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Snowmelt Runoff at a Seasonal Ground Frost Basin in Southern Sakhalin, Russia

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Abstract

In order to investigate the characteristics of snowmelt runoff in a soil frost basin, hydrological observations were made in two hilly small basins at the southern Sakhalin, Russia, from 1999 to 2000. At one basin (F basin) soil froze notably in winter and soil frost occurred little at another basin (NF basin). According to the measurements of soil temperature and snow survey, soil froze under 70cm depth at F basin due to shallow snowcover under 30cm height. Soil did not freeze at NF basin covered with snow of about 80cm height. We considered the effects of soil frost on runoff characters through the comparisons between each basin and between snowmelt and rain runoff. The runoff response to rainfall that had small fluctuation of discharge was observed at F basin. On the other hand, NF basin showed large and rapid fluctuation. We guessed the deep and the shallow runoff path in the soil layer in F and NF basin respectively through the hydrological characters of soils and the relation between stream and soil temperatures in each basin. F basin and NF basin consist of the permeable blown forest soil and clayey gleysol respectively. The runoff responses to snowmelt were similar to those to rain in both basins. There was not the evidence that revealed the extensive generation of overland flow at F basin. Unfrozen area, for example the vicinity of the stream, might suppress overland flow. And we pointed out the possibility of high permeability of frozen soil.

Key words: Ground frost basin, Snowmelt runoff, Rain runoff, Runoff response, Sakhalin

Introduction

Seasonal frozen ground is found throughout northern regions. The difference of hydrological properties between frozen and unfrozen soils has been generally considered to cause the change of runoff process, erosion and the cycle of chemical components for snowmelt. We report the results of comparative observations at ground frost and nearby non-frost basins, and discuss the characteristics of snowmelt runoff at ground frost basins. Study basins are located in southern Sakhalin, Russia in southern marginal region of seasonal ground freezing.

Dunne and Black (1971) found obvious overland flow on frozen ground through direct observation. The generation of overland flow was caused by impermeable frozen soil. However, field measurements (Kane 1980, Kane and Stein 1983) showed that the infiltration rate of frozen soil was not substantially lower than unfrozen soil except in the case of high ice content. Numerical experiments (Zhao *et al.* 1997, Zhao and Gray 1997,1999) yielded similar results. Another simulation (Johnsson and Lundin 1991) showed the notable generation of overland flow at an arable field, however subsurface flow was actually dominant. Shanley and Chalmers (1999) carried out field observations to investigate the effect of frozen soils on snowmelt runoff character over several years. They observed the runoff responses of high peak flow and runoff ratio, which were caused by overland flow, in several cases, however the effect of frozen soils was not clear in many cases. As described above, the generation of overland flow on frozen ground does not always occur. Our knowledge of the permeability of frozen soils and the change of snowmelt runoff at frost basins is inadequate.

This study focuses the change of the runoff response to snowmelt from that to rain at soil frost

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basin. If extensive overland flow generate at frost basin, we must observe the runoff response characterized by high peak flow and quick recession. On the other hand, if the difference of the runoff response between to snowmelt and to rain is not detected, the generation of overland flow is doubt. And the comparison with non-frost basin, where the runoff processes in soil layer for snowmelt and rain is not different, is carried out to clarify the character of frost basin.

Study sites and Methods

Study basins are located near Vzmor'ye, Sakhalin, Russia at 47° 50' N, 142° 30' E (Fig.1). We had expected that at one basin soil frost would occur extensively in winter and at another frost would not be dominant, as will be described later. In this paper, these basins are called F basin (frost basin) and NF basin (non-frost basin) respectively. The areas of the F and NF basins are about 0.26 and 0.10 km^2 and the altitudinal ranges are about 50-130m and 80-140m

