Government of Central Kalimantan

Government of Indonesia

Government of the Netherlands

Master Plan for the Rehabilitation and Revitalisation of the Ex-Mega Rice Project Area in Central Kalimantan






GUIDELINE FOR CANAL BLOCKING DESIGN IN THE EX-MEGA RICE PROJECT AREA IN CENTRAL KALIMANTAN

Technical Guideline No. 4

MARCH 2009

Euroconsult Mott MacDonald and Deltares | Delft Hydraulics
in association with
DHV, Wageningen UR, Witteveen+Bos, PT MLD and PT INDEC

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Table of Contents

List of Annexes

List of Drawings

List of abbreviations

Bakosurtanal	National Agency for Surveys and Mapping of Indonesia
Bappeda	Regional Development Planning Agency
CCFPI	Climate change and forest protection initiative
CIMTROP	Centre for International Cooperation in Sustainable Management of Tropical Peatland, University of Palangkaraya
CKPP	Central Kalimantan Peatlands Project
DGPS	Differential global positioning system
EMRP	Ex-Mega Rice Project (same as ex-PLG, or ex One Million Ha Project)
GPS	Global positioning system
ha	hectare
Inpres	*Instrksi Presiden*, Presidential Instruction
KFCP	Kalimantan Forest and Climate Partnership
MSL	Mean sea level
PLG	*Proyek Lahan Gambut,* the One Million Hectare Peatland Project, also called the Mega Rice Project
PU	*Pekerjaan Umum,* Department of Public Works
SPI	*Saluran Primer Induk*, Parent Primary Canal
SPU	*Saluran Primer Utama*, Main Primary Canal
WI	Wetland International
WWF	World Wildlife Fund

Executive Summary

Canal blocking to raise water-levels will be an important part of any peatland rehabilitation efforts in the Ex-Mega Rice Project area of Central Kalimantan. Canal blocking structures or dams have been built over the past years by various non-government organizations in the area, and although at a relatively small scale, valuable experience has been gained with different types of dams and their construction. This guideline briefly reviews the experience and builds on the experience to provide technical guidelines for design of a blocking strategy. Three typical dam designs are discussed in detail, and design drawings are included.

Depending on canal gradients, the influence of a canal block normally does not extend more than a few km upstream of the block. Therefore, to effectively raise water-levels along an entire canal, a great number of closely spaced blocks are required with a small head difference over each block. However, due to increased subsidence near the canals, most of the big canals constructed some ten years ago now run through shallow depressions. This means that raising the water-levels in the canal will not immediately raise groundwater levels away from the canal, although it will definitely help to prevent a further drop of the groundwater.

To avoid damage caused by overflowing water, shallow bypass channels are recommended to guide the canal flow around rather than over the blocking structure. Dam crests should be well above the canal banks. Where bypasses are not feasible, the “classic” box dam with water flowing over the dam is recommended. The box dam consists of rows of wooden poles across the canal with the space in between the rows filled up with bags of earth. In places where heavy equipment can be mobilized, mechanically compacted peat dams are a good option. These should always be combined with a bypass as overflowing water would be detrimental to the peat soil of the dam.

Simpler flow obstruction structures are considered as well to raise water-levels in the canal. While much cheaper than complete blocking structures, they are less effective and cannot raise water-levels above the canal banks. Their use however is recommended only in canals with small flows, or as additions in between ‘real’ blocks.

Construction of blocking structures in a certain area is best started from the top of the peat dome downwards, both for ease of access and to avoid construction with high water-levels in the canal. The latest, most downstream completed block will temporarily have to accommodate a bigger than the designed head difference, until the next block downstream is constructed. For this reason it is recommended to build all blocks along a certain canal in the same dry season.

In the annexes to this guideline examples are given to calculate water flows, seepage, and dam stability.

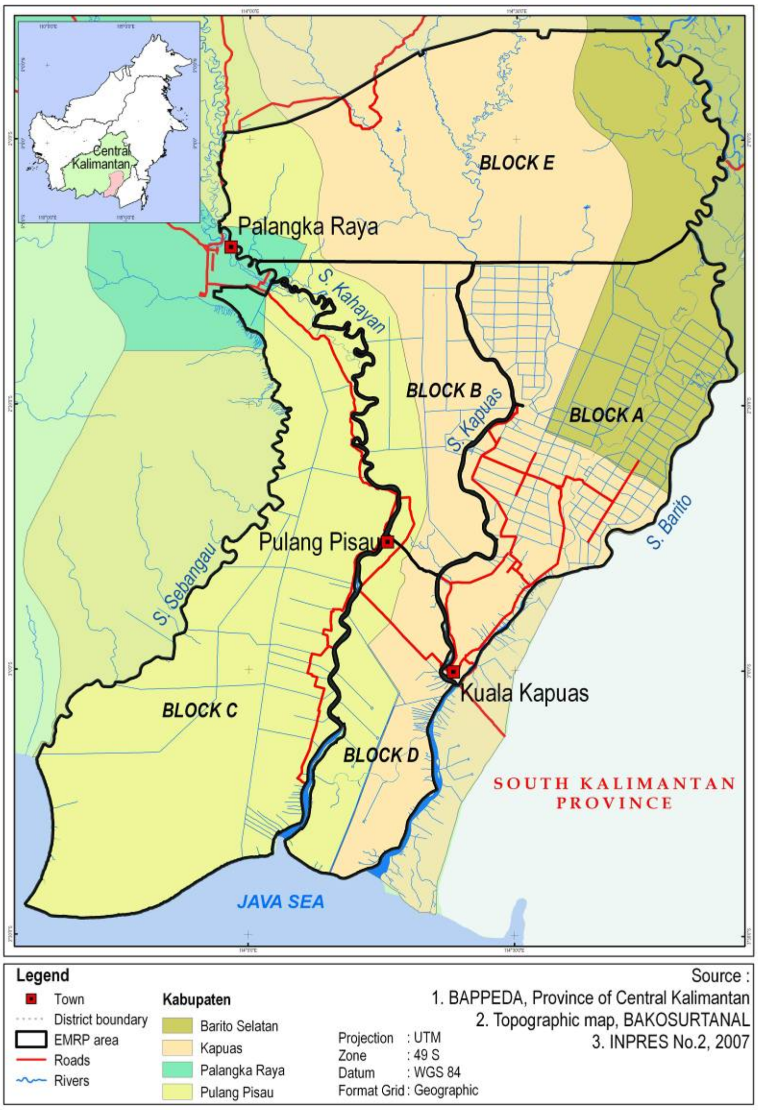
Ringkasan Eksekutif

1 Introduction

1.1 Background

The Ex-Mega Rice Project area is located in Central Kalimantan, Indonesia. It comprises an area of about 1.4 million ha bounded by the Java Sea in the south, the Sebangau River in the west, and the Kapuas Murung/Barito Rivers in the east, see Figure 1.1. Its northern border runs close to the Palangka Raya – Buntok road. Most of the northern and western part of the area is covered with peat soil, featuring as peat domes in between the main rivers with peat depths exceeding 3 m over vast areas.

Figure 1.1: **The Ex-Mega Rice Project (EMRP) area.**
The map shows the subdivision of the area into Blocks A to E, administrative boundaries as well as the grid of straight primary and secondary canals constructed by the PLG project.



The area was the location of the *Proyek Lahan Gambut* or PLG (Peatland Development Project), also called the Mega Rice Project. The project started in 1996 and aimed to open up the area for rice production using water from the Kahayan, Kapuas and Barito rivers. The project area was divided into five different blocks, Blocks A to E. An extensive system of main canals was constructed starting from east-west running primary canals connecting the Sebangau, Kahayan, Kapuas and Barito rivers in between Block E (to the north) and Block A, B and C (to the south). In the south of Block A, on predominantly mineral soils, more intensive infrastructure was constructed and a start was made with transmigrant settlement development.

The canal system has caused drainage of the peat soils that has in turn led to degradation of the area through oxidation and subsidence of the peat, along with frequent fires that have made international headlines. The Mega Rice Project was stopped in 1999, but the abandoned canals continued their detrimental effect on the peat lands ever since.

The Government of Indonesia announced its intention to rehabilitate and revitalise the area through the issuance of Presidential Instruction or Inpres No 2 / 2007. The relevant government departments are instructed to undertake a five-year programme focused on the rehabilitation, conservation and sustainable development of the area.

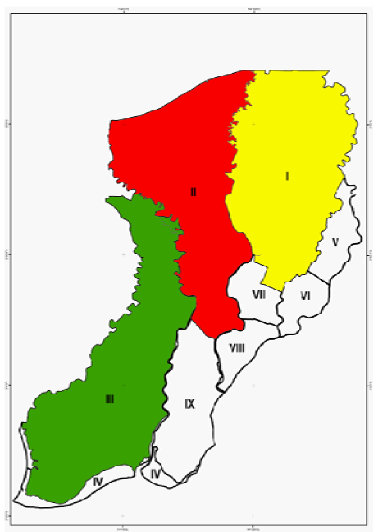
At the request of the Governor of Central Kalimantan Province, the Netherlands Government is assisting the government to implement this programme by producing a Master Plan to provide an integrated framework for action to rehabilitate and revitalise the area.

1.2 Protection and development

The Master Plan for the EMRP area identifies four macro planning zones and nine Integrated Management Units in the area. The macro zones include:

- Protection Zone: includes areas with a peat soils of more than 3 m and areas with important biodiversity values. Here forest and peatland conservation is the primary goal.
- Adapted Management Zone: effectively a buffer between the protection zone and the agricultural development zone, defined by the hydrological boundaries. Peat depths are up to 3 m, and limited development is envisaged in these areas.
- Development Zone: areas that are hydrologically independent of the peat domes and that have no biodiversity value. With predominated mineral soils, these areas are suitable for agricultural development or other economic activities.
- Coastal Zone: mangrove forest and other coastal areas in the south of the EMRP area.

The Integrated Management Units are defined by hydrological boundaries, mainly formed by the main rivers, see Figure 1.2. The peat lands of concern in this guideline are situated in Management Unit I, II and III



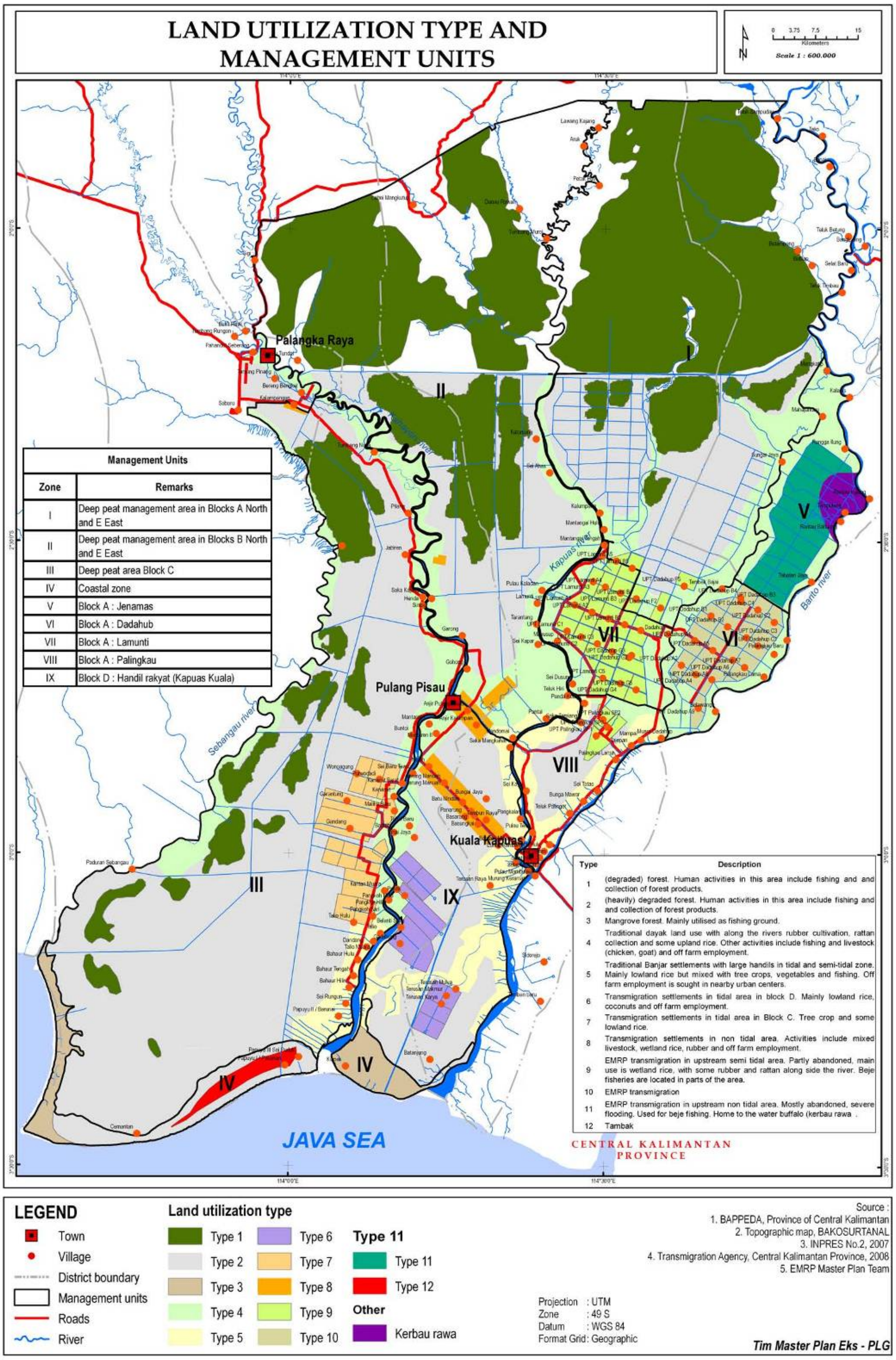


Figure 1.2 – Land utilization types and integrated management units in the EMRP area

1.3 Why Canal Blocking?

Canal blocking, as addressed in this guideline, is part of an overall strategy to rehabilitate and revitalise peat areas, and to separate conservation zones from development zones.

As part of the strategy for rehabilitation of the area, the drainage and resulting subsidence and oxidation of the peat lands needs to be reduced as much as possible. An important way to do this is to block the canals by dams or control structures, in order to reduce water loss from the system and to raise the groundwater level in the wet season to near the surface, as was the case in the original situation. Canal blocking should be part of an integrated approach to peat land rehabilitation, and should be accompanied by programmes for fire prevention, reforestation and community development. The latter should aim at gaining support of the local population for the rehabilitation efforts and at reducing their dependency on exploitation of the forest resources.

Besides conservation and rehabilitation of peat land, another main objective of Inpres 2/2007 is to revitalize agricultural production in the already developed parts of the project area. These areas hence require improved drainage for crop growth. Where these areas border the conservation area, adapted management is required and water control structures are needed to separate the high water-levels to be maintained in the peat lands from (limited) drainage in the agricultural area.

1.4 Scope and objective of this guideline

This guideline aims to build on past experience and give practical information for the planning and design of canal blocking programmes. Standard engineering methods are applied to develop typical designs and examples of calculation procedures are included.

Many canal blocking structures have been built in the area over the past years and much can be learned from the experience in building and maintaining these structures. A number of them have been inspected and the organisations that built them have been interviewed and consulted. The lessons learned are described in this guide and used to optimise the designs.

This guideline aims at providing a technical design methodology for canal blocking programmes. Field conditions differ throughout the area, and the blocking strategy has to be site specific. This guideline includes three typical example designs, as a help to designers in the use of this guideline.

Although the guideline deals primarily with the technical aspects of canal blocking, no canal blocking strategy can be effective without the active cooperation of the local communities. Canal blocks normally also block access to the peatland areas, and where this interferes with the people’s economic activities, alternative livelihood strategies have to be developed. It is also highly recommended, though not further dealt with in this Guide, that the local communities are involved in planning, design and construction of the blocks. Ways how to involve the communities in planning and implementation of infrastructure works are described in more detail in the technical report on Rural Infrastructure of the Master Plan.

The guideline is structured around the steps required for realization of a blocking programme, see Figure 1.3:

- Chapter 2 summarises present conditions in the area as far as relevant for blocking operations;
- Chapter 3 analyses the impact of the canals on the hydrology of the peat lands;
- Chapter 4 gives an overview and evaluation of the experience with canal blocking in the area
- Chapter 5 discusses the development of canal blocking strategies;
- Chapter 6 gives details on the survey, investigation and design process, and includes three typical designs of canal blocking structures;
- Chapter 7 describes construction materials, construction methods, cost estimates and briefly mentions different contracting options.

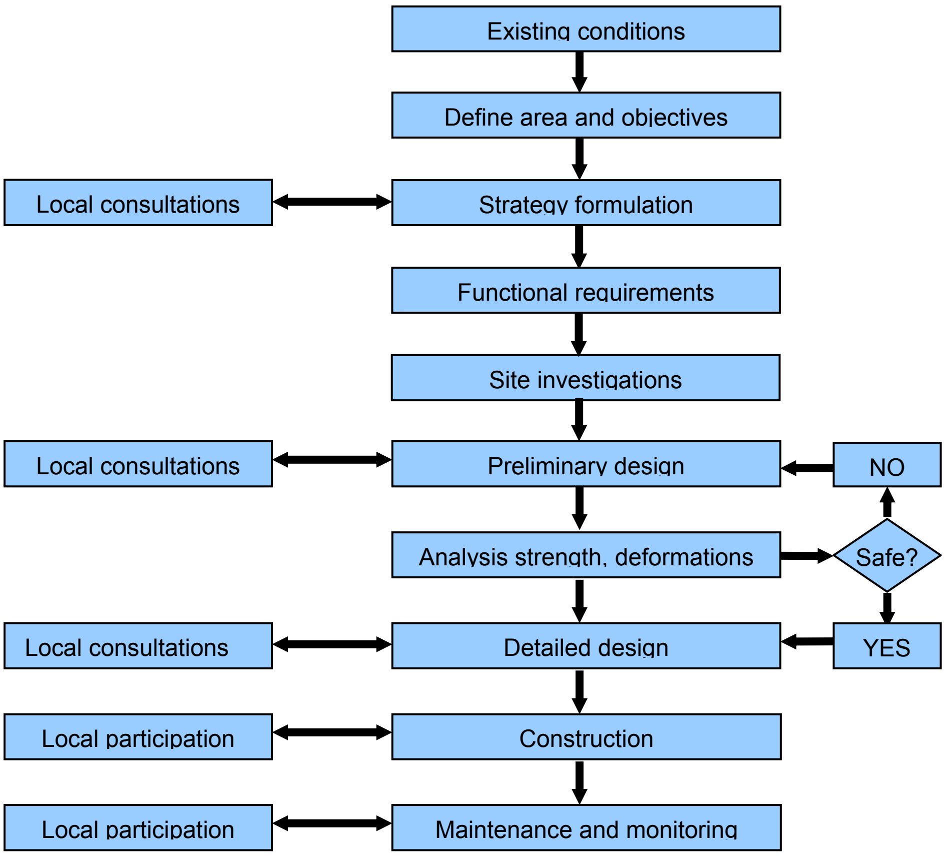


Figure 1.3 – Flow diagram for realization of a canal blocking programme

2 Physical conditions in the EMRP peatlands

The physical conditions in each case need to be assessed from available data and experience in the area, and subsequently to be augmented with surveys and investigations to be carried out (Chapter 5). This chapter describes the general physical conditions in the area as far as relevant for peatland rehabilitation and for defining canal blocking strategies. It is well recognized that the socio-economic condition of the existing population is equally important for the success or failure of blocking operations, but for these aspects reference is made to other reports of the Master Plan study.

2.1 The EMRP Area

The EMRP area is a river delta landscape with predominantly mineral soils along the coast and extensive peat deposits further away from the coast in between the main rivers. Traditional settlements are concentrated along the river banks and levees, and some agriculture is practiced along small canals or *andil*'s extending from the river a few km land inward at most. The interior beyond this riverine zone consists mostly of peat soils and was until recently covered with swamp and peat forests. From the early twentieth century onwards efforts have been ongoing to develop the interior for agricultural settlements, first by digging canals or *anjirs* connecting the main rivers and creating opportunities for spontaneous settlers, and from the 1970's onwards by government organized transmigration settlements. Where these settlements extended into deep peat areas, they were largely unsuccessful and have since been abandoned. The PLG project developed transmigration settlements in the south and east of Block A, where soils are predominantly mineral, before the project was stopped in 1999. By that time, however, the main canals for other intended settlement areas had already been constructed, many of these traversing and draining the deep peat areas.

Only few all-weather roads extend into the area, and access is still predominantly over water. The traditional villages along the rivers depend for their livelihood at least partly on the forested peat lands, and now use also the ex-PLG canals for access to the area and for transport of forest products, a point to be taken into careful consideration when plans to block the canals are made. The poor accessibility will directly impact the blocking operations: access by trucks or heavy equipment is virtually impossible in large parts of the area, and construction materials will all have to be transported by small boats or perahus, and/or to be hand carried.

2.2 Hydrological aspects

Hydrological aspects important for the design of blocking structures include the river level fluctuations, rainfall conditions, and peak flows which can be expected in the canals.

2.2.1 River levels

The hydrological boundaries of the peat lands are formed by the water-levels and flows in the surrounding rivers. Their daily and seasonal fluctuations are fixed (i.e. are not significantly influenced by developments in the peat lands) and they form the starting point for any hydrological intervention.

The Master Plan study has developed a hydraulic simulation model of the rivers and main canals of the EMRP area. The model can give important information regarding the flows and water-levels at any location in the EMRP area. The water-levels are expressed approximately in Mean Sea Level, MSL. The elevations, however, have an accuracy of about 1.0 m so that one should always be careful in drawing conclusions regarding flood levels, required heights of structures etc. Local knowledge and experience remains crucial.

The rivers are fully tidal in the south of the EMRP area, but the further away from the coast the more the river levels and their seasonal fluctuations are influenced by the river flows. The table below shows the main tidal and seasonal water-level fluctuations at selected locations in each river.

River	Location	River depth (m)	River width (m)	Tidal spring-tide range (m)		MWL during wettest month above MWL dry season (m)	Maximum flood level above MWL dry season (m)	Remarks
				Dry season	Wet season			
Barito	River mouth	7	2760	2.40	2.40	< 0.05	1.20	
	Murung junction	9	660	1.50	0.60	1.90	2.30	
	Mengkatib	15	300	1.50	0.15	4.20	4.70	km 188
Mengkatib	River mouth	10	132	1.80	1.40	0.80	1.70	
	Dadahup	11	70	1.80	1.30	1.00	1.80	ap. km 35
	upstream			0.20	0.10	2.00	2.50	
Kapuas	River mouth	7	1800	2.40	2.30	< 0.10	1.30	
	Kuala Kapuas	12	860	2.20	2.20	0.30	1.50	
	Mantangai	12	250	2.20	2.00	0.80	2.00	
	SPI canal	12	250	2.20	1.10	1.70	2.50	
Kahayan	River mouth	7	2150	2.40	2.30	< 0.10	1.30	
	Maliku	22	400	2.20	2.30	0.20	1.40	
	Jabiren	13	250	2.40	2.30	0.40	1.90	
	Palangkaraya	11	340	0.70	0.10	3.20	4.70	

Table 2.1 – River level fluctuations at various locations

Note: Tidal range = the difference in elevation between daily tidal high water and low water.
MWL = mean water-level

Source: Data from Sobek simulation March 2007 – February 2008 by Hydrology cluster, Master Plan EMRPP. Accuracy of simulated water-levels 0.5 to 1.0 m, with higher accuracy close to river mouths.

2.2.2 Rainfall

Average annual rainfall ranges from roughly 2700 mm in the north of the area to some 1900 mm in the south near the coast. Rainfall distribution throughout the year is characterised by a wet season from November to April and a dry season from June to October. Monthly rainfall data are shown in Figure 2.1.

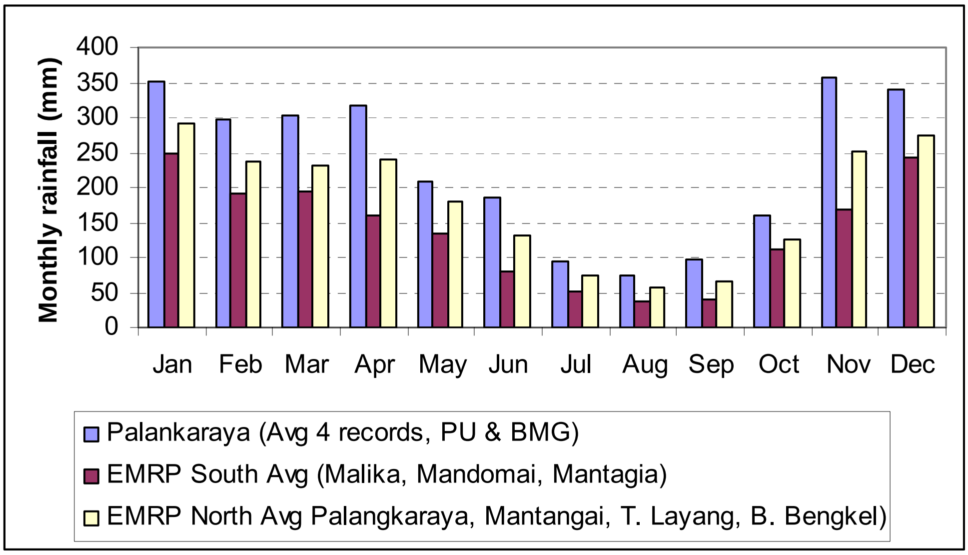


Figure 2.1 – Average monthly rainfall (Data from Hydrology cluster, Master Plan EMRP)

Of paramount importance for the design of blocking structures are estimates of the peak flows which can be expected in the various canals. These peak flows are largely determined by maximum rainfall during short periods (one or a few days). A statistical analysis of Palangkaraya rainfall data, being the only nearby station with a reliable long-term record of daily rainfall, shows the following maximum daily rainfall:

- average annual maximum rainfall (1-in-2 years): 113 mm/day
- 1-in-5 year maximum rainfall: 155 mm/day
- 1-in-10 year maximum rainfall: 171 mm/day

2.2.3 Peak drainage flows

Besides on maximum rainfall intensity, peak drainage flows depend also on the slope of the area, land cover, soil characteristics and size of the drainage basin. There are numerous standard methods to estimate the peak flows, mostly variants from the Rational Method. However, all these methods have been developed for 'normal', i.e. upland, conditions and none applies to lowlands and peat swamps. The lowlands and peat swamps differ from uplands mainly in soil characteristics and in a very small, almost zero surface gradient.

The Department of Public Works calculates peak discharges for design of canals and canal structures in lowlands from the criterion that a maximum 1-in-5-year maximum rainfall during 3 to 6 days should have been fully evacuated at the end of that same period. Within the 3 to 6 day period temporary higher ground or field water-levels are accepted. The calculated maximum drainage flows for crop lands (mineral soils or shallow peat) range from 4.5 to 6.3 l/sec/ha, see Table 2.2. For village areas a higher safety is adopted.

In peatlands, peak flows might be somewhat bigger than in cropped areas, because the groundwater in the peatlands is close to the surface throughout the wet season and little storage capacity is available in the soil to accommodate part of the peak rainfall. Although some storage capacity is available on the irregular and hummocky surface of the peat lands, a large part of the peak rainfall will flow directly as overland flow to the canals, resulting in relatively high peak flows Detailed hydraulic modelling of a peat area in the northwest of Block A has confirmed this process and points to 1-in-10 year peak flows of 7 to 10 l/sec/ha (KFCP 2009). However, the severely degraded peat soils there combined with a relatively dense canal network is likely to cause faster runoff and hence bigger peak flows than elsewhere. Measurement data from peat land in the Kampar peninsula in Riau point to an annual (1-in-2 year) maximum flow of 4 l/sec/ha. In the absence of more accurate methods or data on measured flows, a maximum design discharge of 7 l/sec/ha seems a realistic and safe estimate and has been adopted for the typical designs in Chapter 6.

It should be noted, however, that peak rainfall events are often highly localized and for larger drainage basins (exceeding 2000 ha) an area reduction factor can be introduced (van der Weert, 1994). The peak flows will be further reduced if more blocking structures are constructed resulting in lower flow velocities in the canal, reduced groundwater inflow, and bigger storage in the system..

Crop	Optimum range of groundwater level [m below NGL]	Design capacity of canal system	
		level in tert. canal 0.10 m below NGL	level in tert. canal 0.60 m below NGL
Wetland rice	-0.10 – 0.00	4.9 l/sec/ha	-
Dryland crops	0.30 – 0.60	6.3 l/sec/ha	4.9 l/sec/ha
Homeyard areas	0.30 – 0.60	6.3 l/sec/ha	4.9 l/sec/ha
Village center	0.30 – 0.60	15.0 l/sec/ha	-
Tree crops	> 0.60	4.9 l/sec/ha	4.5 l/sec/ha
Oil palm	0.60 – 0.75	4.9 l/sec/ha	4.5 l/sec/ha
Rubber	0.75 – 1.00	4.9 l/sec/ha	4.5 l/sec/ha

Table 2.2 – Design drainage discharges in lowland development areas
NGL = Natural ground level. Source: Bintek, 2000, and DID (Serawak), 2001

2.3 Peat soils

Peat soils cover most of the western part and the entire northern half of the EMRP area. Areas with peat depth over 3 m cover some 450,000 ha, or about 30% of the area, see Table 2.3 and Figure 2.1. While especially in Block B and E these peat areas are still largely covered by natural forest, in other places the forests have disappeared leaving a poor vegetation of ferns and shrubs. Spontaneous regeneration of the forests is hampered by soil infertility once the forest has been removed, especially lack of micro-elements, and by frequent fires in the dry season as a consequence of the drainage and drying out of the peat soils. The peat soils are up to 7 or 8 m deep, overlaying a mainly sandy subsoil, often with an interface of soft clay.

2.4 Topography

Land elevations in the EMRP area range from close to mean sea level along the coast to maximum about 20 m+MSL in the north of the project area (Block E). A Digital Elevation Model or DEM has been developed for the area by the CKPP and Master Plan studies and is shown in Figure 2.2 (left). Elevations are given in meters above MSL with an accuracy of about 1 m.

Peat depth	Block					Total EMRP
	A	B	C	D	E	
> 3m	72,110	81,507	144,755	-	149,122	447,494
2 - 3	15,007	13,741	58.331	-	31,269	118,348
1 - 2	21,736	18,028	74,004	141	54,425	168,334
0,5 - 1	43,413	14,292	51,546	22,514	61,122	192,887
Mineral soil	158,470	30,760	121,325	117,210	104,640	532,405
Total	**310,736**	**158,328**	**449,961**	**139,865**	**400,578**	**1,459,468**

Table 2.3 – Extent of peat areas in the EMRP area (ha)

Cross sections show that the topography of the peat lands is largely controlled by elevated, dome-shaped peat formations (Figure 2.2, right) parallel to the rivers. These peat domes are high and flat on top and low and relatively steep near the edges. The maximum thickness of the peat can be 7 m and the peak of the peat dome can reach an elevation of 5 m above the level of the river bank. The peat formations are overlying mineral soils which in many places are at an elevation below the flood levels in the adjacent rivers.

