THE INFLUENCE OF EVAPOTRANSPIRATION ON THE GROUNDWATER TABLE IN PEATLAND

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1. Introduction

Groundwater table in the peatland can be regarded as an indicator of water balance of peatland. The groundwater table fluctuates as the result of input and output of water. Input mainly takes form of precipitation and inflow, while output occurrs in form of outflow and evapotranspiration.

In the last decade, hydrological measurements were continuously taken in several peatlands distributed in Hokkaido. Study areas were selected in peatlands showing different stage of transformation, ranging from peatland found in undisturbed, natural stage to completely reclaimed into agricultural land. The water table recorder was used for continuous measurement of the groundwater table fluctuations. The soil moisture suction was measured once in two days in one study area situated in peatland reclaimed into an agricultural land.

Also, the influence of changes in the condition of the vegetation cover upon the evapotranspiration was investigated in one site, by comparing effects of undisturbed and destroyed vegetation on the groundwater level fluctuations.

2. Groundwater table fluctuations in peatland

The fluctuations of groundwater table in peatland occurr mainly in response to precipitation, water inflow, outflow, and evaportranspiration. In bog, the water input results only from precipitation, whereas in fen water input depends from both precipitation and inflow. Such difference in the water supply causes different patterns of water table fluctuations, which can be classified into several categories, shown in Table 1. In bog, the water table rises swiftly during rainfall, and immediately begins to fall as rainfall

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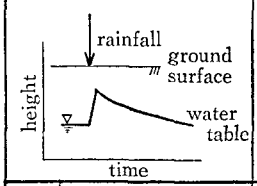
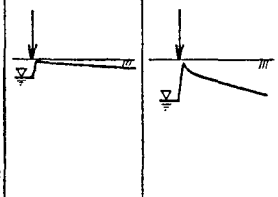
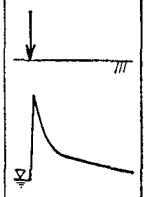
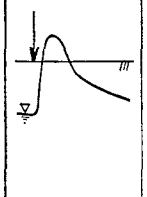
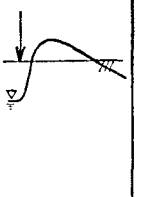
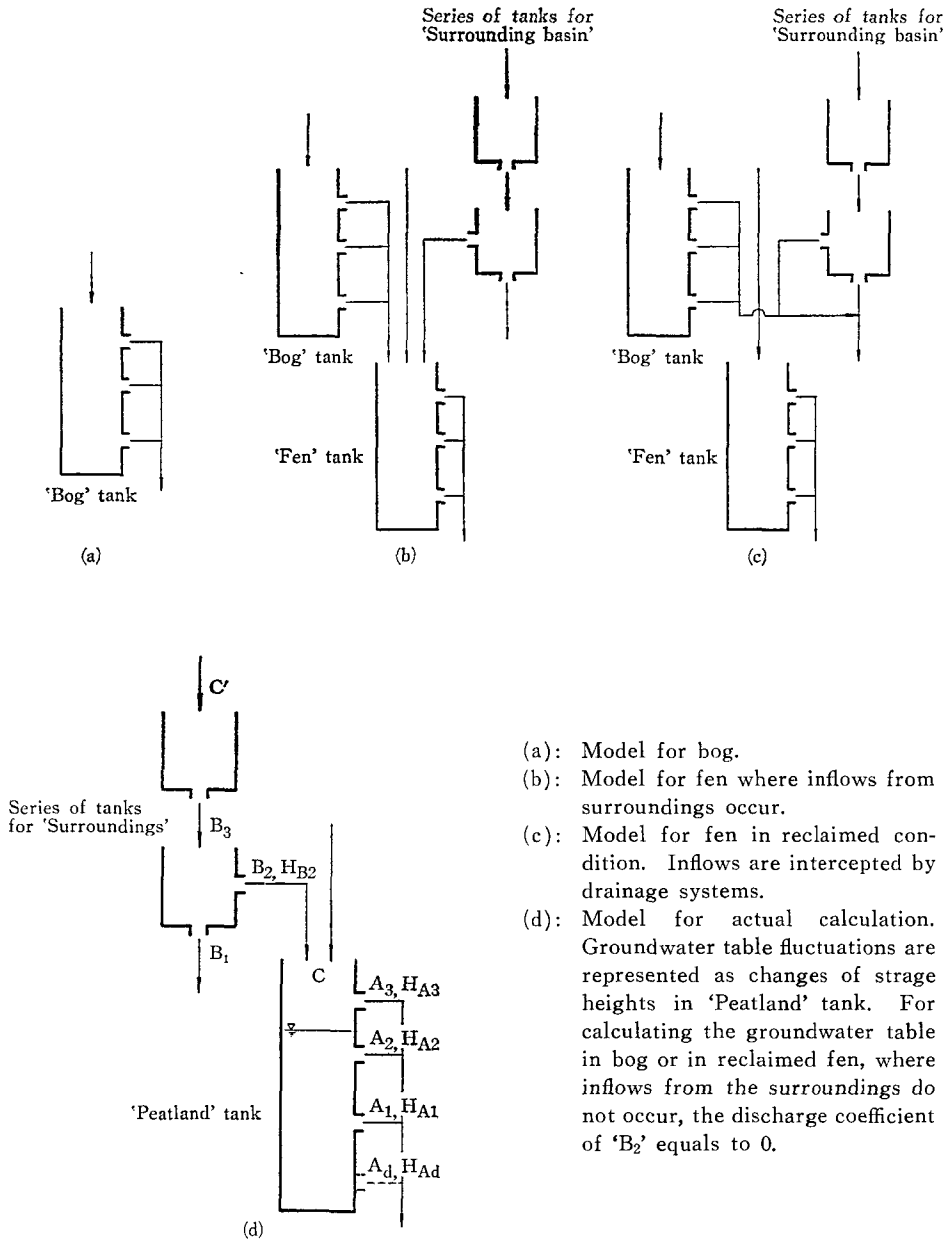
TABLE 1. Classification of groundwater table fluctuation patterns in peatland.