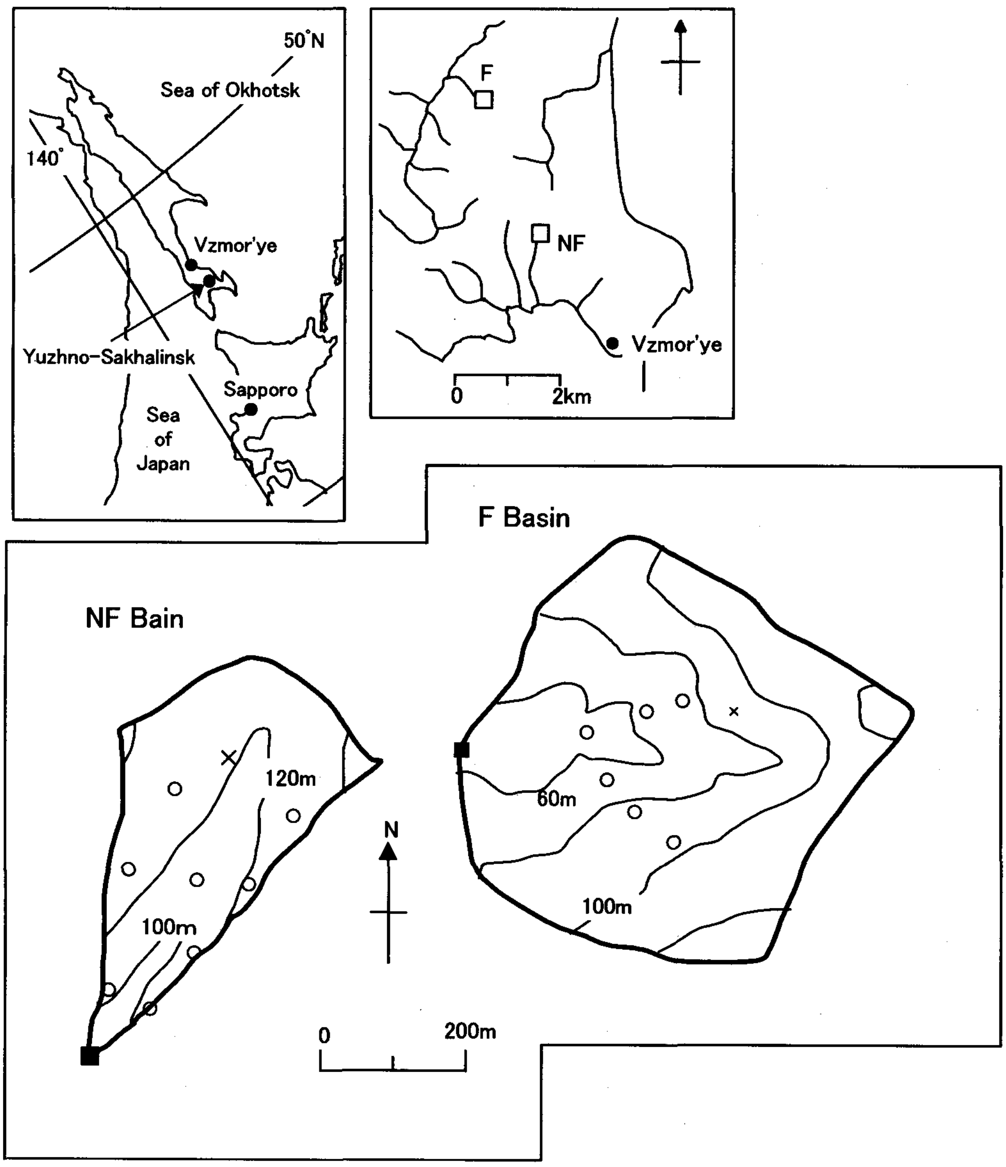

Fig. 1. Study basins. ■: site of water level and stream temperature measurements.
×: site of soil temperature measurement.
■×○: site of snow survey. Contour interval is 20m.

a.s.l. respectively. It should be noted that these values and Fig.1 lack somewhat in accuracy due to being estimates from a rough survey. At Yuzhno-Sakhalinsk, which is located about 100km south from the study area, annual mean air temperature is 2.1℃ and precipitation is about 800mm. The mean temperature in January is –14.1℃ and the precipitation from November to March is about 250mm.

Tree stand, which consist mainly of birch, is not dense at either basin, in particular the density is very low at the upper part of the F basin. Thin tree stand at the F basin was apparently caused by forest fire, as charcoal was detected on the ground surface. In the NF basin, bamboo bushes (*Sasa kurilensis*) of about 1m height cover the forest floor. This is worthy of note. For the growth of *Sasa kurilensis* over 1m height, it must be pressed down onto the ground surface in winter by the load of snowcover over about 1m height in order to prevent cold weather. And the bud in soil of *Sasa kurilensis* dies under about –5℃ (Sasa *et al.* 1992). Therefore the existence of *Sasa kurilensis* community suggests that the surface in the NF basin is covered with snow over 1m height and soil frost does not occur or is limited to a small area. On the other hand, it is expected that the F basin is affected by drifting snow due to the low tree density and that soil frost develops in the large part.

Observations were made from September 1999 to September 2000. Water levels and stream temperatures were measured hourly and two hourly at the outlets of each basin. Discharges at each basin were estimated by the recorded levels and several measurements of flow rates. Soil temperatures were measured at one site in each basin two hourly. The measuring depths were 5,10,20,30,50 and 70cm at the F basin and 5,10 and 20cm at the NF basin. Soil pit observations were made at the sites of soil temperatures measurements in September 1999. In March 2000 before snowmelt season, the surveys of snowcover and stream flows under snowcover were carried out.

Precipitation and snowmelt were not measured, but it was assumed that those were equal between each basin because the distance is small and the tree stands are low in both basins. Later discussion refers to the meteorological data at Yuzhno-Sakhalinsk occasionally. This data is not used for detailed analysis because of the long distance between the study area and Yuzhno-Sakhalinsk. But it is useful for rough discussion. This data is cited from 'the World Surface Meteorological Data' in the Monthly Report edited by Japan Meteorological Agency. This Monthly Report is published by the Japan Meteorological Business Support Center with CD-ROM.

Results and Discussion

1. Conditions of soil, snowcover and stream during winter

In this section, the results of soil temperature measurements and snow survey are described and the aspects of soil frost during winter are searched.

Fig.2 shows the results of soil temperature measurements at each basin. The air temperature in the figure was observed at Yuzhno-Sakhalinsk. In the middle of November, soil temperatures declined rapidly in response to the rapid drop in air temperature. The temperature at 5cm depth at the F basin became sub freezing and did not rise above zero until spring. Soil frost progressed notably into the deeper part of the soil from the middle of January. At the end of March, the temperature at 70cm depth became sub freezing. That means soil frost extended under this depth. The soil temperatures at shallow depths and air temperature fluctuated in similar phase. That suggests shallow snowcover at this site, which cannot prevent heat exchange between the atmosphere and soil surface. At the NF basin, the fluctuations in soil temperature were slight after the middle of November. Thick snowcover probably prevented the penetration of cold content from the atmosphere.

Snow survey was made on March 13 and 14 at 8 sites in the F basin and at 10 sites in the NF basin (Fig.1). Results are shown in Table 1. Snow depths and water equivalents differed widely between each site in the F basin. The probable cause was redistribution by drifting snow. The snow depth at the site of soil temperature measurement was 24cm. It was small as expected by the result of soil temperatures. There was little snow in the area above this site. On the other hand, the snow depths and water equivalents in the NF basin were relatively uniform except for the downstream part. The snow depth at the site of soil temperature measurement was about 80cm. The prevention for soil freezing requires such a depth of snow in this region. The snow drifted in the downstream part that was susceptible to wind due to scattered trees and the narrow ridge and valley. From the above results, we guessed that frozen ground spread in the F basin because of large blown snow field while soil frost was limited to a small area in the NF basin not affected by drifting snow.

Snow stratifications were observed at the outlets of each basin with the snow survey. Depth hoar was dominant at each site and granular snow or ice layer, which indicated melt event, was not detected except in the upper portion. Intense rain or snowmelt most likely did not occur in winter.

