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Effect of Canal Damming on the Surface Water Level Stability in the Tropical Peatland Area Gatot Eko SUSILO\*, \*\*, Koichi YAMAMOTO\*, Tsuyoshi IMAI\*, Takashi INOUE\*\*\*, Hidenori TAKAHASHI\*\*\*\*, Yoshiyuki ISHII\*\*\*\*\*, Hiroshi FUKAMI\*\*\*\*\*, Ken KOIZUMI\*\*\*\*\*, Kitso KUSIN \*\*\*\*\* \*Graduate School of Science and Engineering, Yamaguchi University, 2-16-1 Tokiwadai, Ube, Yamaguchi 755-8611, Japan \*\*Civil Engineering Dept., Universitas Lampung, Jl. Sumantri Brojonegoro 1 Kampus Unila, Bandar Lampung 35145, Indonesia \*\*\*Graduate School of Agriculture, Hokkaido University, North 9, West 9, Kita-ku, Sapporo, Hokkaido 060-8589, Japan \*\*\*\*Hokkaido Institute of Hydro-climate, Frontier 14, N 14 W 3, Kita-ku, Sapporo, Hokkaido 001-0014, Japan \*\*\*\*\*Institute of Low Temperature Science, Hokkaido University, Kita-19, Nishi-8,

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Yos Sudarso, Kampus UNPAR Tunjung Nyahu, Palangka Raya, Central Kalimantan 35145, Indonesia ABSTRACT This research aims to analyze the effect of canal damming on surface water level stability in the drainage canals in the peatland area of Central Kalimantan, Indonesia. The focus of this research is the investigation of surface water level in Kalampangan Canal and Taruna Canal, the two biggest canals on the peatland lying between Sebangau River and Kahayan River. Surface water levels in this research were measured using automatic gauges and loggers for 11 stations. Research results indicate that the surface water level in the dammed area (Lg2) has the most stable water level compared to the ones of other stations.

Statistical analysis using box plot method stated that Lg2 has the lowest range of normal water level compared to other stations. The research results also showed that the water level of Lg2 in the canal has specific water system, which did not depend on the flow regime in the vicinity. Based on the analysis, the dams in the canal were able to retain water in the canal for a long period of time. The dams were able to maintain the water level in Lg2 at an elevation of about + 18.0

m in the condition without water supply or water loss to other areas. Keywords: canal damming, drainage canals, surface water behavior, tropical peatland area

INTRODUCTION About 22.5 million ha of wetland in Indonesia is peatland area. This amount is about 83% of all wetlands in Southeast Asian region (Hooijer et al., 2006). Kalimantan Island is the Indonesian island with the biggest area of peatlands (5.77 million ha) and 3.10 million ha of them exist in Central Kalimantan Province (Wahyunto et al., 2004). This area is about 13.5% of all Indonesian peatlands.

Unfortunately, due to many factors such as anthropogenic and peat fire impacts, the area of peatlands in Indonesia is decreasing day by day. In Kalimantan, deforestation of peat forest peak occurred in the 1980's and 1990's when Address correspondence to Gatot Eko Susilo, Graduate School of Science and Engineering, Yamaguchi University, Email: n502wf@yamaguchi-u.ac.jp Received May 10, 2012, Accepted October 14, 2012.

the most intensive logging in the world happened. On that era, 60 – 240 cubic meters of wood were being harvested per ha.

This is very much bigger if compared to 23 m<sup>3</sup> per ha harvested in the Amazon in the

same era (World Wildlife Fund (WWF) Germany, 2005). Based on WWF data, Kalimantan rainforest area dropped from 73.7% in 1985 to 57.5% in 2000. Future prediction stated that the rainforest in Kalimantan will continuously be reduced and the area that will remain will only be 32.6% in 2020. Based on the data given by Forest Watch Indonesia (2009), the primary cause of deforestation in Kalimantan today is the development of oil palm plantation. For the last two decades, palm oil has been one of the fastest growing commodities in Indonesia.