Category		1	2	3	4	5
Pattern of groundwater fluctuation						
Fluctuations of groundwater table	Type of water table rise	immediate small	immediate rather small	immediate rather large	continuous large	continuous rather large
	Form of water table fall	regular	regular	asymptotic	roughly asymptotic	almost regular
Hydrological conditions	Usual position of groundwater table	high	rather high	low	rather low	high
	Influence of inflow	absent	absent	absent	present	present
	Existence of artificial drainage	absent	absent	present	present but not pronounced	absent
Type of peatland		bog			fen	
State of land use		undeveloped		developed		undeveloped
Remarks		Entirely undeveloped bog in natural stage.	Surface is slightly drained.	Artificial drainage systems completed.	Drainage systems are partialy developed. Inflows from surroundings.	Drainage systems incomplete. Inflows from surroundings.

ceases. Although the upward movement of groundwater table during rainfall is quite swift, the downward movement is very slow. This is due to high porosity and specific yield of bog peat and the absence of drainage system (Category 1, Table 1). In fen, the water table rise continues even after the rainfall ceased. This is due to the fact, that water inflow from upper basin continues even after the rainfall ceased. The peak of groundwater table is relatively high. The rate of fall of water table is quite swift, due to the existence of the river stream which works as the natural drainage system (Category 5, Table 1). When developing the peatland as farmland, the construction of artificial drainage is of primary importance. As the result of drainage, the hydrological conditions of peat and peatland change, which transforms the water table fluctuations pattern. Reduction of the ratio of effective porosity caused by drainage and accompanied shrinkage of peat, decreases the water storage capacity in peat. This tends to expand the range of fluctuations of the groundwater. Also, drainage system intercepts the inflows from the surrounding basin. This causes a swift decline in the groundwater table after rainfall (Category 3, Table 1).

UMEDA (1980) suggested a hydrological model for comparing various patterns of groundwater fluctuations in peatland, called "Peatland tank model for groundwater table fluctuations". This model has been used for discriminating the types of groundwater fluctuations and for assessing the hydrological environment of peatland. In this model, the peatland hydrosystem has been expressed as a series of storage tanks. The water table fluctuations are represented as changes of storage heights in model tanks. In bog, where inflow from the surroundings does not occur, the model has been composed of only a single tank, and water input supplied only by precipitation (Fig. 1 a). The model for fen has been constructed from three series of tanks, one for bog, one for surrounding basin, and one for fen itself (Fig. 1 b). The tank for fen is situated at the lowest position. Its water recharge occurrs in form of precipitation and inflow from both the bog and the surrounding basin. When the artificial drainage systems are provided, fen will be insulated from inflows from adjacent bog and the surrounding basin. It means that the model can be represented by only one tank, situated in the bottom of the tank series (Fig. 1 c).