Following drainage of the area by construction of the PLG canals and in places the removal of the forest cover, a process of subsidence, oxidation and occasional burning started. As a consequence, the original topography has undergone important changes, a process further described in Chapter 3.

2.5 Geo-technical aspects

Most of the area consists of an alluvial (Holocene) layer of peat overlaying clay and silt intercalated with sand deposits in an alluvial and swamp environment. In the north (partly in Block A and B) the Pleistocene Dahor formation surfaces, with a (thickness up to 250 m and consisting of loose, poorly graded quartz sand and soft clay stone. There are no indications of past or current tectonic activity such fault, folding or any seismic activities.

2.5.1 Geotechnical engineering parameters

Information on the geotechnical properties in the project area is scarce. Geotechnical soil investigations have been carried out for a road rehabilitation project at Bereng Bengkel and Basarang (Direktorat Bina Teknik, 2000). A trial embankment was monitored at Bereng Bengkel for development of a guideline on road construction on peat and organic soils (CUR, 2001). In this location a soft clay layer below the peat ranges in thickness from 1-10 m. The deeper sand layer is probably the Dahor formation, see Figure 2.4.

The typical engineering parameters of the soils, based on the above references, are shown in Table 2.4.

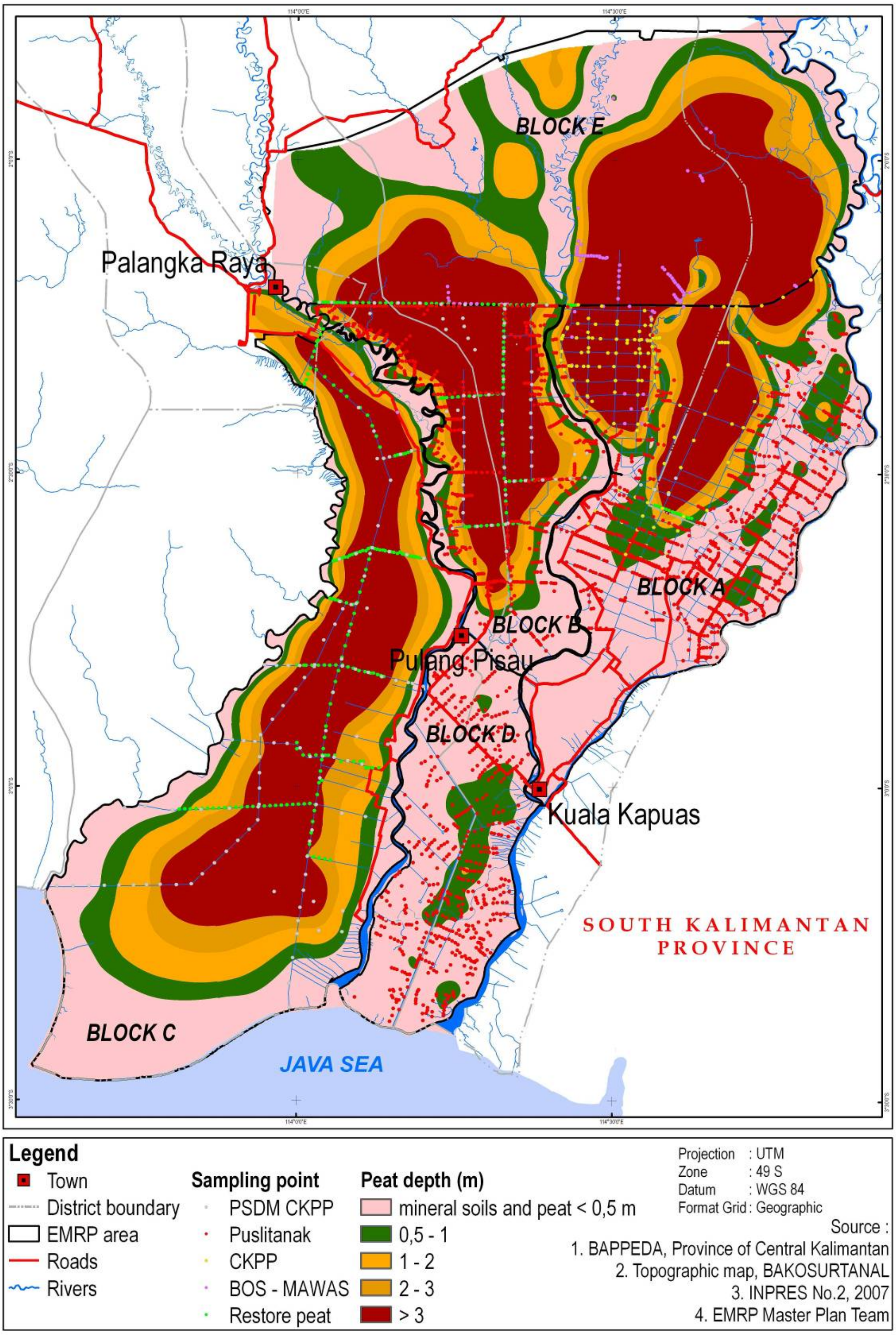


Figure 2.2 – Peat map of the EMRP area with sampling locations
Source: CKPP / Deltares / EMRP

Figure 2.3 – Topography of the EMRP area (left) and typical sections over peat domes in Blocks A, B and C (right)

Source: CKPP / Deltares / EMRP, based on Digital Elevation Model and field surveys.

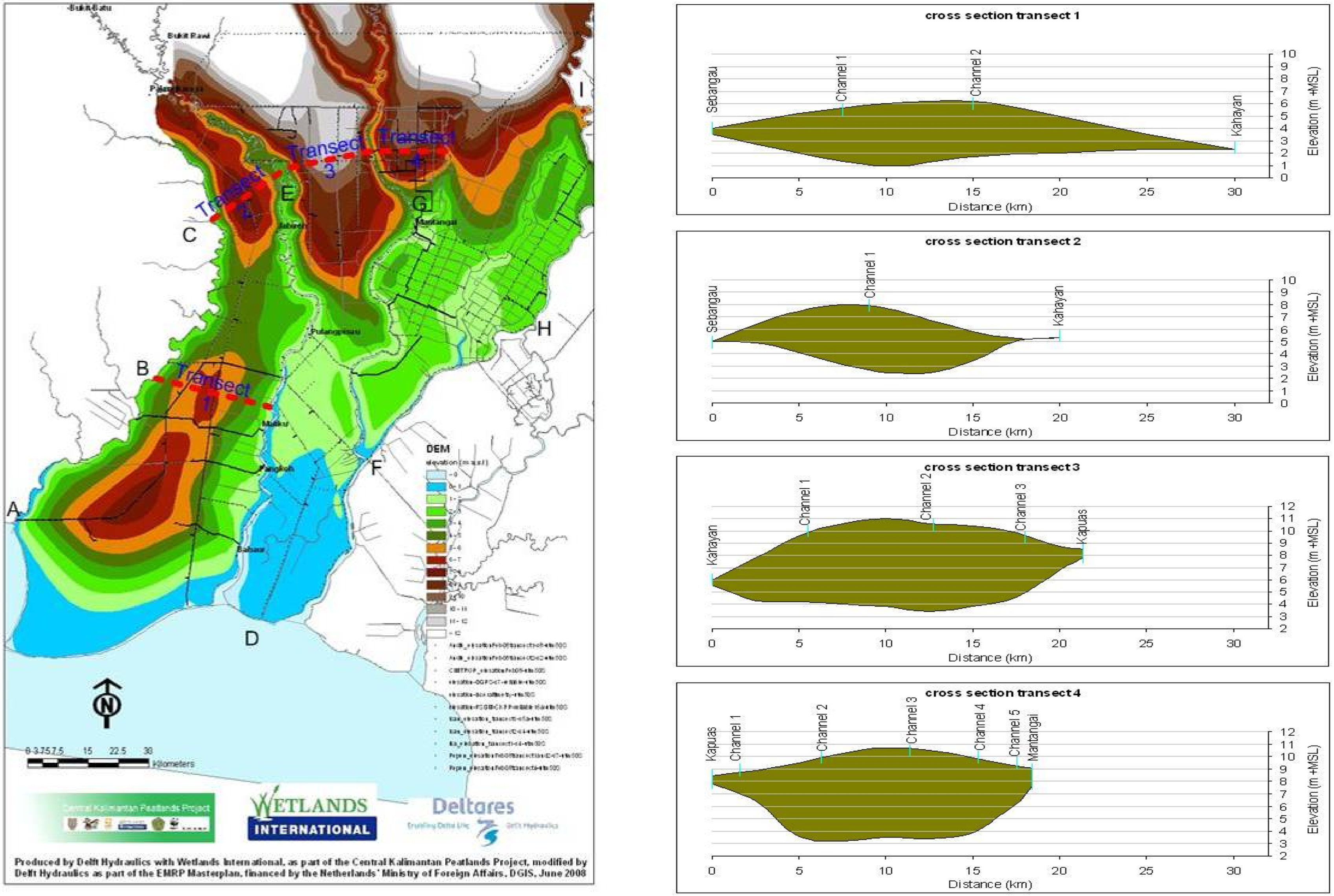
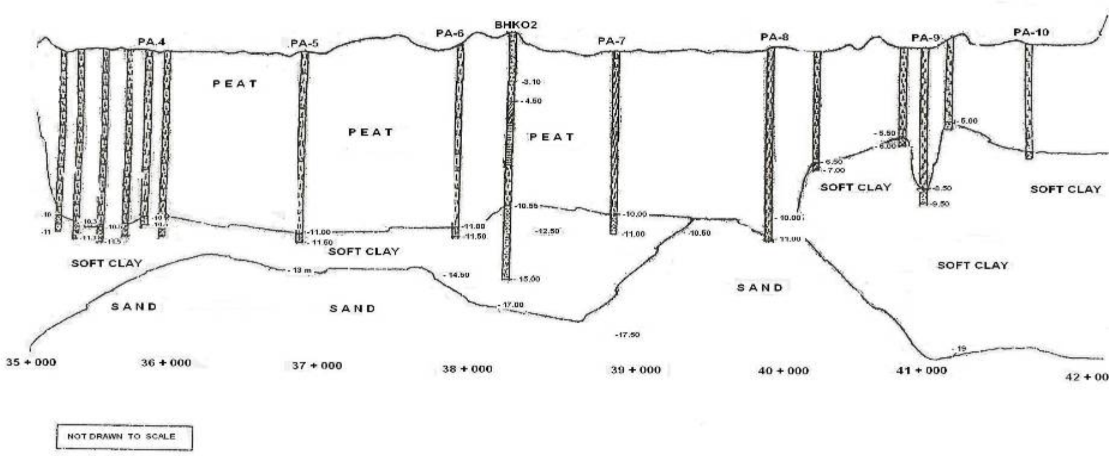


Figure 2.4 – Typical geotechnical section south of Palangkaraya (near Bereng Bengkel, km 35-42). Source: PU



Parameter	symbol	unit	Peat (in situ)		Clay		Sand	
			avg	range				
Cone resistance	q_c	MPa	0.1	0.01–0.2	0.2	0.05-4	40	10-80
Water content	W_n	%	500	100-1000	45	40-50		
Specific gravity	G_s	kN/m^3	14.5	13.0-16.0				
Bulk density	γ_n	kN/m^3	10.5	10-11	16	15-17	19	17-21
Undrained shear strength	C_u	kPa	20	15-25	15	13-18	0	0
Cohesion	C	kPa	1	0.5-2	2	1-3	0	0-1
Internal friction angle	θ	°	17.5	15 – 20	22.5	20-25	30	25-35
Void ratio	e_o	-	10	6-18	1	0.5 – 3	0.3	0.2-0.5
Compressibility index	C_c ( )	-	5	1.4-14	25	10 – 60		

Table 2.4 – Geo-technical engineering parameters

2.5.2 Geohydrological parameters

The following hydrogeological units are distinguished:

- a phreatic aquifer present in the top few meters of the peat layers;
- an aquitard present in the compressed lower meters of the peat layers and clay layers below the peat;
- an underlying aquifer present in the fine to coarse sand of the Dahor Formation, with a thickness of up to 250 m.

There is very little information on the hydraulic conductivity in the study area. In general, the hydraulic conductivity of peat is characterised by the following:

- the hydraulic conductivity is correlated with the degree of compaction and maturity. Compacted or mature peat has a low conductivity;
- the hydraulic conductivity of peat is anisotropic, which means that the horizontal hydraulic conductivity is larger than vertical. Typical anisotropy factors (kh/kv) in peat ranges from 5 to 10 (Gofar, 2006);
- the peat is characterised by a strong heterogeneity, the overall peat matrix has a low conductivity, whilst macropores can form highly transmissive preferential flowpaths.

Field measurements of the hydraulic conductivity of peat, necessary to fully understand and accurately predict the effects of canal blocking are not available. It is assumed that the hydraulic conductivity of peat in the project area ranges from 1.10^{-4} m/day up to 1 m/day, based on field measurements on peat by others (Gofar, 2006; Holden & Burt, 2003). The apparent field conductivity may be higher due to the presence of macropores forming preferential flow paths. This is apparent in peatlands of Sawarak, where hydraulic conductivity values are reported between 0.01 and 160 m/d (PS Konsultant, 2001). An overview of expected typical geo-hydrological parameters is presented in Table 2.5. The pH of the groundwater in peat areas is generally about 4 or lower, and may influence the selection of construction materials for a blocking structure.

Parameter	**Peat (in situ)**		**Clay**		**Sand**	
	Average	**Range**	**Average**	**Range**	**Average**	**Range**
Horizontal hydraulic conductivity, k_h (m/day)	0.01	10^{-4} - 60	0.01	10^{-4}–10^{-1}	20	10-30
Vertical hydraulic conductivity, k_v (m/day)	0.001	10^{-5} –16	0.001	10^{-5}–10^{-1}	5	2-15
Specific yield, S_y (%)	0.5	0.3 – 0.7	0.07	0.05 – 0.1	0.15	0.1–0.2
Specific storativity, S_s ( )	-	-	-	-	10^{-5}	10^{-4}–10^{-6}

Table 2.5 – Geo-hydrological parameters

2.6 Vegetation

Current land cover is estimated to consist of a mix of healthy and degraded forest (37%), severely degraded forest and woodland (14%), shrubland (22%), grassland, ferns and recently burnt land (15%) and agricultural land (12%). Peat swamp forest with high biodiversity value is found in the more remote areas, especially in the north, and healthy stands of mangrove exist in part of the coastal zone. Deep peat (>3m) is protected under Presidential Decree 32/1990 and more than 400,000ha of the peat area >1m deep is now degraded and without forest cover. This area remains a significant source of greenhouse gas emissions.

3 Canals and their impact on peatland hydrology

3.1 The PLG canals

The canal network constructed by the PLG project in Block A and B starts from two parallel 187 km long east-west oriented parent canals (Saluran Primer Induk or SPI 1 and 2) connecting the Barito River at Mangkatip, the Kapuas River north of Mantangai and the Kahayan River near Palangkaraya, In Block C a similar though much shorter canal connects the Kahayan and Sebangau rivers south of Palangkaraya. Concrete water control structures were constructed at the entrances to the SPI canals but these are now damaged beyond repair.

From these main canals, north-south running primary canals branch off, Saluran Primer Utama or SPU, with a combined length of 958 km. These in turn connect to east-west oriented lateral or secondary canals. The north-south canals are generally situated at the top of the peat domes and were intended to supply irrigation water by gravity flow from the rivers into the peat areas. The lateral canals would distribute the water further to the west and east, and then continue to function as drains to carry excess and drainage water back to the river. In the south and east of Block A many of these lateral canals were also provided with gate structures near their outflow into the river, but in the north of Block A and in Block B and C the canals are in open connection with the river.

A similar system was developed in Block D between the Kahayan and Kapuas rivers though with a more Y-shaped layout of the main canal system.

The main canals in Blocks A, B and C are mostly 10 to 25 m wide and 1 to 3 m deep, see the design cross sections in Figure 3.1 (Block A). These sections also show the spoil berms and small drains (*parit gendong*) at the inside of the berms. In most places the berms are still present though much reduced in size as a result of settlement and oxidation/burning. They could nevertheless play a role in canal blocking efforts, either to guide overland flows and keep such flows away from the canal, or as source of dam or canal fill material. The *parit gendong* are in many places heavily overgrown and carry very little water, but there are exceptions where they are even used by boats to bypass obstructions in the main canal.

At present the canals mostly still have more or less their original width but the depth has often decreased as a result of bank scouring. Especially the primary canals are less deep than indicated in the drawing but whether this is due to gradual infilling or whether they were never excavated to the design depth is unknown. Although often more shallow near the banks, many secondary canals still have a depth of 2 to 3 m in the middle of the canal, which is surprising after more than 10 years without maintenance and suggests that very little sedimentation or infilling of the canals is taking place, other than bank scouring.

A network of smaller, tertiary canals was developed for the south and east of Block A only, in the Lamunti, Dadahup, Jenamas and Palangkau areas. In places water control structures and quaternary or on-farm drains have been added there in recent years.

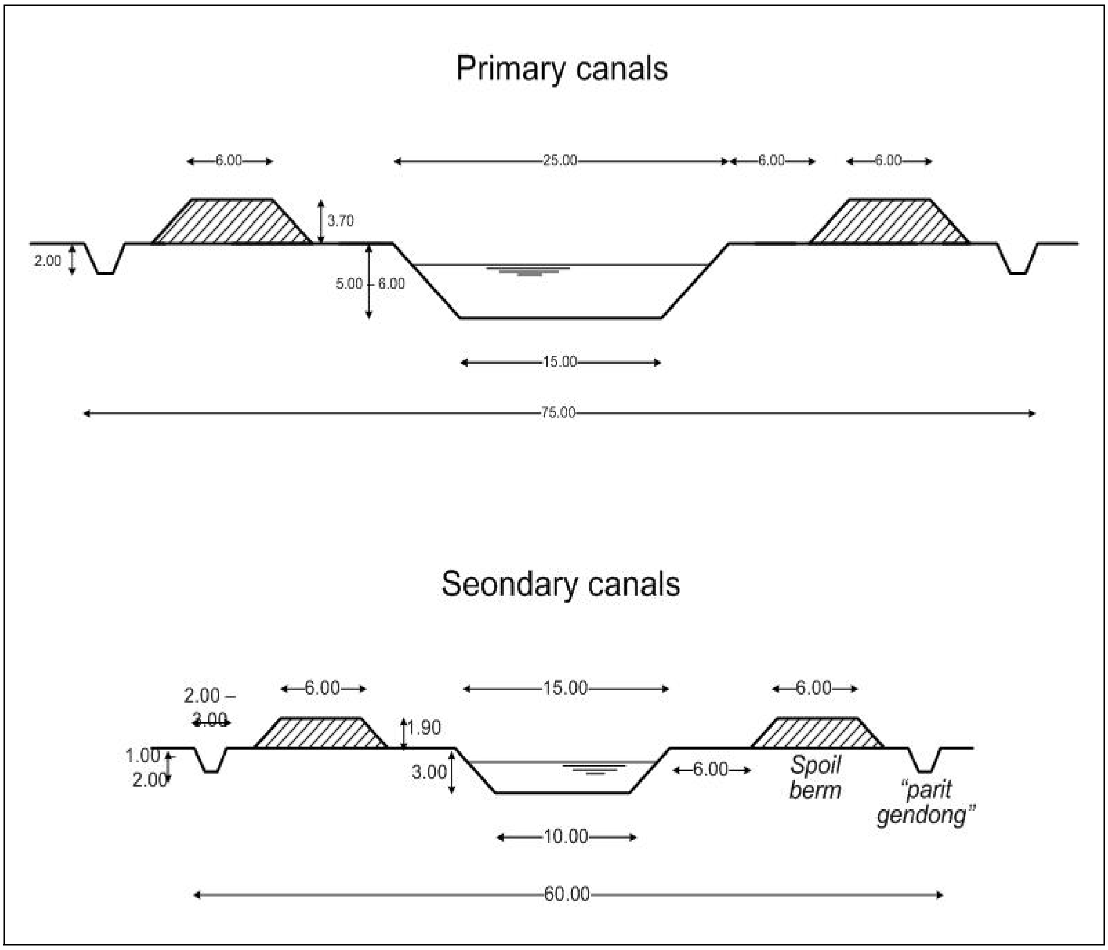


Figure 3.1 – Design dimension of the main PLG canals

3.2 Other canals

Older transmigration canals

In the south of Block C and D, on both banks of the Kahayan River, there are a number of transmigrant settlement schemes dating from the early 1980s. Their dead-ended main canals extend from the river some 10 km or more inland, with tertiary canals spaced every two hundred meter. On the west bank of the Kahayan these canal systems extend into the peat dome between the Kahayan and Sebangau rivers. While most of the transmigrants settled on deep peat lands have been resettled elsewhere, the canals have not been blocked and are still slowly draining the peat dome.

Traditional *andil's*

Along the main rivers there are many small canals or *andil*'s made over the years by the local villagers. Typically some 3 to 5 m wide and 1 to 2 m deep, they extend a few km from the river inland, and serve both as drains for agricultural lands and as access route. While most are concentrated in areas with mineral soil or shallow peat, in some cases they extend into the deeper peat areas as well. Some have also been connected to the ex-PLG canals, hence adding to drain the peat dome beyond. The department of Public Works actively assists the people with cleaning up silted-up *andil*'s or with excavating new ones, if requested, to open up new areas.

Logging ditches

In some areas many small ditches are dug to transport illegally cut timber. These micro canals are mostly 1-3 m wide and 1-2 m deep but can extend many kilometres into the peat dome. Temporary blocks are sometimes installed to maintain water-levels high enough for the floating logs, bit once the illegal logging has stopped and the canals lose their transport function they continue to slowly drain the peat dome. To restore the hydrology these canals also have to be permanently blocked. Such illegal canals are mainly found on the Sebangau site of Block C. In Block B, illegally cut trees are mainly transported overland as water levels are generally too deep (verbal information from CIMTROP), and/or through the ex-PLG canals. The SPI canal in between Block A and E is also frequently used for transport of logs.

3.3 Impacts of canals on the peatland hydrology

3.3.1 Original hydrological situation

The peat areas were originally very poorly drained and water logged. In the rainy season, the groundwater level was practically at the surface and ponding frequently occurred in flat areas on top of the domes. The rainfall surplus (rainfall exceeding evaporation) slowly drained in predominantly east-west direction to the rivers. In the dry season evapotranspiration would lower the groundwater table to well below 0.80 m in many years, but only for periods of up to several weeks. In extreme dry years the water table could fall as low as 1.50 m. Most of the time however, the water table would be close to the surface and the peat nearly fully saturated. The density of open water courses in the peat lands is very low compared to upland areas.

3.3.2 Effect of the PLG canals

The situation drastically changed with the excavation of the PLG canals. These canals cut deep into the peat layers and lowered the groundwater levels close to the canals. The upper peat layers dry out and the surface subsides due to consolidation, decomposition and oxidation, and the occurrence of fires. On average, the annual subsidence is in the order of 10% of the groundwater depth. If the process were to continue, eventually most all peat would disappear, the land surface would approach the level of the drainage base (or the level of underlying mineral soil if that level were higher), well below maximum flood levels in the adjacent rivers. Many areas would suffer from seasonal, if not permanent inundations. The process is schematically illustrated in Figures 3.2 and 3.3.

Subsidence is largest where drainage is deepest, i.e. close to the canals. This is confirmed by numerous measurements in the areas, see the examples in Figure 3.4 and 3.5. As a consequence, forest degradation is also often more severe, and fires more frequent close to the canals then further away. The increased terrain gradients near the canal result in faster surface runoff as well as groundwater flows, adding to increased peak flows in the canals.

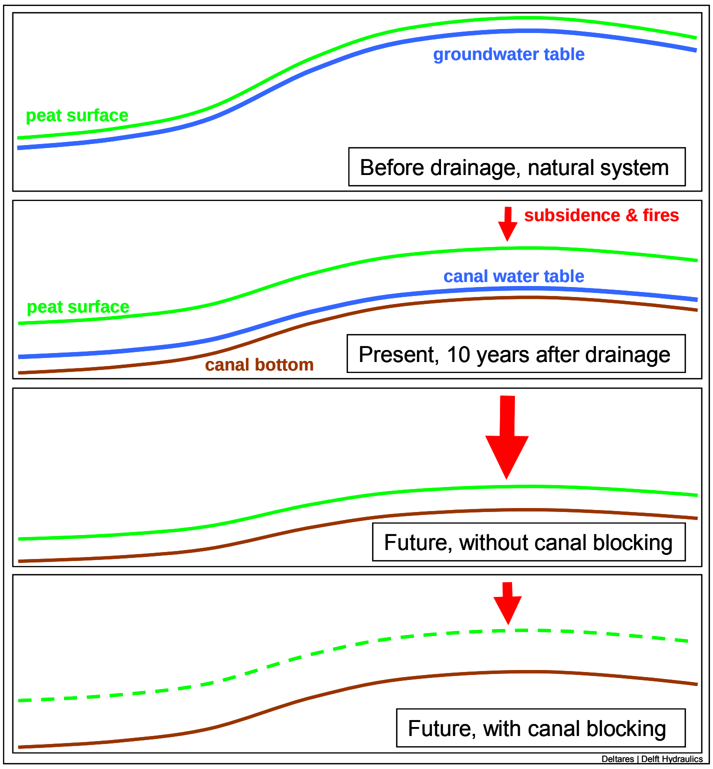


Figure 3.2 – Effect of drainage on peat land surface levels

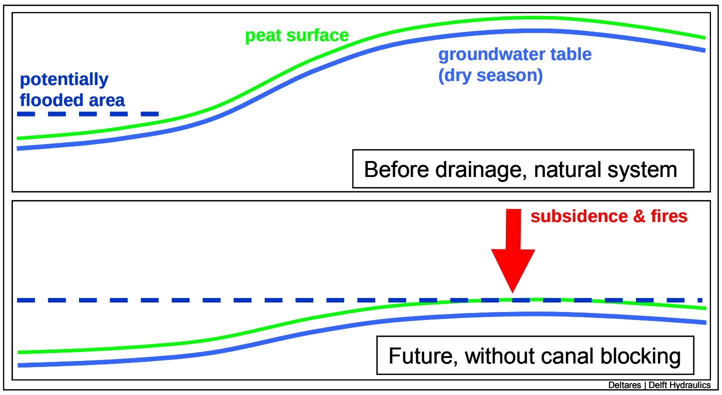


Figure 3.3 – Effect of drainage on inundated areas

The greater subsidence near the canals depends, however, also on the hydraulic conductivity of the peat soil as is shown in Figure 3.6. If the soil conductivity is high, the groundwater further away from the canal will quickly follow the drop in groundwater close to the canal and the subsidence may be more or less even everywhere (upper part of Figure 3.5). In case of lower soil conductivities, e.g. as a result of a long period of subsidence and consolidation of the peat, the water-level midway the canals will remain high and as a consequence less subsidence there than closer to the canal. (lower part of the figure). This is for example the case in the north-western part of Block A where greater subsidence near the canals has resulted in the development of “mini-domes” in between the drainage canals. The canals are now situated in depressions with a width of tens to hundreds of metres. In the north-western part of Block A, with canals spaced every 2.5 km, the land surface close to the canals is on average about 60 cm below the land surface midway between the canals.

Without intervention the situation will worsen over time. The process will continue until the level of the peat is only slightly above the drainage base in adjacent rivers, resulting in an area subsidence of several metres in the centre of the peat domes.

The changes in the peat lands caused by the canals are irreversible. The original conditions can not be restored, but it is possible to mitigate the effects and prevent, or at least limit, further degradation by bringing up water levels through canal blocking.

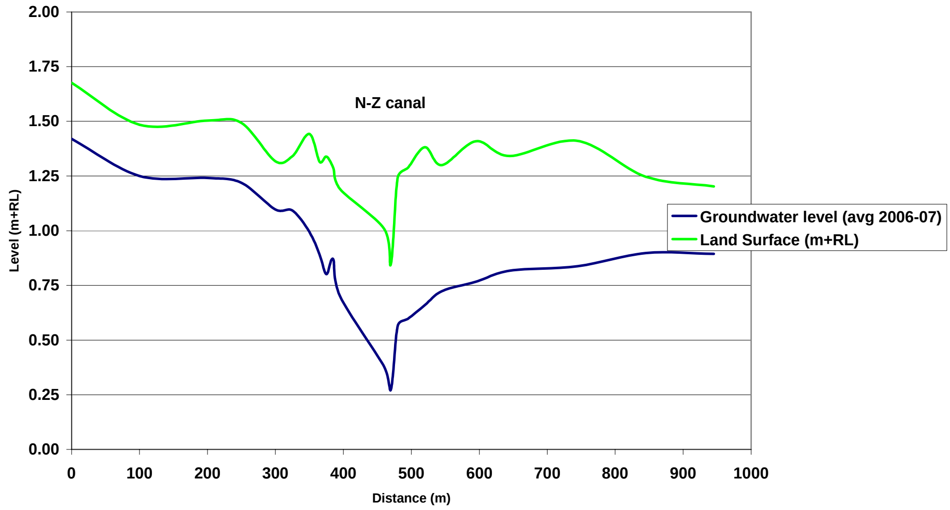


Figure 3.4 – Land levels and groundwater levels at various distances from the N-S primary canal in the north of Block C.
Source: CKPP/Master Plan EMRP

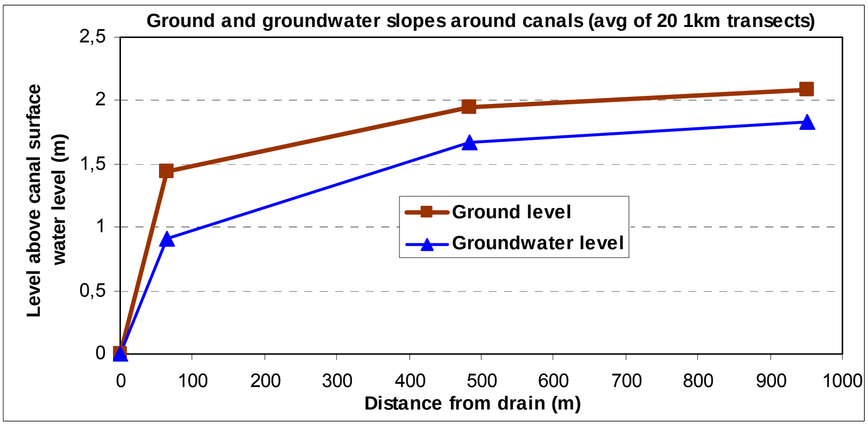


Figure 3.5 – Average surface and groundwater gradients perpendicular to canals (July/August 2007).
Source: EMRP Master Plan, Technical Report "Peatland Subsidence Scenarios in the EMRP Area". Average values of 20 transects.