According to the Director General of Plantations, palm oil plantation area has increased from 1.1 million ha in 1990 to 6.1 million ha in 2006. The Ministry of Agriculture (MoA) states that up to 2007 palm oil plantation area has now reached 6.3 million ha. On the average, there are 260 thousand ha of new palm oil plantation every year. From this amount, Kalimantan constitutes 26% of the whole area. Central Kalimantan Province nowadays is the province with the fastest growth and expansion of palm oil in Indonesia. In 17 years, palm oil plantation area has increased nearly 400 fold.

Up to the end of 2006, there were approximately 816,000 ha of forest area in Central Kalimantan allocated for palm oil development (Forest Watch Indonesia, 2009). Massive land use change in Central Kalimantan Province was not only caused by the expansion of palm oil plantation. In 1995, Indonesian Government launched Mega Rice Project (MRP) in Central Kalimantan. The project aimed to support the national food program by developing peatland areas into agricultural areas, especially paddy fields. In April 1996, the digging of drainage canals in the peat swamp areas was initiated.

Thousands of kilometers of channel have been developed and thousands of hectares of peatland have been changed into dried peatland. The development area was located near Sebangau River, Kahayan River, Kapuas River, and Barito River of Central Kalimantan. The area of development was planned to be 1.5 million ha which consists of Block A, B, C, D, and E (Boehm and Siegert, 2001a and 2001b). However, due to some difficulties in management and issues that relate to environmental degradation of peat soil, which will increase the risk of peat fire (Wösten et al., 2008), the government had stopped the project in 1999 and the area was abandoned.

Nowadays, the government of Indonesia, together with many world foundations and institutions, launched peatland restoration project in order to save the peatland areas in ex-MRP area of Central Kalimantan. In the peatland restoration program, wetland hydrology is the most key element. Hydrologic conditions directly affect various processes governing hydroperiod conditions in the wetland area. Hydrological model is potentially important tool to predict hydroperiod conditions in the area (Boswell and Olyphant, 2007).

Any changes in the hydrologic system, such as the introduction of drainage and development of tropical peatland for any purpose, will lead to severe hydrological changes (Page et al., 2009). When peatland area is drained, the water table would drop significantly. The formally wet peat will be exposed to the open air and as a result, the peat starts to decompose. This condition results in subsidence of the soil to as much as 8 cm per year and releases a large amount of CO<sub>2</sub> to the atmosphere (CKPP, 2007). Water level, both surface and groundwater, in peatland ecosystem is important to be investigated and studied.

Although the success of wetland restoration is not always depending on this aspect, water level plays an important role in the efforts of hydrology rehabilitation and peat fire risk reduction in peatland areas. Groundwater level, for example, was strongly driving the CO<sub>2</sub> emissions from tropical peatland ecosystems (Hirano et al., 2009). In Central Kalimantan, drainage channels built in the MRP era had decreased the groundwater level significantly because the groundwater was drained from the peatland and flowed into the river in surrounding areas.

Technically, peatland restoration in Central Kalimantan aimed to rehabilitate the water table in peatland areas so as to minimize the spread of fire, prevent the loss of the thickness of peat layer, and restore the peatland ecosystem with its natural flora and fauna (Limin et al., 2007). In order to reduce the level of drainage of groundwater from peatland areas of Central Kalimantan, canal blocking was applied. The main purpose of canal blocking was to retard drained water in the drainage channel. Water inundation in the channel will further prevent the discharge from the peat soil and finally encourage the groundwater level stabilization in its surrounding areas.

Wösten and Ritzema (2001), in their study of soil and water management options for peatland development in Sarawak Malaysia, recommended the importance of the construction of dams in the drainage canals in peatlands to raise the water level and restore the integrity of the hydrology of the peat swamp ecosystem, including the stability of the groundwater level. Research carried out by De Vries (2010) on the restoration of degraded peatlands in Central Kalimantan produced the remark that the construction of dams on the drainage channel will affect the local hydrology in the vicinity of the channel.