For actual use of this model, the practical model has been suggested (Fig. 1 d). For fen, where recharge from bog and the surrounding basin occurrs, the upper series of tank operates. For bog as well as for reclaimed peatland, drainage systems of which had been completed, the state of groundwater table can be expressed by only one tank. This is due to the fact



(a): Model for bog.
(b): Model for fen where inflows from surroundings occur.
(c): Model for fen in reclaimed condition. Inflows are intercepted by drainage systems.
(d): Model for actual calculation. Groundwater table fluctuations are represented as changes of strage heights in 'Peatland' tank. For calculating the groundwater table in bog or in reclaimed fen, where inflows from the surroundings do not occur, the discharge coefficient of 'B_2' equals to 0.

Fig. 1. Peatland tank model for groundwater table fluctuations. (UMEDA, 1980)

that inflow from surrounding areas does not occur (and the coefficient of 'B_2' is 0). In each tank, the water discharge has been performed by discharge hole, with the amount of discharge controlled by discharge coefficients such as 'A_1', 'A_2', and 'A_3'. These coefficients are settled by trial-and-error method for each hole. This model can be applied with the data of groundwater level at starting point, and for the precipitation for a whole calculating period. Height of discharge holes such as H_{A1}, H_{A2} and H_{A3} has been determined in the following way. Arrange the whole water level data in order from the highest to the lowest, and then pick the value placed on one third from the top of the whole data set, as the height of H_{A2}. Thus H_{A2} will be placed within the limits of water table fluctuations. H_{A1} and H_{A3} should be decided at 40 cm below and 10 cm above the H_{A2}, respectively. If the drainage is effective, another discharge hole have to be settled as H_{Ad} below H_{A1}. After each coefficient of height had been fixed, the coefficient of discharge hole should be calculated. The coefficients A_1, A_2, A_3 simulate the effect of natural and artificial drainage, evapotranspiration and peat structure. The greater value of these coefficients suggests the facility of water discharge and the effectiveness of drainage. A coefficient which works for the water table rise is named "C". This coefficient indicates the ratio, in which the water level rise due to precipitation and inflow. Higher values of C show lack of effective porosity for water-storage.

The observations of groundwater level and precipitation has been performed during a growing season, by use of a water level recorder with a counterweighted float, a chart, and a synchronous rain gauge. The float was settled in a shallow well dug in the surface of mire. The diameter of the well was about 40 cm, and its depth about 60 cm. The recorded data were read at intervals of 2 hours.

Three diagrams (Fig. 2, 3, 4) show the groundwater table fluctuations, and calculated water table by peatland tank model for each variety of peatland. Fig. 2 shows the water table fluctuations observed in bog in Sarobetsu, northern Hokkaido. The predominant vegetation here is composed of: *Ledum palustre, Chamaedaphne calyculata, Empetrum nigrum, Vaccinium oxycoccus, Sasa palmata* and *Sphagnum papillosum*. Fluctuations of the groundwater level shown in Fig. 2 are not so wide-ranging, and the mean water table is relatively high (just below the surface). This type of fluctuations is typical for Category 1 in Table 1.

Water table fluctuations observed in fen are shown in Fig. 3. The data were obtained from Kushiro peatland, eastern coast of Hokkaido. *Phragmites communis* and *Calamagrostis langsdorffii* dominated in vegetation of

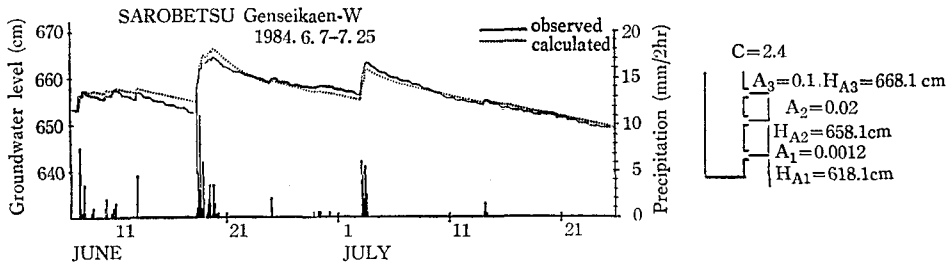


Fig. 2. Groundwater table fluctuations in SAROBETSU Genseikaen-W, with calculated value by peatland tank model.