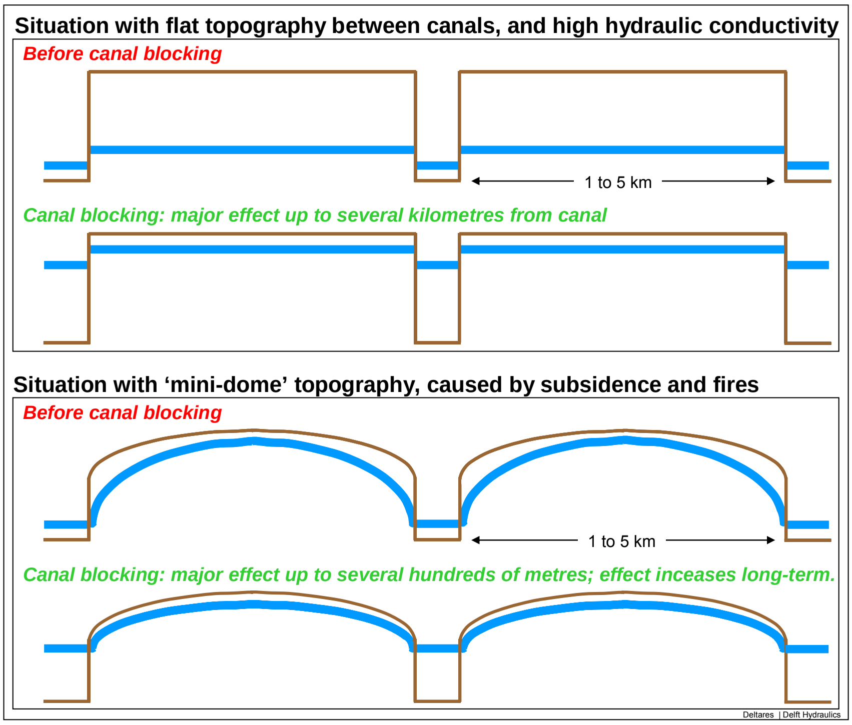


Figure 3.6 – The effect of hydraulic conductivity on groundwater levels and the development of mini-domes

3.3.3 Effect of other canals

Though not as dramatic as the effect of the main PLG canals, the numerous smaller canals are also slowly draining the peat dome and lowering the groundwater levels. This will result in similar effects as caused by the main canals: subsidence, oxidation, fire risks and increased CO_2 emissions. The blockage of these smaller canals is as essential as the blocking of the main canals.

The zone of mineral soil or shallow peat between the peat dome and the river is often used by the local population for various agricultural activities. In some places (Kahayan right bank in the south of Block C) transmigration settlements have been built here. The canals required for agricultural development will lower the groundwater tables, and even if not extending into the deep peat areas themselves, they will nevertheless have an (indirect) impact on the peat dome hydrology. Therefore, adapted management is recommended for agriculture in these areas to minimize this impact: high groundwater tables, selection of crops tolerant to high water tables, cultivation on mounds or ridges, etc. Where canals extend into the deep peat areas, they will have to be blocked.

Another important effect of canals and other activities in the adapted management zone is that they greatly facilitate access to the (edges of) the peat dome. If full development were allowed in areas with a peat depth less than 3 m (according to current regulations) it would be very difficult to avoid further encroachment on the peat dome. New developments in the adapted management zone (e.g. oilpalm plantation) should be considered only with the utmost care.

4 Canal blocking experience

4.1 Introduction

In Kalimantan as well as in other deep peat areas with similar conditions, several mainly non-government organizations have been active in blocking canals in order to raise the groundwater level and to rehabilitate the peat areas. This chapter gives an overview and evaluation of activities over the past few years in Central Kalimantan and elsewhere. The information is based on interviews with members of the organisations involved, field observations, and a study of monitoring data and reports. Important for the exchange of data and local expertise in Kalimantan was a working group on canal blocking structures established during preparation of the present guidelines, in which participated besides the Master Plan team members:

- University of Palangka Raya/CIMTROP;
- Wetlands International;
- Central Kalimantan Province, Public Works department (Dinas PU Propinsi);
- Central Kalimantan Province, Agency for Environmental Management (BPPLHD).

Field visits were undertaken to collect specific information about the channel blocks and to evaluate their current (early 2008) conditions and effectiveness. The visits included the north-western part of Block A (Wetlands' dams), Block C (CIMTROP dams) and the Sebangau National Park (WWF structures). Field notes from the visits are included in Annex 1 of this report. The main conclusions regarding each of the three areas are given below.

4.2 The Kalimantan experience

This section summarizes the experience by organisations active in canal blocking in Central Kalimantan Province. Most of the larger canal blocks are all variants of the box dam, consisting or rows of wooden poles driven across the canal into the bed, with the space in between the rows filled up with soil bags, as schematically shown below.

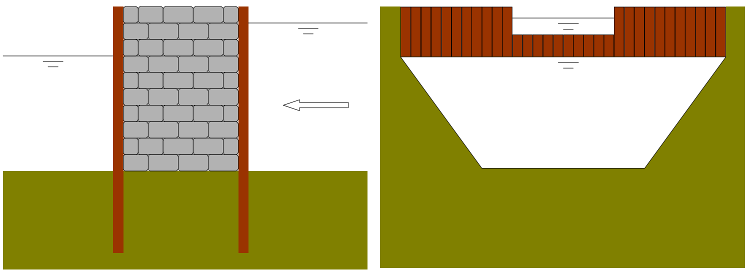


Figure 4.1 – Principle of the box dam, section and front view

CIMTROP

The northern part of Block C and the northeastern part of the Sebangau National Park, both deep peat areas, are research locations of CIMTROP. A fire brigade has been organized, and research is carried out on reforestation and peat conservation. Since 2004 nine block structures have been built in the main canals with a width up to 20 m, and another 50 smaller dams in secondary canals. The design and construction uses local expertise, labour, materials and equipment. The structures are rather light. Construction costs are in the order of Rp. 25 million per block. Several blocks were washed away in the rainy season. The actual lifetime of the blocks is short and they need to be replaced every 2-3 years. There are experiments to consolidate the blocking structures by means of vegetation.

CCFPI/ CKPP / Wetlands International

Wetlands International carried out peat conservation activities under the CCFPI Project and later under the CKPP project in the north-west of Block A. The area is situated north of Mantangai, between the Kapuas and Mantangai rivers. Since 2004 twenty-sis canal blocks have been built with a width varying from 15 to 30 m. The design of the structures is based on structural analyses and local experience and expertise. A local contractor built the structures in cooperation with the local community. Most of the materials were imported from outside the area. Wetlands International published a Guide to the Blocking of Canals and Ditches (Wetland International, 2005, also available from the WI website).

The structures are more robust than the Cimtrop structures. Piles are deeper and the dam body is wider. The canal flow is supposed to partly seep through the structures, and partly flow over the structure. Provisions to divert peek flows over the adjacent land have been added as well. In the later CKPP designs the middle section of the dam is narrowed and equipped with wooden planks to facilitate pulling small boats over the dam, and so avoid that people dig ditches for boat passage around the dam. The narrowing generally tends to weaken the dam. Average costs are in the order of Rp. 100 million per structure. The expected lifetime is about 5 years, due to the use of timber which degrades over time. Geo-textile has been used to limit seepage losses but after one year many of the sheets were already torn. Vegetation is planted around the structure in an effort to let “nature take over” and gradually over-grow the canal.

Local consultations

Figure 4.2 – CKPP box dam built by Wetlands in the north-west of Block A
(dam no. 16, February 2009)

WWF

WWF built four blocking structures with a width up to 15 m, and sixteen small dams, just outside the project area in the Sebangau National Park. The soils vary from shallow peat close to the Sebangau River to deep peat further inland. The design of the structures is similar to the those of Wetlands International. A contractor built the larger block structures and the local community built the smaller ones. All materials were imported from outside the area.

Figure 4.3 – Box dam with large head difference during peak flow

Source: EMRP

PU

PU has not built any blocking structures in the peat conservation areas, but they are constructing many water control structures in the canals of the developed areas. The structures are mostly in the tertiary canals, 4 to 6 m wide, and made of concrete, masonry or a combination. Some tests with fibreglass structures are ongoing. The structures serve to control rather than block canal flows, and are equipped with gates, either stoplogs, flap-gates or sliding gates. Without extensive bottom and side slope protection, seepage often develops below or besides the structure, and head differences of more than half to one meter can rarely be maintained for long periods, even though soils are predominantly (soft) clayey. Depending on their size, costs of the structures range from Rp. 50 to 150 million. The structures are built by contractors.

The large water control structures built in some of the primary canals by the PLG project are mostly heavily damaged and beyond repair. Nevertheless, the remaining concrete foundations could possibly be incorporated in future blocking structures.

4.3 Experience elsewhere

This section reviews experiences under similar conditions elsewhere, not necessarily specific on canal blocking structures.

Peat lands in Sarawak, Malaysia

Two million hectares of lowland peat swamps are being developed for agriculture in Sarawak, Malaysia. About 25% of the proposed area is on peat with similar hydrological and geotechnical conditions as in the EMRP area. A manual “Water management guidelines for agricultural development in lowland peat swamps” has been published by the government of Serawak (DID, 2001). While mainly dealing with water level control for agricultural land use, the manual also includes recommendations on appropriate technologies for peat land conservation.

Road construction over peat and organic soils

An Indonesian guideline for the design, construction and maintenance of roads and embankments on peat soils has been published (CUR 207, 2001). This guideline focuses on geo-technical aspects and gives information about the structural behaviour of peat, appropriate construction materials and their characteristics, and the effectiveness of various construction improvement techniques. The manual is partly based on experience from building and monitoring trial embankments near Bereng Bengkel (Central Kalimantan) for road construction over deep peat soils.

Kampar

Valuable experience with canal blocking has been gained in large-scale acacia plantations on deep peat soils in the Kampar peninsula, Riau Province. The plantations are traversed by large canals, spaced 800 m, which besides for drainage are also used for access and, after harvest (once every five years), for transport of the wooden logs in large barges. The latter function determines the size of the canals which is much bigger than would be needed for drainage only. To avoid the negative impact of the canals on the peat land, canal blocks are constructed which during harvest periods can be temporarily removed again. These blocks consist of:

- an earth dam built solely from local peat soil, excavated, dumped and compacted by excavators;
- a shallow bypass canal around the block to accommodate the drainage flows including peak flows after heavy rain. The initially designed multiple, narrow and rather deep bypass channels (see Figure.4.4) proved vulnerable to erosion, even if protected with geo-membrane, and these are now being replaced by very wide and shallow bypass channels.

The structures are built by hydraulic excavators in a couple of days only. Experience so far is very positive provided that any water flow over the dam is prevented.

Figure 4.4 – Kampar, Sumatra, peat dam with narrow bypass

Source: Deltares | WI Delft

4.4 Evaluation and lessons learned

Valuable experience has been gained from the past canal blocking efforts in Central Kalimantan, especially regarding the design of the blocks and the way how to construct these. Most of the structures are effective to create a water step, or head difference, in the canal, and they have been built with only a minimum of material imported from outside the region. With the limited means available to the organizations who built them, much has been achieved. However, the large PLG canals were built by an enormous operation involving many large construction companies with dozens of heavy equipment and huge budgets, and to really undo their work would require a similar big operation.

The following conclusions and lessons learned are drawn from the Central Kalimantan experience.

- While effective to raise upstream canal water-levels, the effect on groundwater levels is likely to be small in view of the fact that the canals have “eaten themselves into the land” and are now situated in small depressions. Nevertheless, raising the canal water is important to prevent further drops of the groundwater tables.
- The effect of each block extends only a few km upstream, depending on the created head difference and the canal gradient. To raise the water-levels along an entire canal many more blocks with small head differences would be required.
- With the limited means available, it is tempting to try to create blocks with a big head difference to maximize the effect of the block. However, the bigger the head difference, the bigger the water pressure on the dam and the higher the seepage flows through or around the dam. With the materials and construction methods at hand, head differences of more than half a meter prove difficult to maintain.
- The Wetland built dams, especially the earlier CCFPI dams, appear to be the strongest, although also the most expensive. The later CKPP design is likely weakened by the narrower section in the middle of the dam. The structures should be deeply embedded in preferably the mineral subsoil to avoid instability.
- The expected lifetime of the dams is about 5 years. In many cases there is little sign of nature taking over by re-growth or sedimentation in the upstream canal, and new dams will soon need to be built. To promote re-growth in the canal, dam building may have to be combined with partial infilling of the upstream canal and planting of (water tolerant) tree species.
- Water flows over the dams damage the dam crests. The overflowing water takes away dam fill material and creates flow paths through the dam below the crest, hence reducing the head difference and effectiveness of the dam and threatening to further damage the dam..
- Seepage and piping through as well as below and around the dam is a serious threat and calls for small head differences over the dam, and long dam bodies. Dam fill material should preferably be clayey soil.
- The dams require regular inspection and a maintenance organization capable of reacting quickly to repair small damage before such damage becomes bigger.
- Involvement of the local people in planning, design and construction of the blocks is important to gain their support, but is no guarantee that the dams will be safe from human intervention. Small bypass channels should be considered for dams in canals that are frequently used for transport of goods or people. Planks provided for pulling boats over a lower section of the dam proved not very long-lasting. Providing alternative livelihoods for the local population could decrease their dependency on the forest resources, but this is at best only a solution in the long term.

Experience from outside the region largely confirms the above conclusions. Small head differences over the dams and a large number of dams are essential to effectively raise water-levels, and to act as a safety in case one or more of the dams would fail.

The earth-fill dams of the Kampar experience offer an attractive alternative to the box dams for places accessible by heavy equipment.

The box below illustrates the evaluation through lessons learned from a recent dam failure.

DAM FAILURE IN BLOCK C

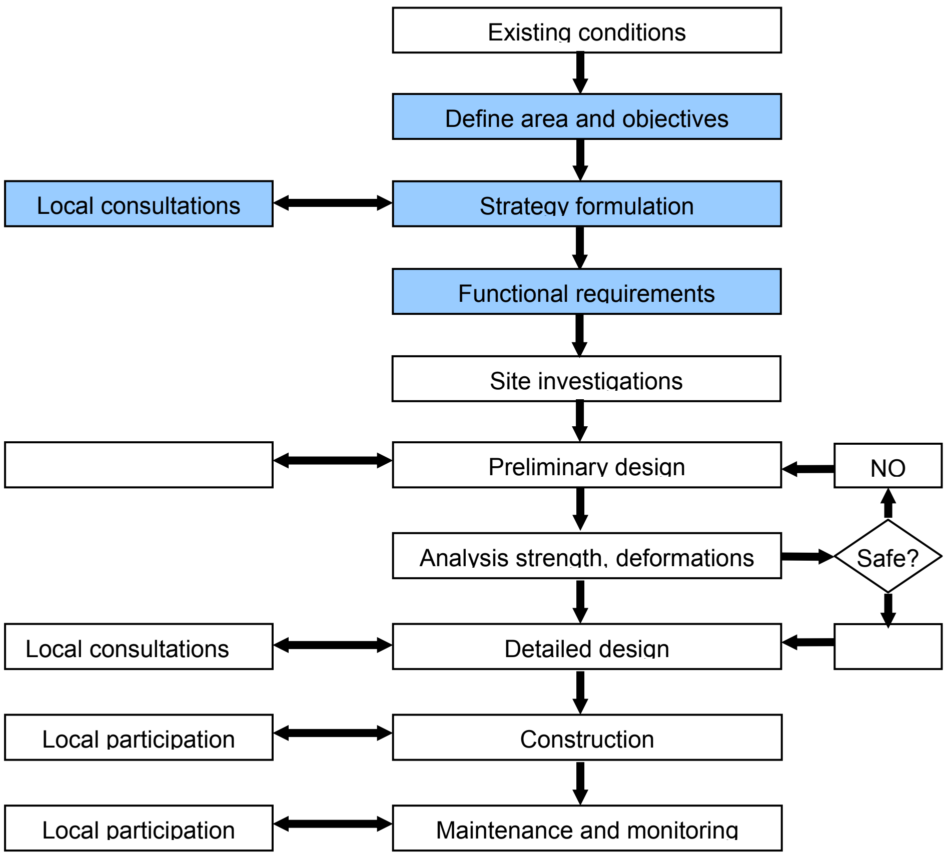
A short time after its completion, a dam in the north of Block C broke down. The dam was intended to raise the water-level above the canal banks so that all canal flow could be diverted and continue as overland flow. The dam consisted of two rows of gelam poles (Ø 5-10 cm) spaced 0.5 to 1 m apart with geo-textile on the inner sites, and the dam core filled with bags of peat soil. Side wings on both sites extended up to 10-15 m inland. The poles of the side slopes were short, extending 0.3 to 0.5 m into the peat. At the time of the disaster, the upstream water level was at least 2 m higher than downstream, but still below the level of the surrounding peat land, so no water could be diverted away from the dam. After a site inspection the main lessons learned appeared to be:

- The dam was built at the wrong location. Flow diversion will only be successful if the difference between the water level in the canal and the land level is not too big and the surface runoff can indeed flow away from the dam.
- A too big difference in water levels over the dam. The big head difference caused seepage through the dam and the soil besides the dam, which turned into piping and washed out the soil until one of the banks gave way.
- The dam was too short. The top of the dam was only around 0.5 m, the base around 1.0–1.5 m long, making the dam very susceptible to seepage.

5 Design of a blocking strategy

Blocking the existing canals will be an important part of any peat land rehabilitation strategy. This chapter compares the different options for canal blocking and outlines the main steps to come to an overall blocking strategy before the design of the individual blocking structures can start.

The strategy will be developed in close consultation and preferably with the active participation of the local communities, and will result among others in the selection of the most appropriate type of blocks for different locations, and in functional requirements of the canal blocks (head differences, with or without navigation facilities etc.) as input for the detailed design. It is part of the overall canal blocking process as indicated in the figure below.



5.1 Strategy formulation and data requirements

The strategy to be formulated will have to address the following main issues:

(1) Define area of intervention and objectives of the intervention
(2) Desired head differences over the blocks and required number of blocks
(3) The way how canals (peak)flows should be accommodated (over the dam, though bypasses, or flow diversion over land)

(4) Type and location of blocking structures
(5) Implementation schedule and sequencing of construction.

These issues are dealt with in the next sections of this chapter.

The strategy will be based mainly on existing information regarding conditions in the area. An overall idea of the topography, depth of peat soil and hydrology is provided by the CKPP/EMRP data (Chapter 2) and at this stage no more detailed surveys regarding these aspects are required. Site visits or reconnaissance surveys, however, may be required to gather more information on the dimensions and conditions of the canals in the area:

- location and layout of the canal system, including interconnections;
- depth and width of the canals;
- re-growth status in the canals, accessibility, and present use made of the canals;
- elevation of canal banks and land levels away from the canal in relation to canal water-levels;
- canal flow directions and relative size of flows;
- condition of existing canal structures or dams (if any).

5.2 Area selection and objectives of intervention

Area selection

The area to be selected will evidently be located in the peat conservation zone. It is strongly recommended that an entire hydrological unit is selected, bordered by main rivers. If only part of such a unit is selected, e.g. only the top of the peat dome, it will be impossible to avoid big water losses at the boundary of the selected area, because the canals further downstream will not be blocked and water-levels there will remain low. This will also be the case where in between the deep peat area and the river there are settlements and cultivated areas, part of the so-called Adapted Management Zone. Special measures are needed here, e.g. a succession of several closely spaced blocks in canals traversing this zone, to maintain high water-levels in the peatlands and to allow sufficient drainage for agriculture or plantations in the adapted management zone.

Besides the physical conditions of the area including accessibility, the area selection should consider the following aspects of the area:

- Bio-diversity value of the area;
- Present access and use made of the area by the local communities;
- Land rights, both traditional or customary rights and licenses granted to private sector companies;
- Development plans of various government agencies covering the area;
- Ongoing activities from NGOs, universities etc. (see also Chapter 4)

Objectives

The conservation of peatland requires high groundwater levels and the elimination or at least a strong reduction of the drainage effect of the canals. In most cases the objective of the canal blocking will be to bring up canal water-levels in the wet season as high as possible, preferably close to or even above the canal banks. During the dry season water-levels should also be pushed up, but it will be impossible to avoid a drop well below the land surface due to evaporation. There may however be exceptions, e.g. in case of deep canals where keeping the canals water-levels in the wet season close to the surface would require excessively high and hence costly structures, or in case the block should be passable by boats also during periods of low water-levels in the canal.

The canal blocking should also aim at creating conditions where vegetation can start to grow in the canal or can encroach on the canal from the sides. As most types of canal blocks will be made of non-permanent material, the design of the blocks themselves should also aim at creating possibilities for “nature to take over”.

Besides the main objective of raising canal water-levels, another objective of the blocking strategy may be to limit access to the area, especially by illegal loggers and people trying to develop the area for agricultural development. Some access by the local communities should in most cases be allowed, if only for maintenance of the canal blocks and of other rehabilitation related works. However, any activity which would jeopardize the rehabilitation efforts should be strictly prohibited and the canal blocks can help to prevent people from undertaking such activities. Which canals should be blocked entirely and in which parts of the area limited access should still be allowed will have to be decided in close consultation with the local communities. With the recommended small head differences over the dams (see next section) it is anticipated that no special facilities will be required for overhaul of small boats over the dams as these could be pulled over the land adjacent to the block.

5.3 Head difference and required number of dams

To bring the water everywhere along the canal close to the target water-level a great number of closely spaced dams are required with a small head difference over each dam (difference between upstream and downstream water-level elevations), see Figure 5.1. Widely spaced dams with big head differences are much less effective as the impact of the raised water-level always extends over a limited distance upstream of the dam only. Small head differences over the dams with closely spaced dams are highly recommended for several reasons:

- push up water-levels all along the canal as high as possible
- reduce seepage through or around the dam
- reduce risk of dam failure due to high water pressure
- reduce impact of dam failure on canal water-levels and on head difference at other dams.
- combined with bypasses, increase infiltration and storage, hence reduce (peak)flows

A head difference of less than 40 cm, preferably around 20 cm is recommended.

The required number of dams N depends on the head difference and the canal gradient:

$$N = \text{canal gradient (m/km)} \; / \; \text{Head difference (m)}$$

On top of the peat domes gradients are often less than 10 cm per km and a head difference of 20 cm would require 0.1 / 0.2 = 0.5 blocks per km, or one block every two km. Along the edges of the dome gradients may increase to as much as 1 m per km, which would require 1 / 0.2 = 5 blocks per km, or one block every 200 m. Of course it may be decided to apply a different strategy for different canals or for different parts of the area. Much will depend also on the type of block selected.

The more dams, the higher the costs. However, with small head differences, hence less water pressure and seepage risks, a cheaper type of dam could be selected, at least in some of the locations.

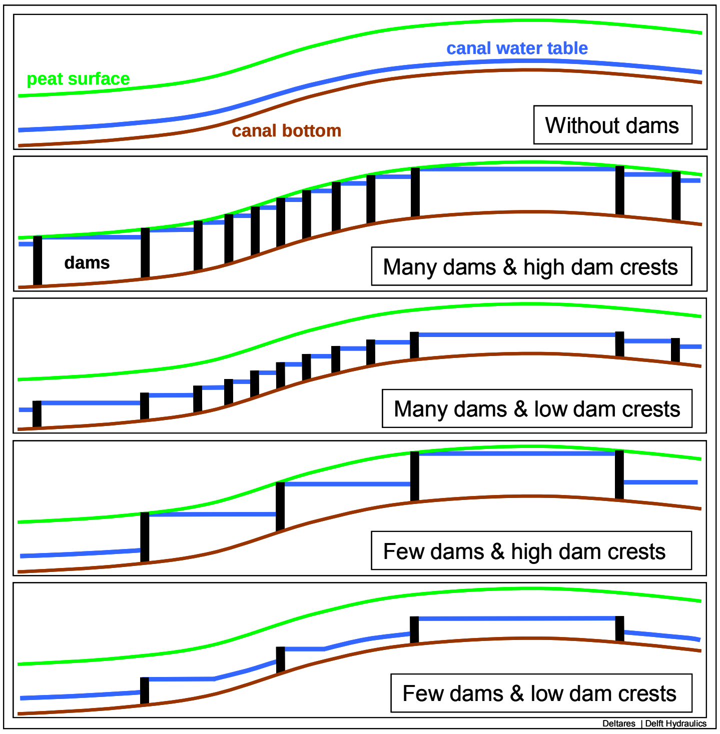


Figure 5.1 – Relation between dam crest height, head difference over dams and number of dams requireed

5.4 Canal flows: overflow, bypass, or flow diversion

An important decision is required on how to accommodate the canal (peak)flows. In principle there are three options:

- flow over the dam, either over the crest of the dam or through a specially constructed spillway;
- flow through a bypass besides the dam;
- flow diverted as overland flow away from the canal.

The options are discussed below.

Flow over the dam
In this case the overflow level of the dam will have to be lower than the canal banks to avoid damage to the banks left and right of the dam by overflowing water. Besides a lower overflow level, a main disadvantage of this option is that any overflow over the dam tends to weaken the dam body. With wood and soil being the only building materials in most cases, it will be practically impossible to build a strong spillway of the required capacity, while overflow over the crest risks to erode the fill material of the dam and to enhance leakage.

Flow through bypass
The bypass is a broad depression more or less parallel to the canal and slightly lower than the adjacent terrain through which the canal flow bypasses the structure. Making as much as possible use of local conditions, in most cases some shallow excavation work will be needed to create and connect the bypass to the canal upstream and downstream of the dam. The bypass should run at

safe (at least 10 m) distance from the dam.
The advantage is that there is no overflow over the dam. The dam crest should be constructed above highest high water-level (about 1 m above the canal banks). Another advantage of this option is that by flowing out over a broad area more infiltration and temporary storage in the soil is created, reducing or retarding canal (peak)flows. However, the terrain may not always allow the construction of a bypass, especially further downstream along a canal where flows become big and the required width of the bypass would become excessive.

Flow diversion
In this option the canal flow is forced out of the canal and out of the depression formed by the canal to continue as overland flow left and right away from the canal. Such overland flow, or shallow groundwater flow after infiltrating into the soil, was presumably the natural drainage system of the peat lands before canal construction. A complication is that the canal depressions have led to the mini-dome landscape so that the water would have to be “pushed over the edge” of the mini-dome. The dam would have to be extremely wide, up to several hundred meters, the dam crest would have to be dangerously high holding back a vast “lake”, while small head differences over the dam would be out of the question as making such a big dam every few hundred meter would not be feasible. Flow diversion might be an option in special cases where no or only a very shallow depression has been formed yet, but for most canals it is not considered a suitable option.

Conclusion
In general the bypass option is preferred because it avoids damage by water flows over the structure and it promotes water storage in the area. However, bypasses may not be feasible everywhere, e.g. in places where no natural depression is available and where excavation of a bypass would become very expensive, or in canal sections with large (peak)flows which might cause erosion of the bypass channel. In that case canal flows over the dam will have to be accepted. In principle a combination might be considered, e.g. small flows over the dam and peak flows through a bypass or vice versa, but in practice it will be difficult to ‘dictate’ the flows and surprises can be expected.

Sometimes a distinction is made between canals running over the flat top of the peat dome and/or parallel to the contour lines, and those running away from the top of the peat dome to the main river, i.e. across the contour lines. The first would have smaller flows, lower depressions, and would therefore be more suitable for diversion of canal flows than the latter. While the latter certainly have steeper gradients and hence greater flow velocities, flow volumes and formation of the depression are not necessarily bigger. Much depends on the area drained by the canal and on interconnections with other canals, and each case should be viewed separately.

5.5 Type of canal blocking structures

Blocking structures could be made either from hard material like concrete and masonry or from wood, earth and other natural materials. The following types of structures are considered realistic to block the canals in Central Kalimantan

- Concrete or masonry dam
- Wooden dams filled up with earth
- Earth dams, either manually or mechanically constructed
- Wooden poles with debris/soil to slow down flows
- (partial) infill of canals

Any of these may or may not be combined with the use of plastic sheets, geotextile or geomembrane to reduce seepage.

Concrete or masonry structures

In deep peat areas structures of concrete or masonry are normally no option because of their weight and the requirement for deep, hence expensive foundations. However, in special cases their use should not be excluded altogether. They might be considered for example at the most downstream dam location along a canal where the conservation area borders a developed area or where the canal discharges into the river, and where hence a big head difference need to be overcome. The mineral soil here will often be closer to the surface than on the dome, making construction less complicated. Nevertheless, particular attention will be needed to reduce seepage below or around the structure, even in case of mineral soil at the surface, and installation of seepage screens should be considered. Concrete structures are the common type of structures built by PU and for more details reference is made to guidelines of PU (1986), national standards and others (e.g. USDI 1974).

Manually built dams of wooden poles and earth

This is the classic box dam, built of vertical wooden poles and filled with bags of mineral soil. A lot of experience with various types of box dams has been gained in the EMRP area. Based on an evaluation of this experience (see Chapter 4) the recommended box dam would be similar to those built by the CCFPI project, i.e. with a straight crest. Where possible, the canal flow should be diverted through a natural or manmade bypass and the dam should have a higher crest than the CCFPI dams to avoid any damaging overflow. The box dams are relatively expensive requiring much labour and materials (poles, mineral soil) from outside but they have the advantage of being built with local manual labour. The design of the dam is further described in Chapter 6.

Earth dams

Building dams of mineral soil is not considered a viable option in the peat dome areas because all soil would have to be transported from outside the area by small boats and/or hand carried to the construction site. This would make such dams very costly. Moreover, the mineral soil would be subject to settlement as its weight would compress the peat soil below. Earth dams made of local peat soil are an option provided the dam is sufficiently long (at least 12 m) and the peat can to some extent be compacted to avoid seepage. The dam could be made either manually or mechanically by excavators or bulldozers. The latter would be cheaper and would allow a much better compaction, but mobilization of the equipment to the dam site may be a major problem.

No canal water should ever be allowed to flow over the earth dam as this would cause serious erosion. Covering the dam by sheets of plastic or geo-membrane would not be a long-lasting solution. Similar to box dams, all canal flow should be guided through a bypass around the structure. The crest of the dam should be well (1 m) above the canal banks, and initially an additional height should be given to compensate for subsidence.