Stream flows were seen under snowcover at the outlets of each basin. At least the soils in the vicinity of streams did not freeze. The flow rates at the both streams were about 0.1 ls^{-1}, which corresponded to under 0.1 mmd^{-1} in runoff height. In the northern part of Japan, which is adjacent to Sakhalin, the discharge during mid winter in a mountainous basin is about 1mmd^{-1} (Motoyama *et al.* 1986, Fujiwara *et al.* 1994). Observed discharges in this study were considerably small compared to the above value.

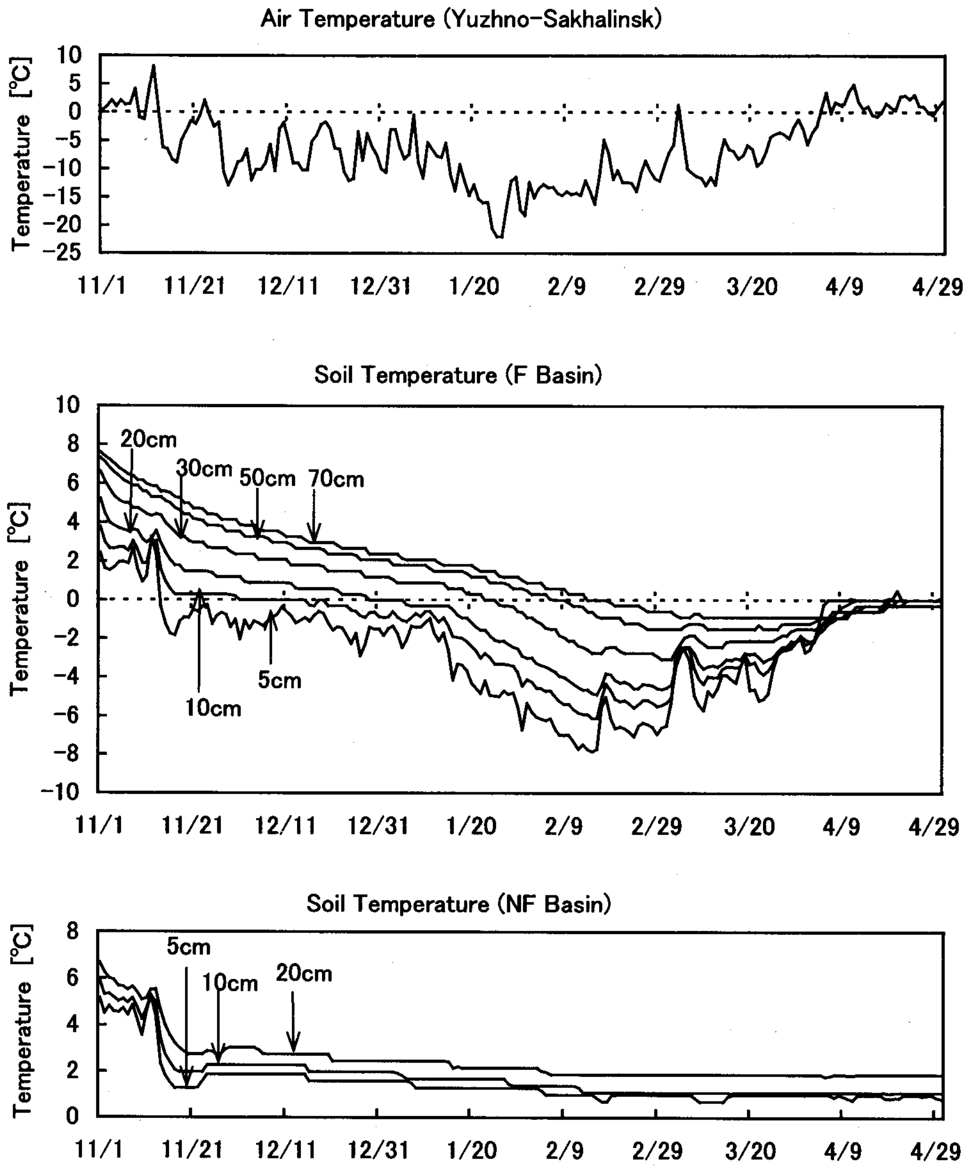

Fig. 2. Daily mean air and soil temperatures (1999-2000).

2. Characteristics of rain runoff

The characteristics of runoff from summer to autumn are described in this section before the discussion about snowmelt runoff. The main purpose of this study is to clarify the effect of soil frost on flood formation to snowmelt, thus we focus as well on storm runoff formation during the non-frost season. Because of no observation of precipitation, it will be discussed based on the character derived from hydrograph and the relation between stream and soil temperatures.

2.1. Runoff response

Fig.3 shows the runoff hydrograph from June to September 2000. Since the area of the basins is uncertain, we do not use specific discharge. Precipitation data at Yuzhno-Sakhalinsk is added in the figure. The fluctuations of the discharges were consistent with rain events regardless of the long distance between the basins and Yuzhno-Sakhalinsk.

The runoff responses to rain were differed considerably between each basin. As shown in the figure, the discharge at the NF basin performed rapid increases and decreases to rainfall and the peak flows were large. On the other hand, the fluctuation of the discharge at the F basin was calmer. During the no rain period, the F basin kept a relatively high flow, however the flow at the NF basin became considerably low.

Comparison of peak discharge for 20 events between each basin is shown in Fig.4. The peak discharge at the NF basin was several times larger

Table 1 Results of snow survey

(1) F Basin

Site	HS cm	HW mm
valley (downstream) *1	34	80
valley (midstream)	174	588
ridge of left bank (downstream)	78	172
ridge of left bank (midstream)	61	165
ridge of right bank (downstream)	104	277
ridge of right bank (midstream)	127	390
ridge of right bank (upstream)	71	217
slope(upstream) *2	24	47

(2) NF Basin

Site	HS cm	HW mm
valley (downstream) *1	132	425
valley (midstream)	85	237
ridge of left bank (downstream)	45	113
ridge of left bank (midstream)	94	277
ridge of left bank (upstream)	71	198
ridge of right bank (downstream)	38	117
ridge of right bank (midstream)	76	215
ridge of right bank (midstream)	66	185
ridge of right bank (upstream)	75	243
slope(upstream) *2	78	193

HS: Height of snow. HW: Snow water equivalent
*1: site of water level and stream temperature measurements. *2: site of soil temperatures measurement.

than that at the F basin. Since the area of the NF basin is smaller than the F basin, the difference of specific discharge is larger.