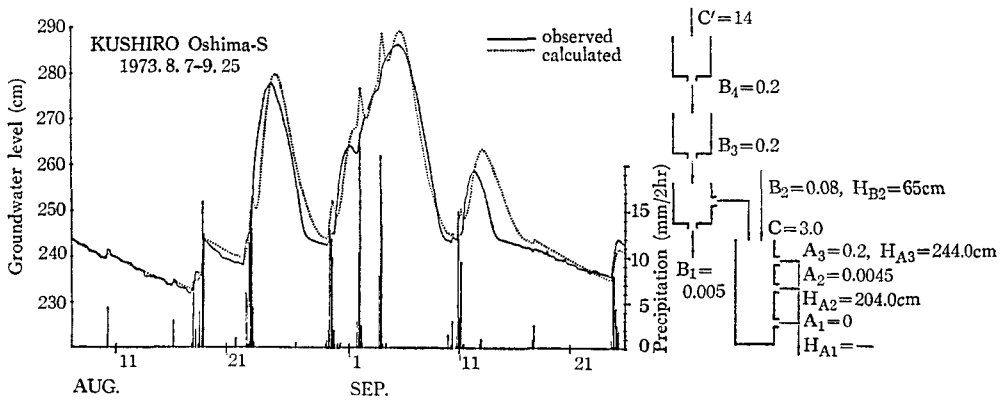


Fig. 3. Groundwater table fluctuations in KUSHIRO Oshima-S, with calculated value by peatland tank model. Extra tank was added on top of series of 'Surroundings' tanks, to conform the delay of inflow to the fen.

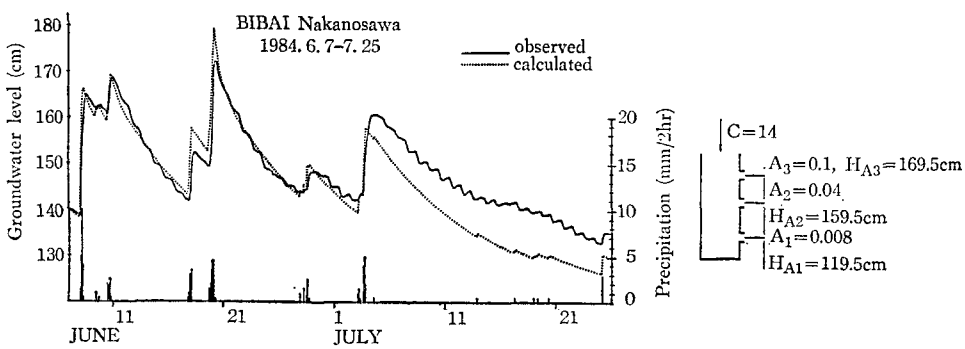


Fig. 4. Groundwater table fluctuations in BIBAI Nakanosawa, with calculated value by peatland tank model. Here, the ground surface was tilled and the vegetation was destroyed on June 28th.

this observation area. Here, the influence of stream flow is apparent, which is indicated by sharp and high peaks in the water table fluctuations diagram (Fig. 3). These peaks occur about two days after the rain. These fluctuations of groundwater table belong to Category 4, Table 1.

In Fig. 4, the groundwater fluctuations observed in reclaimed peatland are shown. The water table was observed at Bibai Nakanosawa in the Ishikari peat complex, central Hokkaido. The site was reclaimed about 50 years ago, and subsequently cultivated as rice paddy for several years. At present, the site is left fallow. The peat surface has been dressed with clay about 20 cm thick as the preparation for cultivation. Since 1940's, areas surrounding the observation plot have also been changed extensively into paddy fields. Drainage and irrigation networks pass through areas adjacent to the observation site. In the vegetation of this site, the following species were recognized. *Phragmites communis, Pteridium aquilinum, Artemisia montana, Polygonum perfoliatum* and others. As shown in Fig. 4, the mean water table is situated relatively deep, and the range of fluctuation is quite wide. The rise of groundwater table after rain is sharp and high, and the fall starts as soon as rainfall ceases. This type of water table fluctuations can be put into Category 3, Table 1. The march of groundwater table shows distinct stepwise fall during dry periods, with steep fall occurring in the