Palisades with debris block

With a palisade is meant a row (possibly two rows for added strength) of poles driven into the bottom across the canal with a spacing of some 20 to 40 cm, and with large volumes of shrubs, small trees, branches and other debris as well as peat soil from the canal sides put into the canal upstream of the palisade, generating a block of at least 20 m long. See Figure 5.2.

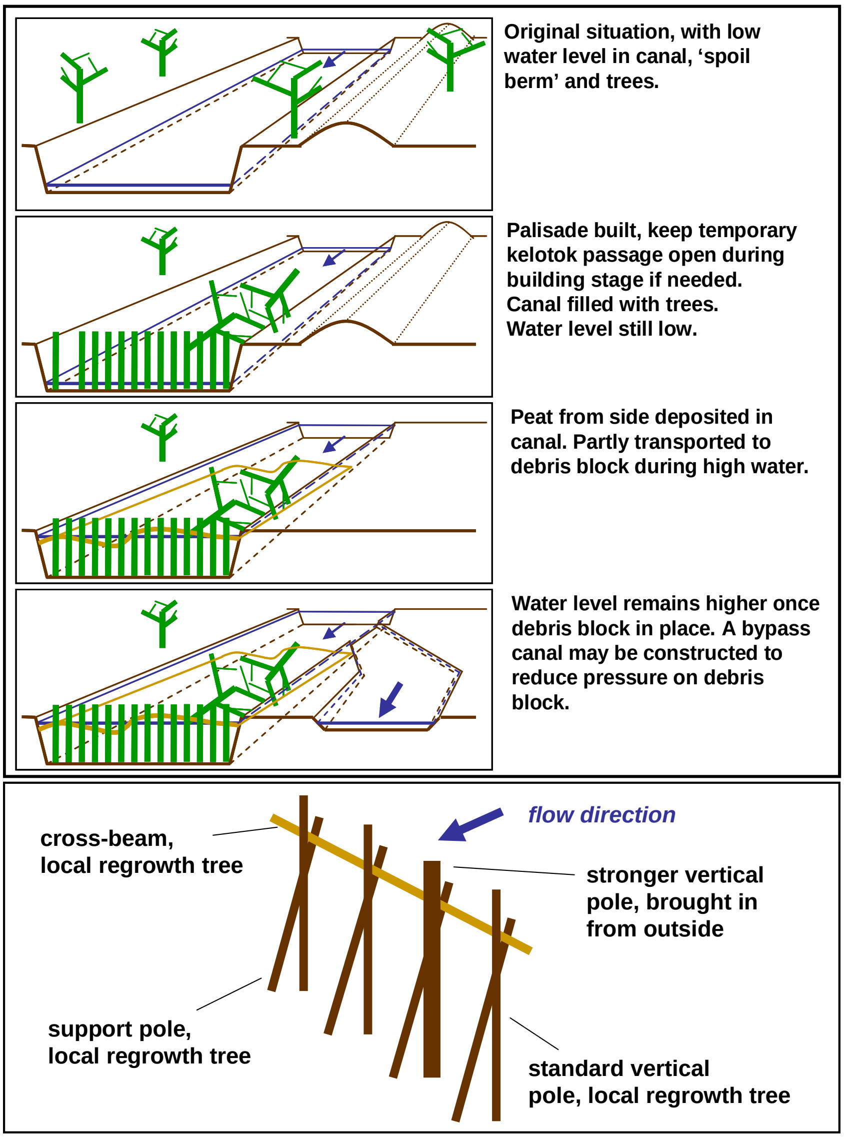


Figure 5.2 – Palisade block

The palisade block probably cannot raise the water-level above the canal banks, so either there will be flow over the block or deeper bypasses need to be made than for the box and compacted peat dam. This type of block should therefore only be used for canals with small flows, and for small head differences, like in canals on top of the dome. The advantage is that the blocks use few or no material from outside the area, and labour requirements are low. As little experience exists in the area with this type it should be tried out first before implementation on a large scale. If heavy machinery is available, a hybrid of this dam with the compacted peat dam concept may be considered.

(partial) infilling of canals

Complete infilling of canals would require large quantities of soil which could only be handled by heavy equipment. Partial infilling of the canal with peat material from the canal sides could in principle be done manually. Although this will never result in a complete block, it will increase canal roughness and reduce flow velocities and thereby increase water-levels if implemented over long stretches of canals. The fill material should be excavated shallowly from both sides of the canal as any deep excavation would risk to create a new flow path for the water. Infilling may be suitable only in shallow canals with low flows and with relatively high embankments (or there where the canal has subsided relatively deep into the land). The infill should be combined with planting of flood-tolerant species to help reduce flow velocities and keeping the soil in place (see Annex D). As no experience exists in the area with this type of block, it should be tried out first at different locations to assess its effectiveness and to determine best construction methods before implementation on a large scale.

Comparison of different types
A comparison of the different types of canal blocks is given in the table below. It is evident that different types should be selected for different conditions. In canals with low flows (usually on top of the dome) 'soft' blocks (palisades, infill) could be preferred once these have proven to be effective. Where equipment can enter the area, compacted peat dams are likely the preferred option because of their lower costs, and in other places box dams will be the best. Where many closely spaced dams are required a combinations of box or compacted peat dams alternated with soft blocks (palisades, infill), could be considered. As said earlier, concrete or masonry dams should also not be excluded for particular sensitive locations. Costs will evidently play an important role in selecting dam types.

Characteristics and suitability	Concrete structure	Wooden box dam	Manually built peat dam	Mechanically built peat dam	Palisade block	(Partial) infilling of canal
Characteristics:						
- Strength	++	+	– –	+	+/–	+/–
- Durability	++	–	+/–	+	+/–	+/–
- Risk of leakage through dam	++	+	– –	+	–	–
- Community participation in construction	–	++	++	–	++	+
- Cost	– –	–	+	+	++	–
Suitability:						
- Small canals (<2 m wide)	–	+	+	–	+	++
- Large canals, small drainage basin	+	++	–	++	+	+/–
- Large canals, large drainage basin	++	+	– –	++	–	– –

Table 6.2 – Comparison of recommended canal blocking options
++ very favourable   + favourable   – unfavourable   – – very unfavourable   +/– uncertain

5.6 Location of structures

Initial locations of the blocking structures will follow from the selected head difference and the (rough) topographic contour map of the area. If the head difference is 20 cm, there should be five structures between every two 1-meter contour lines. More precise location will be determined during the detailed design process and will be based on the presence of natural depressions for bypasses and/or availability of embankment material for infilling etc. The same applies to the type of structure: the initially preferred type should be indicated for each location, but the final selection should be made during the detailed design stage when more data are available on the local conditions. In general, palisades or infilling might be preferred for small canals and the most upstream section of larger canals where drainage basin and hence flows are small, while box dams and mechanically built compacted peat dams are likely preferred for bigger canals.

Particular attention is required for the most downstream structure along a canal where large head differences can be expected, and a concrete structure may have to be considered.

5.7 Functional requirements

The developed strategy will serve as basis for the detailed design of the blocking structures (Chapter 6). It is good practice to summarize the strategy in a number of functional requirements or design parameters for use by the designers:

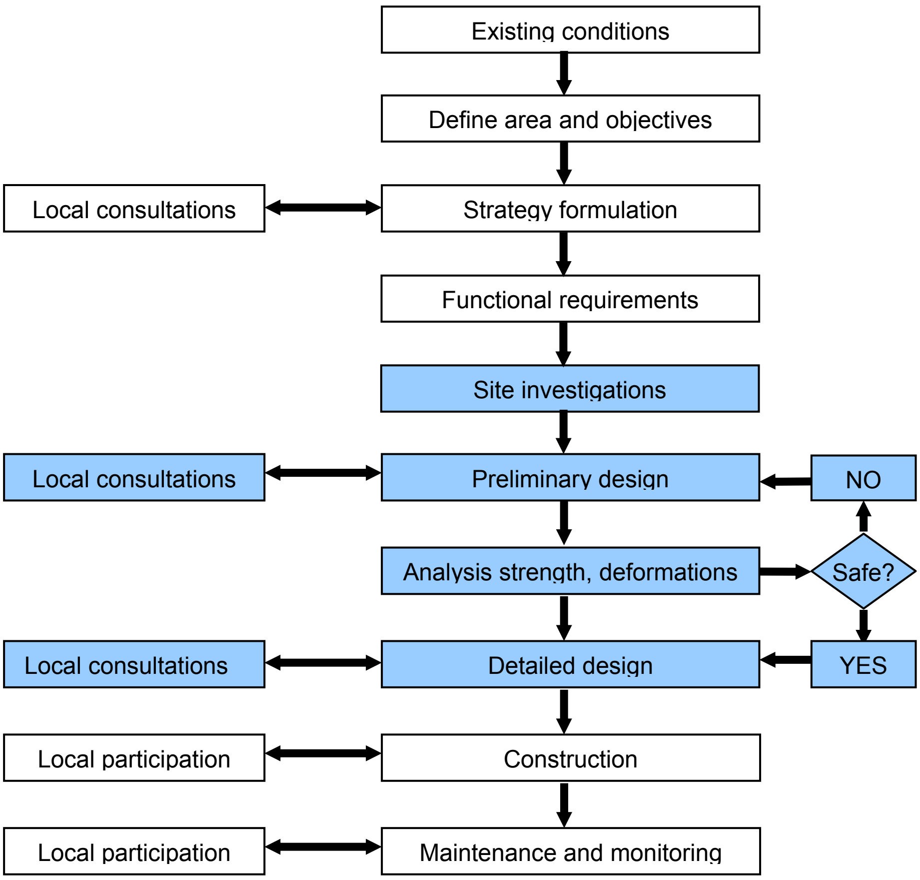
- a map showing initial locations and preferred type of structures;
- target water-levels upstream of the blocks in relation to canal banks and/or land levels;
- head differences and crest heights;
- preferred options for canal flow over or around the blocks;
- navigability and accessibility requirements (if any);
- any other requirements which may arise locally.

As canal blocking is only one part of a peatland rehabilitation plan, the other activities and their requirements should be considered as well. E.g., reforestation might require certain canals to remain easily accessible; wildlife conservation might require broader land bridges over certain canals; fire protection might require water storage at strategic locations; the same with fisheries development as part of possible alternative livelihood strategies for the local population, etc.

Together with all information collected during the strategy formulation stage the listed requirements will then form the starting point for the detailed designs, to be followed by cost estimates and implementation planning.

6 Design of blocking structures

Once the overall blocking strategy has been decided and the approximate number and location of blocking structures is known, field surveys and site investigations are required as basis for the design of the structures. Preliminary designs will be followed by local consultations, strength analysis, cost estimates and the preparation of final designs. This chapter addresses these steps in the overall process, see the figure below.



6.1 Surveys and site investigations

The following surveys and investigations will usually be required:

- topographical survey;
- hydrological investigations;
- geotechnical soil investigations
- hydrogeological soil investigations.

The level of detail of each of these surveys depends on the type of canals and structures to be built. A small structure requires less detailed investigations than a larger one. Previous experience gained in the area can contribute to lower survey and investigation requirements. Table 6.1 presents an overview of the different requirements related to the size of the structure.

Survey	overall planning	small (< 2 m)	medium (2 - 10 m)	large (> 10 m)
Topography				
topographic maps	1:10,000	1:50.000	1:10.000	1:10.000
aerial photography/satellite imaginary	yes	yes	yes	yes
spot height		4	8	8
topographic profiles at canal	always	no	sometimes	always
Hydrological surveys				
monitoring data water levels	yes	no	sometimes	sometimes
flood marks	yes	yes	yes	yes
discharge measurements	sometimes	no	no	sometimes
Hydrogeological surveys				
slug tests (hydraulic conductivity)	yes	no	no	sometimes
groundwater monitoring data	yes	no	2 wells	4 wells
Geotechnical surveys				
hand auger holes	yes	no	2	profile: 1 every four meters
cone penetration test	yes	no	sometimes	yes
bulk density analysis	yes	no	yes	yes
Atterberg limits/grainsize analysis	yes	no	yes	yes
vane shear test	yes	no	sometimes	sometimes

Table 6.1 – Overview of surveys and site investigations

6.1.1 Topographical survey

The main objectives of the topographical survey are to:

- establish an elevation reference level in the area related to permanent benchmarks
- determine the blocking level (CBS weir level or sill level in bypass);
- determine the canal layout (width, depth, connections to other canals)
- assess size of drainage area of each block

Existing topographical maps and satellite images (Google earth) can be used to obtain a first indication of gradients and direction of gradients in the area but are not detailed enough for design purposes. GPS measurements are useful to determine locations (x, y coordinates) but elevations measured by GPS are far from accurate enough for use in the lowland areas, unless a detailed DGPS survey is set up.

Large canal blocking structures
Detailed information on canal bathymetry and elevation of the area along the canal is required for design of the spillway and bypass levels. It is strongly recommended that for medium and large structures a complete topographical levelling is carried out, with all elevations related to one and the same reference level. The reference level should be tied to permanent benchmarks in or near the area, as well as to water-level observations in the river at the downstream boundary of the

area. The measurements can be done either by conventional topographic surveys or by high-quality radar imaging from low-flying aircraft or helicopters. Maps with contour lines every 20 cm should be drawn.

Small canal blocking structures
For smaller structures, and depending on the blocking strategy chosen (crest/spillway elevations related to land levels), a complete topographical survey of the area may not be necessary and so-called free-board measurements can be sufficient to determine crest/spillway elevations. In these measurements canal water-levels are related locally to land elevations by levelling with an instrument or a water tube, while during periods of no or very low flows the water-level in the canal can be considered to be horizontal to relate different structure locations to each other.

Close to canal sides land elevations have often been disturbed by the canal digging activities, deposition of spoil material, and/or construction of embankments. Measurements of land elevations should therefore always avoid the canal banks and measuring spots should be selected well away from the canal.

Canal geometry
Canal cross sections should be measured at all selected structure sites, or, if the sites have not been selected yet, at regular intervals along the canals (1 km or less). The sections should be related to the reference level in the area or, if no reference level has been established, to local land levels. Special attention should be paid to record whether canals are interconnected to other canals. The surveyors should also record the vegetation status in the canals: no vegetation, some vegetation extending from the banks into the canal, and/or light or dense vegetation growing in the middle of the canal.

Drainage areas
Knowledge about the size of the drainage basin of a canal is needed to estimate peak flows. For dead-ended canals catchment boundaries can be estimated from the topographic contour lines and/or from the layout of the canal system. For interconnected canals this becomes more hazardous, and hydraulic modelling of the canal system can help to estimate the peak flows. If present, maximum flood marks seen on tree trunks or other permanent features, or indicated by local people, should be included in the topographic survey as well.

6.1.2 Hydrological investigations

The main objectives of the hydrological investigations are to:

- determine hydrological boundary conditions of the area (water-levels in main rivers)
- determine design water-levels and discharges in the canals
- in case of a new type of blocking structure: monitor the effectiveness of the structure.

The main rivers towards which the canal system is discharging form the hydrological boundaries of the area. Knowledge of their daily and seasonal water-level fluctuations in relation to the land elevations in the area is important to determine the blocking requirements in the downstream canal reaches. Together with modelled or estimated river flows they are also essential input for the hydraulic modelling of the canal system. If no river level records exist, measurements are required preferably during as long a period as possible. In case of tidal rivers hourly measurements are required, otherwise daily measurements are sufficient. It is strongly recommended that the measurements are continued also after the current period of investigations is completed, in order to support future surveys and/or monitoring efforts in the area.

Maximum peak flows in the canals can be initially estimated from the size of the drainage area and the drainage module of 7 l/sec/ha as mentioned in Chapter 2. More detailed information, especially in interconnected canals where drainage boundaries cannot be accurately drawn, can be provided by hydraulic modelling of the canal system.

Flood marks on vegetation or other permanent features in the area can be used to assess maximum water-levels. From these, maximum flows can be estimated using the Manning equation if the canal cross-section and canal gradient are known. However, the accuracy of such estimates is often not high and the results should only be used in comparison with other estimates or modelled maximum flows.

When a new structure design is implemented, monitoring is required to assess the effectiveness of the structure. The monitoring should preferably start at least one wet and dry season before the structure is built to be able to assess the changes brought about by the structure. The monitoring should include the up- and downstream canal water-levels as well as groundwater-levels around the structure, see also the next section.

6.1.3 Hydro-geological investigations

The main objectives of the hydro-geological investigations are to:

- determine the hydraulic conductivity of the soil;
- determine the groundwater levels in the area around the structure;
- determine the effectiveness of the structure.

Collecting groundwater monitoring data requires the installation of monitoring wells that are regularly manually gauged, or fitted with data loggers. As both options are relatively expansive it is recommended that groundwater monitoring only be undertaken at selected sites, for new designs or in areas where there is little information on hydraulic conductivity.

The hydraulic conductivity can in principle be determined by the slug tests. This involves installation of a monitoring well in which the groundwater level is lowered using a bailer. The subsequent recovery rate of the groundwater level is used to calculate the hydraulic conductivity using standard equations such as Hvorslev or Bouwer-Rice. It is noted that if the soil is very permeable, which is often the case in peat areas, the groundwater recovery may be too fast to measure accurately. In that case only a rough estimate can be given of the minimum conductivity.

Slug tests are also useful to check the conductivity of the fill material of a dam. This is obviously only useful if the conductivity determines the seepage rate (i.e. no cut-off screens or impermeable geotextile are used). If the conductivity is too high (resulting in loss of water during the dry period) additional measures may be required such as compaction or installation of a cut-off screen.

6.1.4 Geotechnical investigations

The main objectives of the geotechnical investigations are to:

- determine the depth and type of the mineral soil (2 tons Cone Penetration Tests, or CPT's, or hand auger boreholes);
- to retrieve soil samples and to determine the engineering properties of the soil (weight and strength).

Data on the depth of mineral soil are not required for small structures, such as an earth fill in a canal less than 2 m wide. This information is imperative for larger structures to determine the required length of foundations piles and possibly seepage screens. These measurements can be used to choose the exact location of the blocking structure. Peat depths often vary considerably over short distances, and where a peat depth of more than 7 m is found, a location more up- and downstream should be investigated as well to find a more suitable site. Four auger boreholes are recommended for medium sized structures. For large structures, profiles are recommended with a auger hole every four meters. The type of mineral soil should also be described: soft clay has lower bearing capacity meaning that the piles should be longer, whilst sand has more potential for piping which means that additional seepage protection may be needed.

Cone penetration tests are necessary for large structures on piles.

Vane tests and bulk density analyses are simple field tests to determine the weight and strength of the soil. These measurements are recommended when new designs are made that require structural design calculations.

6.2 Preliminary design

The preliminary design involves the following steps:

- determine the overall geometry of the structure, width and height;
- selection of materials (chapter 7);
- make some draft sketches;
- discuss the draft design with relevant agencies and communities.

Below, the designs are described of the three blocking structures most likely to be implemented at a large scale in any blocking programme:

(1) manually built box dam
(2) mechanically built compacted peat dam
(3) palisade block

The first two structures require a full engineering design based on survey data and the preparation of detailed design drawings for each location. For the simpler palisade dams this is often not needed, as these will be built by local people based on their experience, and their shape and dimensions will much depend on locally available material.
Typical design drawings for each of the three structures are attached to this report.

6.2.1 Box dam

The manually built box consist of two, or for larger dams three, rows of tightly spaced vertical wooden poles across the canal, with a distance of some 6 to 10 m between the rows. The poles are 8 to 10 m long and extend into the mineral soil below the peat. Horizontal beams connect the upper ends of the poles to keeps them in line, while other cross beams connect the rows to each other to add strength against horizontal pressure. Additional inclined scores behind the dam may be added. This is basically the design used by Wetland dams for the CCFPI dams in Block A, but with a higher crest level to prevent overflow.

The space in between the rows may be subdivided into smaller boxes and is then filled up with bags of soil. The bags should be carefully placed to avoid large openings between the bags, and should be trampled upon to compact the soil to a certain degree. The soil should preferably be clayey or other mineral soil to avoid leakage, but because of the high costs involved locally available peat soil might replace part of the clay, e.g. a core of clay bags supported on either side by peat bags. Because of their weight, bags with mineral soil might cause some subsidence of the underlying peat, and an additional height should be given to the fill material (about 10% of the peat depth) to compensate for this. Some compaction of the peat below the structure, however, may be beneficial as it will help to prevent seepage. Bags filled with peat soil, on the other hand, are more vulnerable to uplift by the water pressure and are subject to settlement themselves after installation. Also in this case sufficient over-height should be provided to compensate for the settlement. The top layer of the fill material could also best be mineral soil, both to keep the underlying (peat) bags in place and as a growth medium for vegetation to cover and protect the dam.

Geo-membrane can be added to make the dam as water-tight as possible, although the life time of such sheets is often not very long.

Special attention is needed to the connection between the dam and the canal bank. To reduce the risk of leakage through the (permeable) peat soil of the canal bank left and right of the dam, the dam body should be extended several meters into the bank. These extensions could also be given a greater length (in the direction of the canal) than the main body of the dam, somewhat similar to the hourglass shape principle of the Wetlands' CKPP dams.

The dam is constructed entirely manually and takes from several weeks for smaller dams to two or three months for bigger ones to complete.

6.2.2 Compacted peat dam

A compacted peat dam consists of peat soil excavated from the surrounding area and deposited into the canal. Compacting the peat after depositing is essential to reduce its permeability. To avoid leakage the dam body should be sufficiently long (15 m or more) and the head difference over the dam should be kept small. The height of the dam should be well above the highest high water-level, or at least one meter above the canal banks, to avoid any flow over the dam which would risk serious erosion damage. Even though the peat is compacted during construction of the dam, additional settlement of the dam body and the underlying peat should be anticipated by adding an initial over-height of at least 0.50 m to the dam.

Because of the large quantities of soil material involved and the required compaction of the peat, the dam should be built mechanically. At least two excavators are needed, one to excavate the soil and the other (possibly in combination with a dump truck or swamp dozer) to deposit the soil in the canal and compact the peat by running repeatedly over it. Once the equipment is on site, the dam can be completed in a matter of days, depending on the size of the dam. Extensive experience with this type of dam has been gained in canals of pulpwood plantations on the Kampar peninsula in Riau.

Depending on the qualities of the peat, especially in deeper canals with a big head difference the horizontal pressure of the upstream water may become too big to prevent deformation or translation of the dam body. Geo-technical calculations can help to assess the risk. In this case it may be necessary to add a number of vertical poles anchoring the dam in the underlying peat and mineral soil.

Covering the dam with geo-textile or –membrane is sometimes propagated where overflow over the dam can be expected. Experience shows, however, that the geo-textile does not hold very long and as soon as it is torn or displaced, serious damage to the dam body can be expected. This option is therefore not recommended.

A major issue is mobilization and demobilization of the equipment to the site. Transport from outside the area will likely be on pontoon over the main river and possibly into the larger canals. From there the equipment has to travel overland to the site. Even in the dry season locally strengthening of the path with logs may be needed. Temporary dams may need to be constructed by the excavator to cross canals. A considerable time will be required to get the equipment on site and this may limit the compacted peat dam option to relatively easy accessible sites only. Wherever the equipment can be brought in, it should be used for as many dams as possible in that part of the area.

6.2.3 Bypass channels

Both the box dam and compacted peat dam are preferably provided with a bypass through which all canal flow is diverted. The bypass should make use of shallow depressions in the immediate vicinity of the site, and the presence of such depressions should be carefully investigated when selecting the exact location of the canal block. If no such depressions exist they may have to be created by excavation. Care should be taken in that case that vegetation will re-grow in the bypass, preferably before any large flows are allowed to pass which could cause erosion of bare peat soil. The bottom level of the bypass should not be more than a few decimeter below the level of the canal banks as otherwise the objective of raising the water-levels as high as possible is jeopardized.

The required width of the bypass depends in principle on the size of the maximum canal flow:

$$Q = v \times A = v \times w \times d \quad (m^3/sec), \quad \text{or:} \quad \text{width } w = Q / (v \times d)$$

with: Q = the design peak flow (7 l/sec/ha multiplied by the size of the drainage area, possibly reduced with an area reduction factor, see Section 2.2.3)

v = the flow velocity (m/sec)

A = the cross section of the bypass (m^2)

Flow velocities over the bypass during peakflows will be high and may be up to 2 m per sec (much lower during normal flow conditions). For a typical dam site with a drainage basin of 20 km^2 the peakflow will be 0.007 x 20 x 100 = 14 m^3/sec and a minimum bypass cross section of 14 / 2 = 7 m^2 is required. This could be provided by a bypass channel 20 cm deep by 35 m wide (or 30 cm deep by some 23 m wide, etc.).

The layout of the bypass should be away from the dam, with the in- and outlets preferably at least some 40 to 50 m up- and downstream of the dam. With the recommended head difference of 20 cm over the structure no serious scouring is expected, but in case of bigger head differences the in- and outflow may have to be protected by a row of wooden poles.

In many places along the larger canals there are still remnants of the spoil berms resulting from the original canal excavation. In the PLG canals these berms are at a distance of about 6 m from the canal (see Figure 3.1). The berms could well be used, possibly after some rehabilitation, to keep the bypass flow at a safe distance from the dam. A connection between the berm and the dam could be added to prevent any overland flow close too the dam.

6.2.4 Palisade block

Palisades need to be strong enough to withstand the pressure of the canal block of debris that should accumulate upstream of it. The palisade should be open to water flow, which will reduce pressure on the palisade. Water steps over these blocks should be very limited, less than 0.1m or preferably 0.05m, so they must be built at short intervals of a few hundred metres only. If ‘debris blocks’ are created that are several times the canal width, most pressure will be deflected to the canal sides. In all, pressure on palisades should be reduced enough to allow use of light constructions made of local tree.

Palisades will allow water to pass freely if they are no less than 0.25 to 0.5m apart. For an average canal of some 10m wide, 2 rows of poles plus strengthening material will require 50 to 100 poles. The availability of such numbers of poles is a prerequisite to being able to build the palisades, although material may be sourced from further away in some cases.

The strength and design requirements for palisades, and therefore the material requirements, will vary in different conditions. Where canals are deeper and/or flow volumes are greater, stronger constructions will be needed. Depending on material availability this may be achieved by using more poles, placed in more rows, or by using stronger and longer poles. In some dead-end canals where flow volumes are limited and trees are already overgrowing much of the canal, a single row of poles palisade may suffice.

Locally available poles will usually be from trees that have regrown in recent years (gelam and other species), and will rarely be over 0.1m in diameter and 4-5m long, resulting in rather light construction material. Constructions can be strengthened by building them in two rows, with the downstream row at an angle to support the upstream row and with cross-beams to link vertical poles together (see Figure 5.2). They will be further strengthened by adding a few larger poles in the middle of the canal, at least 0.2m in diameter and 7m long, which will in many cases have to be imported from elsewhere.

It may be best to build all palisades in specific areas over short periods, parallel to partly filling up canals. As canal filling needs to be done in the dry season, to prevent materials from floating away before the palisades are in place, palisades are probably also best constructed in the dry season. Building palisades before partly filling up canals is an option only in some well-protected areas as palisades without debris blocks will be easily destroyed b people seeking to maintain access.

Because many palisades need to be built in a short period, it will be best to have this done by a number of teams at once. These teams will all need access during building. It is therefore best to originally build the palisade with an opening wide enough for boats with work crew and supplies to pass. This may be mostly the smaller ‘ces’ boats as the larger ‘kelotoks’ are usually too large to be used in the dry season in most canals, but may be needed to supply poles from further away in some cases.

The wooden poles that form palisades should be inserted at least 1.5m into the peat, with the stronger ones in the middle going in 2 to 3 metres. The top of poles should be above the water table in the wet season, and above the canal sides. Ideally, debris blocks may be able to push up water levels to at least the surrounding peat surface in the longer term, but this may not be possible if bypasses are also constructed.

Most palisades may not survive for much more than 1 or 2 years, as the construction and materials are light. By the time palisades collapse, the debris blocks should be strong enough to remain in place by themselves and let “nature take over”.

6.2.5 Local consultations

Even if the blocking strategy is fully supported by all stakeholders, it is strongly recommended to hold another round of consultations on the draft designs. Simple sketches, maps and plans should be prepared for ease of understanding by non-technical people. The consultations would also be a good opportunity to start or continue discussions on implementation modes (provision of materials, requirements and availability of labour), contracting options) and the role the local communities and their leaders could play.

6.3 Safety analysis

The canal blocking structure is subject to a number of outside forces threatening the stability of the structure:

- differences in water pressure upstream and downstream of the structure risk to overturn the structure, or to move or deform the structure in downstream direction (translation);
- seepage and piping through the soil below and besides the structure risks to wash away the soil material and ultimately to cause collapse of the structure;
- scouring or erosion by overflowing water.

The risks are further described below, together with possible design measures to counteract them. The risks can be quantified using standard geo-technical calculation procedures as given in Annex C, together with calculation examples. It should be noted however, that the calculation methods have all been developed for “normal’ soil conditions (i.e. non-peat soils) and their use in peat lands requires caution. The material parameters of peat soil and other local materials to be used in the formulas are poorly known, and may vary widely from place to place depending on degree of decomposition, subsidence, water content and other factors. Nevertheless, the calculations give an indication of the risks involved and should be standard practice certainly for the larger structures.

6.3.1 Overturning and translation

If the outside pressure is greater that the internal resistance of the structure, the structure will overturn or be deformed. The outside pressure is defined by the design water-levels, and the resistance depends on by the size and weight of the dam body, the shear strength of the foundation material (peat soil), and the length and anchorage of the vertical poles. The standard calculation procedures are shown in Annex C. The following measures should be considered in case the calculations (supported by local experience) would suggest instability:

- Increase the size and weight of the dam body in the direction of the outside force: widen the dam, for box dams use heavier fill material;
- Keep the head difference over the structure small;
- Add more and/or longer poles to anchor the structure firmly in the underlying mineral soil.

6.3.2 Seepage and piping

Piping is a process where soil material is eroded from either within the structure or from the soil surrounding it, due to an excessive seepage flux. This occurs when the hydraulic head gradient in the soil is larger than the pressure to keep the grain in place. Piping eventually creates preferential flow paths in which the seepage velocity is higher than in the surrounding soil matrix. This causes progressive internal erosion, and increasing over time ultimately leads to collapse or loss of functionality.
Measures to protect the structure against erosion include:

- Keep the hydraulic gradient small: a small head difference over the structure and a long dam body;
- Use preferably clayey soil material as dam fill material; make sure the fill is well compacted;
- Extend the dam wings into the banks of the canal;
- Use geo-textile or membrane sheets (although its life time is expected to be short);
- For concrete structure: add a seepage screen of planks, ferro-cement or other material;

6.3.3 Erosion

Fast flowing water causes erosion, and the critical velocity depends on the kind of soil material and soil cover, see Table 6.2. The design discharge is used to calculate the flow velocity for either a spillway using a weir equation, or a bypass using the Strickler equation, see Annex B. The calculated velocity should always be lower than the critical velocity.

