Property of Sediment Movement in Azusa River (Kamikochi)

Akihiko IKEDA[1*], Yuki IGARASHI[1], Osamu FUSHIKI[1], Hiroki UEMORI[1], Shoji IGARASHI[2], Masahide HASEGAWA[3] and Hidenori SAKO[4]

[1] Sabo and Landslide Technical Center, Japan (4-8-21 Kudan-minami, Chiyoa-ku, Tokyo 1020074, Japan)
[2] Kagoshima Prefectural Office
(10-1 Kamoike-Shinmachi, Kagoshima City, Kagoshima 8908577, Japan: Former in Matsumoto Sabo Office, MLIT)
[3] Matsumoto Sabo Office, Hokuriku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan
(1-8-28 Motomachi, Matsumoto City, Nagano 3900803, Japan)
[4] Hokuriku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan
(1-1-1 Misakicho, Chuo-ku, Niigata City, Niigata 9508801, Japan: Former in Matsumoto Sabo Office, MLIT)
*Corresponding author. E-mail: ikeda@stc.or.jp

Upstream region of Azusa River is widely known as Kamikochi, renowned for its beautiful mountainous scenery. Heavy rain causes sediment discharge including debris flow and significant riverbed aggradation in main stream of the Azusa River that sightseeing facilities were damaged and tourists were isolated due to severed roads and footpaths in the past. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has installed rainfall and water level gauges in the entire watershed and observed the actual condition of sediment movement to predict the future river bed changes and sediment discharge. In this paper, we will present the property of sediment movement and rainfall-runoff processes in the upstream region of Azusa River (Kamikochi) based on actual condition of sediment movement and results of monitoring data. The active sediment production and discharge source are identified, and one reason of the riverbed changes (aggradation and degradation) estimated that the riverbed width and meandering with the quantity of the sediment discharge. The sediment movement that causes the riverbed change tends to occur during the flood time.

Key words: Kamikochi, property of sediment movement, monitoring, rainfall-runoff processes

1. INTRODUCTION

The upstream region of the Azusa River in the Shinano River System which runs through the western part of Nagano Prefecture is widely known as Kamikochi, renowned for its beautiful mountainous scenery. Kamikochi is designated not only as the Chubu Sangaku National Park but also as a special place of scenic beauty and a special natural monument in Japan. With Taisho-ike pond located at the foot of Mt. Yakedake (2,455m), an active volcano, as the downstream end, Kamikochi is a grand valley at the elevation of 1,500m that is surrounded by high mountains as much as 3,000m high in the Northern Japan Alps including the Yari-Hotaka range. The watershed area is 112.4 km^2, channel length of the main stream is 17.0km and an average riverbed gradient is 1/55 (the section of Taisho-ike pond to Yokoo is 1/150). The main stream of the Azusa River is braided, while the average riverbed width is approximately 100m, the minimum and maximum riverbed width is approximately 50m and 200m. Significant changes of the riverbed width forms the contraction and expansion section repeatedly.

In the upstream region and the tributary, sediment production and discharge are active due to the steep terrain and fragile geology such as volcanic rocks and granite, as well as severe weather conditions. A massive amount of sediment discharge from these areas and erosion along the main stream cause a significant riverbed aggradation of the main stream. The riverbed has been increased 0.27m on average in the entire main stream between 2003 and 2010 based on LiDAR analysis. Thus, during the flood it is feared that there will be flooding into the important district of Kamikochi consisting of sightseeing and lodging facilities located along the main stream. Furthermore, heavy rain may causes debris flows and sediment discharge from the tributaries and significant riverbed aggradation in main stream that sightseeing

and lodging facilities were damaged and tourists were isolated due to severed roads and footpaths in the past.

