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Runoff characteristics in the Gozha Glacier region on the south slope of the West Kunlun Mountains

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Abstract

The drainage area of the Gozha glaciated region is 223.9 km^2, in which 105.2km^2 is occupied by glaciers, covering 47% of the total area. The firn line of glaciers ranges around 6000m a.s.l. The termini of glaciers are at about 5390m a.s.l..

At the hydrographic station at the Base Camp (5260m a.s.l.), the annual mean air temperature is −6.7°C, and average annual precipitation in the drainage area is 227.5 mm. Of the total runoff in this glaciated region, glacier melt water occupies 80% and precipitation 20%.

The river discharge is very limited in the Gozha glaciated region; the depth of the glacier runoff is 200.2mm. The specific discharge of the glaciers is 17.7 L/skm^2. The net glacier runoff coefficient is 0.73. The mean runoff coefficient of the whole glaciated region is 0.51. It is conjectured that the characteristic values of runoff in this region are the smallest among all known glaciated regions in China.

Owing to the short melting period and the concentration of precipitation, the annual discharge is confined to the warm and rainy months between June and August (80% of the annual total).

In the glacier covered area, the proportion of the glacier discharge in July to September occupies 90% of the annual total. The period of intensive ablation in this region lags a month behind that of other continental type glacier regions in China.

The variation coefficient C_V reaches a maximum of 0.32 in July and averages 0.16 over a year, which means that the yearly variation of runoff is quite stable. The former is mainly related to the pre-ablation precipitation, while the latter results from ablation in different years.

1. Introduction

During the Sino-Japanese Joint Glacier Expedition in the West Kunlun Mountains in June – August of 1987, a systematic observation of hydrology and meteorology was carried out in the Gozha glaciated region which located on the south slope of the West Kunlun Mountains and plentiful data were gained. This paper studies the basic characteristics of glacier discharge based on those data .

2. Regional geographical conditions in the research area.

Glacier melt water from the Gozha glaciated region directly drains into Gozha Lake, which is an inland lake. A meteorological observation station and a general hydrographic station were set up at Base Camp (5260m a.s.l., 3km away from the end of Gozha Glacier). Another hydrographic station was set up on the Tianshui River, 5400m a.s.l., 2km away from Base Camp.

At the two hydrographic stations, a relationship is established among the water level, discharge current velocity and cross-sectional area (Fig. 1).

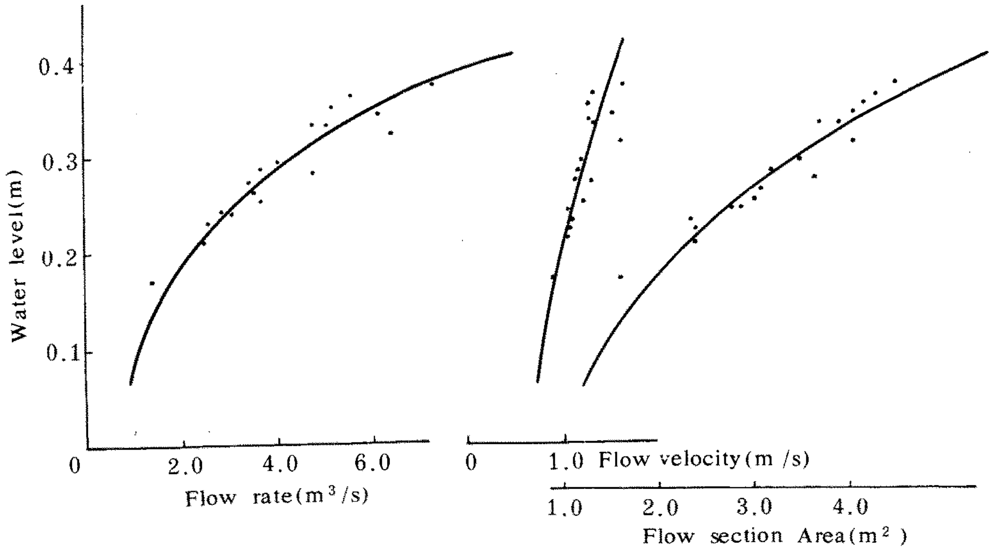

Fig. 1. Relation of water level to flow rate, flow velocity, and the flow cross-sectional area at Base Camp on the south slope of the West Kunlun Mountains.