Bank material	Critical velocity (m/s)
in situ peat	0.3 – 0.7
clay	0.5 – 1.0
peat with vegetation	1.0 – 2.0
structure (wood, clay/peat with geotextile, sand bags)	2.0

Table 6.2 – Critical flow velocities for different bank materials

The canal bed downstream of a weir, overflow or outflow of a bypass needs to be protected against erosion by pile rows or sand bags at the canal bottom to dissipate the energy of the overflowing water. Other measures to be considered:

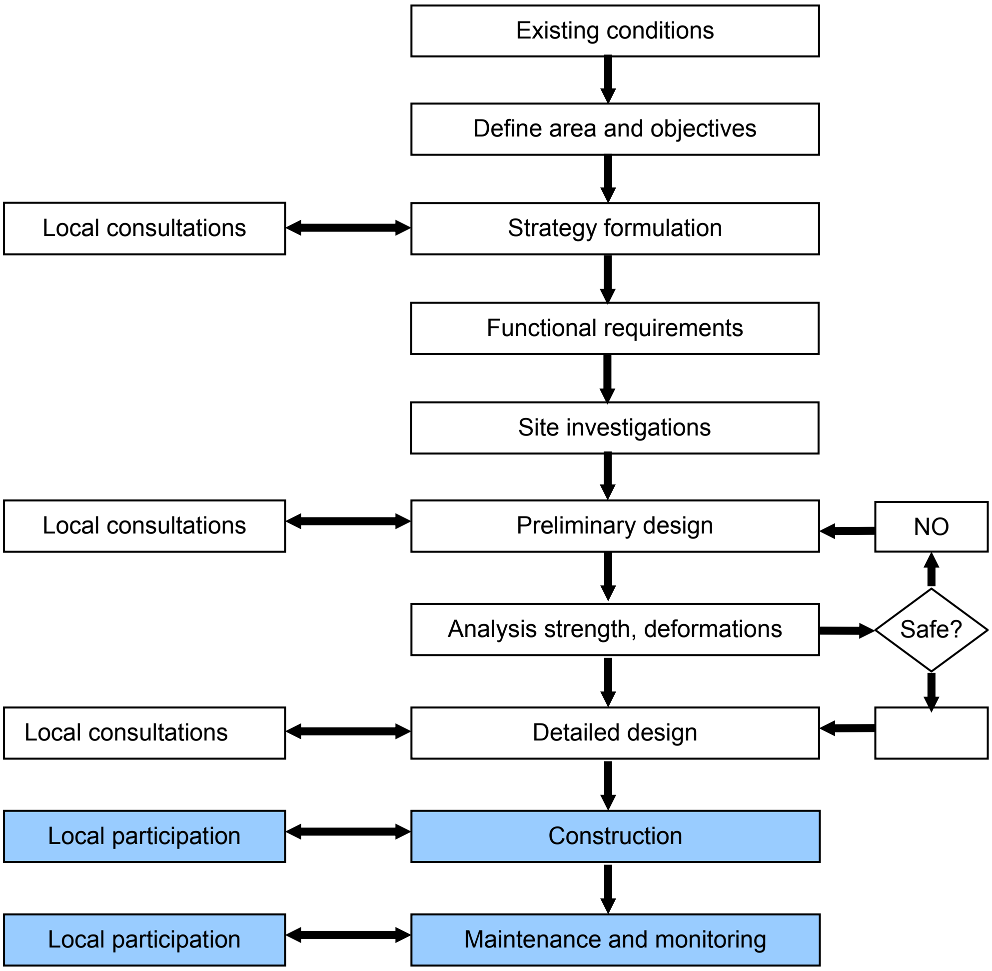
- Avoid overflow over dams or over the land close to the dam;
- Widen the bypass or add a second bypass on the other side of the canal;
- Keep bypass channels well vegetated;

6.4 Detailed design

Once the preliminary designs have been accepted and approved and the designs are considered safe, the design drawings can be finalized and worked out in detail. No major changes in the design should be required at this stage. The final designs will include location drawings, plan views and cross sections and where necessary detailed drawings of particular construction items to enable a contractor to build the structures. The drawings will follow national standards (PU 1986), and will be accompanied by technical specifications regarding quality of construction materials and implementation methods, and bill of quantities listing all required materials. The latter will serve to prepare the cost estimates, see Chapter 7.

7 Implementation

This chapter gives an overview of implementation aspects: construction materials, cost estimates, construction sequencing, contract modes and finally monitoring and maintenance of the structures. See the flow chart below. The local communities could play a very important role in the implementation, both in construction and the monitoring/maintenance of the structures, but these aspects are dealt with only very briefly. Different options for community participation are described in more detail in the technical note on Rural Infrastructure prepared by the EMRP.



7.1 Construction Materials

Peat

Peat is evidently the most widely available construction material in the area. Put in plastic bags (fertilizer or rice bags) it is often used as fill material for dam bodies. However, reworked peat is easily eroded when the bag is torn, and its structural properties and erosion resistance are better as long as the fibre structure remains intact. Reworked peat therefore is not suitable as fill material for box dams, unless in combination with mineral soil, preferably clay. It can be used for earth fill dams only if well (mechanically) compacted and if the dam body is long (>15 m). The low weight and high permeability give the structure little strength and it is susceptible to excessive seepage.

In situ peat has a shear strength of around 20 kPa, which is reduced to 5-10 kPa after reworking. The bulk density and compressibility are less affected by reworking.

Mineral soil (clay, silt and sand)

Clay, silt and sand are found below the peat, but in most of the conservation area it is at too great depth to be economically extracted. Sand and clay is found locally near the Kahayan and Kapuas rivers from where it can be transported by small boat to the construction site. In places, some mineral soil is present in the old canal embankments, apparently the result of deep canal excavation, but quantities are too small to be of practical use.

Mineral soil is suitable as fill material for box dams. The permeability of clay and silt is low, which helps to minimise seepage. Sand is more permeable, and moreover easily carried away by flowing water. The mineral soil is best placed in bags in the dam to prevent it from flowing away, but care should be taken that the bags are tightly packed to avoid seepage in between the bags.

The structural properties of sand and clay (angle of internal friction, bulk density), if compacted, are similar to those of the same material in situ. Clay, if well compacted, can be used along embankments exposed to moderate flow conditions (up 0.3 to 0.7 m/s).

Rattan and bark

Rattan is a root like fibre that grows from the many types of rattan palm trees (*Calamus rotang*). Most rattan palms are distinct from other palms in having slender stems, 2–5 cm diameter, with long internodes between the leaves. Their growth habit also differs, not being trees but vine-like, scrambling through and over other vegetation. Rattan mats and bark could be used occasionally to protect sensitive parts of a construction, but the material do not last long.

Timber piles

Gelam and Belangeran poles are the trees used for box dams. The trees are straight, have water-resistant wood, grow fast, and are locally available. Belangeran wood is particularly suitable for the vertical poles because of its elasticity and resistance to rot in a peat environment, but is lately becoming more and more scarce. Poles with 0.1 m diameter are preferred for its strength and ease of handling. The thicker poles are more heavy while much smaller poles will deform too much. The maximum available length is approximately 10 m. This means that foundation down to the mineral soil is possible in peat depths of at most 7 to 8 m. For deeper peat foundation the poles have to be lengthened which reduces their strength.

Structural design parameters of timber are specified in the Indonesian Standard NI-5 PKKI (1961) Peraturan Kayu Indonesia. Belangeran wood is classified as strength class 2 and durability class

2. The strength parameters of fully submerged timber must be reduced by a factor of 2/3. The engineering properties for Belangeran wood are (including 2/3 reduction):

- density = 0.86 gr/cm^3
- bending strength, σ_{bend} = 67 kg/cm^2;
- tension strength, σ_{tr} = 57 kg/cm^2;
- compression strength, σ_{tk} = 17 kg/cm^2;
- shear strength, τ_n = 8 kg/cm^2;
- lifetime = 5 years.

Hardwood plank
Hardwood planks of ironwood or Belangeran have been used for canal blocking in various locations because of its durability and the fact that it is locally found at the forests. However, the use of this material is not recommended if needed in large quantities, due to high cost of transportation and for environmental reasons. In limited quantities hardwood planks are used as cover for spillways or boat overhauls, or to keep poles and geotextile in place. The Department of PU uses hardwood planks for seepage cut off screens. Ironwood planks are sometimes stolen by local people because of their high value.

Based on the NI-5 PKKI (1961), the ironwood has the strength class 1 and durability class 1. Ironwood has the following engineering characteristics:

- density = 1.04 gr/cm^3
- bending strength, σ_{bend} = 100 kg/cm^2;
- tension strength, σ_{tr} = 87 kg/cm^2;
- compression strength, σ_{tk} = 27 kg/cm^2;
- shear strength, τ_n = 13 kg/cm^2;
- lifetime = 8 years.

Bags and geotextile
Ordinary plastic bags (fertilizer, rice bags) are often used to keep the peat or mineral soil in place. Geo-textile or plastic sheets (*kain terpal*) are often used as seepage screens in the dam body, and sometimes to cover the top of a dam to limit seepage and erosion by overflowing water. Experience learns that ordinary bags filled with mineral soils quickly tear open, and it is therefore recommended, though more expensive, to use bags made of geo-textile.

Steel
Besides nails, screws or other pins to connect the wooden elements, iron or metal is not used in canal blocking structures because of the high costs, the vulnerability to corrosion in the acid environment and the limited availability of skilled workers. Moreover, any items of iron are sought after by local people, and are hence vulnerable to theft.

Concrete
The major drawbacks of using concrete in canal blocking structures, cast in situ or prefabricated, are the fact that good aggregate (sand and gravel) is not available locally, and that the weight of concrete structures would require deep and costly foundations. With only acid peat water available in the area the quality of concrete works would be low.

Prefabricated concrete and ferro-cement sheet piles would be an attractive option. Proper quality control is possible at the factory, but transport of the elements to the site is problematic as the elements are easily broken. The concrete quality must be in accordance with NI-2 PBI-1971, Peraturan Beton Indonesia.

Comparison of Materials

A comparison of the relative costs, durability, availability, environmental aspects and labour requirements related to the use of the different materials is given in Table 7.1.

Materials	Advantages	Disadvantages	Cost	Durability	Availability	Environmental aspects	Labour requirements
Peat	locally available relatively cheap	very easily eroded	++	--	++	++	Local people, no special equipment required
Clay, silt	locally available relatively cheap easy workability	easily eroded	+	0	0	++	Local people, no special equipment required
Rattan	locally available strong relatively cheap easy workability	only usable as erosion protection	++	+	+	+	Local people, no special equipment required
Timber pile	light weight easy handling relatively cheap	short life time difficult to get the required dimension	0	+	++	0	Local people, no special equipment required
Hardwood plank	long life time light weight easy handling	needs treatment expensive	-	++	+	-	Local people, no special equipment required
Geotextile	long life time	not locally available	-	++	-	0	Local people with technical guidance
Steel	strong material	easily corroded expensive not locally available	--	0/-	-	-	Skilled workers with special equipment
Concrete	long life time strong material good quality control of prefab elements	not locally available expensive needs special workers and equipment	--	++	-	--	Skilled workers with special equipment

Table 7.1 – Comparison of construction materials

-- highly unfavourable, - unfavourable, 0 neutral, + positive, ++ very positive.

7.2 Cost estimates

The costs of the canal blocking include labour, material and in some cases heavy machinery costs. The labour costs include salaries, insurance, transportation, and food and accommodation on site for workers and equipment or boat operators. Material costs include building materials like wooden poles, soil, bags, geo-textile, nails etc. as well as purchase or rental/operation costs of instruments, tools, boats, etc. Machinery costs are expressed as unit rates and include all operation and maintenance costs of the machines.

Standard unit costs for various activities and materials are published regularly for each District by the Department of Public Works, but the costs do not include transport to the construction site. Moreover, costs of local materials may vary considerably as supply is often limited. Unit costs have as good as possible been estimated from PU standards as well as from information obtained locally, in particular from the Wetlands Int. dam blocking activities in the northwest of Block A. See Table 7.2. From the unit costs, overall costs have been calculated for different blocking structures, see Table 7.3.

Costs are evidently also influenced by the implementation and contracting methods. For the mechanical peat dam, mobilization costs of the equipment have been included on the assumption that the costs are shared among a number of dams constructed in the same part of the area. For work likely to be implemented by a contactor (peat dam and infill) taxes equal to 10% of the construction costs have been added in accordance with government regulations.

The costs of an entire blocking programme evidently depends on the number and the type of blocks selected. Assuming an average canal gradient of 0.50 m per km and a required head difference of 20 cm, the required number of blocks for a canal of say 10 km length would be twenty five, which would cost some Rp. 2.5 billion if all would be box dams.

Item	Unit	Rate (Rp.)
Transport		
Transport, bulk	ton per km	25,000
Transport, glotok per day (150 km)	day	1,020,000
Transport, chess per day (100 km)	day	550,000
Materials, manual installation		
Gelam poles	piece, >4m	60,000
Gelam poles installation, box dam	1 m length	717,500
Gelam poles installation, palisades	1 m length	239,167
Kain terpal	m2	5,000
Geo-textile	m2	40,000
Bags	piece	1,500
Filling bags with mineral soil	m3	24,000
Transport of bags with mineral soil and installation	m3	50,000
Filling canal with peat soil	m3	14,000
Manpower		
Unskilled labour	manday	65,000
Skilled labour	manday	80,000
Foreman	manday	100,000
Supervising engineer	manmonth	10,000,000
Mechanical earth work		
Excavator	hour	600,000
Swamp dozer	hour	600,000
Shallow excavation, mineral soil	m3	20,000
Shallow excavation, peat soil	m3	15,000
Moving, dumping, peat soil	m3	12,000

Table 7.2 – Unit costs for construction of canal blocks

Box dam, 15 m, 6 m long	Unit	Quantity	Costs
Gelam poles installation	m	50	35,875,000
Connections, nails, wire			4,000,000
Bags	piece	10,000	15,000,000
Filling bags with mineral soil	m3	280	6,720,000
Transport of bags with mineral soil	m3	280	14,000,000
Geo-membrane	m2	90	3,600,000
Camp for 40 persons	unit	1	4,000,000
Transport of people, material (excl. poles, soil)	glotok	7	7,140,000
Earthwork for bypass	m3	100	1,400,000
Miscellaneous			3,000,000
TOTAL			**94,735,000**

Compacted peat dam, 15 m width, 20 m long	Unit	Quantity	Costs
Mobilization of equipment			8,400,000
Excavation	m3	1,426	21,396,375
Transport and compaction	m3	1,426	21,396,375
Camp for 5 persons	unit	1	1,000,000
Miscellaneous			2,000,000
PPN 10%			5,419,275
TOTAL			**59,612,025**

Palisade dam, 15 m canal width	Unit	Quantity	Costs
Gelam pole installation	m	30	7,175,000
Partial infill of canal with peat soil	m3	500	7,000,000
Debris collection	manday	30	1,950,000
Camp for 40 persons	unit	1	4,000,000
Transport of people, material (excl. poles)	glotok	4	4,080,000
Earthwork for bypass	m3	100	1,400,000
Miscellaneous			2,000,000
TOTAL			**27,605,000**

Partial infilling of canals per 100 m of canal with cross section of 30 m2, infill 15 m3/m	Unit	Quantity	Costs
Mobilization of equipment			8,400,000
Excavation	m3	1,500	22,500,000
Transport and dumping	m3	1,500	18,000,000
Camp for 5 persons	unit	1	1,500,000
Miscellaneous			2,000,000
PPN 10%			5,240,000
TOTAL			**57,640,000**

Table 7.3 – Costs of typical canal blocking options

7.3 Construction sequencing

It is important that as much as possible all blocks along a certain canal or system of interconnected canals are constructed during the same dry season, to avoid that many dams are exposed to larger than the intended head differences in the following wet season. The most downstream dam in a series will always be exposed to a larger head difference and a different design may have to be adopted there. The total area of the blocking programme should be subdivided into annual target areas (evidently depending also on available budgets), with all blocks in a target area to be constructed in the same dry season.

For logistical reasons it is best to start blocking canals furthest away from the access point, usually at the top of the dome, so access is maintained for subsequent activities. From a hydrological point of view it is also recommended to start blocking at the top of the dome. If blocking was started from the downstream end, water-levels upstream of the block would go up and complicate construction of the following dams.

The canal blocks completed upstream will also help to some extent in reducing overall canal flows. Because of the higher water levels less groundwater inflow can be expected and more storage in the system will be available, especially in case of wide bypass channels. The lower water-level gradients will reduce peak flows.

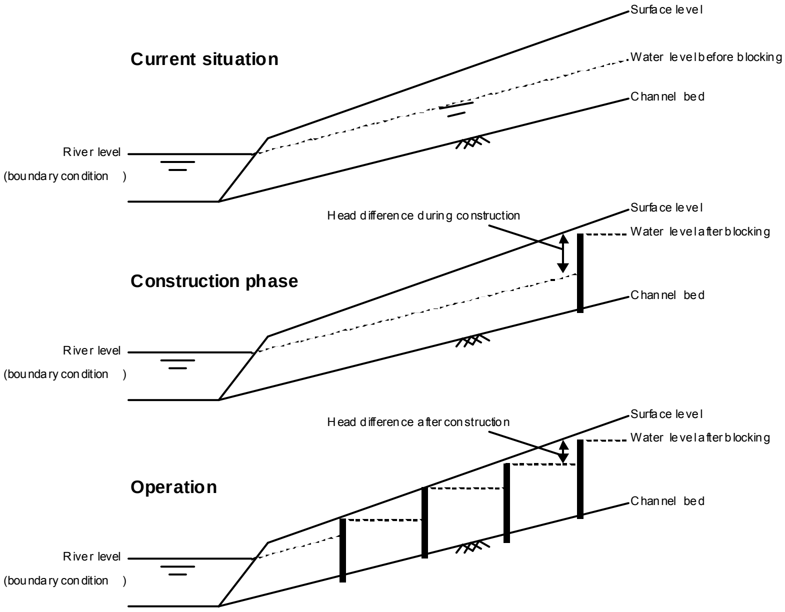


Figure 7-1: Construction phasing

7.4 Implementation methods

Implementation of construction work can be done either by Force Account or by contracting the work out. Force Account might be suitable for large Government Departments having their own equipment and technicians, but in other cases contracting the work out to contractors or to the local community is the best option.

Contracts should preferably include a maintenance guarantee period during which period the contractor is responsible for the maintenance of the structure. The contract may include monitoring activities as well.

7.4.1 Community involvement

Except for the mechanically filled earth dams, the blocking structures described in this report can be built by local people, who often have already experience in building canal blocks for logging or other forest activities. Contracting to local communities has several advantages, both for the community and for the contracting agency:

- Creating income for the community
- Enhancing the skills of the community
- Making optimum use of local expertise
- Creating a sense of ownership
- Relatively cheap (no overhead costs or profit margin for contractor)
- In most cases better quality of the work

Either the entire dam construction or part of the work could be contracted out to the community (e.g. supply of materials on site, driving in poles, filling of soil bags etc.). Other components of the work could be contracted out to other groups or to the same group after completing the first job. Much depends also on the capacity of the contracting agency to handle different contracts simultaneously and to coordinate and supervise the various activities. Options for community involvement in the construction process including payment mechanisms are further explored in the Technical Note Infrastructure by the EMRP.

7.4.2 Construction companies

In case of larger or more complicated works the assistance of a construction companies may be required. In that case the community could still be involved either as subcontractor for specific items of the work, or by being employed as labour. Requirements for community involvement should be included in the construction contract.

In case a large number of dams have to be built in a relatively short period, the amount of work may exceed the capacity of the local labour force. Also in that case (part of) the work could be contracted out to a construction company employing labour from outside the area. Another advantage will be economies of scale: the large quantities of construction material required could possibly better or cheaper be procured from outside the area and transported in large quantities to the area.

Employment of construction companies will require tendering among qualified companies in line with government regulations. The contracting agency (or a consultant assigned by the agency), will have to prepare the tender dossiers including detailed design drawings, bill of quantities, technical specifications, and any other contract stipulations deemed necessary or desirable.

7.4.3 Construction supervision

In all cases the need for proper supervision of the construction can not be over-emphasized. The supervision is usually done by the contracting agency but the agency may not have sufficient and competent technical staff for the job, especially if construction takes place at several places simultaneously. Either supervisors have to be employed from outside, or the entire supervision could be contracted out to a consultant company. Supervisors should be required to stay on-site for the entire duration of the construction work, and should be provided with adequate instructions and with technical specifications about what materials and workmanship are acceptable and what should be rejected.

7.5 Monitoring and maintenance

After completion of construction the blocking structures should not require regular attendance or operational activities like water gates in developed areas. However, monitoring the condition of the structures is essential to identify any damage or maintenance requirements as early as possible. Although the structures will usually be built in either government-owned (ex-PLG) canals or community-made canals, the maintenance of the structures will usually remain the responsibility of the agency who built them.

7.5.1 Monitoring

Regular monitoring and maintenance is essential to keep the structure in working condition, but this is often much more difficult than for ‘normal’ hydraulic infrastructure works because of the remoteness of the site and the difficult access.

A programme for periodic visits to the blocking structures has to be in place in order to monitor their condition and to identify any damage at an early stage. A distinction should be made between damage which needs immediate repair and repairs which could be done at a later stage. Besides visual observation of the dam’s condition and if necessary measurements of changes in the dimensions (settlement of fill material, deformation of structure elements), also the head difference in canal water-levels should be read from staff gauges upstream and downstream of the dam, and should be compared with readings from previous visits. Sudden changes in the head difference could indicate leaking or piping. A written report illustrated with photos and sketches should be made of each visit.

The visits could well be combined with monitoring the effectiveness of newly developed dam types. Besides the head difference in canal water-levels, groundwater-levels, land surface elevations, soil parameters, or vegetation characteristics could be observed to monitor any changes brought about by the dam.

7.5.2 Maintenance

Regular or routine maintenance activities include small repairs which can be done by just two or three persons, possibly combined with and at the same time as the monitoring visits. For bigger repairs a special work force needs to be mobilized. This can be either managed by the agency paying the labourers a daily fee, or by the entire work can be contracted out to a community group or contractor. Especially if a contractor is involved it would be more efficient to combine repairs of several structures in one contract.

Another option is a maintenance contract for a longer period, whereby the contractor (community group or private company) is required to keep the structure in proper working condition throughout the contract period. However, problems may arise if sudden peak flows or other unforeseen events severely damage the structure, and repair costs would exceed the contract sum.

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Annex A

Field observations early 2008

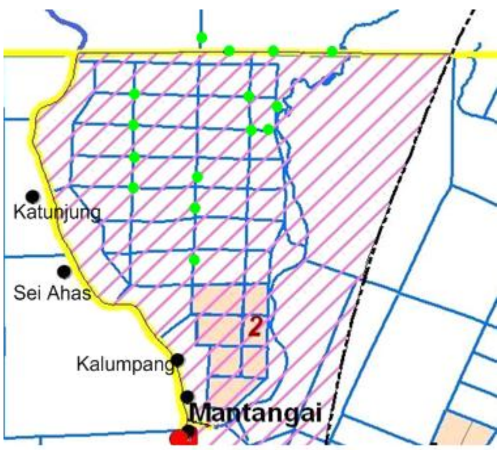
This annex describes observations made during field visits by the EMRP-study team members in early 2008 as part of the preparations for this guideline. The field visits included the north-western part of Block A (Wetlands' dams), the northern part of Block C (CIMTROP dams) and the Sebangau National Park (WWF structures).

A.1 Field visit Block A (28-30 Jan. '08)

The width of the ex PLG canals in this area varies from 10 to 25 meters. Most of the area consists of severely degraded peat land covered by ferns and low bushes, with only in the north-eastern corner some remaining forests. Along the canals the vegetation is often slightly denser, and some small trees are growing here. In the south and west, along the Kapuas River where the peat soils are less deep, agriculture is practiced by people from nearby villages. Small-scale illegal logging is still ongoing in the forested part of the area and more so in Block E to the north. Forest products, fish and wildlife are actively collected by the villagers and many of the canals are occasionally accessed by the people in small *klotoks*.

Since 2004 Wetlands International has constructed 26 dams in the area, of which five in the twin SPI canals in between Block A and E. For locations see the map below. The first seven dams, constructed in the framework of the CCFPI project, are robust and consist of three rows of wooden poles (gelam, balerang) across the canal, with the space in between filled with bags of soil. The later CKPP dams a spillway annex boat transit was included, and the dam body made more narrow. All canal flow is to seep through or flow over the dam. Geo-textile was used to reduce seepage and prevent the fill soil from being carried away by the overflowing water.

Location of dams made by Wetland International, north-western part of Block A



Eight dams have been inspected during the field trip. Because of very high water tables during the visit no precise measurements could be made. All of the visited dams have been constructed in 2007.

CKPP Dam 1, Katunjung area

This channel block was previously labelled CKPP no. 3, but later renumbered and now known as CKPP no. 1. Observations:

- size of the dam: 25 m wide x 10 m length;
- size of the spillway: 4 m width x 2 m length;
- width of the upstream canal: 20 m, downstream 5 m; there is some vegetation in the canals;
- head difference over the structure is approximately 0.7 to 1.1 m;
- diameter of the poles is about 15-20 cm, the structure is in good condition;
- the peat filled bags on top of the dam are damaged, there is little vegetation on the dam;
- there is a significant stream of water flowing through the dam. There are no signs of erosion or seepage around the dam.

Comparing the dam now with pictures taken shortly after completion of the structure, one year earlier, the main difference is that the fill material has settled, some soil bags have disappeared and some bags are torn open. Seepage through the structure has increased.

CKPP dam 1

CKPP dam 2, Katunjung area

Observations:

- size of the dam: 20 m width x 6 m length;
- size of the spillway: 4 m width x 2 m length;
- width of the upstream and downstream canals: 20 m, there is little or no vegetation in the canals;
- head difference over the structure is 0.5 to 0.8 m;
- the diameter of the poles is about 15-20 cm, diagonal struts are used on the downstream side to reinforce the structure. The structure is slightly damaged and deformed;
- some bags to fill up the dam were washed away and the bags in the dam are damaged. The bags are mainly filled up with peat, there is no vegetation on the dam;
- there is a significant flow over and through the dam. There are clear signs of seepage and erosion on both sides of the dam.

Comparing the situation now with pictures taken shortly after completion of the structure shows that one year after construction many soil bags have been washed away. The structure is slightly deformed, the downstream side of the dam settled more than the upstream side. Erosion occurred around the structure and on the banks at the downstream side.

CKPP dam 2

CKPP dam 3, Katunjung area

This channel blocking was previously labelled CKPP no. 1, now renumbered CKPP no. 3. Dense vegetation and high water-levels prevented a close inspection, but the structure appeared to be in good condition. At the time of the visit the water was flowing over the length of the structure.

CKPP dam 3

CKPP dam 4, Sei Ahas area

Observations:

- size of the dam: 10 m width x 4 m length;
- size of the spillway: 2 m width x 1.5 m length;
- width of the upstream and downstream canal: 10 m, there are small trees growing in the canals;
- the head difference over the structure is approximately 0.5 m;
- the diameter of the poles is about 15-20 cm. The structure is in good condition, only the

geotextile ihas disappeared;

- the bags on top of the dam are damaged, there is little vegetation on the dam;
- all water flows through the structure below the spillway
- there seems to be some sedimentation at the downstream side of the spillway. This would indicate the water does not flow very often over the spillway.

Comparison with earlier pictures shows quite some damage to and settlement of the soil bags. The geotextile and some of the bags disappeared.

CKPP dam 4

CKPP dam 5, Sei Ahas area

Observations:

- size of the dam: 25 m width x 6 m length;
- size of the spillway is approximately 3 m width x 2 m length;
- width of the upstream and downstream canal upstream: 20 m, there are small trees growing in the canal;
- head difference over the structure: 0.8 to 1.2 m;
- the diameter of the poles is about 15-20 cm. The structure is in good condition;
- the dam is not fully filled up with bags, some have been taken away or the bags settled about 0.3 m. The bags on top are damaged, there is little vegetation on the dam;
- there appeared little or no leakage through the structure.

CKPP dam 5

CKPP dam 6, Sei Ahas area

Observations:

- size of the dam: 25 width x 6 m length;
- size of the spillway: 4 m width x 2 m length;
- width of the upstream canal upstream 25 m, downstream canal 20 m; there is no vegetation in the canals;
- head difference over the structure: 0.6 m;
- diameter of the poles: 15-20 cm, two diagonal struts are used to reinforce the structure. The structure is not deformed;
- the bags on top of the dam are partly washed away. The bags are filled up with both peat and clay, some are damaged. There is no vegetation on the dam;
- there is a significant flow over and through the dam. There are clear signs of erosion on both sides.

Compared to one year earlier, it appeared that many soil bags have been washed away and erosion occurred on both sides of the dam.

CKPP dam 6

Tabat 7 Sei Ahas

The structure was completely submerged during the visit, with a head difference of about 30 cm. The structure is about 25 m width x 7 m length.

CKPP dam 7

Tabat 12 Kalumpang

Observations:

- size of the dam: 25 m width x 8 m length;
- size of the spillway: 3 m width x 1.5 m length;
- width of the canal upstream is 20 m, downstream 15 m, there is no vegetation in the canal;
- head difference over the structure is approximately 1.0 m;
- the diameter of the poles is about 15-20 cm, the structure is deformed and not in al good condition. Some poles seem to be missing, and the upstream part of the structure settled more than the downstream part;
- almost all bags on one side of the structure near the spillway were washed away;
- there is a significant flow through the dam.

Compared with the situation one year earlier after completion of construction shows that many bags have been washed away and erosion occurred in the canal downstream of the structure.

CKPP dam 12

Conclusions

In general the structures were in a good condition and functioned well. A head difference of about 1.0 m was maintained, while one structure was submerged. The gelam poles that used for construction of the dam body seemed strong and long enough. The main problem observed at all dams was settlement of the fill soil and damage to or even complete disappearance of soil bags on top of the dam, with the fill material being washed away. In two locations the geo-textile sheets had disappeared from the top of the dam. It should be noted that this is the condition only about one year of construction.

Seepage through the dam occurred at almost all structures. For some locations there was erosion/piping beside the structure due to seepage and/or overflow.

It is clear that more maintenance of the dams is needed to add or replace missing soil bags. Leakage should be stopped as far as possible, which may require to take out the soil bags and re-install them properly.

A.2 Field visit Block C-North (25 and 31 Jan. '08)

The northern part of Block C is under surveillance of CIMTROP and the university of Palangkaraya. A fire brigade has been organized, research on reforestation is ongoing, and several canal blocks have been built in the area. The area consists of a peat dome in between the Kahayan River and the Sebangau River, with a maximum elevation of about 4 m and peat depths up to 8 m. A primary canal of about 15 m wide connects the two rivers, and in the middle a 20 m wide north-south main canal splits off running over the centre of the dome all the way down to the coast.