The dams in the channel are multifunctional and can be used for reducing local drawdown, retarding subsurface drainage during the dry season, and retaining floodwater during the wet season. Jaenicke et al. (2011) found that the blocking of drainage canals by dam building has become one of the most important measures to

restore the hydrology and the ecological function of the peat soil. Construction of dams across drainage canals is necessary to raise the elevation of surface water and re-establish the hydrological status, including the groundwater level, of the peat swamp ecosystem (Wösten and Ritzema, 2001).

The stability of surface water in the canal damming area in the drainage channel in the peatland area became an important aspect to drive the groundwater discharge from the surrounding peatland. However, it still required an investigation on whether the canal blocking is capable of maintaining the stability of the surface water level in a sustainable manner. Therefore, this research aims to present the analysis of surface water level stability under canal damming (located in between 2 dams or canal blocking) and non canal damming (situated in the location with no dam or canal blocking) conditions in the drainage canals in the tropical peatland area of Central Kalimantan, Indonesia. The focus of this research is the investigation of surface water level behavior in Kalampangan Canal and Taruna Canal of Block C area in the ex-MRP.

**RESEARCH METHODOLOGY** Study area Block C area of ex-MRP is located between Sebangau River and Kahayan River and constitutes about 726 km<sup>2</sup> in area. The location is within 2° 15' 6.223" S, 113° 59' 9.807" E (Northwest), 2° 15' 4.278" S, 114° 14' 14.344" E (Northeast), 2° 39' 56.539" S, 114° 14' 17.946" E (Southeast), and 2° 39' 58.84" S 113° 59' 13.135" E (Southwest).

Due to the development of drainage canals at the MRP era, the area became over drained and as a result the land became very dry during the dry season and experienced a high risk of peat fire.

Since the event of the massive fire in 1997/1998, due to El Niño and its existing condition, and several peat fires for almost every year, the peatland area became degraded where about 78% has been burned once or more times. Until now, the area is still vulnerable to fire, especially fire caused by anthropogenic factors (Hoscilo et al., 2011). The focus of this study is the investigation of surface water level stability in Kalampangan Canal and Taruna Canal, the biggest canals located on the Block C of ex-MRP area, as shown in Fig. 1.

Kalampangan Canal is the canal which connects Sebangau River and Kahayan River. The length of the constructed canal is about 10.9 km with an average channel width and depth of about 30 m and 4 m, respectively. The canal is crossed by Taruna Canal at the point of approximately 4.3 km from Sebangau River. Some canal dammings have been established along Kalampangan Canal in order to increase the groundwater table in surrounding areas. Dam3 and Dam4 are located 2.7 km and 3.9 km away from Kahayan

River, respectively. On the other side, Dam7 and Dam5 are located 7.3 km and 7.5 km away from Kahayan River, respectively.

However, Dam7 and Dam5 have collapsed and could not function to increase the groundwater table in surrounding areas. There were water level measuring devices and loggers installed along the Kalampangan Canal (7 units) and along the Taruna Canal (4 units). Fig. 1 - Location of the study. Lg1 until Lg11 are the surface water level measuring devices and loggers. White triangles are used to symbolize the dam set to stabilize the groundwater table in surrounding areas.

Data acquisition and data management Surface water level in this research was measured using automatic gauges and loggers (OYO S&DL mini) for 11 stations. Data recorded were hourly surface water level data.