The character of the recession limb of hydrograph was investigated. It has been empirically known that recession limbs can be approximated by straight line in semi-log scale in many cases. Since such approximation could be applied to the observed hydrograph, we used exponential function $Q=Q_0e^{-kt}$ in order to present the recessions. Q is discharge, Q_0 is initial discharge and t is time. k, which is called recession coefficient, represents the character of recession. For the same 20 events in Fig.4, k ranged from 0.01 to 0.08 h^{-1} at the F basin and from 0.05 to 0.35 h^{-1} at the NF basin. The mean values of k were 0.027 h^{-1} and 0.16 h^{-1} at the F and NF basin respectively. The recession coefficient at the NF basin is considerably larger than the F basin as expected on hydrograph (Fig.3).

The runoff responses and recession coefficients as described above suggest the runoff paths through which supplied water discharge into the stream quickly and slowly in the NF basin and F basin respectively. These results will be taken up in the discussion of snowmelt runoff.

2.2. Stream and soil temperatures

The difference of runoff response between each basin is surely attributable to the difference of runoff processes. In order to clarify the processes, the characters of stream temperatures were investigated. The temperature of supplied water and the heat exchange in the soil layer at the slope and in the stream determine the stream temperature. When the flow rate is high, the exchange of heat in the stream is very little due to the large speed and the large heat capacity of large water mass. Thus the exchange at the slope controls the formation of stream temperature. The comparison between stream and soil temperatures must provide information about runoff processes in the soil layer at the slope. For example, Kobayashi *et al.* (1994) investigated the runoff path in soil layer using the comparison of stream with soil temperatures during snowmelt and rain. According to their results, the stream temperatures during rain and snowmelt runoff approached to the soil temperature at the same depth.

Fig.5 shows hydrograph, stream and soil temperatures from July 21 to August 3 for 2000 during which five storm runoffs occurred. 16 ls^{-1} and 81 ls^{-1} of the max discharges at the F and NF basin were observed around noon on August 1 during this period.

Firstly the result of the F basin is described. During the non-rain period, the stream temperature was lower than the soil temperature of 5cm depth, however both temperatures showed diurnal fluctuation in the same phase. This indicates that the stream temperature is affected by solar radiation in the same way for soil surface. However the stream temperature performed a different aspect during rain runoff. On July 22, the stream temperature began to decline just after the onset of rain runoff. If storm runoff did not occur on this day, the stream temperature must rise because the soil surface temperature rose. The stream temperature before the event was around the soil temperature of 30cm depth, after that it fell near to the temperature of 70cm depth. It was not clear on July 26 and 30. However on July 27 and, August 1 and 2, we could see that the stream temperature changed in a different phase from the soil surface temperature. On August 1, the stream temperature rose in spite of the decline of the soil temperature of 5cm depth. The change of the stream temperature seemed to relate to the soil temperature in the deep part, which rose during this period. Finally the stream temperature fell under the soil temperature of 70cm depth on August 2. During rain runoff, the stream temperature showed the different trend from the soil surface temperature and performed the change similar to the soil temperature at the deep part of soil layer or got near the temperature. These results suggest that the dominant runoff path exists at the deep part of the soil. The

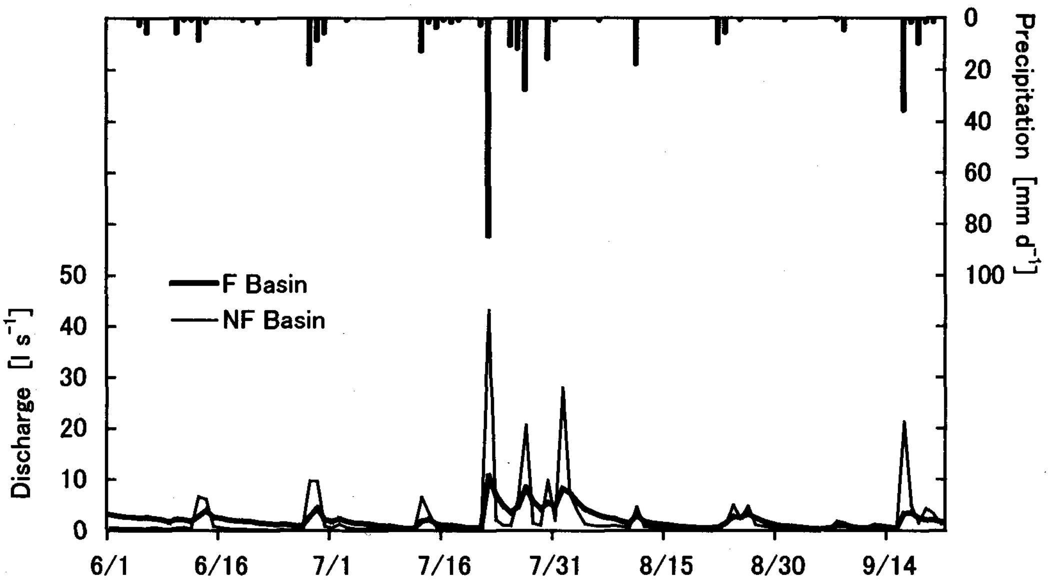

Fig. 3. Daily precipitation at Yuzhno-Sakhalinsk and daily mean discharges at the F and NF basins for 2000.