Dam no. 3 was visited on January the 25th. This time the group was guided by Mr. Suwido Limin and his CIMTROP team. In this chapter only a description of the observed structures is given. In Annex A a note from Henk Ritzema is attached about all six dams in the area. For more information or pictures of the building process Mr. Kitsho from CIMTROP can be contacted as well.

Location of dams made by CIMTROP in the north of Block C

Dam 1 and 2

Dam 1 and 2 are constructed in the north-south main canal. At the location of Dam 1, the peat depth is more than 8 m. The poles (8 m) were not long enough to give the dam a solid foundation. The dams suffered damaged in December 2005 and January 2006 as a result of seepage through the base of the dams. They were repaired in March 2006, but again damaged, and now beyond repair, in June 2006.

Dam 2 collapsed in the middle of the canal. The conclusion that seepage was the main cause of the collapse is based on the fact that the canal bed was severely eroded there. The canal follows the top of the peat dome, has no steep gradient, and the head difference over the dam was relatively small.

CIMTROP dam 2

Dam 3, 4, 4 and 6

Dam 3, 4, 5 and 6 are all located in the Kalampangan Canal, the primary canal connecting the Kahayan and Sebangau Rivers. The sites for the dams were chosen at locations where the canal cross-sections had not been completed up to the design width of about 20m. The canal width at the selected locations is 3 to 4 m, with almost vertical side slopes. The dams are founded on the mineral subsoil.

Dam 3

Dam 3 was constructed about three years ago in a narrow part of the canal. The structure consists of several rows of Gelam poles with a diameter of 3 to 5 cm. Normal flow passes through a pipe installed in the dam body, but for increased flows a spillway has been constructed. The spillway is 2 m wide and covered with a sheet of geo-textile. It seems to function well and there is no sign of erosion along the spillway. However, the structure itself is largely deformed and a large amount of fill material has flushed away. Seepage was observed at the downstream side of the structure.

CIMTROP dam 3

Dam 4

Heavily covered with vegetation, no close inspection was possible. With a horizontal pipe installed through the dam near the canal bottom, the head difference over the dam was small. The dam might not be very effective.

Dam 5

Only recently completed, the dam collapsed on 28-01-08, just three days before the site visit. The dam was intended to raise the water-level above the canal banks and was therefore equipped with side wings to divert the canal flow as overland flow away from the canal. The dam body had a considerable height, and high water pressure followed by severe seepage was the likely cause for the dam collapse. The dam consisted of two rows of gelam poles (Ø 5-10 cm) spaced 0.5 to 1 m apart with geo-textile on the inner sites, and the dam core consisting of bags filled with peat. The wings on both sites extended up to 10-15 m inland. The poles of the side slopes were rather short, extending no more than 0.3 to 0.5 m into the peat. Seepage eroded the right bank of the canal and the peat soil underneath the wing was completely washed out. This core of the dam remained intact. At the time of the disaster, the upstream water level was at least 2 m higher than downstream, but still below the level of the surrounding peat land, so no water could be diverted away from the dam. The high head difference increased the seepage through the banks of the dam, slowly eroding the slope at the downstream site.

CIMTROP dam 5

The following lessons can be learned from this dam failure:

- The dam was built at the wrong location. Flow diversion will only be successful if the difference between the water level in the canal and the land level is not too much and if the surface runoff will flow away from the dam. At this location the canal slope is perpendicular to the slope of the peat dome. Thus the gradient, flows and velocities are high, water is always directed back to the canal and will try to flow around the dam.
- A too big difference in water levels upstream and downstream of the dam. Such a big head difference causes seepage flows through the dam and through the soil under and besides the dam, which turns into piping and washing out of the soil. At the location of this dam the difference between canal water-level and the surrounding land surface was more than 2 m.
- The dam was too short. The top of the dam was only around 0.5 m, the base around 1.0–1.5 m long, making the dam very susceptible to seepage.

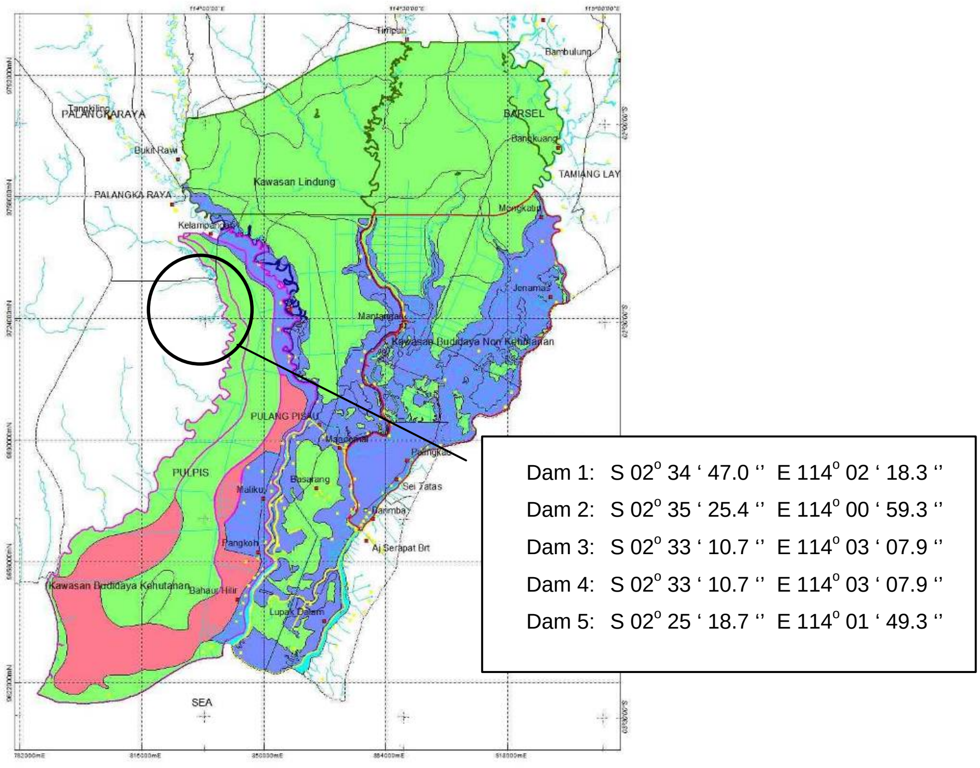
Evaluation and conclusions

With very limited resources, the CIMTROP dams are relatively inexpensive structures with a short lifetime. No overall strategy covering the entire area can be implemented. The gelam poles have a diameter of less than 10 cm and are often too short. The short length of the dams, combined with probably a high permeability of the local peat soils, makes seepage and piping the most critical issue, and a more solid design is needed.

A.3 Field visit Sebangau National Park (12 Feb 08)

The World Wildlife Fund or WWF has built four large dams and about 16 small dams in the Sebangau National Park. This park is just outside the project area, west of the Sebangau River. The area is a peat conservation area and the peat thickness at the location of the dam structures varies from 0.5 m to about 4 m.

Two of the larger dams and three of the smaller dams were visited.



WORKING AREA of EMRP MP MAP

Location of the WWF dams in the Sebangau National Park

WWF Dam 1

Observations:

- size of the dam: 15 m width x 5 m length;
- size of the spillway: 1.5 m width x 5 m length;
- width of the upstream and downstream canals: 12 m, there is no vegetation in the canal;
- head difference: 0.1 m;
- the diameter of the poles is about 5-10 cm. At the upstream side the poles are covered with planks. The structure is in good condition, all parts are well connected
- the bags in the dam body are said to be filled with clay.
- there is little vegetation on top of the dam, while water is said never to flow over the dam outside the spillway, and there were no signs of erosion on the dam
- there is no water seeping through the dam
- there is a naturally created bypass on one side, but no water seems to be flowing through it in the dry season, and the head difference over the structure is then normally larger than at the time of the visit.

The area was burnt shortly before construction of the dam. The structure was completed on 28-06-05. Illegal loggers once damaged the structure after which WWF repaired it and built a field office next to the structure. The dam has not been damaged since and is in good condition. There are no signs of deformation or failure of the structure. The costs for this large and robust structure are about Rp 1,000,000,000. The high costs are mainly due to high costs for transportation, with the timber brought in from Palangkaraya.

WWF Dam 1

WWF Dam 2

Observations:

- size of the dam: 12 m width x 5 m length;
- size of the spillway: 1.5 m width x 5 m length;
- width of the canal upstream is 7 m, there is no vegetation in the canal. The water level in the canal in relation tot the surrounding area is high;
- width of the canal downstream is 7 m, there is no vegetation in the canal;
- head difference: 1.0 m;
- the diameter of the poles is about 5-10 cm. At the upstream side the poles are covered with planks. The structure is in good condition, and all parts are well connected
- two types of sheets were used to make the structure watertight: a grey stiff plastic and an orange geotextile-like material;
- there is a wooden drop structure to dissipate the energy and to avoid erosion on the downstream side;
- the bags in the dam body are said to be filled with peat.
- there is little vegetation on top of the dam, while water is said never to flow over the dam outside the spillway, and there were no signs of erosion on the dam.
- in contrast to WWF dam 1 there are no bags placed behind the inlet of the structure, only diagonal struts to support the inlet structure;
- there is no water seeping through the dam.
- seepage through the canal bank created a bypass along the structure on one side while on the other side there was a clear sign of seepage as well but so far no serious erosion.

The design of this dam is similar to the design of WWF Dam 1, the difference being in the width of the structure in proportion to the width of the canal and while the head difference over this structure is much larger than at Dam 1.

WWF Dam 2

WWF Dam 3, 4 and 5

The local community has built a number of smaller structures that were designed and funded by WWF. Dam 3, 4 and 5 are located close to the Sebangau River. Being entirely submerged at the time of the visit no close inspection was possible. The dams are said to function well in the dry season, with a head difference of about 1 m. The structures are designed to be passed by small local boats. The distance between two structures in a canal is about 1000 m. These small structures cost about Rp. 15,000,000.

Evaluation and conclusions

The design of the WWF structures seems to be effective in raising the upstream water-levels. Unfortunately no review of monitoring data could be undertaken to confirm this conclusion. The structures are robust and after almost three years they are still in good condition. Erosion created bypasses around Dam 1 and Dam 2 which so far carry water only in the rainy season. There is a danger that over time these bypasses will become bigger reducing the effectiveness of these dams.

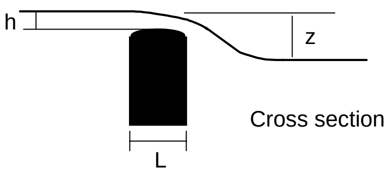
Annex B

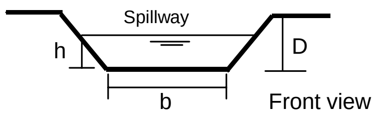
Water flow and seepage calculation

Box 5.2. Calculating the capacity and Q-h relation of a spillway

Input characteristics:

Spillway width at bottom, b	8	m
Height of water over the spillway, h	0.2	m
Maximum water height, D	1	m
Length of the spillway, L	3	m
Head difference over spillway, z	0.5	m





Equations

The discharge over a broad or sharp crested weir is given by $Q = c\,b\,H^{3/2}$

where:

Q is the discharge (m^3/s)

b is the spillway width (m)

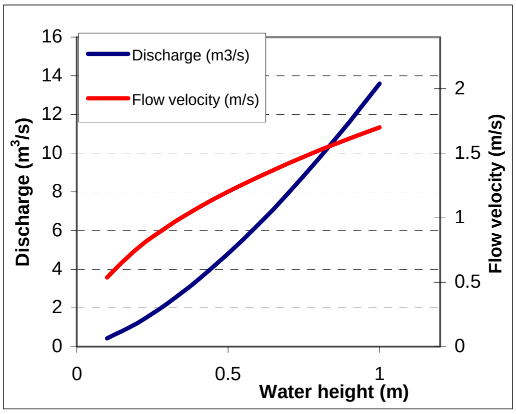
h is the water level

c is a weir factor — for broad crested weir (h<0.5L or h < 3 z), c = 1.7; for sharp crested weir (h>0.5L or h << z), c = 1.9

Calculation

Determine weir type: h=0.2, L=3 --> broad crested weir

Discharge at 0.2 m water height, Q=	1.22	m^3/s
Flow velocity at 0.2 m water height, v=	0.76	m/s
Maximum discharg Q_{max}=	13.60	m^3/s
Maximum flow velocity, v_{max}=	1.70	m/s



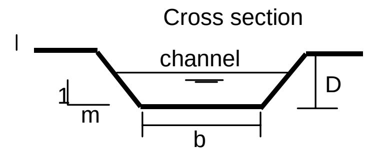
B.1 Discharge and flow velocity over a canal block (weir formula)

Box 5.3. Estimating bypass Q-h using the Strickler equation

Input characteristics:

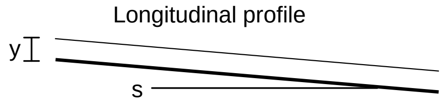
Channel slope is estimated based on the desired head difference over the structure over a distance of 100 m.

Channel slope, s	1.0E-03	m/m
Channel width at bottom, b	50	m
Water depth, y	1	m
Bank slope, m	1	m/m
Strickler coefficient	40	$m^{1/3}/s$
Channel depth, D	2	m



Strickler coefficient for excavated channels

	normal	range
clean short grass	40	25-40
some weeds	30	20-35
brushwoods	20	10-20
standing timber	15	5-15



Equations

Based on the Strickler formula: $Q=kAR^{2/3}s^{1/2}$

where:

Q = channel discharge in m^3/s

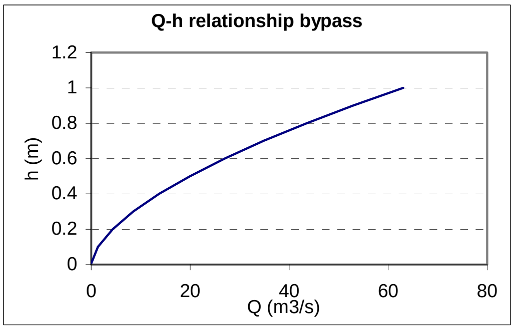
k = Strickler coefficient in $m^{1/3}/s$

A = wet cross sectional area m^2, A = (b+my)y

R = hydraulic radius in m, R = A / (b+2y(1+m2)1/2)

Calculation

y	Q(m/s)	v (m/s)
0.01	0.03	0.06
0.1	1.36	0.27
0.2	4.32	0.43
0.3	8.49	0.56
0.4	13.71	0.68
0.5	19.88	0.79
0.6	26.93	0.89
0.7	34.81	0.98
0.8	43.47	1.07
0.9	52.88	1.15
1	63.01	1.24

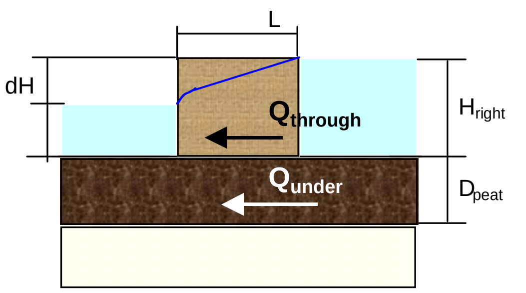


B.2 Discharge and flow velocity through a channel (Strickler formula)

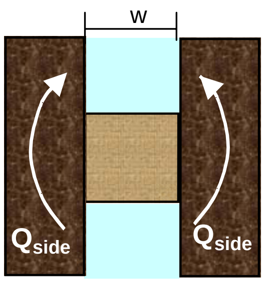
B.3 Seepage flow through and around a block structure

Input characteristics:

Head difference over structure	dH=	0.5	m
Water depth in channel, before block	H_{right}=	2	m
Water depth in channel, after block	H_{left}=	1.5	m
Length of the dam	L=	2	m
Width of the dam	w=	10	m
Hydraulic conductivity of fill material	k_{fill}=	5	m/day
Hydraulic conductivity of in-situ peat	k_{peat}=	30	m/day
Thickness of peat under channel	D_{peat}=	4	m
Thickness of peat next to channel	$D_{peat,total}$=	6	m



cross section



plan view

Equations

The seepage can be separated into three components:

Flow through the structure: $$Q_{through} = \frac{wk_{fill}(H^2_{right} - H^2_{left})}{2L}$$

Flow under the structure: $$Q_{under} = \frac{dHwk_{peat}D_{peat}}{0.88D_{peat} + 2L}$$

Flow besides the structure: $$Q_{sides} = 2\frac{\Delta Hk_{peat}D_{peat,total}}{\pi}Ln\left(\frac{200}{L}\right)$$

These equations assume that there is no seepage cut off screen.

Calculation

Flow through the structure	22	m^3/day
Flow under the structure	80	m^3/day
Flow besides the structure	264	m^3/day
Total flow	366	m^3/day
	0.004	m^3/s

Annex C

Dam safety analysis

General

A canal blocking structure is subject to outside forces which threaten the stability and integrity of the structure. The main risks or possible failure mechanisms are:

- differences in water pressure upstream and downstream of the structure, risk to overturn the structure or to move/deform the structure in horizontal direction (translation);
- seepage and piping through the soil below and besides the structure reduces the function of the structure and threatens its integrity which ultimately may cause collapse of the structure;
- scouring or erosion by overflowing water.

As long as the resistance of the structure against these forces exceeds the outside forces the structure is safe. The failure mechanisms are illustrated in Figure C.1.

The outside forces depend on load conditions (height of upstream and downstream water-levels and water flows). The load conditions should be assessed for the most critical conditions in both the wet and the dry season, see Figure C.1 (right column). From the load conditions the outside forces are calculated using standard formulas and methods as described in textbooks (PU 1986, USDI 1974, see also the example below). To account for uncertainties in the load conditions the forces are multiplied with safety factors as given in Table C.1.

The resistance of the structure against the outside forces depends on the dimensions and construction of the structure, the weight of its various components, and material strength parameters like shear strength, cohesion, friction coefficient and others, see Table 2.4. Calculation of the resisting forces again follows standard formulas and methods depending on the shape of the structure and the selected materials. It should be noted that the material parameters for peat soil are not well known and possibly highly variable for different kinds of peat or situations. To allow for uncertainties in the values of the material parameters the forces are divided by safety factors as given in Table C.2.

If the outside forces exceed the resistance of the structure, the design should be adjusted by changing the structure's dimensions and construction, and/or by the use of different materials. However, because of the many uncertainties involved and the large variability in local conditions, one should always be very in careful in interpreting the calculations results.

Figure C.1 – Failure mechanisms

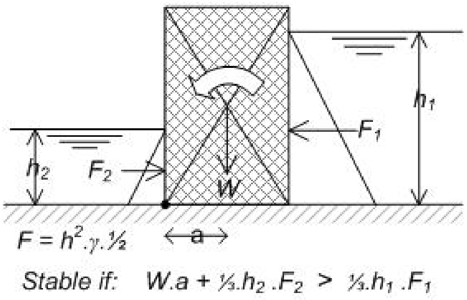
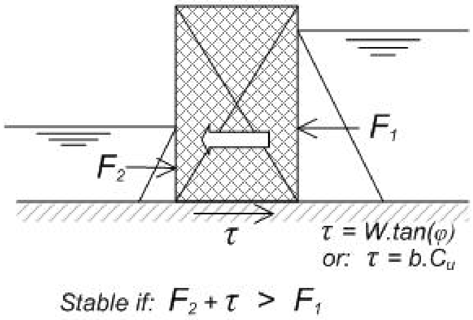
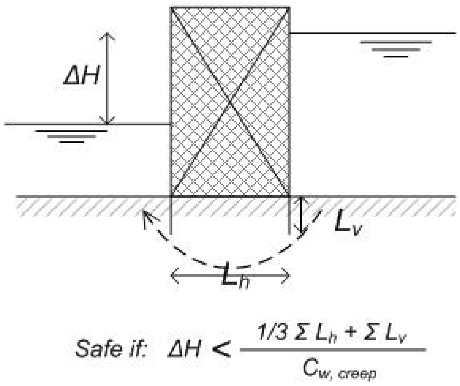
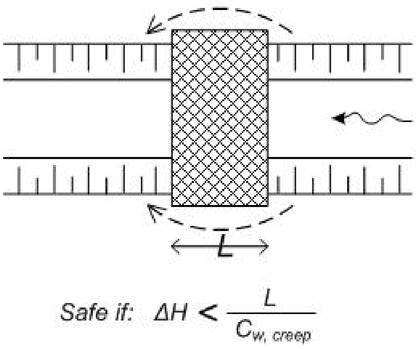
Failure mechanism	Critical conditions to check
Stability against overturning 	Check: $M_s \leq M_r$ *Rainy season:* - maximum head difference by free overflow: (large head difference and strong current) - maximum head difference by submerged overflow (small head difference, but maximal current) *Dry season:* - maximum head difference by high water levels (large head difference and high point of action) - maximum head difference by low water levels
Stability against horizontal movement (translation) 	Check shear strength: $\tau_s \leq \tau_r$ *Rainy season:* - maximum head difference by free overflow (large head difference and strong current) - maximum head difference by submerged overflow (small head difference, but maximal current) *Dry season:* - maximum head difference by high water levels (large head difference and high point of action) - maximum head difference by low water levels
Seepage and piping below structure 	Piping formula of Lane (1935): $\Delta H \leq \Delta H_{crit} = \frac{\frac{1}{3} L_H + L_v}{C_{w,creep}}$ where: ΔH = head difference over structure (m) ΔH_{crit} = critical head difference (m) L_H = horizontal seepage path (m) L_v = vertical seepage path, over cut off screen (m) $C_{w,creep}$ = material factor: 5 to 7 (safety factor is included in material factor)
Seepage and piping along structure 	Piping formula of Bligh (1910): $\Delta H \leq \Delta H_{crit} = \frac{L}{C_{w,creep}}$ where: L = seepage path (m) $C_{,creep}$ = material factor: 12 to 15 (safety factor is included in material factor)

Table C.1 – Load safety factors

Load condition	Load safety factor
upstream water level (rainy season situation)	f_L=1.2 limited by the physically highest possible water level
upstream water level (dry season situation)	f_L=1.2 limited by the level of downstream spillway or bypass
downstream water level (rainy season situation)	free overflow: 0.3 m above downstream weir, f_L=1.0 submerged overfow: 0.3 m under upstream water level, f_L=1.0 no downstream weir: river level
downstream water level (dry season situation)	equal to level of downstream weir: f_L 0.8 equal to canal bed if no downstream weir
design flow (rainy season situation)	1 in 10 year: f_L=1.1 1 in 1 years: f_L=1.3
design flow (dry season situation)	no criteria

Table C.2 – Overview material safety factors

Material condition	Material safety factor
Soil density	f_m=1.1 (favourable) f_m=1.0 (unfavourable)
Undrained shear strength over bottom (earth dam with peat soil)	f_m=1.35 minimum value >10 kPa
Undrained shear strength over bottom (earth dam silty clay)	f_m=1.35 minimum value > Max(20 kPa, 0.25 x vertical effective pressure)
tangent of internal friction angle for soil	f_m=1.15
cohesion of soil	f_m=1.6
wood	f_m=1.5 minimum bending strength is: minimum shear strength is: minimum pressure strength is: minimum tension strength is:
concrete	f_m=1.2 (pressure) f_m=1.4 (tension)
construction steel	f_m=1
Anchor force in high tension wire of opposite rows of gelam piles	is HT wire or alternative “tie rod” material available

Seepage and piping

Piping is a process where soil material is eroded from either within the structure, or the natural material surrounding it, due to an excessive seepage flux. This occurs when the hydraulic head gradient in the soil is larger than the pressure to keep the grain in place. Piping eventually creates preferential flow paths in which the seepage velocity is higher than in the surrounding soil matrix. This causes progressive internal erosion, that increasing over time, and ultimately leading to collapse or loss of functionality.

Two forms of piping are distinguished in Figure C.1:

- piping below the structure, where the flow path is partly horizontal and partly vertical.
- piping through the banks around the structure, where the flow path is purely horizontal;

The soil has greater strength against internal erosion by vertical seepage. This makes a seepage screen is especially efficient. The procedure to check the safety against piping consists of the following steps:

- the conceptual design is used to determine the potential seepage paths;
- if the seepage path contains vertical parts, the critical head difference (ΔH) is calculated using the formula of Lane shown in Figure C.1;
- if the seepage path contains no vertical parts, the critical head difference (ΔH) is calculated using the formula of Bligh shown in Figure C.1;

Seepage will be limited and piping is unlikely to occur when the seepage cut off screen is placed into an (impermeable) clay layer. If the seepage screen is placed in sand, piping can still occur and the screen has to be sufficiently long.

Often, the design head difference occurs during the construction phase of a dam, in particular if a series of dams is built starting from downstream. The safety factor for a temporary head difference during the construction phase can be reduced by 50% as piping is a process that will gradually increase over time.

Erosion

In case of overflow dams, the downstream canal bed needs to be protected against erosion by pile rows or sand bags at the canal bottom to dissipate the energy of the overflowing water.

The design peak discharge is used to calculate the water level and flow velocity for either a spillway using a weir equation or a bypass using the Strickler equation (see Annex B). The flow velocity should remain below the critical value mentioned in Table C.3.

Table C.3 – Critical flow velocities for different bank materials

Bank material	Critical velocity (m/s)
in situ peat	0.3 – 0.7
clay	0.5 – 1.0
peat with vegetation	1.0 – 2.0
structure (wood, clay/peat with geotextile, sand bags)	2.0

Safety analysis for simple structures with short lifetime

The wide range of the properties from local construction materials combined with local construction methods result in uncertainties for the structural behaviour. Failure of these structures results in a small risk to human life. The design must be based on local experience in similar situations. Based on these experiences an overall safety factor > 1 must be reached.

Safety analysis for simple structures with long lifetime

The structural behaviour can be predicted more precise for these structures because modern construction materials are used. Failure of these structures results in a small probability for material damage. Structural design calculation with partial safety factors is possible now.

Safety analysis for complex structures with long lifetime

The structural behaviour can be predicted more precise for these structures because modern construction materials and building methods will be used. Failure of these structures results in a significant material damage loss of human life or irreversible environmental damage.

Structural design calculation will have to follow the standard procedure according to the Indonesian Standards.

Calculation example

Below an example is given of the safety analysis for a typical box dam. Because of its length of 11 m overturning is not critical and the safety calculation includes translation, seepage, and scour/erosion.

Channel and structure characteristics		
Channel width @ bottom	10	m
Channel depth	2	m
Width of structure	17.5	m
Length of structure	11	m
Pile length	7	m
Peat depth	5	m
Channel bank slope	1:1	
Bypass length	100	m
Bypass depth	0.2	m
Bypass width	50	m
Catchment characteristics & discharge		
Catchment size	1392	Ha
Peak flow (1-in-10 year, based on 7 l/sec/ha)	9.7	m^3/s
Median flow (half bank full, based on Strickler flow)	5	m^3/s
Low flow (based on 1.5 mm/day, see v.d. Weert, 1994)	0.2	m^3/s

Safety analysis for horizontal force

Dry season	Maximum horizontal load	Horizontal sliding critical
Water level upstream	crest level	CL
Water level downstream	-2.0	m CL, 1 m water depth
Assumed foundation level	-5 m	Bottom of peat level
Horizontal pressure over 17.5 m width	17.5*(0.5*2.0^2+2.0*3.0)*10= 1400 kN	
Weight of structure (11 m long)	11*17.5*(2.0*12+3.0*2)=5775 kN	peat+mineral soil in bags
Horizontal friction	11*17.5*10=1925 kN (only cohesion)	or 5775*0.25= 1443 kN (friction over bottom of peat)
Shear effect of piles (3 rows)	3*7*17.5*4=1470 kN	4 kN/pile (7 piles/m) (through passive resistance from deeper layer)
Horizontal force incl. load factor	1.2*1400 =1680 kN	
Resistance incl material factors	1443/1.35+1470/1.5=2048 kN	
Stability factor	2048/1680=1.2	

The above analysis shows the following:

- the structure can be stable for a water level difference of 2 m, even slightly more;
- the contribution of the shear force from the piles into the mineral soil bottom under the

peat is significant, about as important as the bottom friction.

- the contribution of the (effective) weight is significant. It is assumed that the bags are filled with a mix of peat and (local) mineral soil. Core fill with bags with (clayey) sand (above water effective weight 16 kN/m^3 and underwater effective weight about 8 kN/m^3) would increase the friction by about 85%, and the safety factor by 50%.

Seepage analysis

The critical situation exists in the dry season. The horizontal seepage path is about equal to the dam width (11 m). The vertical seepage path is slightly higher, due to the pile embedment, (assume 13 m for three pile rows). The critical head difference is than about 2.4 m, which is higher than the design head difference. Actually there is little safety margin.

Erosion capacity

Flow velocity in the bypass during peak discharge with a gradient of 20 cm will be:

$v = 1/n * R^{2/3} * i^{0.5} = 1/0.03 * 3.4^{2/3} * (0.20/100)^{0.5} = 0.7$ m/sec, or well below the critical value for vegetated peat. However, in case of unprotected peat there would be an erosion risk.

Annex D

Planting trees to solidify canal blocks

The Master Plan technical report *Biodiversity & the EMRP* recognises four species groups that have potential for utilisation in canal blocking and peatland rehabilitation programmes. The suitability of the species depends on the flooding regime:

1. Deepwater areas (deeply flooded for long periods),
2. Deeply flooded areas (frequently deeply flooded areas),
3. Moderately flooded areas (regularly, shallowly flooded areas), and
4. Rarely flooded areas.

For each of these flooding types, a suite of suitable species has been recognised and is listed in Table D.1. At each canal location it is therefore important to recognise what the flooding regime is, and tailor the species to be planted accordingly for the channel blocking programme. Type 1 is suited to deep-sided channels, type 2 for partially infilled channels, type 3 for largely infilled channels, and type 4 for completely infilled channels. Figure D.1 illustrates how these canal green-engineering types appear.