In this research, the surface water level data used to identify the surface flow behavior in Kalampangan Canal is the daily data derived from the hourly data recorded by the stations as follows: Lg11 at Kalampangan Canal for period of September 3, 2010 – May 4, 2011 Lg1 at Kalampangan Canal for period of July 7, 2010 – May 4, 2011 Lg2 at Kalampangan Canal for period of July 7, 2010 – May 2, 2011 Lg3 at Kalampangan Canal for period of July 8, 2010 – May 2, 2011 Lg4 at Kalampangan Canal for period of July 8, 2010 – January 14, 2011 Lg5 at Kalampangan Canal for period of July 8, 2010 – May 4, 2011 Lg10 at Kalampangan Canal for period of July 13, 2010 – May 4, 2011 Lg6 at Taruna Canal for period of July 8, 2010 – May 2, 2011 Lg7 at Taruna Canal for period of July 10, 2010 – May 3, 2011 Lg8 at Taruna Canal for period of July 10, 2010 – May 3, 2011 Lg9 at Taruna Canal for period of February 1, 2011 – May 5, 2011 Canal damming mechanism Canal damming in peatland area, including Kalampangan Canal, is usually built using local wood which is organized in such a way and filled with sand-bagged peat soil. The dams are quite effective to restore the surface water into natural level. However, construction of the dams are labour-intensive and expensive.

It is necessary to consider many technical and economic aspects in making a selection of which canals and ditches are most urgently needed to be blocked (CKPP, 2007). The dams also have some technical weaknesses related to the characteristics of the construction and the stability of peat soil in the location of construction. Therefore, construction design in peatland area is the most important knowledge that has to be mastered before the design of the dams. Figure 2 illustrates the construction of the dam for canal damming in Kalampangan Canal. Fig.

2 - Illustration of canal damming in Kalampangan Canal (adopted under permission from Ritzema et al., 2008).

Normal water level analysis Normal water level in the channel for every station was calculated by statistical box plot method (Chambers et al., 1983). The area between quartile 1 and quartile 3 of the box plot was considered as the dominant water level in the channel. This dominant water level was, furthermore, assumed as the normal water level. The length of the normal water level range also indicates the fluctuation range of water level. The smaller the range, the more stable is the water level of the station.

Flow regime identification analysis Pearson correlation method has been used to identify the relationship of water level of two stations. The method is one of the most popular methods for measuring dependence between two quantities and given as (Rodgers and Nicewander, 1988):

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y}$$

$$r_{xy} = \frac{\sum_{i=1}^n x_i y_i - n \bar{x} \bar{y}}{(n-1)s_x s_y}$$

where:  $r_{xy}$  = correlation coefficient between  $x$  and  $y$   $x_i$  = water level at station  $x$  at time  $i$   $\bar{x}$  = average water level at station  $x$   $y_i$  = water level at station  $y$  at time  $i$   $\bar{y}$  = average water level at station  $y$   $s_x$  = standard deviation of water level at station  $x$   $s_y$  = standard deviation of water level at station  $y$   $n$  = number of data The correlation values in this analysis were divided into 3 categories: weak relationship ( $r_{xy} < 0.3$ ), moderate relationship ( $0.3 < r_{xy} < 0.7$ ), and strong relationship ( $r_{xy} > 0.7$ ).

If the water level of two stations have strong relationship with each other, this means that the water level of one station was affected by the water level in other station and vice versa. For example, if the  $r_{xy}$  value of Lg5 and Lg6 is greater than 0.7, and the average water level in Lg6 is higher than the one in Lg5, this circumstance means that the water level in Lg6 affects the water level in Lg5. The correlation analysis was, furthermore, combined with the visual analysis in order to determine the flow regime in the channel.

RESULTS AND DISCUSSION Water level performance Figures 3 and 4 illustrate the performance of the water level data of Kalampangan Canal and Taruna Canal and their box plot. The box plot has been modified by removing the whiskers in order to find the dominant range of water level. The box plot shows that the water level of Lg2 is the most stable water level with the normal water level of 0.13 m, which is between elevations +17.96 m and +18.09 m. Other stations, except Lg11 and Lg1, have normal water level range between 0.2 m and 0.4 m. Normal water levels of Lg11 and Lg1 were the most extreme which were 1.33 m and 1.20 m, respectively.

All numerical displays of the normal water level range are presented in Table 1.

Fig. 3 - Variations in the water level of Kalampangan Canal and Taruna Canal. The black bold line is the water level under canal damming condition (Lg2, located between Dam3 and Dam4). Fig. 4 - Boxplot showing the range of the normal water level at every station.

Table 1 - Normal water level range of Taruna Canal and Kalampangan Canal. All values are in meter.