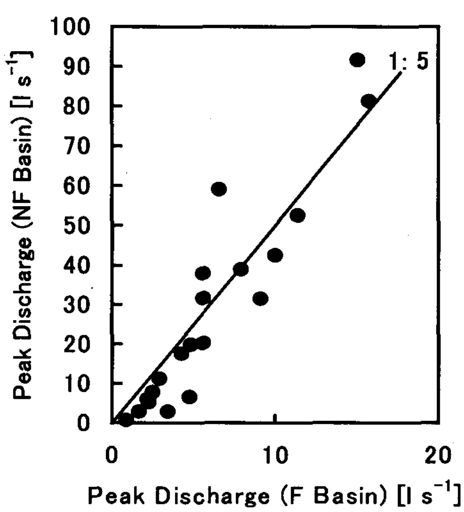

Fig. 4. Comparison of peak discharges for rain between the F and NF basins.

path would probably be under 70cm depth because the stream temperature fell under the soil temperature of that depth on August 2.

At the NF basin, there was not a large difference among the stream and soil temperatures of 5cm and 20cm depth. The soil temperature of 5cm depth fluctuated in a smaller range than that at the F basin. Perhaps the bamboo bushes at the forest floor prevented solar radiation. During the non-rain period, the stream temperature fluctuated in the same range and phase of soil surface temperature. After the start of rain runoff, the stream temperature went near the soil temperature of 20cm depth. It was clear on July 22, August 1 and 2. The runoff path around 20cm depth is possibly expected.

The fluctuations of temperatures during rain runoff at each basin as described above were found in other rain events except for several cases of small flood, in which the stream temperatures were probably affected by the heat exchange in the streams.

2.3. Runoff processes for rain

The surface in the F basin is covered with brown forest soil of about 1m in thickness in which clay content is not high. The soil in the NF basin is gleysol and rich in clay. It is easily supposed that the F and NF basins consist of permeable and impermeable soil respectively. The soil layer in the NF basin was saturated with water up to the very shallow part on the day of soil pit observation in September 1999. The high water table is reasonable from the existence of gleysol. The runoff process at the NF basin is considered as follows. Rainwater cannot percolate deeper into the soil and so it remains in the saturated zone near the surface and is discharged into the stream through the saturated zone. On the other hand, at the F basin, supplied water passes through the deep part of the soil layer after the percolation. Such runoff processes are consistent with the presumption derived from the fluctuations of stream and soil temperatures. And that is not inconsistent with the runoff responses that are characterized by small and large fluctuations of discharges at the F and NF basins.

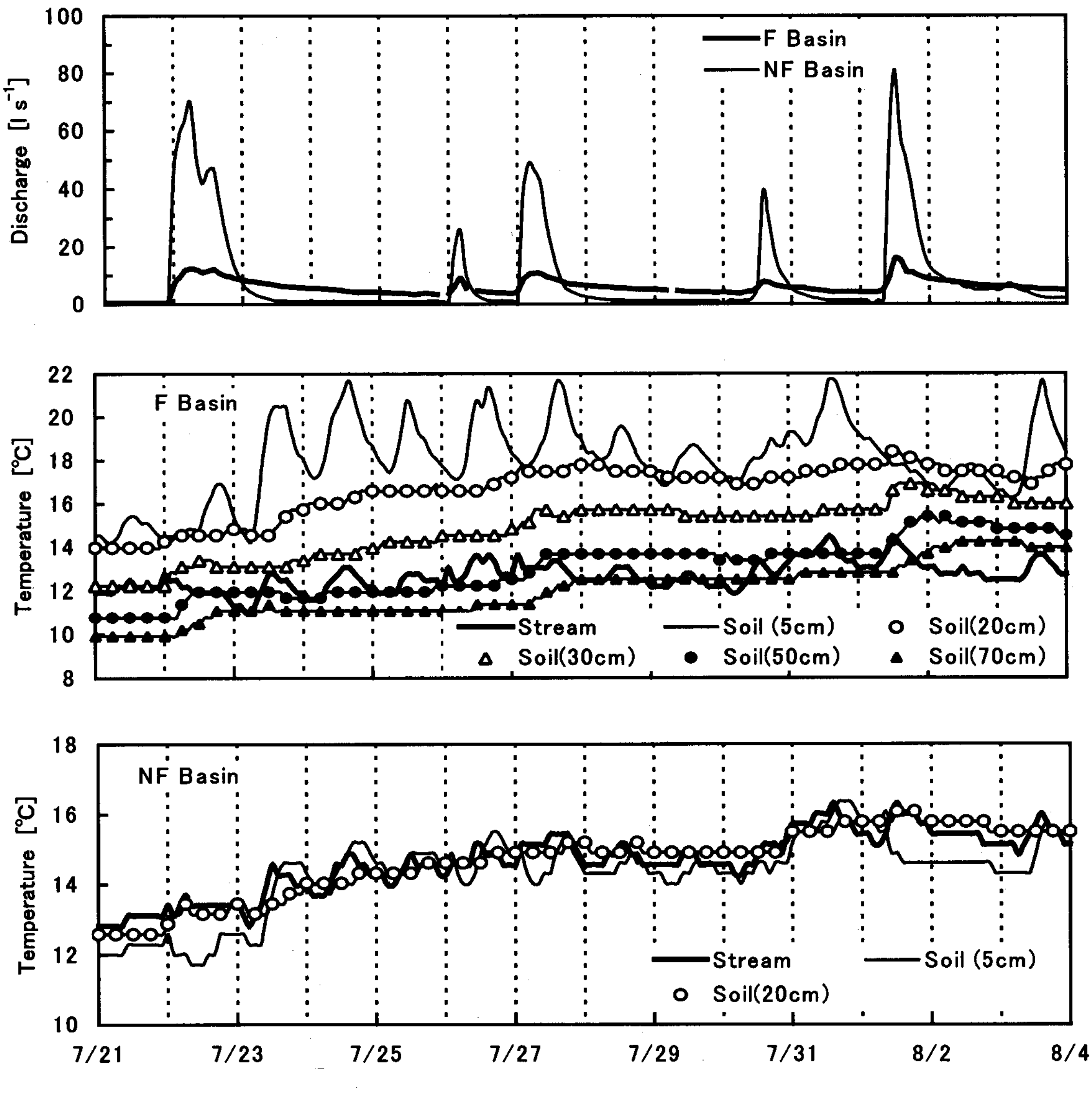

Fig. 5. Runoff hydrograph and stream and soil temperatures at the F and NF basins for 2000.