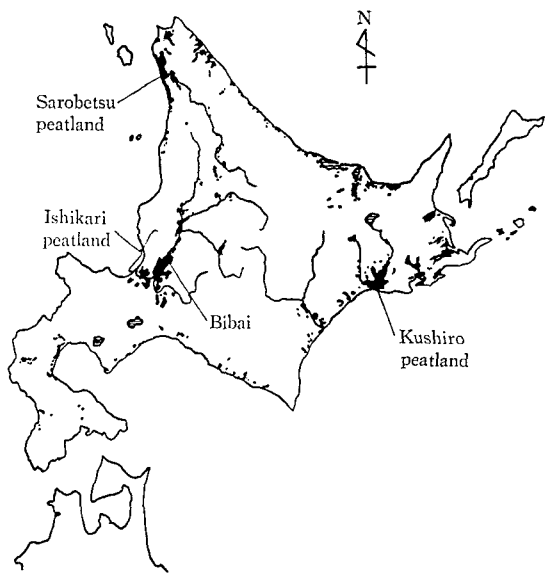


Fig. 5. Distribution of peatlands in Hokkaido and location of observation sites.

daytime and gentle fall or no change of water table occurring at night. This form of water table march is obviously caused by evapotranspiration. Similar but more gentle stepwise march of groundwater table can also be seen in the bog in Sarobetsu (Fig. 2).

The location of sites, where groundwater table has been observed, as well as the distribution of peatlands in Hokkaido, are shown in Fig. 5.

3. Evapotranspiration in peatland

Evapotranspiration is one of the most important factors of peatland hydrology, and many studies have been conducted on this problem. However, only few studies have been concerned with the relationship between evapotranspiration and the fluctuations of the groundwater table. BOATMAN (1983) suggests that the stepwise pattern of water table fall is brought about largely by evapotranspiration. HEIKURAINEN (1963) observed the stepwise fall of groundwater table in an afforested mire in Finland. He explained the behaviour of groundwater table, which shows in some case two periods of fall each day, as the effect of transpiration of *Betula* sp. He also estimated the rate of evapotranspiration by using the correlation coefficient between the amount of rainfall and the water table rise, converting water table recession into estimates of evapotranspiration.

In Fig. 2 and 4, the stepwise water table fall have indicated the influence of evapotranspiration. The rate of fall of the water table caused by evapotranspiration can be calculated by following formula;

$$-\Delta h_n = -(\Delta h_{en} + \Delta h_{fn})$$

$$= -\Delta h_{en} - \frac{m}{24}\Delta h'_{f(n-1)} - \frac{24-m}{24}\Delta h'_{fn}$$

$$-\Delta h_{en} = -\Delta h_n + \frac{m}{24}\Delta h'_{f(n-1)} + \frac{24-m}{24}\Delta h'_{fn}$$

here: n=date; $-\Delta h_n$=the rate of fall of water table in one whole day (cm/day); $-\Delta h_{en}$=the rate of fall of water table due to evapotranspiration (cm/day); $-\Delta h_{fn}$=the rate of fall of water table due to groundwater flow (cm/day); $-\Delta h'_{f(n-1)}$=the rate of groundwater table fall from the evening of $(n-1)$'s day to the morning of n's day (cm/day). This equals to the fall of groundwater table due to groundwater outflow during the night of $(n-1)$'s to n's day; m=midtime of the effective evapotranspiration (hr).

These descriptions are shown on the diagram in Fig. 6. In practice, for the reason of convenience, the evaluation of rate of groundwater table fall caused by evapotranspiration have been done graphically. An example

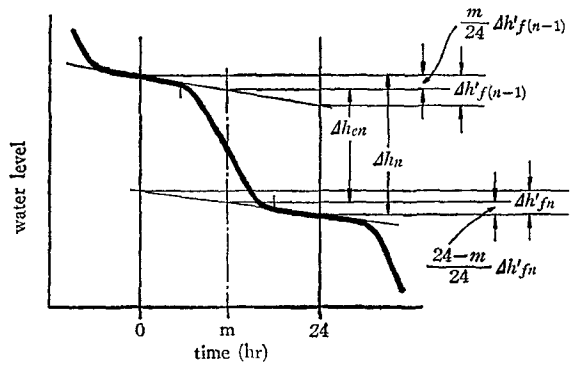


Fig. 6. Analytical method of evaluating rate of fall of groundwater table caused by evapotranspiration.