The area and number of glaciers above each hydrographic station are shown in Table 1. Three observation sites for air temperature measurement were set up at 6250m, 6000m and 5180m (beside Gozha Lake).

There are 13 glaciers in this drainage basin, most being valley glaciers. The largest valley glacier is Gozha Glacier with area of 33.5km^2, from 5390m to 6530m a.s.l. The main source of runoff at No. 1 is melt water from this glacier, which accounts for 70% of the total glacier melt discharge in this region. The second large glacier is Chongce Ice Cap with area of 16.4km^2, from 5720m to 6370m a.s.l. The ablation on this glacier is slight, only in the middle of August does the ablation area emerge. There are 7−9 moraine lakes around the area. The melt water first drains into those lakes, then disappears in the form of infiltration and evaporation. Outflow directly into rivers was very small. The glaciers in the Tianshui River basin are mainly cirque glaciers, with the end of the glacier tongue above 5600m a.s.l. The firn line is about 6000m a.s.l. The mean elevation of the basin is 5915m a.s.l..

At Base Camp, in the period of intensive glacier ablation, the monthly mean air temperature were 2,3 °C and 2.6°C in July and August respectively. where annual mean temperature was −6.7°C. At the tongue of Gozha Glacier, the mean temperature in the ablation period (from May to September) was −0.7°C,

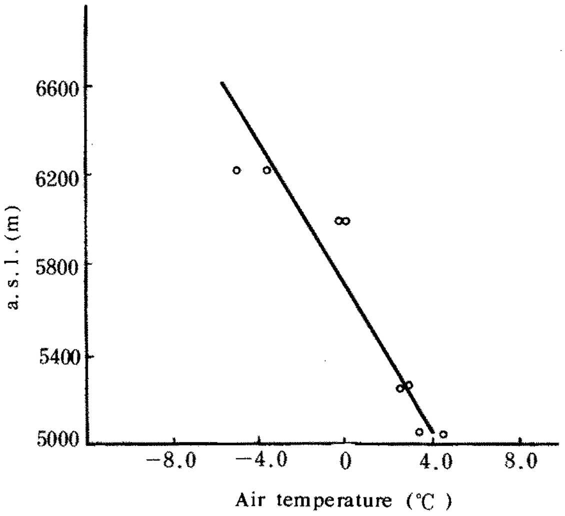

Fig. 2. Air temperature variation with altitude in the Gozha glaciated area in the West Kunlun Mountains.

Table 1. Distribution of glaciers and the valley area above hydrographic stations in the Gozha glaciated area.

Station name	Base Camp	Tianshui River Station
Valley area (km^2)	223.9	66.0
Number of glacier	13	6
Glacier area (km^2)	105.2	22.3
Glacier coverage(%)	47	34

which was −4.5℃ at the firn line on the glacier. In the glaciated area, air temperature decreases with the increase of elevations (Fig. 2). The lapse rate is 0.63℃ per 100m.

Precipitation in this area belongs to the middle-north plateau summer precipitation type (Li, 1986). It is mainly concentrated in July and August. At the Base Camp (5260m a.s.l.) the total precipitation in July and August was 91.8 mm. Because of the influence of the southwestern monsoon, the precipitation in July was 75.8mm, whereas it was only 16.0mm in August. Precipitation depended on elevation (Table 2). Precipitation at 5800m a.s.l. was nearly twice that at 5260m a.s.l.. It is calculated that annual precipitation near firn line is about 437.5 mm. Thus it is clear that although it is very dry and less precipitation at the edge of the mountains, the precipitation in the interior of the West Kunlun Mountains is still considerable. In addition, the low air temperature promotes the formation of large glaciers.