3. Characteristics of snowmelt runoff

The difference of the surface soils provides the difference of the characters of rain runoffs between each basin as described in the previous chapter. We will discuss the characteristics of snowmelt runoff through a similar analysis.

3.1. Runoff response

Fig.6 shows the hydrographs at each basin and air temperature at Yuzhno-Sakhalinsk. When the daily mean temperature became positive on April 4, remarkable discharges started at both basins. Rain would fell on snowmelt on this day. After that, active discharge continued with diurnal fluctuation except on unseasonable days. Diurnal fluctuation of discharge was caused by that of surface snowmelt. Diurnal fluctuations ceased around the middle of May when snowcover disappeared in most areas in the basins. The fluctuations of discharges at the F and NF basins were small and large respectively in the same way as in the rain event.

A comparison of peak flows is shown in Fig.7. In the figure, the data is divided into two periods before and after May 4. In most cases, the peak flows at the NF basin were larger than the F basin, but the differences were small and the inversions occurred occasionally in the late period The disappearance of diurnal fluctuation at the F basin was several days later than the NF basin. It indicates that the expansion of snow free area at the NF basin was earlier. That would cause the smaller differences or the inversion of peak flows during the late period. The discussion below uses the data during the early period.

The trend lines in Fig.7 have the intercept on the F basin axis while the line for rain event (Fig.4) passed around the origin. This intercept was yielded from the

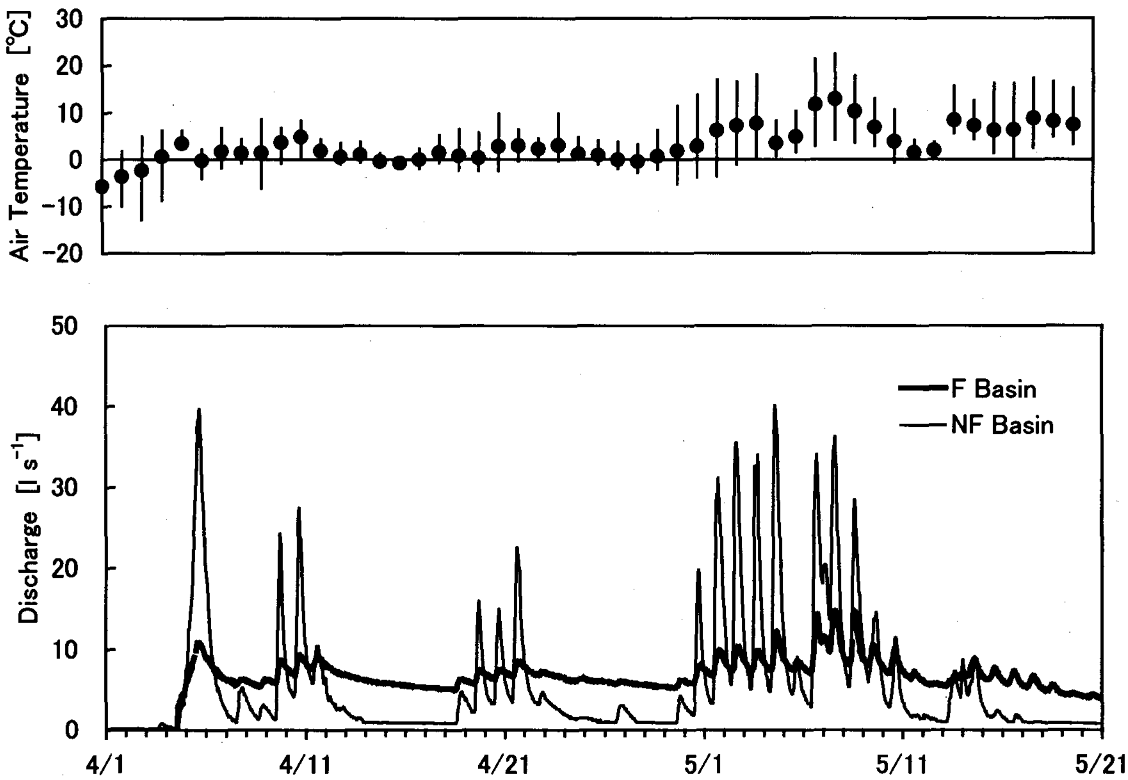

Fig. 6. Daily mean temperature and snowmelt runoffs at the F and NF basins for 2000.
Upper: Daily mean temperature at Yuzhno-Sakhalinsk. Bar means diurnal range.
Lower: Runoff hydrograph.

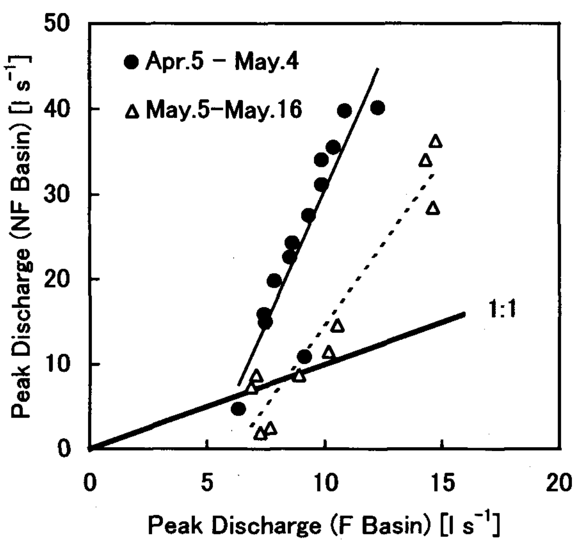

Fig.7. Comparison of peak discharges for snowmelt between the F and NF basin. Solid line and broken line mean the trend for early and late periods respectively.

larger pre-discharge in snowmelt runoff. Since snowmelt occurs on a daily basis, snowmelt runoff often starts while the discharge generated on the preceding day continues. Then pre-discharge for snowmelt runoff was larger than rain runoff. The pre-discharge at the F basin was particularly large because of the slow recession. That is the reason for the shift of the trend line toward the F basin.