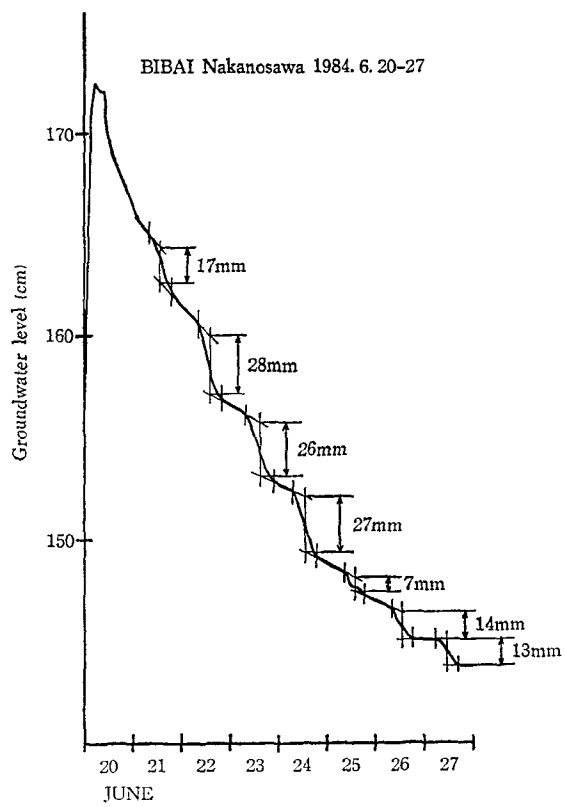


Fig. 7. An example of graphical solution for evaluating rate of fall of groundwater table caused by evapotranspiration.

TABLE 2. Maximum and average rate of groundwater table fall due to evapotranspiration in bog and reclaimed peatland.

Maximum/Average	SAROBETSU Genseikaen-W	BIBAI Nakanosawa
1984 June 12–15	8/7	24/22
June 21–27	6/5	28/19
July 5–13	8/6	27/20

(mm/day)

TABLE 3. Soil profiles of peat obtained from undisturbed bog of Sarobetsu and reclaimed peatland of Bibai.

Depth (cm)	SAROBETSU		BIBAI			
	15	30	10*	20	30	40
Dry bulk density (g/cm^3)	0.09	0.10	1.03	0.26	0.13	0.12
Specific gravity	1.58	1.56	2.52	1.59	1.55	1.69
Porosity (%)	94.5	93.4	59.1	83.6	91.6	92.9
Ignition loss (%)	95.0	96.8	16.7	69.7	92.7	92.4
Decomposition (%) (Sieve analysis)	76.7	82.5	—	96.7	90.2	70.7

* dressed soil

of this graphical solution is shown in Fig. 7.

The maximum and the average rate of the water table fall due to evapotranspiration, in bog and reclaimed peatland, worked out by the method mentioned above, are shown in Table 2. Although Table 2 suggests that the influence of evapotranspiration on the groundwater fall is more sharp in reclaimed peatland, it does not always mean that the amount of evapotranspiration is greater in reclaimed peatland. The amount of evapotranspiration is expected to be larger rather in bog kept in the natural state, than in reclaimed peatland. This is due to the fact that there is an abundant supply of water in the natural bog when compared to reclaimed peatland. The reason that water table fall in reclaimed peatland appeared more sharp than in undeveloped bog, can be attributed to low specific yield of dressed soil and of highly decomposed peat in the reclaimed area. Properties of peat obtained from both sites are shown in Tabel 3. Because the peat has been covered with clay in Bibai, and soil porosity available for water storage is small, the loss of moisture in form of evapotranspiration occurrs mainly from the surface 10 cm layer, and lower layers supply moisture to the upper

layer, as shown in the diagram of soil moisture suction in Fig. 8. It is also seen from Fig. 8, that the moisture loss is larger in 30 cm than in 20 cm depth. This indicates that the effect of transpiration is stronger in the depth of 30 cm than in the depth of 20 cm.