3. Main factors affecting glacier ablation

Air temperature reflects the combined influences of solar radiation, turbulence heat exchange and other factors. From daily mean discharge, air temperature and precipitation (Fig. 3) at Base Camp during the observation period, the variations of discharge and air temperature apparently coincide, although precipitation is not synchronous with the other two factors. Therefore, the principal factor influencing glacier ablation is air temperature.

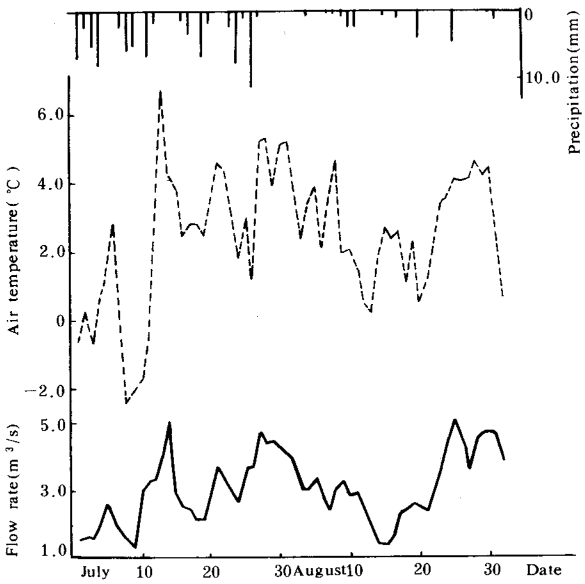

Fig. 3. Variation of flow rate, air temperature and precipitation at Base Camp in July and August, 1987.

During June and July, the rivers are mainly supplied by melt water from seasonal snow; the discharge is very small during cloudy, snowy or negative temperature periods, and very large during fine or positive temperature interval. The ablation mainly takes place at the end of the glacier tongue and in the nonglacier area.

From August to the middle of September, the rivers are mainly supplied by glacier melt water, and temperature varies little.

The relation between 3-day mean discharge and air temperature can be expressed by an exponential curve (Fig. 4), which showed two different curves during June-July and August-September.

Table 2. Comparison of precipitation (mm) Base Camp (5260m) and ABC (5800m) from August 6 to 19, 1987.

Date(August)	6	7	8	9	10	11	14	19	Total
ABC (5800m)	1.0	1.3	1.4	4.8	2.7	1.5	0.3	3.0	16.0mm
BC (5260m)	0.1	0.2	0.6	2.2	1.8	0.0	0.3	3.9	9.1mm

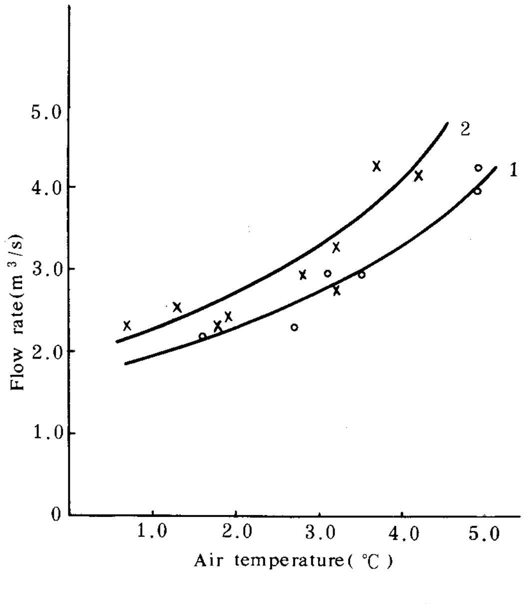

Fig. 4. Relationship between three-day average flow rate and air temperature at Base Camp during the melting season, 1987. Curve 1 (circles) is in June and July, and curve 2 (crosses) is in August and September.

4. Calculation of glacier runoff

1) Calculation of Runoff in the glacier region.