Station	Low normal water level	High normal water level	Normal water level range
Lg11	16.82	18.14	1.33
Lg10	17.80	18.19	0.39
Lg1	16.93	18.13	1.20
Lg6	17.95	18.29	0.34
Lg2	17.96	18.09	0.13
Lg7	18.03	18.36	0.33
Lg3	17.74	18.04	0.30
Lg8	17.92	18.19	0.27
Lg4	17.88	18.11	0.23
Lg9	17.87	18.16	0.29
Lg5	17.95	18.19	0.25

Correlation analysis and flow regime identification results Table 2 shows the results of the correlation analysis for water level in Kalampangan Canal and Taruna Canal using Pearson correlation method.

The upper part of the table displays all the values of correlation coefficient ( $r_{xy}$ ) between the water levels of two stations. The lower one contains only significant  $r_{xy}$  in order to find a pair of stations which has a strong correlation in their water level. Based on the correlation analysis, significant  $r_{xy}$  values are produced by the relationship between Lg11 and Lg2; Lg11 and Lg1; Lg1 and Lg2; Lg3 and Lg4; Lg3 and Lg5; Lg3 and Lg6; Lg3 and Lg8; Lg3 and Lg7; Lg5 and Lg7; Lg5 and Lg6; Lg5 and Lg8; Lg6 and Lg7; and Lg6 and Lg8. Based on these results, it has been identified that there are 3 flow regimes in the canal system: Flow regime which consists of Lg3, Lg4, Lg5, Lg6, Lg7, and Lg8.

In this regime, Lg8 is the upstream area and Lg3 is the downstream one. However, opposite flow is possible in this regime. Flow regime which consists of Lg2, Lg1, Lg11. In this regime, Lg2 is the upstream area and Lg11 is the downstream one. There is no possibility of opposite flow in this regime. Lg9 and Lg10 are independent systems which may be affected by Sebangau River fluctuation. In general, the flow regimes in the canals are displayed in Fig. 5. Furthermore, based on the analysis and field study, flow regimes of Kalampangan Canal and Taruna Canal can be explained as follows.

In the normal condition, or no rain, the water level condition of Lg11 and Lg1 is driven by the fluctuation of Kahayan River and water supply from Lg2. If Kahayan River water level went down significantly, the water level on Lg1 also dropped and vice versa. In Lg2, the water level tends to be stable. Water level on this station in normal condition is around +18 m due to the canal damming. In Lg3, the water was originally coming from

Lg8 which flowed through Lg7, Lg6, and Lg4. Some water from Lg6 also flowed into Lg5.

However, the fluctuation of water level in Lg5, due to Sebangau River water level fluctuation, forced the water to flow back into Lg4 and Lg3. Canal section around Lg3 received continuous flow from the system driven by Lg8. The flow was not accumulated in the canal but went outside the canal through the small channel located close to Lg3 which was built for transportation purpose. The water in Lg8 was originally coming from the discharge of

groundwater drained from the peat soil into the canal. Some water in Lg8 also flowed into Sebangau River through Lg9. Table 2 - Correlation analysis results for the water levels of two stations.

Station	Lg11	Lg1	Lg2	Lg3	Lg4	Lg5	Lg10	Lg6	Lg7	Lg8	Lg9	Lg11	-0.99	0.73
	0.23	0.47	0.41	0.66	0.31	0.34	0.21	-0.09	Lg1	0.99	-0.70	0.23	0.40	0.36
	0.57	0.31	0.32	0.17	-0.02	Lg2	0.73	0.70	0.43	0.39	0.40	0.44	0.47	0.43
	0.33	-0.12	Lg3			0.95	0.99	0.42	0.99	0.88	0.88	-0.21	Lg4	0.95
	0.94	0.57	0.94	0.89	0.93	N/A	Lg5		0.99	0.94	0.57	0.99	0.89	0.89
	Lg10			0.45	0.47	0.44	0.24	Lg6		0.99	0.94	0.99	0.90	0.88
	-0.18	Lg7		0.88	0.89	0.89	0.90	0.86	-0.18	Lg8		0.88	0.93	0.89
	0.88	0.86	-0.13	Lg9						N/A				

N/A: Data are not available Fig.