Giving due consideration to the natural environment of Kamikochi, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has implemented sabo works to prevent such sediment related disasters since 1970s in conjunction with and through close consultation with the Ministry of the Environment, Forestry Agency, and Nagano Prefecture. In addition, based on the "Kamikochi Vision 2014" created in 2014 by the "Chubu Mountain National Park Kamikochi Liaison Conference", related organizations including the MLIT have been addressing disaster prevention projects while giving due consideration to the ideal state of Kamikochi. Thus, it is necessary to clarify the actual condition and property of sediment movement in the upstream region of the Azusa River, and predict the future riverbed changes and sediment discharge. In the past study of the Azusa River, the factor of sediment movement such as geology, grain size of riverbed material, structure of riparian forest and its formation, geomorphological dynamics of riverbed including channel shifts were clarified that based on aerial photograph interpretation and field investigation [e.g., *Rees*, 1967; *Shin et.al.*, 1999; *Shimazu*, 2013]. Incidentally, MLIT in cooperation with universities have undertaken field observations of debris flow in Japan at locations where the debris flow occurs frequently, and clarified the flow property of debris flow [e.g., *Takahashi*, 1977; *Suwa et.al.*, 1990; *Ikeda et.al.*, 2003]. However, the rainfall-runoff process and discharge including debris flow that dominates the sediment movement in the entire watershed of the Azusa River are not clarified. To this end, the MLIT observes the rainfall of the entire watershed including ridge lines and the discharge of the main stream and tributary that causes the sediment movement. Based on actual sediment movement and these monitoring results, this study introduces the property of sediment movement and rainfall-runoff processes in the upstream region of the Azusa River (Kamikochi) that has been clarified.

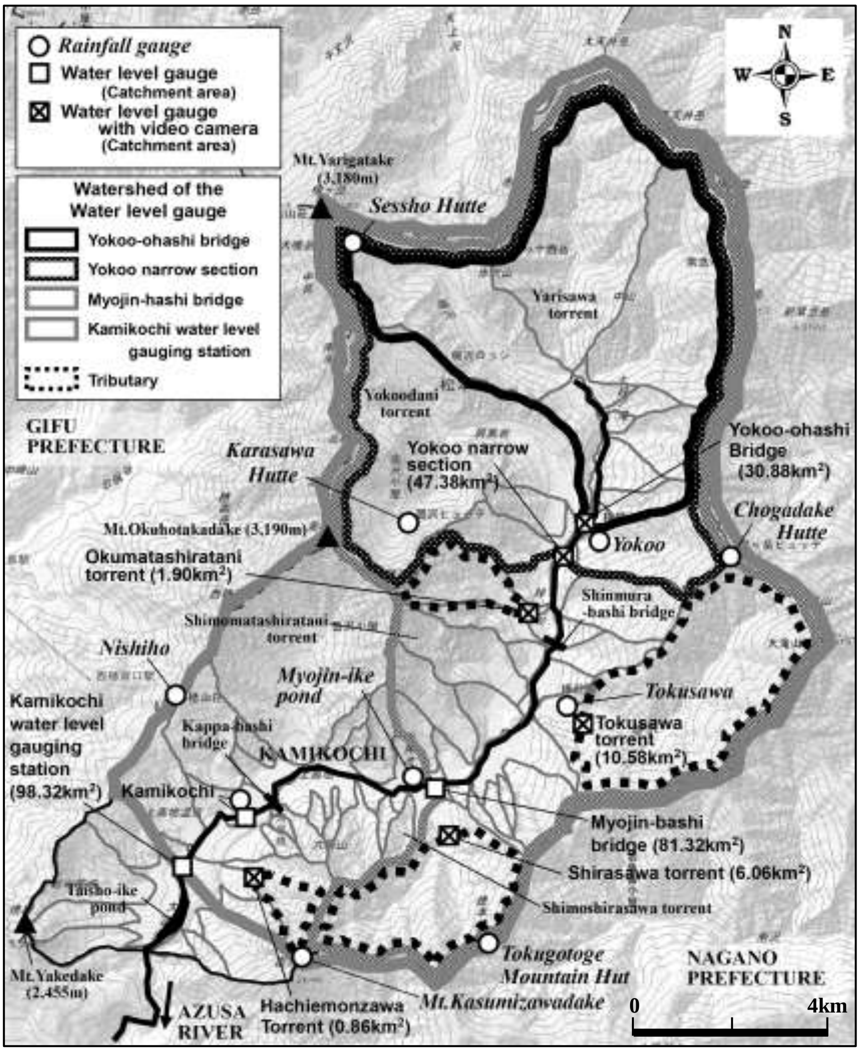

Fig.1 Location of the monitoring sites

2. OUTLINE OF MONITORING METHOD

In the upstream region of the Azusa River, sediment movements are being monitored to grasp 1) actual condition of sediment movement, 2) conditions dominate the sediment movement, and 3) the effect of sediment movement in the Kamikochi.

The actual condition of sediment movement are observed by aerial photograph interpretation, topography analysis based on LiDAR (1m mesh) in the entire watershed, and riverbed cross-sectional surveying, and field investigations along the main stream and tributaries since 1975.