Two formulas are set up separately for 3-day mean air temperature between the Base Camp and Ganggumuluoke hydrographic station, 300km away from Base Camp at the Yurunkax River on the north slope of the West Kunlun Mountains.

$$T_1=0.86\ T_0-5.77 \quad (r=0.80,\ n=18). \quad (1)$$

$$Q_1=0.01\ Q_0+0.78 \quad (r=0.88,\ n=23). \quad (2)$$

where T_1 and T_0 are the 3-day mean air temperatures (℃), at Base Camp and Kangxiwar Station respectively, Q_1 and Q_0 are respectively 3-day mean discharge at Base Camp and Ganggumuluoke Station on the Yurunkax River (m^3/s), r is the correlation coefficient, and n is the number of samples.

From the correlation coefficients we are convinced that the two formulas are reliable. They are used in interpolation and extension of the year's incomplete data of air temperature and discharge.

The relationship between the daily mean discharges at the Base Camp, Q_1, and the discharge at Tianshui River Station (on the upper reach), Q_2 can be expressed as:

$$Q_2=0.2333\ Q_1^{1.21} \quad (r=0.84,\ n=45). \quad (3)$$

From equation (3), the discharge at Tianshui River Station in the no-observation period was estimated.

2) Ablation Period of the Glacier

Positive temperature first appeared at the end of May. An advance party found water flowing in the river bed at Base Camp at the beginning of June, but the discharge was very small and the stream disappeared from 4:00 to 11:00 (CST). [CST, Chinese Standard Time, is GMT plus 8 hours. The noon time is about 14:40 (CST).] Continuous negative temperature appeared at the end of September. The record of discharge of the Yurunkax River on the north slope of the West Kunlun Mountains shows that air temperature and discharge descend very abruptly at the beginning of September. Thus the ablation period lasted from the end of May to the end of September, about 130 days in total.

3) Glacier runoff

In the discharge, glacier melt water was estimated separately from precipitation-formed runoff. Curves of discharge, air temperature and precipitation at the two stations are shown in Fig. 5.

In a small closed basin in the high alpine region, underground water can be regarded as consisting of the seepage loss of precipitation and glacier melt water. The components of underground water could not be separated in this paper.

In this paper we put the snow and ice melt water from the glacier during the ablation period and precipitation runoff on the glacier surface during summer into the category of glacial runoff. Runoff from the seasonal snow melt and precipitation on bare valley slopes are regarded as rainfall supply from the nonglacier area.

There is little snowfall in the Gozha glaciated region, and the precipitation during spring and summer is completely in snowfall. After each snowfall, the snow on the bare valley slopes melts completely within several hours or 1 – 2 days due to the increase of air temperature. During continuous fine days the rivers are only nourished by the snow and ice melt water from the ablation area of the glacier. Thus we set up the relationship between daily discharge and mean temperature, for the days when there was no precipitation for at least three days. The relationships are in exponential form (Fig. 6).

The formulas are as follows:

$$Q_{1A}=0.98\ e^{0.28T} \quad (r=0.99,\ n=8). \quad (4)$$

$$Q_{1B}=1.82\ e^{0.20T} \quad (r=0.91,\ n=13). \quad (5)$$

$$Q_{2A}=0.19\ e^{0.42T} \quad (r=0.96,\ n=8). \quad (6)$$

$$Q_{2B}=0.24\ e^{0.46T} \quad (r=0.83,\ n=12). \quad (7)$$

where Q ia the daily glacier melt discharge (m^3/s), suffix 1, 2, A, B mean respectively at Base Camp, at Tianshui River Station, during June – July, and during August – September. T is daily mean air temperature (℃) at Base Camp on the corresponding day, r is the correlation coefficient, and n is the number of samples.

The glacier melt discharge can be estimated from air temperature by these formula (4), (5), (6) and (7). Subtracting the glacier melt discharge from the total discharge, we obtained the precipitation-formed runoff.