It is well known, that the peat in acrotelm layer can not be fully filled with water, or completely dried, due to peculiar features in the moisture storage of peat. According to laboratory test, only 3 to 4% of moisture content evaporates from a peat monolith each day (Fig. 9). This percentage equals to 0.3-0.4 mm of evaporation for the 1 cm fall of water table per

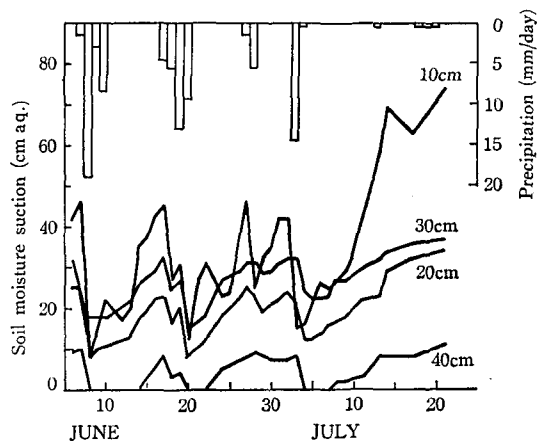


Fig. 8. March of soil moisture suction measured in reclaimed peatland of Bibai. Here, the top layer of 20 cm is dressed soil.

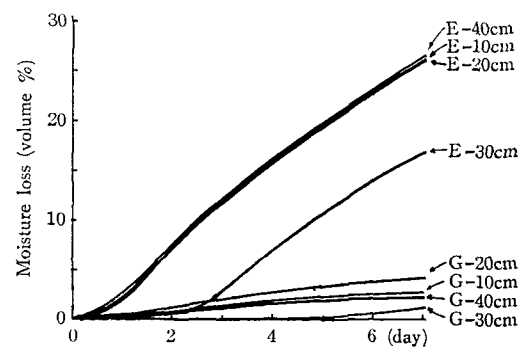


Fig. 9. Increase of moisture loss due to gravitational discharge and evaporation from peat monolithes of Bibai. Prefix "E-" indicates the moisture loss due to both gravitational discharge and evaporation, while "G-" indicates the loss caused only by gravity.

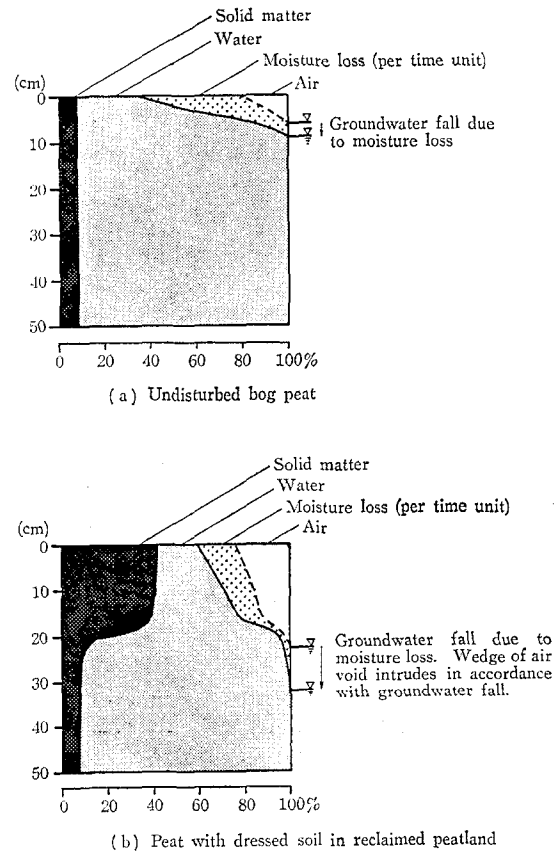


Fig. 10. Schematic profile of soil moisture distribution.

day. In Fig. 10, schematic profiles of soil moisture distribution are shown for the clay-dressed reclaimed peatland, and for the undisturbed bog. In the case of peatland dressed with clay, the wedge of air voids drives sharply into lower layer due to the fall of water table, but the quantity of moisture evaporated from groundwater is quite small. In bog, the intrusion of air void wedge is also sharp, but it does not pierce so deep, as the abundant supply of water near the surface contributes to the greater part of evapotranspiration.

The influence of changes in plant cover condition on evapotranspiration can be seen as the change in the groundwater table fluctuations pattern in the results of observations in Bibai. On June 28th, the surface surrounding the observation site was tilled and almost all vegetation was destroyed (except about 5 m × 5 m plot left for observation with vegetation). The three photo-