The rainfall and discharge, which dominates the sediment movement, are observed by installing rainfall gauges and water level gauges since 1981. Rainfall gauges are installed at 6 locations in the mountain huts and ridge lines (elevation around 2,000m; Sessho Hutte, Karasawa Hutte, Chogadake Hutte, Nishiho, Tokugotoge Mountain Hut and Mt.Kasumizawadake), and 4 locations along the main stream in the grand valley (elevation around 1,500m; Yokoo, Tokusawa, Myojin-ike pond and Kamikochi). Rainfall gauges in the ridge line are used for observation only when the mountain huts are open (for 5 months of the non-snow season). Water level gauges are installed at 4 locations in tributaries where sediment discharge flow into the main stream is significant (Okumatashiratani torrent, Tokusawa torrent, Shirasawa torrent and Hachiemonzawa torrent), and 5 locations in the main stream from upstream to downstream (Yokoo-ohashi bridge, Yokoo narrow section, Myojin-bashi bridge, Kamikochi and Kamikochi water level gauging station). At Okumatashiratani torrent, Tokusawa torrent, Shirasawa torrent, Hachiemonzawa torrent, Yokoo-ohashi bridge and Yokoo narrow section, the video camera has also installed for observing the flow condition. The discharge of main stream is calculated according to the relationship between the water level and discharge (H-Q formula) and the discharge of tributaries according to Manning’s formula.

Herewith, spatial distribution of rainfall and discharge from the upstream (sediment production source) to downstream (sediment deposition area) in the entire watershed of upstream region of Azusa River became clear. The location of monitoring equipment is shown in **Figure 1**.

3.ACTUAL CONDITION AND PROPERTY OF SEDIMENT MOVEMENT

Based on observed and investigation results since 1975, sediment discharge that flow into the main stream frequently were confirmed such as Yokoodani torrent, Okumatashiratani torrent, Shimomatashiratani torrent, Tokusawa torrent, Shirasawa torrent, Shimoshirasawa torrent and Hachiemonzawa torrent. Especially, in Yokoodani torrent, Okumatashiratani torrent and Hachiemonzawa torrent are characterized by huge amount of sediment discharge flow into the main stream as debris flow.

Figure 2 shows the average riverbed variation from 1975 to 2017 of the main stream. In this period, 4 large-scale flood occurred in 1979, 1983, 1993 and 2006 that caused inundation damage and also eroded mountain trail and road along the riverbank in the upstream. In the section of Yokoodani torrent to Yokoo narrow section that is the upstream end of the main stream, significant riverbed degradation caused by 1993 flood but no major riverbed change causes since then. At the junction of Okumatashiratani torrent, huge amount of sediment discharge flows out forming a wide debris fan that causes the expansion in the main stream. Furthermore, this fan blocks the main stream and causes a riverbed aggradation in the upstream toward Yokoo narrow section. Along with this, downstream section of this fan toward Shinmura-bashi bridge that is the contraction point, significant riverbed degradation has caused. In the section of Shinmura-bashi bridge to Tokusawa torrent that little change in the riverbed width, 1993 flood flushed out the riverbed deposit and causes significant riverbed degradation, no major riverbed