5. Basic characteristics of runoff

1) Annual runoff

The characteristic values of runoff of the rivers in

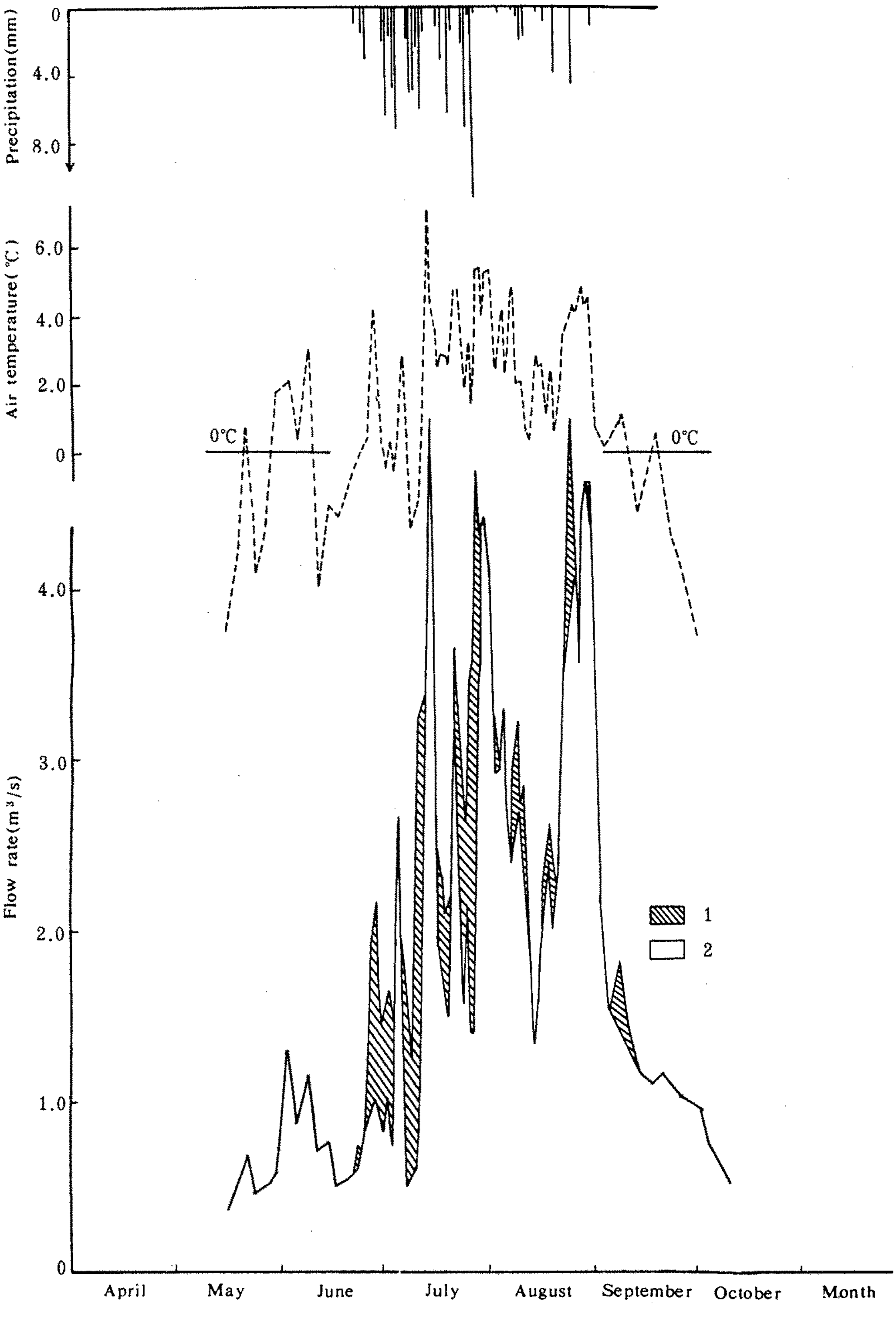

Fig. 5. Variation of flow rate, air temperature, precipitation and composition of runoff at Base Camp. The flow rate is separated into the precipitation runoff (1) and the glacial runoff (2).