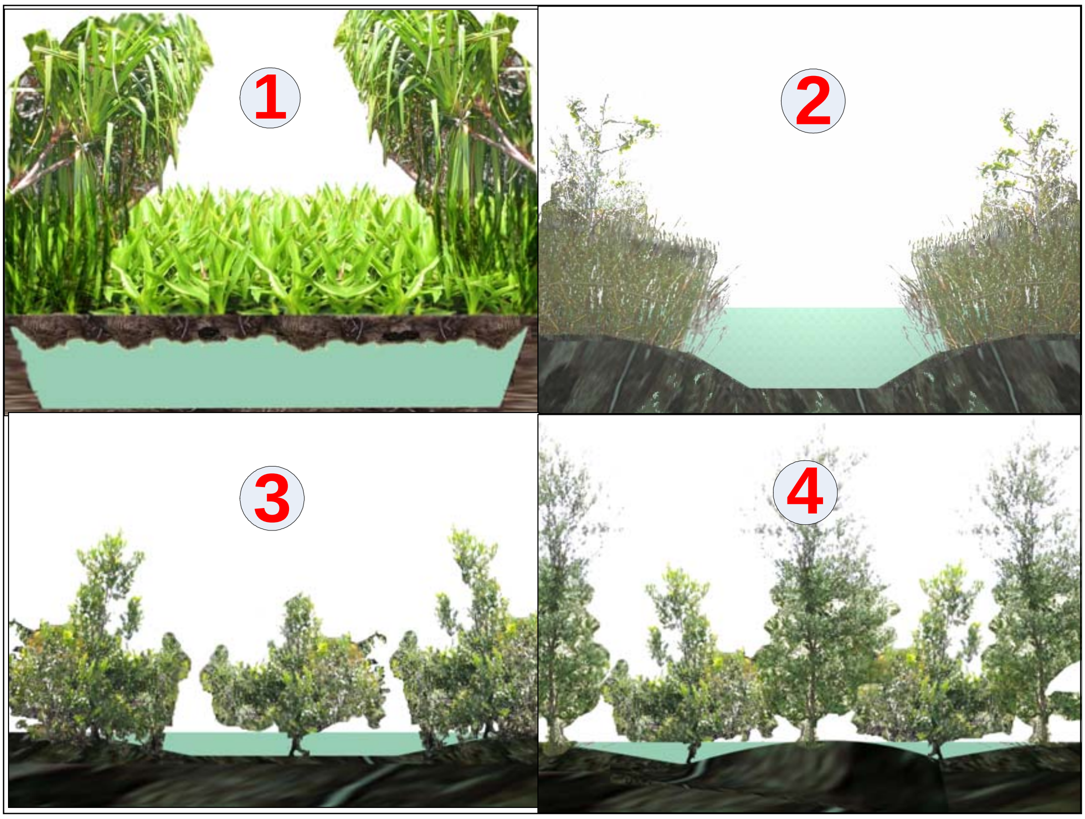


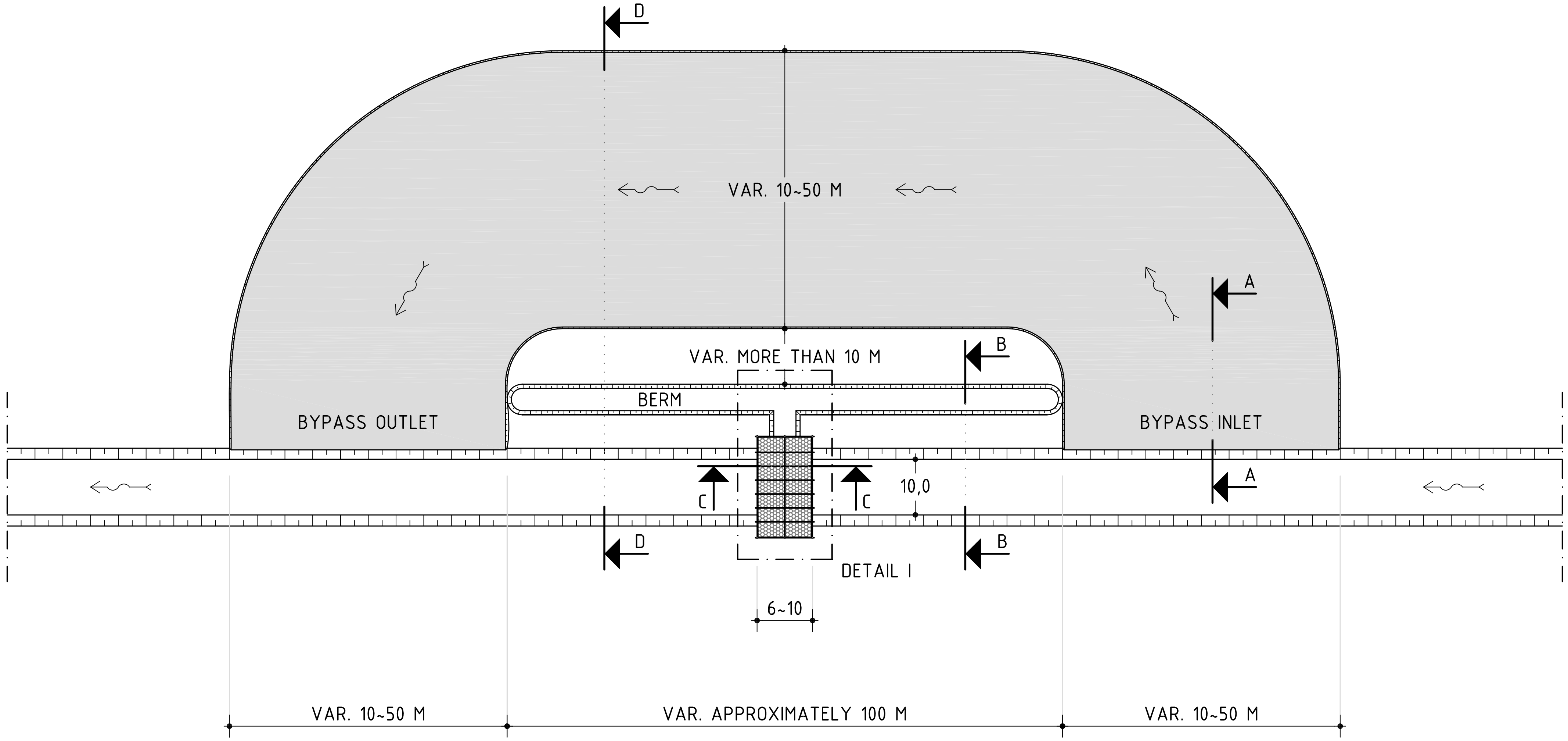
Figure D.1 – Canal regreening types

Over time, these types will naturally evolve from one type into another. Studies elsewhere in Indonesia show that deeper peat layers often consist of *Pandanus* roots and stems, indicating that infilling of deeper waters may be an initial stage in natural peat formation in at least some areas (in Kalimantan and Sumatra).

Table D.1 – Species for green engineering

No	Green canal blocking	Peat swamp forest restoration	Engineering species	Species	local name
1	Steep sided canals	PSF areas deeply flooded for long periods	***Group-1: deep water*** • *Hanguana malayana* • *Pandanus helicopus*	• *Hanguana malayana* • *Hypolytrum nemorum* • *Pandanus helicopus*	• *bakung* • *?* • *rasau*
2	Sloping sides of (eroded or backfilled) canals	Frequently deeply flooded PSF areas	***Group-2: deeply flooded*** • *Combretocarpus rotundatus* • *Lepironia articulata*	• *Combretocarpus rotundatus* • *Lepironia articulata* • *Mallotus borneensis* • *Morinda philippensis* • *Psychotria montensis* • *Stenochaena palustris*	• *tumih* • *purun* • *perupuk* • *?* • *?* • *Kiapak*
3	Largely infilled canals, with shallow pools	Regularly (shallowly) flooded PSF areas	***Group-3: moderately flooded*** • *Cratoxylon glaucescens* • *Ploiarium alternifolium* • *Shorea balangeran*	• *Blechnum indicum* • *Cratoxylon glaucescens* • *Ploiarium alternifolium* • *Shorea balangeran* • *Stenochlaena palustris*	• *?* • *gerongang* • *asam-asam* • *belangiran/kahui* • *Kiapak*
4	Infilled canals	Flooding rare or absent in these PSF areas	***Group-4: rarely flooded*** • *Alstonia spathulata* • *Dyera polyphylla*	• *Alstonia spathulata* • *Blechnum indicum* • *Dyera polyphylla* • *Macaranga* sp. • *Stenochlaena palustris*	• *pulai* • *?* • *jelutung/ patung* • *mahang* • *Kiapak*
	as above, with shade trees	*as above, with shade trees*	***Group-4b: rarely flooded, shade requiring***	• *Alseodaphne coriacea** • *Baccaurea bracteata* • *Dialium patens ** • *Diospyros evena* • *Durio carinatus ** • *Ganua motleyana* • *Gonystylus bancanus* • *Peronema canescens ** • *Shorea pinanga ** • *Tetramerista glabra **	• *gemor* • *rambai* • *?* • *uring pahe* • *durian hutan* • *?* • *ramin* • *?* • *?* • *punak*

* Note: these species require testing, as they have not performed well in earlier tests, but this may be because of lack of shading.



PLAN VIEW

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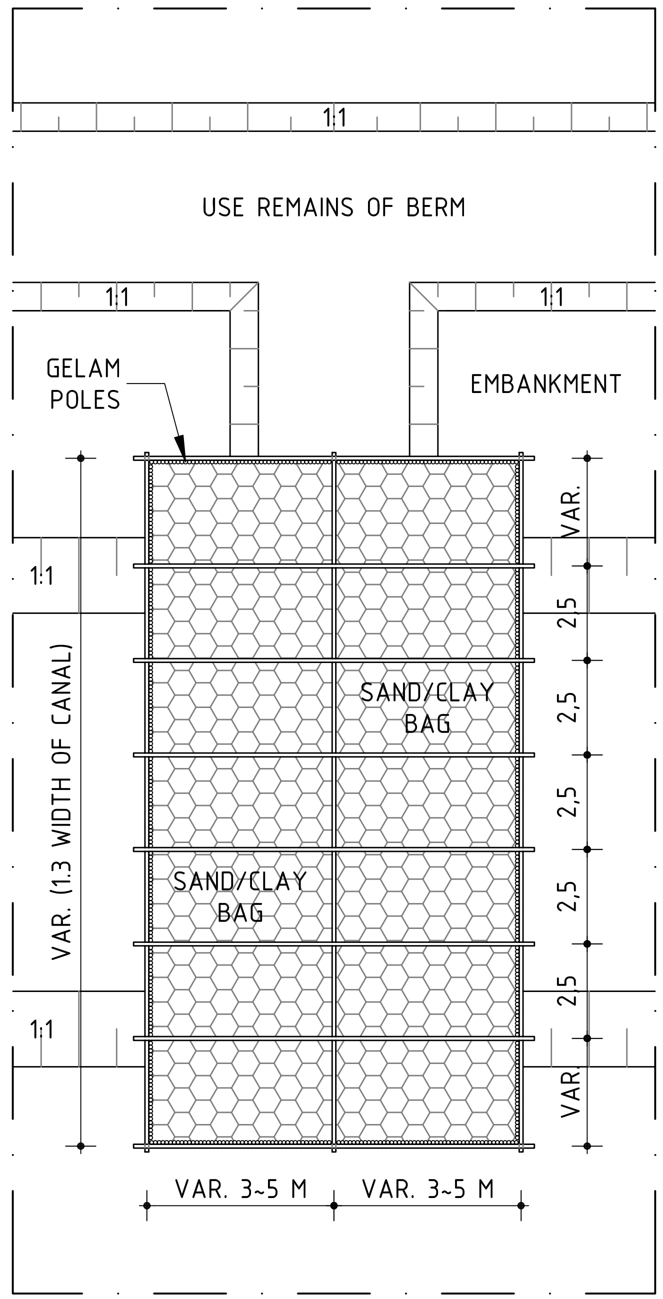


DETAIL I

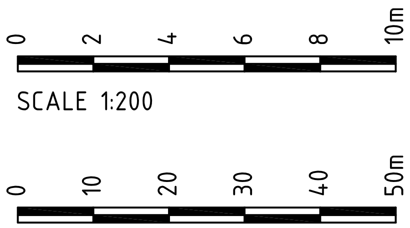
SCALE 1:200

NOTES :

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE
2. ALL LEVELS ARE IN METERS
3. BYPASS FOLLOWS NATURAL SHALLOW DEPRESSION
4. CONSTRUCTION OF BERM IS OPTIONAL (ONLY IF REMAINS STILL PRESENT)
5. FOR CROSS SECTIONS REFER TO DRAWING INA 493-1-2001

LEGEND :

- BYPASS CHANNEL
- SAND OR CLAY BAG
- WATER FLOW



GOVERNMENTS OF INDONESIA AND THE NETHERLANDS

MASTER PLAN EMRP AREA IN CENTRAL KALIMANTAN

TYPICAL DESIGN 1 BOX DAM

PLAN VIEW

EUROCONSULT MOTT MACDONALD AND
DELTARES | DELFT HYDRAULICS
IN ASSOCIATION WITH
DHV, WAGENINGEN UR, WITTEVEEN+BOS,
PT MLD AND PT INDEC

Drawn	Ibnu Hanan
Checked	Hilko Timmer
Authorized	Bernard van Leeuwen
Date	30-03-2009

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Name	Date	Paraf
REVISION		
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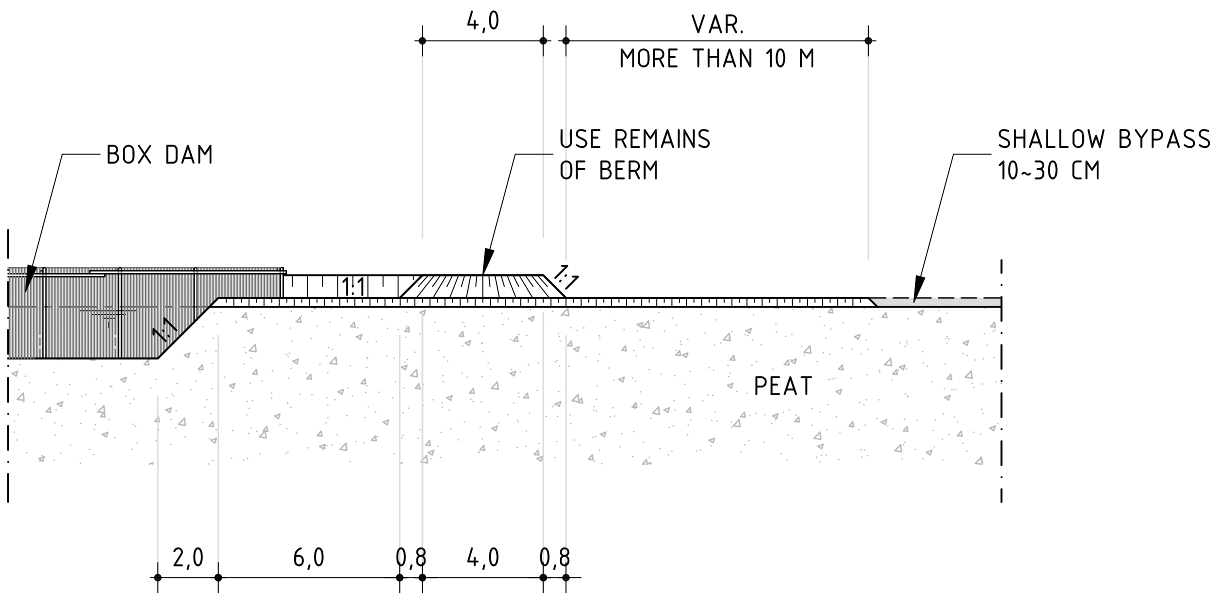

SECTION A-A

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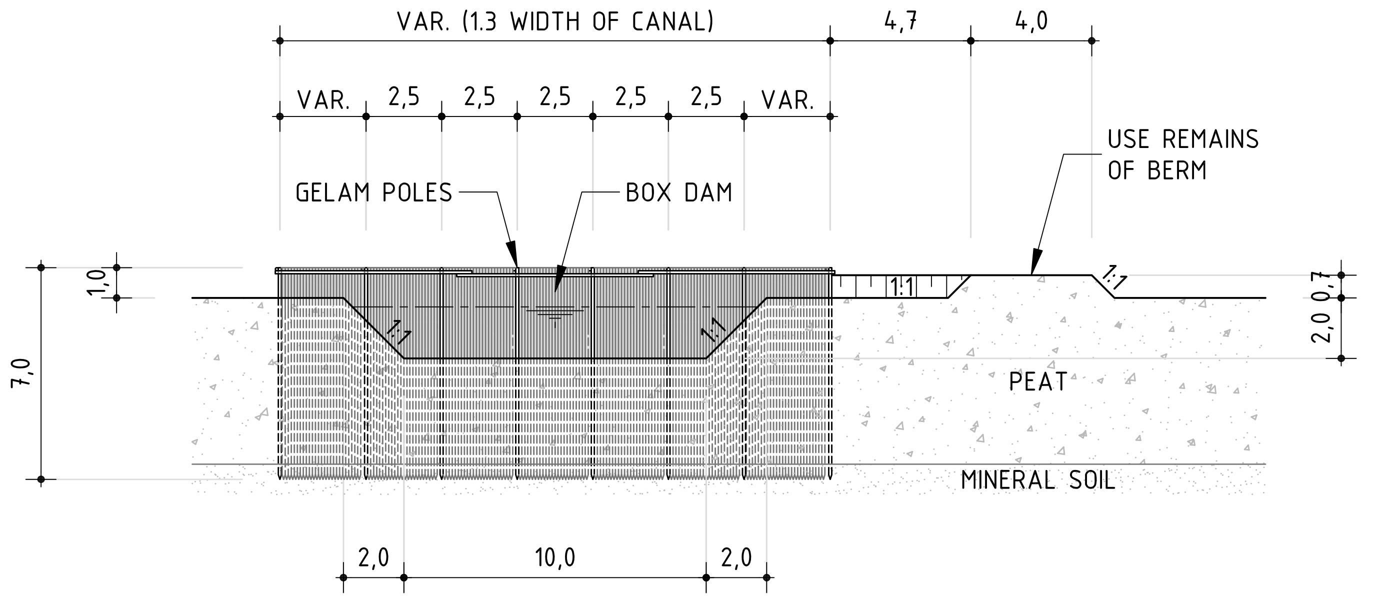

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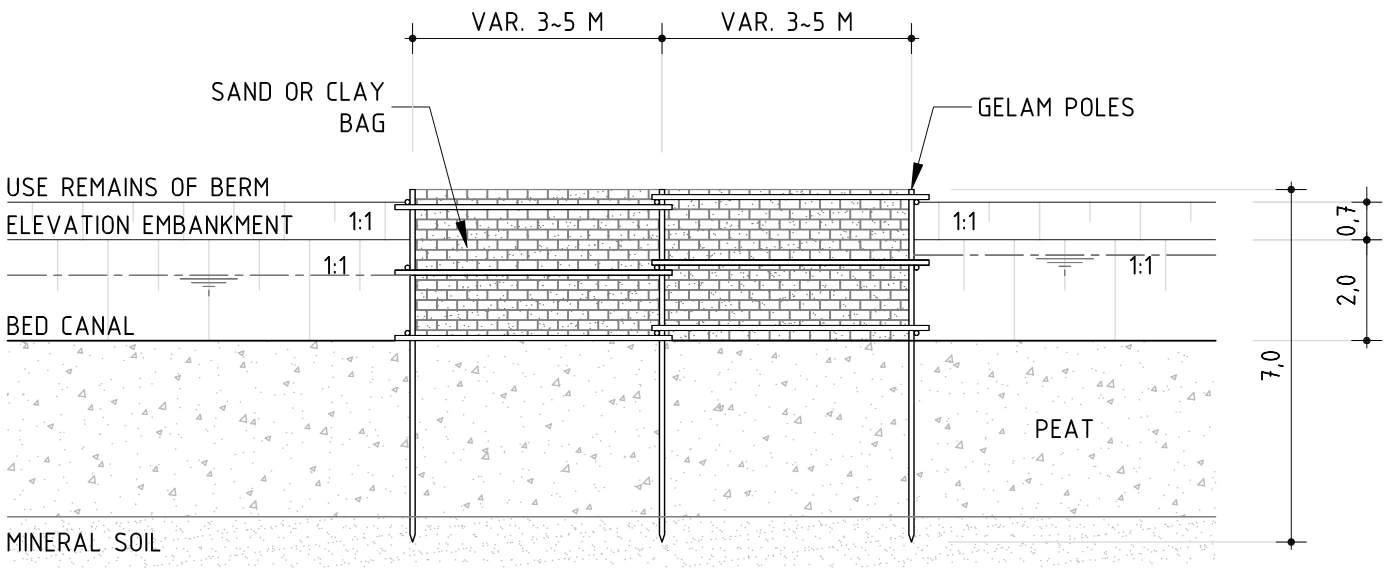

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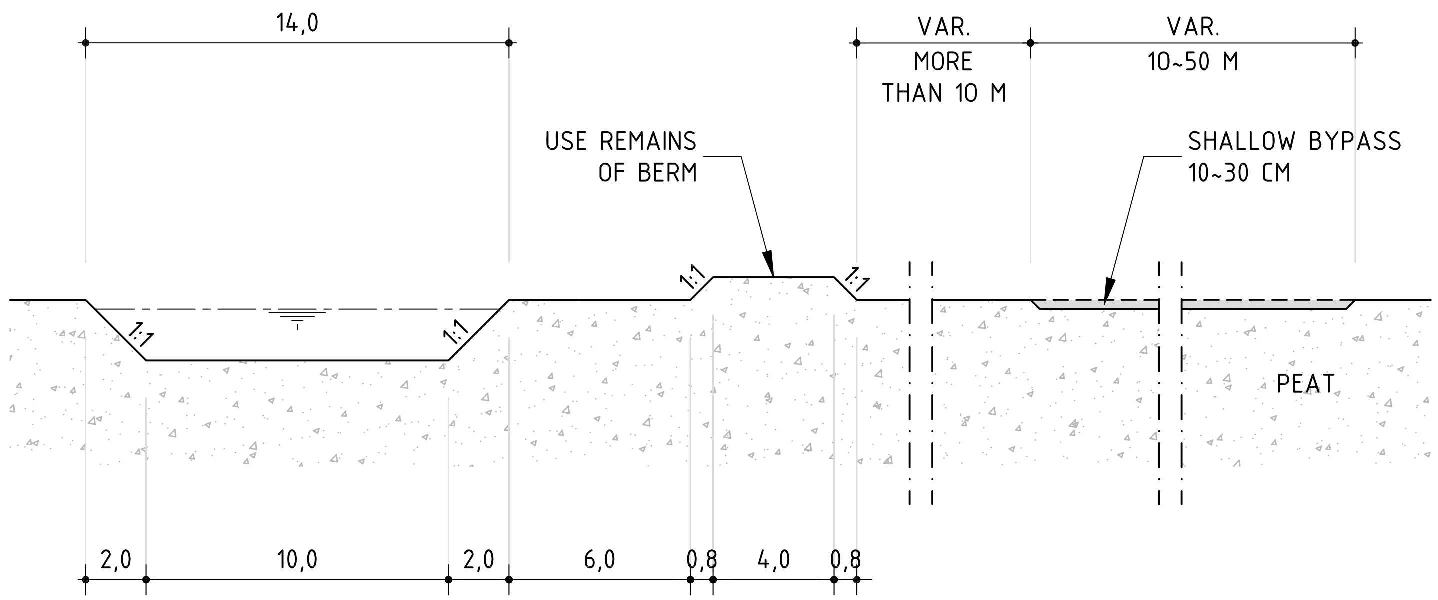


SECTION D-D

SCALE 1:250

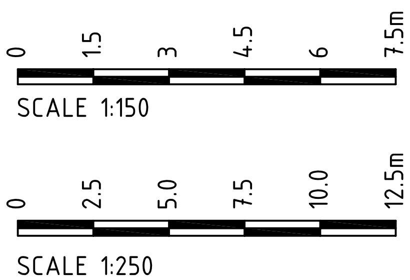
NOTES :

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE
2. ALL LEVELS ARE IN METERS
3. BYPASS FOLLOWS NATURAL SHALLOW DEPRESSION
4. CONSTRUCTION OF BERM IS OPTIONAL (ONLY IF REMAINS STILL PRESENT)
5. FOR PLAN VIEW REFER TO DRAWING INA 493-1-2000

LEGEND :

EXCAVATION FOR BYPASS

SAND OR CLAY BAG



GOVERNMENTS OF INDONESIA AND THE NETHERLANDS

MASTER PLAN EMRP AREA IN CENTRAL KALIMANTAN

TYPICAL DESIGN 1 BOX DAM

CROSS SECTION

EUROCONSULT MOTT MACDONALD AND DELTARES | DELFT HYDRAULICS IN ASSOCIATION WITH DHV, WAGENINGEN UR, WITTEVEEN+BOS, PT MLD AND PT INDEC

Drawn	Ibnu Hanan
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Date	30-03-2009

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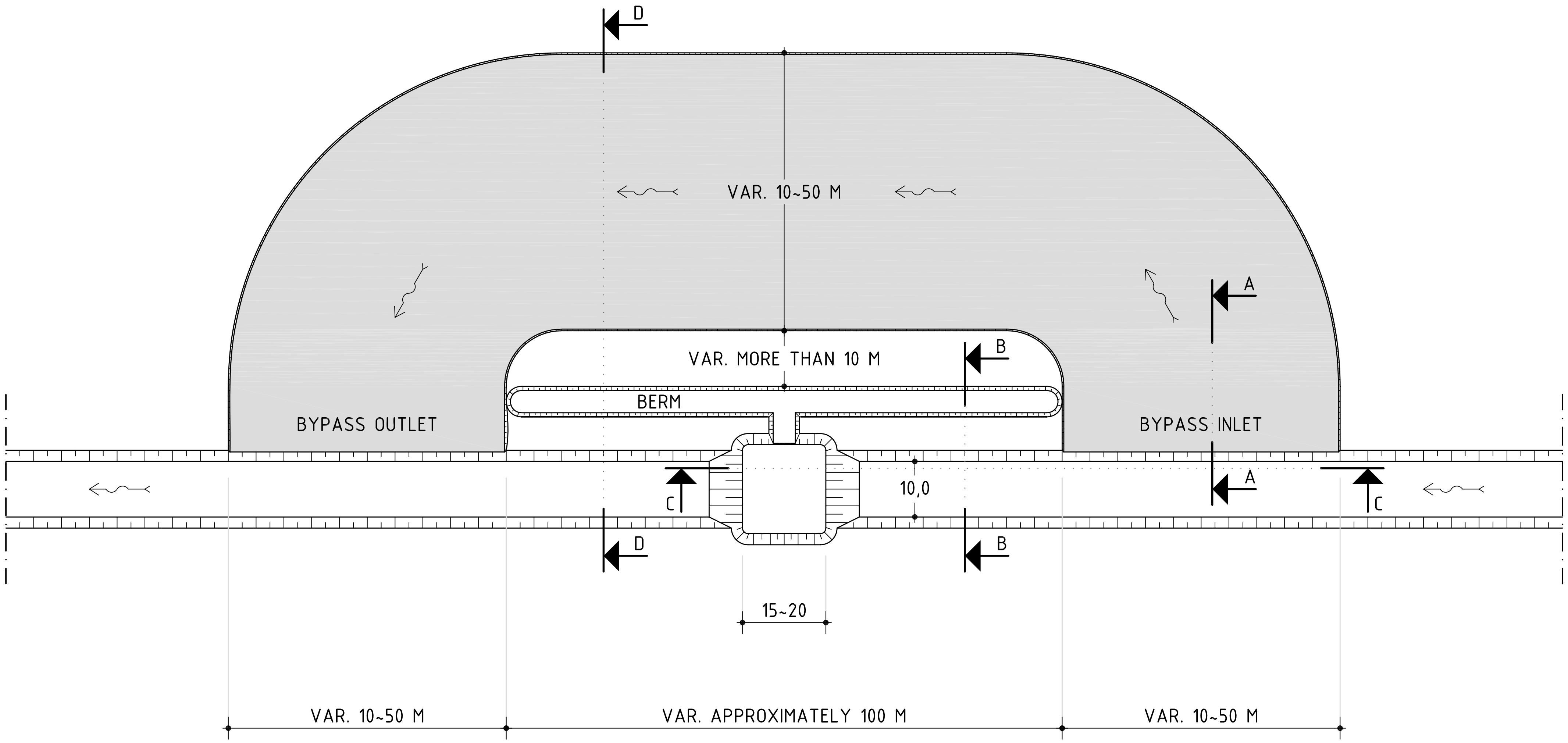

NOTES :

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE
2. ALL LEVELS ARE IN METERS
3. BYPASS FOLLOWS NATURAL SHALLOW DEPRESSION
4. CONSTRUCTION OF BERM IS OPTIONAL (ONLY IF REMAINS STILL PRESENT)
5. FOR CROSS SECTIONS REFER TO DRAWING INA 493-1-2003

LEGEND :

BYPASS CHANNEL

WATER FLOW

0 10 20 30 40 50m

SCALE 1:1.000

GOVERNMENTS OF INDONESIA AND THE NETHERLANDS

MASTER PLAN EMRP AREA IN CENTRAL KALIMANTAN

TYPICAL DESIGN 2 COMPACTED PEAT DAM

PLAN VIEW

EUROCONSULT MOTT MACDONALD AND DELTARES | DELFT HYDRAULICS IN ASSOCIATION WITH DHV, WAGENINGEN UR, WITTEVEEN+BOS, PT MLD AND PT INDEC

