam	Deltares, ITB
KR_246-R1	3	16-Nov-17	336021	9951412	3.09	Silty Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_246-R2	3	16-Nov-17	336010	9951412	2.79	Silty Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_246-R3	3	16-Nov-17	335996	9951418	3.09	Silty Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_249-R1	3	11-Nov-17	337234	9951397	3.54	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_249-R2	3	11-Nov-17	337221	9951402	4.07	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_249-R3	3	11-Nov-17	337226	9951407	3.58	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_252-R1	2	06-Nov-17	338825	9951352	4.87	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_252-R2	2	06-Nov-17	338827	9951356	5.30	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_255-R1	3	11-Nov-17	336637	9951377	3.52	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_255-R2	3	11-Nov-17	336646	9951372	3.40	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_255-R3	3	11-Nov-17	336657	9951375	4.03	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_256-R1	3	11-Nov-17	336632	9950893	3.64	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_256-R2	3	11-Nov-17	336641	9950893	3.67	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_256-R3	3	11-Nov-17	336650	9950896	3.72	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_257-R1	3	11-Nov-17	336598	9950425	3.05	Clay	bushes/shrub	Desa Terentang Dalam	Deltares, ITB
KR_257-R2	3	11-Nov-17	336598	9950428	3.14	Clay	bushes/shrub	Desa Terentang Dalam	Deltares, ITB
KR_257-R3	3	11-Nov-17	336589	9950427	3.11	Clay	bushes/shrub	Desa Terentang Dalam	Deltares, ITB
KR_262-R1	3	08-Nov-17	334828	9954745	4.12	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_262-R2	3	08-Nov-17	334826	9954728	3.68	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_262-R3	3	08-Nov-17	334826	9954715	3.63	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_263-R1	3	08-Nov-17	334905	9955464	4.51	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_263-R2	3	08-Nov-17	334905	9955452	4.73	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_263-R3	3	08-Nov-17	334910	9955452	4.77	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_264-R1	3	08-Nov-17	335012	9955976	4.58	Clay	ferns	Desa Dungun	Deltares, ITB
KR_264-R2	3	09-Nov-17	335016	9955946	4.97	Clay	ferns	Desa Dungun	Deltares, ITB
KR_264-R3	3	09-Nov-17	335011	9955955	4.78	Clay	ferns	Desa Dungun	Deltares, ITB
KR_266-R1	3	12-Nov-17	332530	9955500	3.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_266-R2	3	12-Nov-17	332513	9955500	3.19	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_266-R3	3	12-Nov-17	332507	9955498	3.04	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_267-R1	3	13-Nov-17	331857	9955507	3.39	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_267-R2	3	13-Nov-17	331847	9955507	3.45	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_267-R3	3	13-Nov-17	331821	9955506	3.43	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_268-R1	3	13-Nov-17	331269	9955503	3.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_268-R2	3	13-Nov-17	331284	9955501	3.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_268-R3	3	13-Nov-17	331297	9955502	2.96	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_271-R1	3	13-Nov-17	329861	9955582	2.47	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_271-R2	3	13-Nov-17	329880	9955585	2.33	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_271-R3	3	13-Nov-17	329867	9955584	2.59	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_272-R1	3	18-Nov-17	329113	9955599	2.92	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_272-R2	3	18-Nov-17	329107	9955601	2.52	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_272-R3	3	18-Nov-17	329093	9955599	2.50	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_276-R1	3	13-Nov-17	328917	9952111	2.84	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_276-R2	3	13-Nov-17	328915	9952113	2.95	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_276-R3	3	13-Nov-17	328902	9952111	2.58	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_277-R1	3	13-Nov-17	328876	9951610	2.15	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_277-R2	3	13-Nov-17	328825	9951578	2.57	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_277-R3	3	13-Nov-17	328838	9951557	2.38	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_278-R1	3	13-Nov-17	328903	9950997	1.84	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_278-R2	3	13-Nov-17	328915	9950991	1.73	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_278-R3	3	13-Nov-17	328919	9950991	1.76	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_280-R1	3	20-Nov-17	327120	9955317	1.50	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_280-R2	3	20-Nov-17	327128	9955318	1.25	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_280-R3	3	20-Nov-17	327133	9955316	1.32	Clay	Op Plantation	Desa Jangkang	Deltares, ITB
KR_283-R1	3	20-Nov-17	327109	9953966	1.69	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_283-R2	3	20-Nov-17	327105	9953964	1.84	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_283-R3	3	20-Nov-17	327100	9953967	1.60	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_284-R1	3	20-Nov-17	327086	9953120	2.91	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_284-R2	3	20-Nov-17	327078	9953125	2.87	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_284-R3	3	20-Nov-17	327082	9953123	2.88	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_288-R1	3	18-Nov-17	327045	9951470	2.79	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_288-R2	3	18-Nov-17	327039	9951469	2.87	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_288-R3	3	18-Nov-17	327043	9951469	2.77	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_289-R1	3	18-Nov-17	327030	9950972	2.51	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_289-R2	3	18-Nov-17	327029	9950968	2.39	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_289-R3	3	18-Nov-17	327027	9950968	2.36	Clay	Op Plantation Mix Ferns	Desa Dungun	Deltares, ITB
KR_293-R1	3	20-Nov-17	321895	9950029	0.82	Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_293-R2	3	20-Nov-17	321896	9950030	0.78	Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_293-R3	3	20-Nov-17	321890	9950034	0.73	Clay Mix Peat	ferns	Desa Teluk Nangka	Deltares, ITB
KR_294-R1	3	20-Nov-17	322342	9950077	1.44	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_294-R2	3	20-Nov-17	322347	9950084	1.49	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_294-R3	3	20-Nov-17	322348	9950081	1.53	Clay	ferns	Desa Teluk Nangka	Deltares, ITB
KR_302-R1	3	10-Nov-17	341572	9956576	5.23	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB

LocationId	TotalReplicates	Date	X-UTM49S	Y-UTM49S	Peat Thickness	Mineral Soil	LULC	Location	Field Team
KR_302-R2	3	10-Nov-17	341576	9956565	5.46	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_302-R3	3	10-Nov-17	341575	9956561	5.15	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_305-R1	3	10-Nov-17	339115	9956628	5.58	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_305-R2	3	10-Nov-17	339115	9956619	5.46	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_305-R3	3	10-Nov-17	339114	9956565	5.40	Clay	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_306-R1	3	10-Nov-17	339121	9953476	5.46	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_306-R2	3	10-Nov-17	339120	9953463	5.61	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_306-R3	3	10-Nov-17	339124	9953457	5.63	Clay Mix Peat	Op Plantation	Area Kebun Sawit BPG	Deltares, ITB
KR_308-R1	3	11-Nov-17	336420	9950966	3.45	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_308-R2	3	11-Nov-17	336422	9950972	3.17	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_308-R3	3	11-Nov-17	336427	9950966	3.51	Clay	Op Plantation	Desa Terentang Dalam	Deltares, ITB
KR_310-R1	3	10-Nov-17	334940	9952469	2.20	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_310-R2	3	10-Nov-17	334932	9952468	2.41	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_310-R3	3	10-Nov-17	334937	9952465	2.20	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_312-R1	3	12-Nov-17	334000	9955038	2.91	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_312-R2	3	12-Nov-17	334001	9955026	3.19	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_312-R3	3	12-Nov-17	333997	9955017	3.11	Clay Mix Peat	Op Plantation	Desa Dungun	Deltares, ITB
KR_314-R1	3	13-Nov-17	329312	9951738	3.09	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_314-R2	3	13-Nov-17	329300	9951729	3.01	Clay	Op Plantation	Desa Dungun	Deltares, ITB
KR_314-R3	3	13-Nov-17	329283	9951718	3.16	Clay	Op Plantation	Desa Dungun	Deltares, ITB

Annex 5 – Peat thickness map of Kubu Raya at 1:50,000 scale, RBI tile index 1315-62



Annex 6 – Peat thickness map of Kubu Raya at 1:50,000 scale, RBI tile index 1415-41