Table 3. Parameters of annual runoff in the Gozha glaciated area, from May to September, 1987.

Station name	Runoff type	Mean discharge Q (m^3/s)	Runoff volume W $(10^6\ m^3)$	Specific discharge M $(L/s.km^2)$	Runoff depth R (mm)	Runoff composition (%)
Base Camp	Combination runoff	2.31	25.97	10.3	116.0	100
	Glacier runoff	1.86	21.05	17.7	200.2	81
	Precipitation runoff	0.45	4.92	3.8	41.4	19
Tianshui River Station	Combination runoff	0.64	7.09	9.7	107.4	100
	Glacier runoff	0.46	5.07	20.7	227.9	71.6
	Precipitation runoff	0.18	2.02	4.1	46.1	28.4

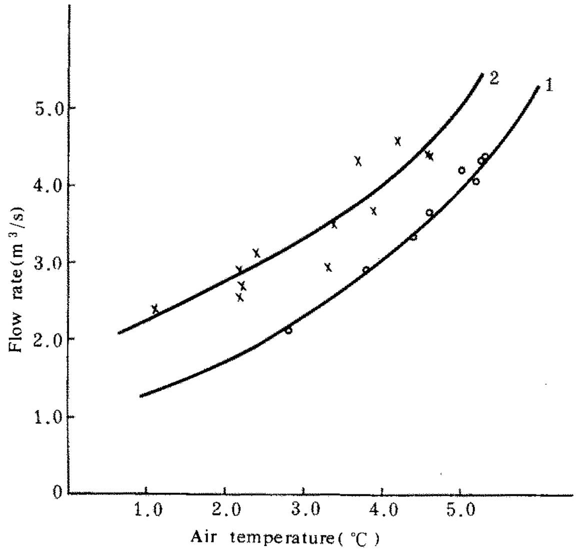

Fig. 6. Relationship between daily mean flow rate and daily mean air temperature during no precipitation days at Base Camp. Curve 1 (circles) is in June and July, and curve 2 (crosses) is in August and September.

the Gozha glaciated region during 1987 are shown in Table 3.

From Table 3 we can see that the discharge in the Gozha glaciated region is not at all great. Considering the Base Camp, the annual runoff depth and specific discharge are 116.0mm and 10.3 L/skm^2 respectively in the glaciated region. Net glacier runoff is 200.2 mm, and specific discharge of the glacier runoff is 17.7 L/skm^2. If it is assumed that the two ice caps in the region do not melt and their area is excluded from the total glacier area, the net glacier runoff depth and the specific discharge become 245.0mm and 22.1 L/skm^2 respectively.

The annual runoff is also related to the glacier type. For example there are two ice caps in the basin above Base Camp and none in the basin above Tianshui River Station; thus the runoff in the former basin is smaller than that in the latter.

In order to determine mean runoff coefficient, precipitation must be assessed. The water balance equation is as follows in a closed basin.

$$P = R + E. \tag{8}$$

where P, R, E are respectively the annual precipitation, discharge and evaporation.

In this equation R is known. Evaporation in the basin is composed of two parts: evaporation from the glacier area and nonglacier area. According to observation in July and August, monthly evaporation on a bare ground surface is about 20.0mm. On the firn surface of Chongce Ice Cap, Takahashi *et al.* (1989) estimated the evaporation rate of 1.36 mm/d from July 23 to August 18, 1987, by which monthly evaporation is about 40mm. Thus we obtain average monthly evaporation of 22.3mm in the whole basin. Assuming that the evaporation takes place mainly during May to September in the melting period when air temperature is above 0℃, we obtain an annual evaporation of 111.5 mm. From equation (8) the mean calculated annual precipitation is 227.5mm. The mean runoff coefficient of the glaciated region becomes 0.51. Calculating runoff coefficient for the glacier area in a similar manner, this becomes 0.73. The supply from glacier melt water is the largest, accounting for 70—80% of the annual total discharge. This percentage of glacier supply is larger than that of other continental glacier regions.