As in the above circumstances, Fig.7 cannot be compared with Fig.4 directly. The increment from pre- to peak flow rate is addressed for comparison. This increment is caused by direct runoff, which is the component that quickly forms floods. In general, this component is not clearly estimated on a hydrograph, however this increment is considered as one of the indexes to present the character of direct runoff. Results are shown in Fig.8. As shown in the figure, the increment of discharge at the NF basin was about seven times larger than that at the F basin for both rain and snowmelt events. If overland flow was generated extensively during the snowmelt period in the F basin, the increment in the F basin increased and the difference between each basin decreased.

The recession coefficients, which were estimated by the exponential approximation for falling limb, were compared with those for rain runoff (Fig.9). The mean values were 0.011 h^{-1} and 0.080 h^{-1} for F and

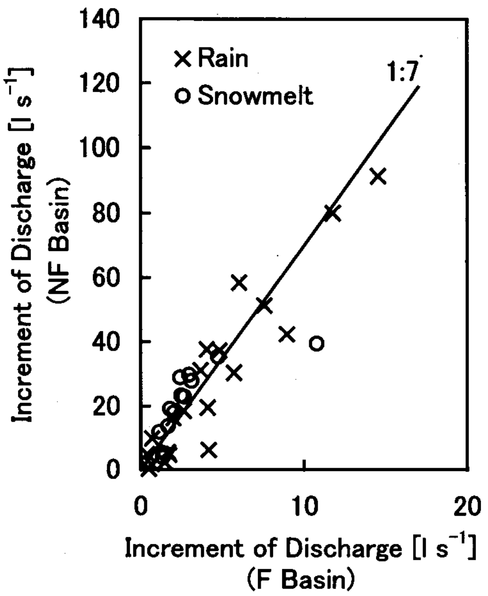

Fig. 8. Comparison of the increment of discharges for rain and snowmelt between the F and NF basins.

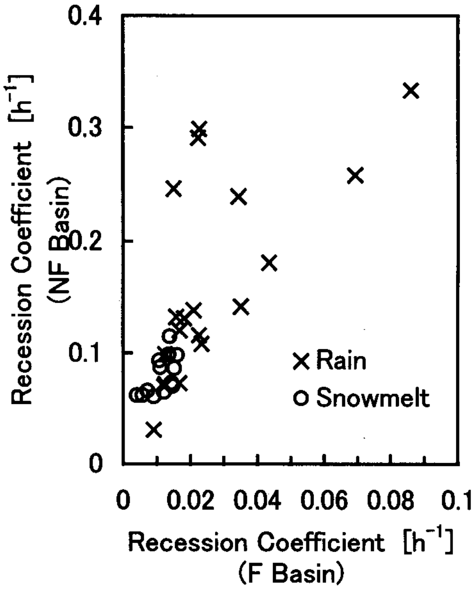

Fig. 9. Comparison of the recession coefficients in rain and snowmelt runoffs between the F and NF basins.

NF basin respectively for 13 snowmelt events. These were smaller than the mean values for rain runoff. The recession coefficients for rain events were distributed widely. But the relation of the recession coefficients between each basin was similar in the low range, in which the coefficients for snowmelt runoff distributed. It was guessed that the recession character of snowmelt runoff did not change from rain runoff.

We could not find evidence that revealed the extensive generation of overland flow at the F basin during the snowmelt period. On the contrary, subsurface flow might be dominant at the F basin in the snowmelt period because the relations of the direct runoffs and of the recessions between each basin were similar to those for rain runoff. The recession coefficients of 0.01 – 0.02 h^{-1} at the F basin were close to the values that Nomura *et al.* (2001) estimated for a mountainous basin in northern Hokkaido, Japan, where subsurface flow in the deep part of the soil layer would be dominant for snowmelt runoff.

Table 2 Stream and soil temperatures at NF Basin

[℃]

	Stream	Soil		
		5cm	10cm	20cm
Ave.	2.2	0.9	1.1	1.9
min.	1.2	0.1	0.5	1.6
Max.	2.4	1.3	1.4	2.2

Period: Apr.4 – May 4

3.2. Stream and soil temperatures

The runoff mechanisms were searched through the analysis of stream and soil temperatures in the same manner as for rain runoff. Table 2 presents the stream and soil temperatures in the NF basin. The long term and diurnal fluctuations of both temperatures were not observed. The mean stream temperature of 2.2℃ was near the mean value 1.9 ℃ of the soil temperature at 20cm depth. During rain runoff, the stream and the soil at 20cm depth temperatures were near as well (Fig.5). These results indicate the same runoff processes in soil layer for both snowmelt and rain. In the discussion of runoff response, it is assumed tacitly that the runoff processes in the NF basin during snowmelt period did not differ from the rain runoff processes. The character of the temperatures described above supports this assumption.