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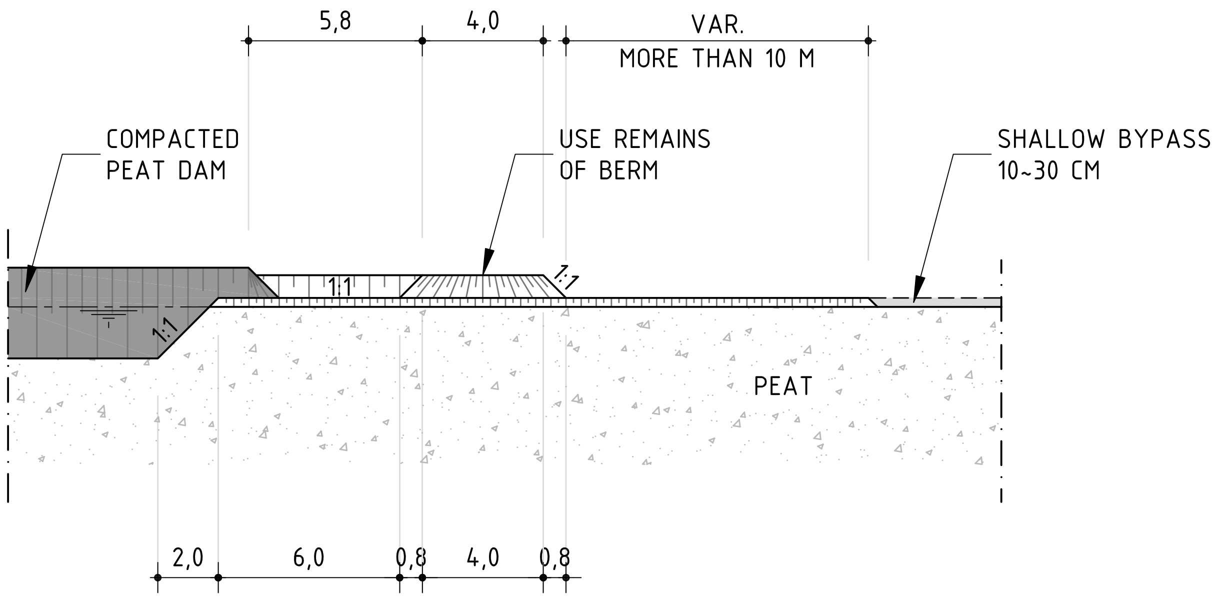
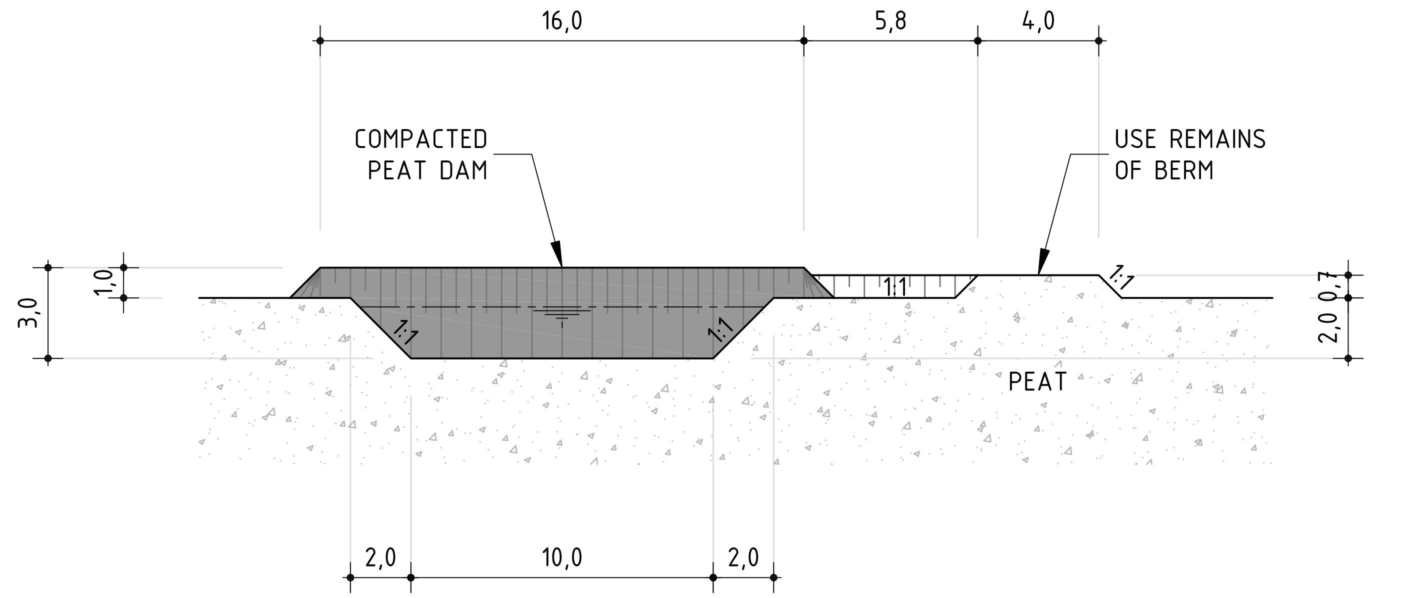


SECTION A-A

SCALE 1:250



SECTION B-B

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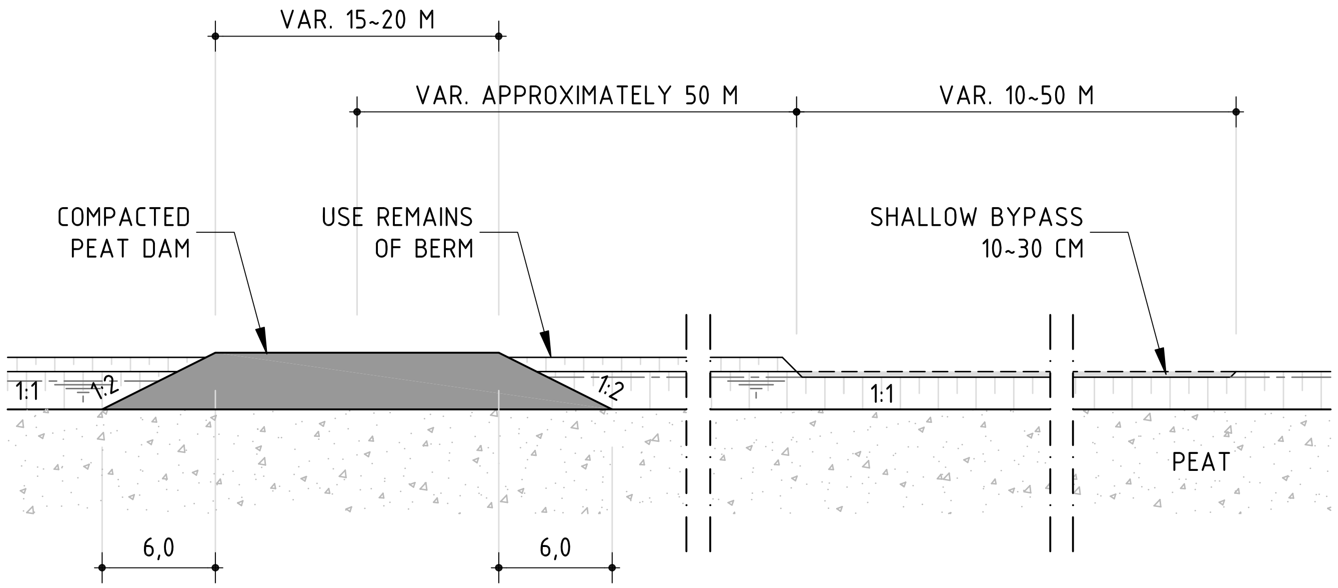

SECTION C-C

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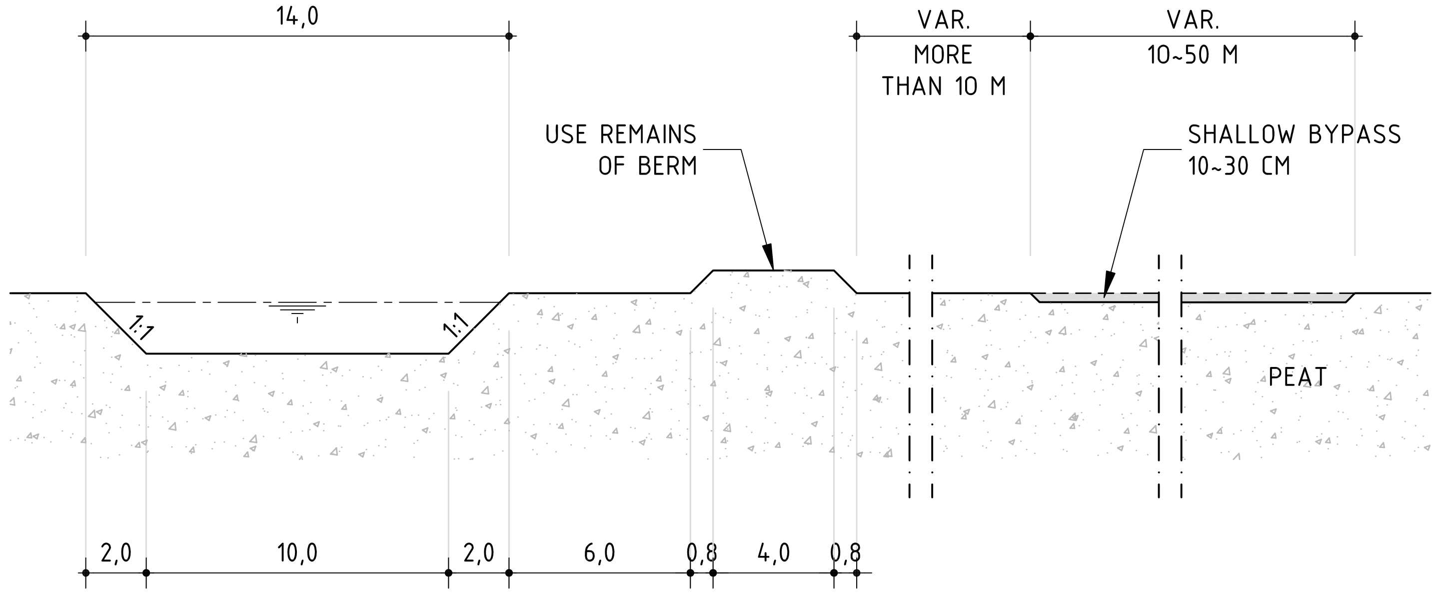


SECTION D-D

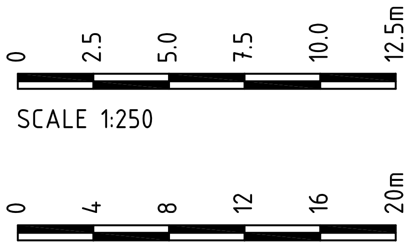
SCALE 1:250

NOTES :

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE
2. ALL LEVELS ARE IN METERS
3. BYPASS FOLLOWS NATURAL SHALLOW DEPRESSION
4. CONSTRUCTION OF BERM IS OPTIONAL (ONLY IF REMAINS STILL PRESENT)
5. FOR PLAN VIEW REFER TO DRAWING INA 493-1-2002

LEGEND :

- EXCAVATION FOR BYPASS
- COMPACTED PEAT



GOVERNMENTS OF INDONESIA AND THE NETHERLANDS

MASTER PLAN EMRP AREA IN CENTRAL KALIMANTAN

TYPICAL DESIGN 2 COMPACTED PEAT DAM CROSS SECTION

EUROCONSULT MOTT MACDONALD AND DELTARES | DELFT HYDRAULICS IN ASSOCIATION WITH DHV, WAGENINGEN UR, WITTEVEEN+BOS, PT MLD AND PT INDEC

Drawn	Ibnu Hanan
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Date	30-03-2009

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Name	Date	Paraf
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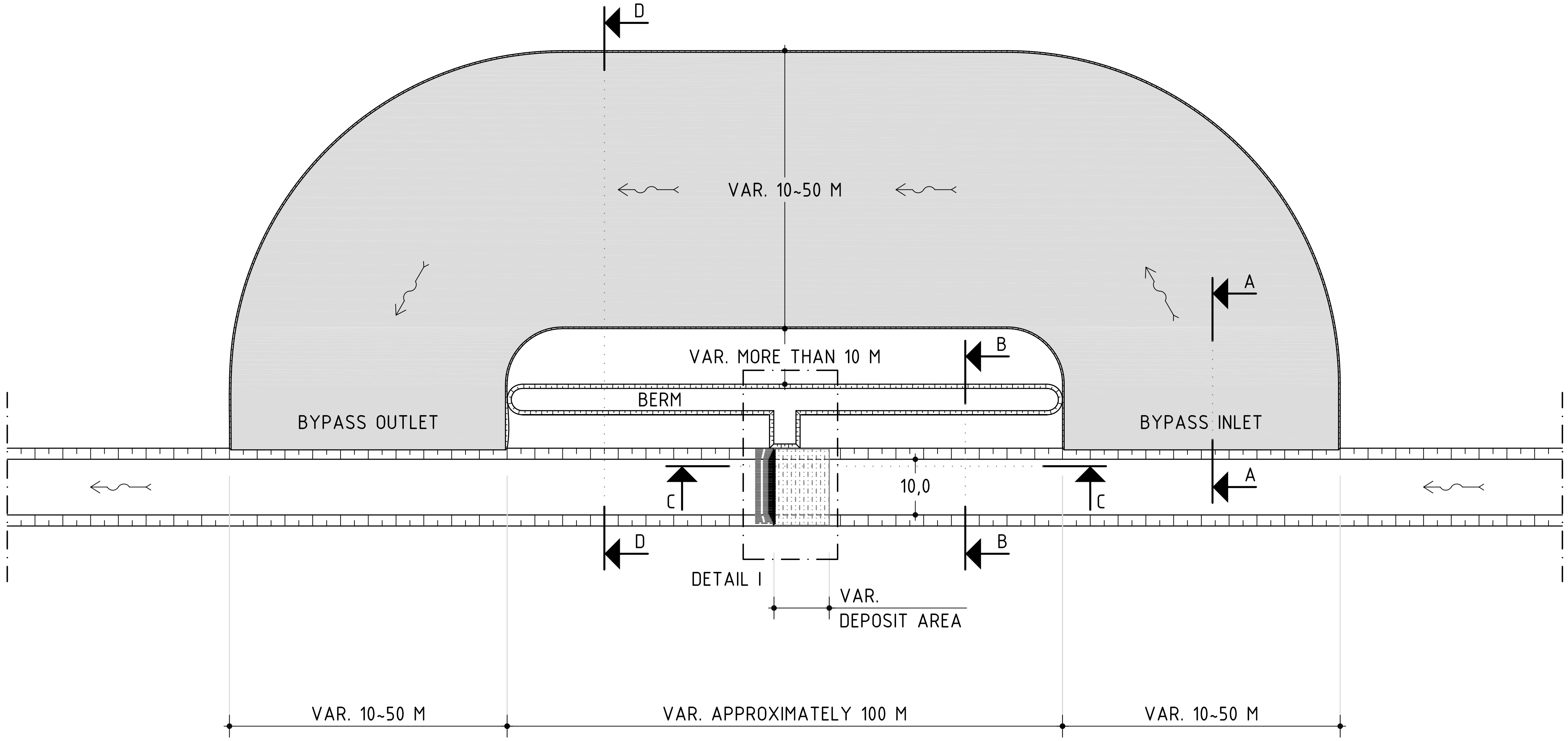

PLAN VIEW

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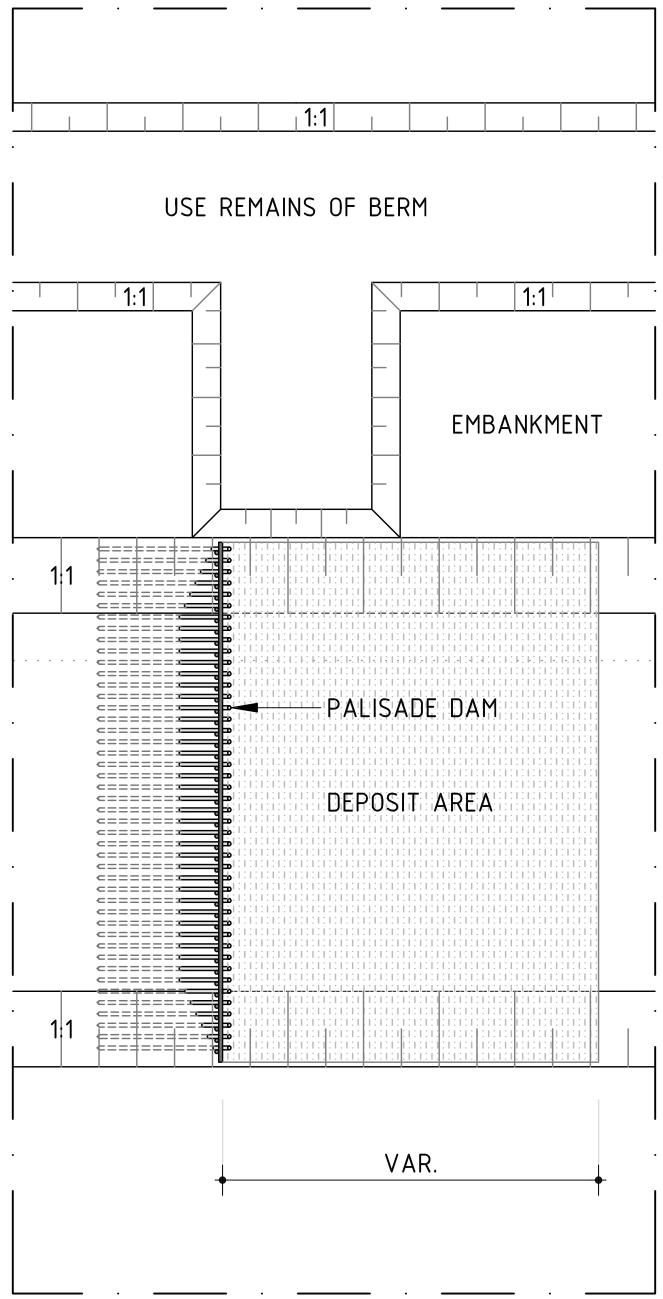


DETAIL I

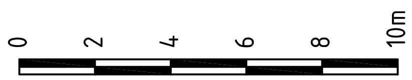
SCALE 1:200

NOTES :

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE
2. ALL LEVELS ARE IN METERS
3. BYPASS FOLLOWS NATURAL SHALLOW DEPRESSION
4. CONSTRUCTION OF BERM IS OPTIONAL (ONLY IF REMAINS STILL PRESENT)
5. FOR CROSS SECTIONS REFER TO DRAWING INA 493-1-2005

LEGEND :

- BYPASS CHANNEL
- DEPOSIT AREA
- WATER FLOW



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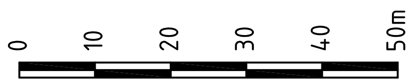

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GOVERNMENTS OF INDONESIA AND THE NETHERLANDS

MASTER PLAN EMRP AREA IN CENTRAL KALIMANTAN

TYPICAL DESIGN 3 PALISADE DAM

PLAN VIEW

EUROCONSULT MOTT MACDONALD AND DELTARES | DELFT HYDRAULICS IN ASSOCIATION WITH DHV, WAGENINGEN UR, WITTEVEEN+BOS, PT MLD AND PT INDEC

Drawn	Ibnu Hanan
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Date	30-03-2009

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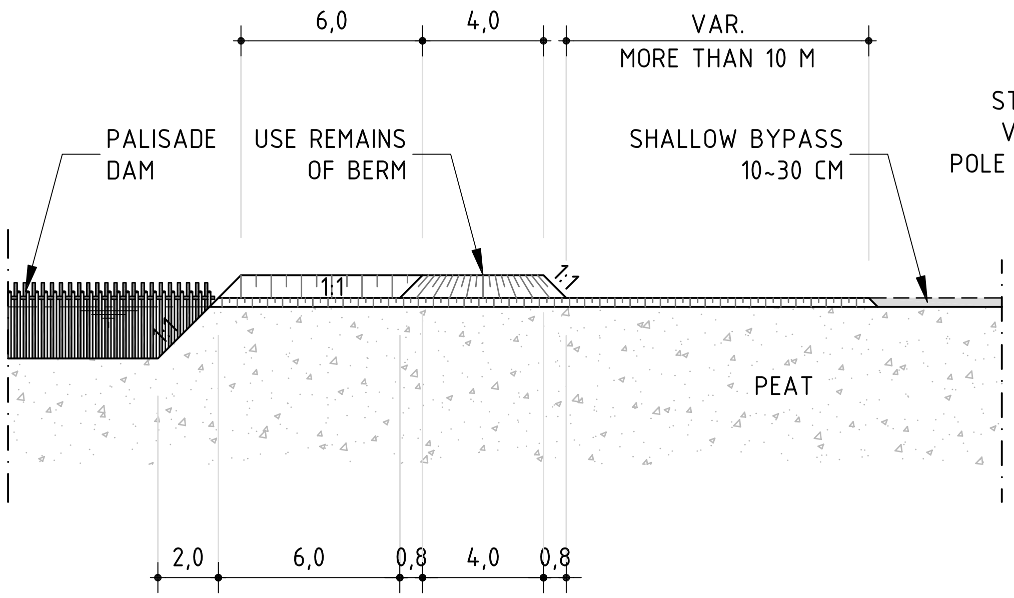

SECTION A-A

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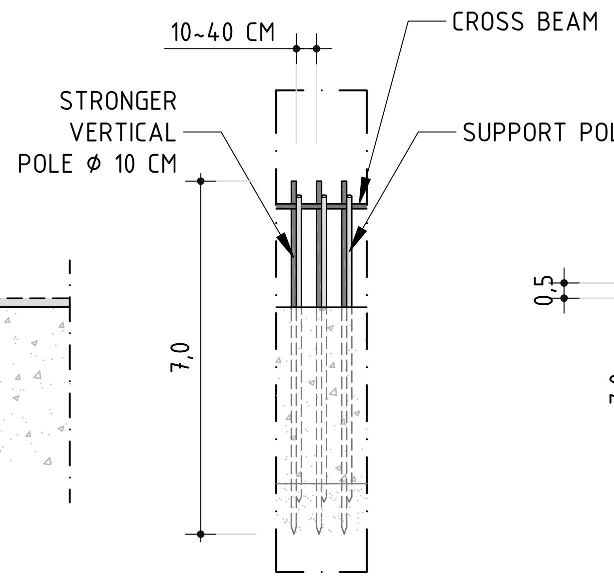

DETAIL I

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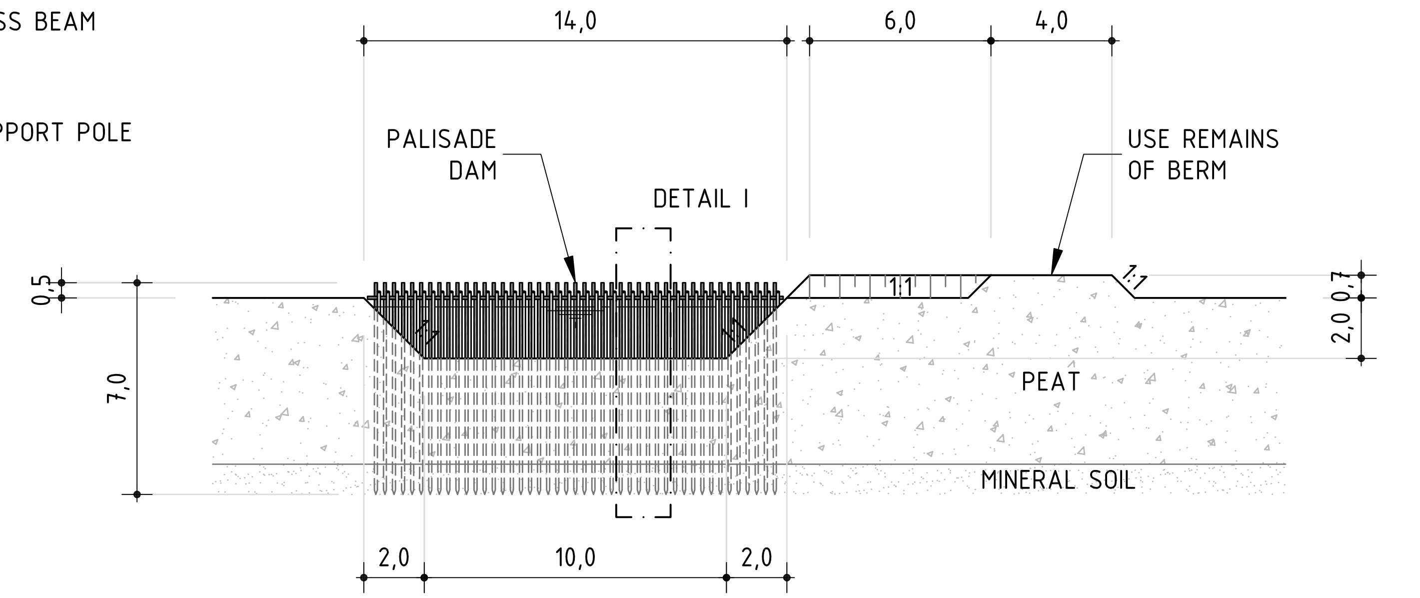

SECTION B-B

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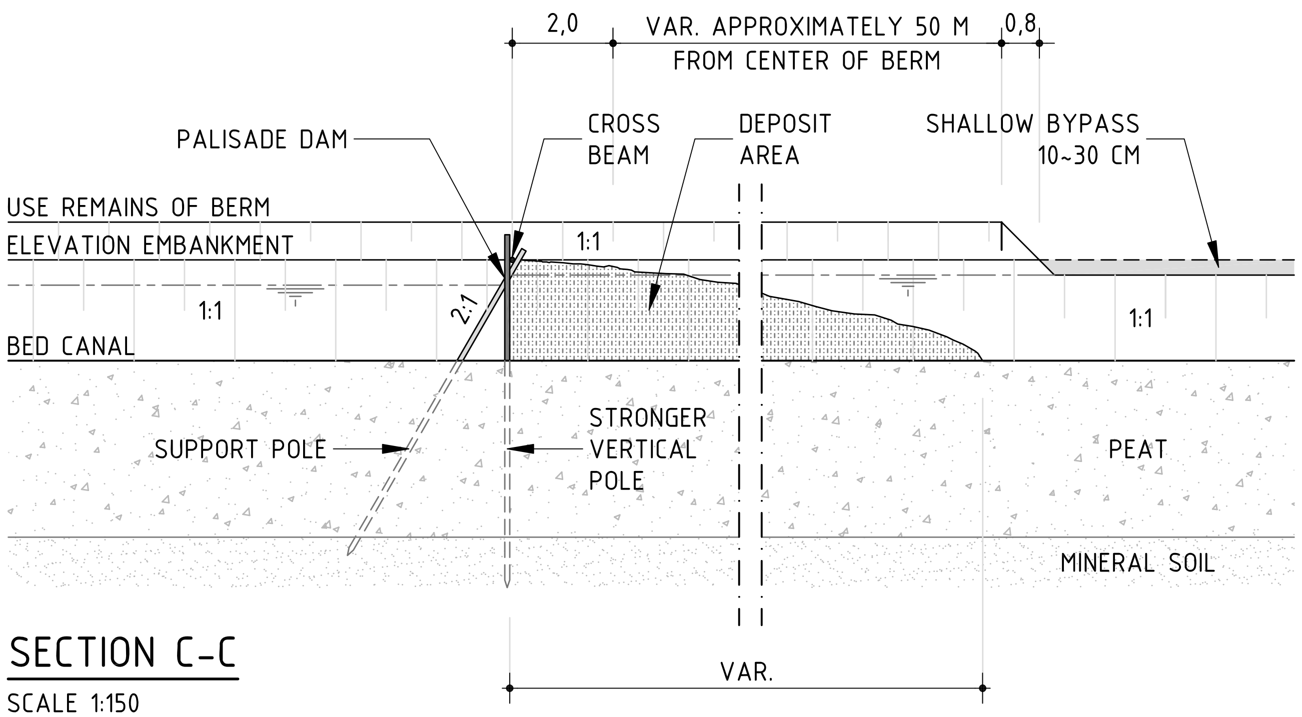

SECTION C-C

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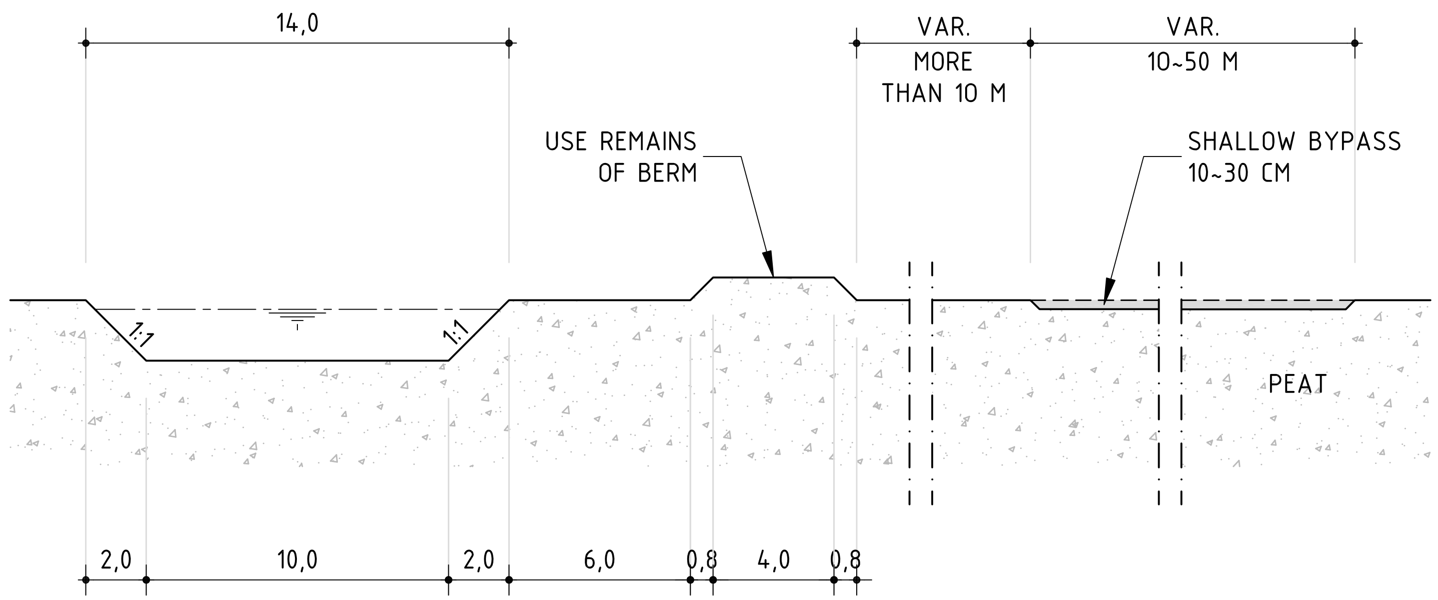


SECTION D-D

SCALE 1:250

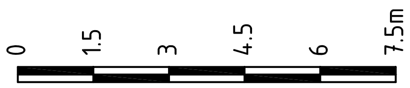
NOTES :

1. ALL DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE
2. ALL LEVELS ARE IN METERS
3. BYPASS FOLLOWS NATURAL SHALLOW DEPRESSION
4. CONSTRUCTION OF BERM IS OPTIONAL (ONLY IF REMAINS STILL PRESENT)
5. FOR PLAN VIEW REFER TO DRAWING INA 493-1-2004

LEGEND :

EXCAVATION FOR BYPASS

DEPOSIT AREA



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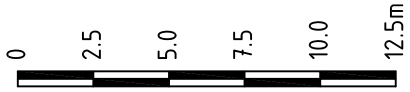

SCALE 1:250

GOVERNMENTS OF INDONESIA AND THE NETHERLANDS

MASTER PLAN EMRP AREA IN CENTRAL KALIMANTAN

TYPICAL DESIGN 3 PALISADE DAM

CROSS SECTION

EUROCONSULT MOTT MACDONALD AND
DELTARES | DELFT HYDRAULICS
IN ASSOCIATION WITH
DHV, WAGENINGEN UR, WITTEVEEN+BOS,
PT MLD AND PT INDEC

Drawn	Ibnu Hanan
Checked	Hilko Timmer
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Date	30-03-2009

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Name	Date	Paraf

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Scale	1:150, 1:250

INA 493-1-2005

Size	A3

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