2) *Diurnal variation of runoff*

The highest water level lagged behind highest air temperature for 5 hours every day (Fig. 7). The water temperature variation is synchronous with air temperature. In other words the daily maximum air temperature and water temperature appear at about 17:00, whereas the maximum water level appears at 22:00. The minimum daily air temperature and water tem-

Table 4. The annual distribution of runoff at Base Camp in the Gozha glaciated area in 1987.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total	June – August
Combination runoff	0	0	0	0	1.7	12.0	33.0	35.0	18.3	0	0	0	100%	80 %
Glacier runoff	0	0	0	0	0.9	8.9	30.7	39.0	20.5	0	0	0	100%	78.6%

Table 5. The *Cv* value of runoff in the Gozha glaciated area.

Month	1	2	3	4	5	6	7	8	9	10	11	12	May–September
Cv					0.12	0.27	0.32	0.23	0.22				0.16

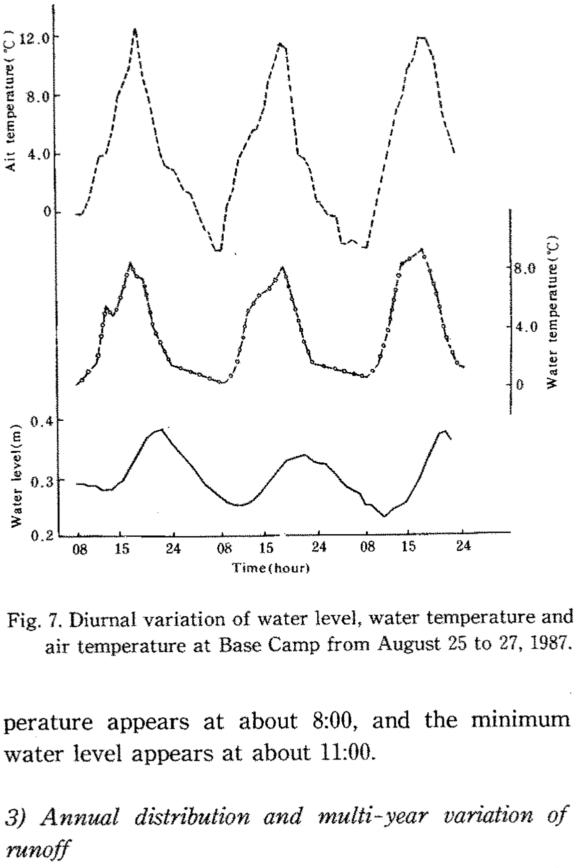

Fig. 7. Diurnal variation of water level, water temperature and air temperature at Base Camp from August 25 to 27, 1987.

perature appears at about 8:00, and the minimum water level appears at about 11:00.

3) Annual distribution and multi-year variation of runoff

In Table 4, the distribution of annual discharge is shown. The period of positive air temperature is very short and the precipitation is concentrated in summer. In a hot and wet year the discharge from June to August may amount to 80% of the year's total.

The short series of discharge data in the Gozha glaciated region is extended based on the long term discharge data of Ganggumuluoke hydrographic station on the Yurunkax River on the north slope of the West Kunlun Mountains. The empirical formula is:

$$Q_1 = 0.009\,Q + 0.55 \quad (r = 0.95,\ n = 13). \tag{9}$$

where Q_1 and Q (m^3/s) represent the 10-day mean discharges at Base Camp and Ganggumuluoke hydrographic station respectively, r is the correlation coefficient, and n is the number of samples.

According to the extended series of 26 years, the annual discharge of 1987 was very close to the multi-year mean. It is suggested that the discharge data observed in 1987 can represent the multi-year average regime of the Gozha glaciated region.

The coefficient of variation C_V reflecting the yearly variation characteristics of the discharge in the glaciated region is shown in Table 5.

The statistical results show that the monthly change of the coefficients of variation is considerable. The maximum appears in July, $C_V = 0.32$, because the discharge in July is influenced by the preceding seasonal precipitation.

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