The time series of the soil temperatures in the F basin are shown in Fig.10. On April 4 when active runoff started, the temperatures at all soil depths were below the freezing point. The temperature at the 5cm depth rose rapidly to 0℃ after that and the other temperatures reached 0℃ progressively from the shallow to deep part of soil. The temperatures at 50cm and at 70cm became 0℃ at the end of April and early May respectively. The stream temperature at the F basin fluctuated little, as in the NF basin. The mean ,maximum and minimum temperatures from April 4 to May 4 were 0.9, 1.2 and 0.3 ℃ respectively. To all appearances, the lower temperature than the NF basin means the large contribution of the overland flow through the ground surface under snowcover where the soil temperature

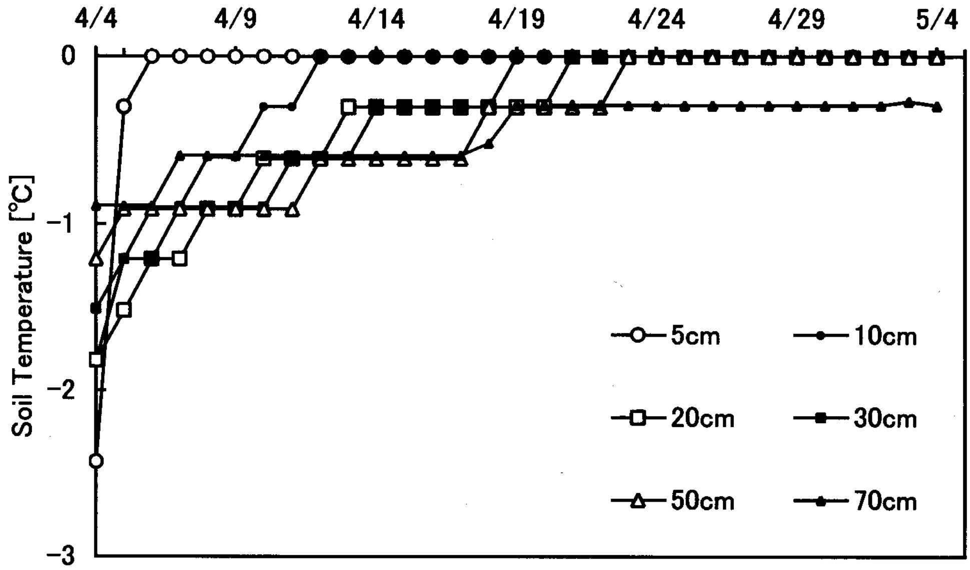

Fig. 10. Soil temperature during snowmelt period at the F basin.

is fixed at 0℃. However the temperature of subsurface flow is not warmed up due to cold soil. Then one can' not distinguish between subsurface and surface flows by stream temperature.

3.3. Discussion of snowmelt runoff processes at the ground frost basin

In early April, overland flow was likely generated at the site of soil temperature measurements in the F basin because subsurface was in a state of subfreezing. However other results did not seem to reveal the extensive generation of overland flow. One reason is the complexity of the factors that control runoff. Though the study basin is small, it is not under uniform conditions over the entire basin. There were some unfrozen areas in the F basin. For example, the vicinity of the stream did not freeze probably because the stream flow continued during winter. The non-uniform distribution of snowcover depth in the basin assumes that the development of soil frost was various. Unfrozen area or dissolved area at early snowmelt period might abate overland flow due to high permeability. If macro pores exist, the relation between the generation of surface flow and the infiltration ability at the ground surface must be confused, as described in Johnsson and Lundin (1991).

The permeability of frozen soils is one of the most important problems. Dunne and Black (1971) captured directly the overland flow on frozen ground and Shanley and Chalmers (1999) detected the runoff response affected by overland flow in several events. In these cases, the soil surface contained rich ice. Such a soil has very low permeability as shown by Kane and Stein (1983). These results indicate that the critical factor that controls the generation of overland flow is the ice content at surface soils. Shanley and Chalmers (1999) mentioned rain and snowmelt in winter as conditions to raise ice content because the supplied water refroze easily at the cold soil surface layer. According to the meteorological data at Yuzhno-Sakhalinsk, two rain events and several days of positive maximum air temperature were observed during winter. The liquid water would be brought to the snow surface on these days. However, we did not detect wet-metamorphosed snow particles at the lower part of snowpack at the end of winter. The liquid water did not reach the ground surface during the winter. Therefore high ice content at the soil surface was probably not realized.

Our observations did not detect the change of runoff character caused by overland flow on the frozen ground. Conversely the results of the comparison with rain runoff seem to indicate the dominant subsurface flow during the snowmelt period at the F basin. It is not obvious whether the permeability of frozen soils became substantially lower. If the high permeability of the soil at the F basin was kept during the snowmelt period, the character of the snowmelt runoff would be similar to rain runoff as described in this paper. The permeability of frozen soil is sensitive to ice content, which is controlled by winter weather. We must point out the possibility of the yearly change of the runoff character.

Conclusions

Hydrological observations were made at the ground frost basin (F basin) in southern Sakhalin, Russia from 1999 to 2000. We investigated the characteristics of snowmelt runoff at the frost basin through comparisons with rain runoff and the non-frost basin (NF basin). Our results showed that the extensive generation of overland flow at F basin was doubt. The results are as follows.

(1) Soil temperatures were measured at one site in each basin. Soil frost extended under 70cm depth at the measuring site in F basin while soil temperature was positive in NF basin during winter. Since snow blowing filed spread in F basin, we guessed that soil frost occurred in large area. In NF basin snow accumulation was uniform comparatively.

(2) F basin showed the response of small fluctuation of discharge to rainfall while NF basin showed the large fluctuation. The relation between stream and soil temperatures and the character of soils in each basin suggested that the discharge in F basin passed through deep part of soil layer, which was at or under about 70cm. In NF basin the dominant path was located at about 20cm depth.

(3) Runoff responses at each basin to snowmelt were similar to those to rain. Evident change caused by soil frost was not observed. Stream temperatures were about 1℃ and 2℃ at F and NF basins respectively. But the lower temperature at F basin does not mean the large contribution of overland flow readily because subsurface flow through cold soil has low temperature. In NF basin, the stream temperature corresponded with the soil temperature of 20cm depth in the same way for rain event.

(4) We pointed out the possibility of the dominant subsurface flow in F basin during snowmelt period because the runoff response to snowmelt did not differed from that to rainfall. One reason of the occurrence of subsurface flow is the existence of some unfrozen or weak frozen area in the basin. And the permeability of frozen soil might be kept because winter condition suggested that ice content in soil surface was not high. We should mention that runoff processes might change yearly because of the difference of soil frost condition.

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