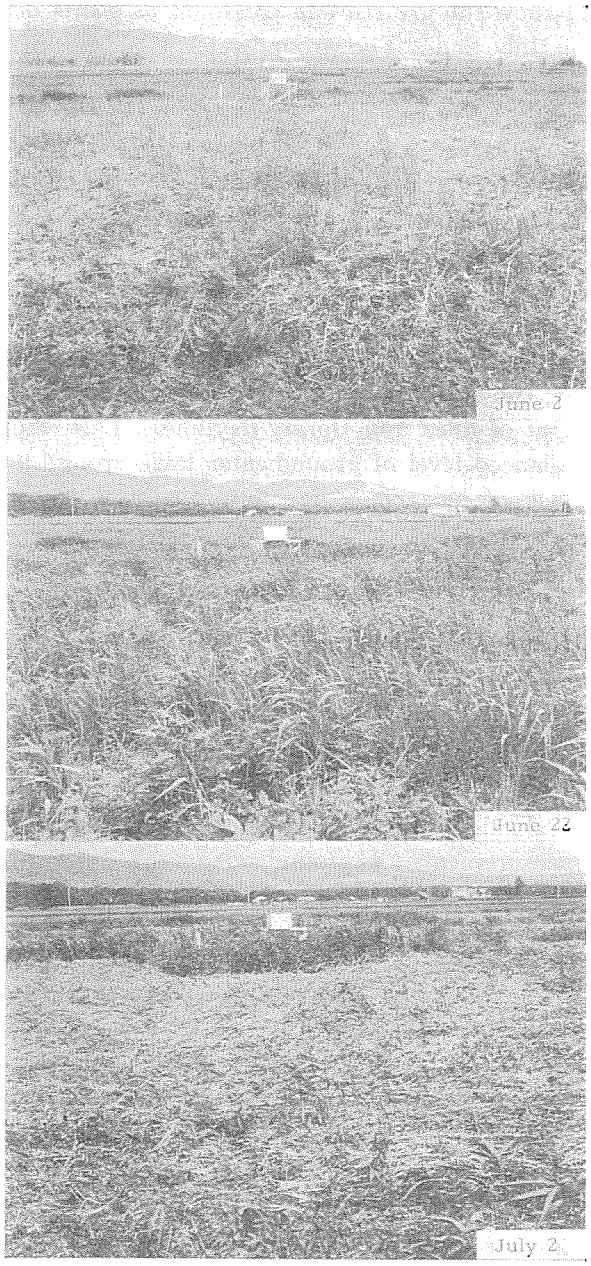


Fig. 11. Growth and condition of plants during the period from June 2nd to July 2nd, 1984, at Bibai Nakanosawa. Water level recorder can be seen in the center of each photograph.

graphs in Fig. 11 show the growth and condition of plants during the period from June 2nd to July 2nd. The groundwater table calculated by peatland tank model, shows good conformity with observed water table before end of June. But since July, after the surface was tilled, the calculated water table begun to fall continuously below the observed water table. This is due to the reduction of effect of transpiration caused by tilling of ground surface. Another influence of surface tilling can be infered from the daily fluctuations of groundwater table after tilling. The diagram (Fig. 4) shows undulated pattern in the falling daily march of the groundwater table during the dry period. It drops during daytime and rises a little during the night. This movement of groundwater table can be explained as follows. The evapotranspiration inside the observed area, where plants (mainly reeds) were kept uncut, exceeded that of tilled area during daytime. This resulted in the formation of an unbalanced level of groundwater table around observation well. Because of this lack of balance, a flow into the well occurred during the night, rising the water table.

Summary

During last decade, the groundwater level measurements were carried out for several peatlands distributed in Hokkaido, northern Japan. Groundwater table fluctuations were classified into several categories according to their fluctuating patterns, and hydrological conditions and land use of investigated peatlands. "Peatland tank model for groundwater table fluctuations" was applied for evaluating the patterns of groundwater table fluctuations.

From the measurements of groundwater table fluctuations in bog of Sarobetsu and reclaimed peatland of Bibai, strong influence of evapotranspiration on groundwater fluctuations was suggested. Groundwater table shows steep fall during the daytime and relatively stable level during the night. Also the influence of changes in the condition of the surface vegetation upon the evapotranspiration was recognizable after the vegetation in the reclaimed peatland was tilled. The changing condition of the vegetation caused decline in the rate of water table fall. Although measured water table fluctuations showed apparent influence of evapotranspiration, the laboratory measurements of the peat moisture content suggested, that the amount of water, which actually moved from groundwater to the atmosphere, is fairly small. This means that the greater part of water for evapotranspiration was supplied from soil moisture, contained between ground surface and the groundwater table in the reclaimed peatland. The soil moisture suction measured in the reclaimed peatland suggests the fact mentioned above.

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