### 5 - Flow regimes in Kalamangan Canal and Taruna Canal.

As a conclusion of the analysis, based on the values of correlation coefficient in Table 2 and flow regime analysis, the area between Dam3 and Dam4 (Lg2) in the canal has a specific water system, which did not depend on the flow regime in the vicinity. This specific characteristic was demonstrated by the value of r which was not significant between Lg2 and Lg3 to Lg9.

Although the value of r between Lg2 and Lg11 and Lg1 showed a significant relationship, it does not mean that Lg2 was affected by Lg11 and Lg1. Instead, Lg2 was affecting Lg11 and Lg1 because Lg2 provided water supply to Lg11 and Lg1. Water sources for Lg2 are mainly rainwater and discharge of drained peat soils. In the rainy season, this area will always be filled with water and become water supplier for the surrounding area. In the dry season, this area becomes a reservoir for the discharge of drained peat soils in the vicinity. These conditions make the area of Lg2 to have a relatively stable water level throughout the year.

Canal damming and surface/groundwater level stability Technically, canal damming in

the drainage channel is developed with a purpose to retain water flow in the upstream area or in the area between them. Inundation area formed by canal blocking will reduce the groundwater discharge from peat soil in surrounding areas. Furthermore, the control of groundwater discharge will prompt the increase and stability of groundwater level in the vicinity. Moreover, the stability of surface and groundwater will restore the land into pre-drainage condition by promoting the growth of vegetation along the canals.

The studies demonstrating a close link among canal damming in the drainage channel, the stability of the surface water level, and the stability of the groundwater level in the local area around the channel in peatland area have been undertaken by several researchers (Wösten and Ritzema, 2001; De Vries, 2010; Jaenicke et al., 2011). Limin et al. (2007) found that canal damming at several points in Kalampangan Canal has increased the water table to as far as 400 m on each side of the channel. The maximum water table increased to about 151 cm one year after canal damming. Canal damming also guaranteed water availability in the channel during the dry season.

This circumstance promoted positive effect on vegetation regrowth shown by the healthy condition of some native flora in the channel. Ritzema et al. (2008) also found that canal damming in Taruna Canal has promoted surface water level into natural condition and elevated the groundwater level in the vicinity to 0.75 m on the average. So far, investigation on the relationship between canal damming, stability of surface water level in the drainage channel, and groundwater level behavior in the whole peatland area of Block C has never been implemented yet.

In the future, modeling the efficacy of hydrological restoration through blocking the canal has to be undertaken for a larger scale area by using a more extensive monitoring method to confirm the power of canal blocking in restoring the tropical peatland area of Central Kalimantan. CONCLUSIONS The effect of canal damming on the surface water level stability in Kalampangan Canal and Taruna Canal in the Block C of ex-MRP area in Central Kalimantan has been discussed in this research and some conclusions were obtained as follows: Statistical analyses showed that the surface water level in Lg2 which is between Dam3 and Dam4 has the most stable water level if compared to the ones of other stations.

This fact was supported by the analysis using box plot method showing that Lg2 has the lowest range of normal water level if compared to other stations. Correlation analysis and flow regime identification also showed that the water level of Lg2 in the canal has a specific water system, which did not depend on the flow regime in the vicinity. The analysis indicated that the water sources for Lg2 are mainly rain water and discharge of drained peat soils.

In the rainy season, this area will always be filled with rainwater and in the dry season, this area becomes a reservoir for the discharge of drained peat soils in the vicinity. These conditions make the area between Dam3 and Dam4 (Lg2) to have a relatively stable water level throughout the year. Some studies have demonstrated a close link among canal damming of the drainage channel, the stability of the surface water level, and the stability of the groundwater level. Canal damming also gave a positive effect to vegetation regrowth in the channel.

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