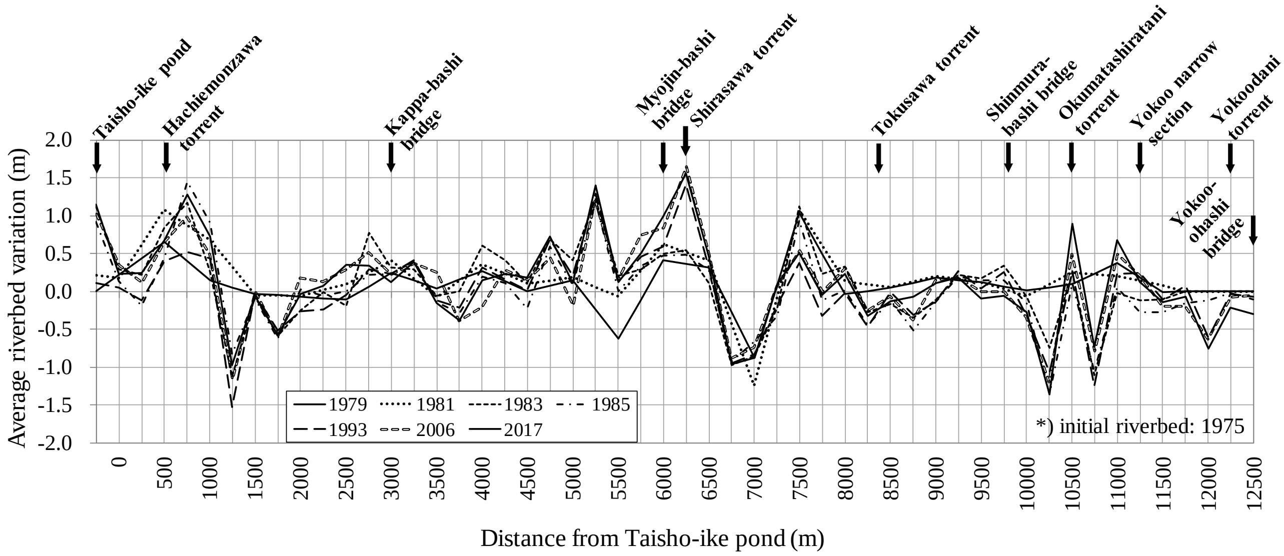

Fig.2 Average riverbed variation from 1975 to 2017

Table 1 Flood event at Kamikochi in recent years

Date of flood event	Rainfall condition: Maximum hourly rainfall (mm/hr) Kamikochi	Yokoo	Ridge line	Continuous rainfall (mm) Kamikochi	Yokoo	Ridge line	Duration of rainfall (hr)	Discharge condition: Peak Discharge (m^3/s) [Specific discharge ($m^3/s/km^2$)] Yokoo-ohashi bridge	Yokoo narrow section	Kamikochi
July 1st, 2015	7.0	12.5	8.0	52.0	111.0	71.0	18	51.27 [1.66]	41.45 [0.87]	100.68 [1.24]
October 2nd, 2015	20.0	8.5	26.0 (Karasawa Hutte)	56.0	27.0	167.5 (Karasawa Hutte)	21	46.71 [1.51]	34.68 [0.73]	69.29 [0.85]
May 11th, 2016	9.0	10.0	–	64.0	100.5	–	18	48.01 [1.55]	–	114.71 [1.41]
June 25th, 2016	16.5	13.5	29.0 (Karasawa Hutte)	83.5	139.0	158.0 (Karasawa Hutte)	17	61.55 [1.99]	–	127.67 [1.57]
September 18th, 2016	13.0	14.0	32.0 (Karasawa Hutte)	175.0	231.0	418.5 (Sessho Hutte)	33	32.40 [1.05]	–	81.21 [1.00]
July 1st, 2017	19.0	21.0	16.0	362.0	583.5	381.0 (Nishiho)	127	96.54 [3.13]	92.12 [1.94]	206.91 [2.49]
September 7th, 2017	8.5	13.0	25.0 (Sessho Hutte)	112.0	164.0	325.5 (Sessho Hutte)	52	52.23 [1.69]	23.81 [0.50]	85.90 [1.06]

Fig.3 Installation of rainfall and water level gauges

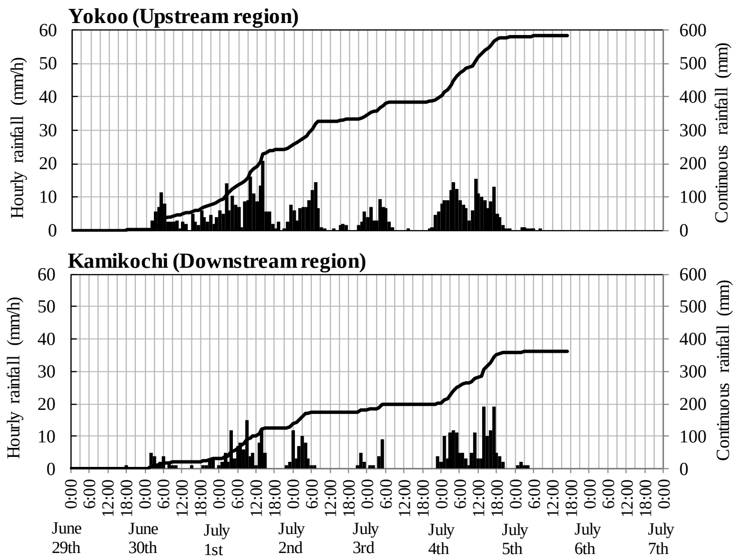

Fig.4 Rainfall condition during the flood on July 1st to 4th in 2017

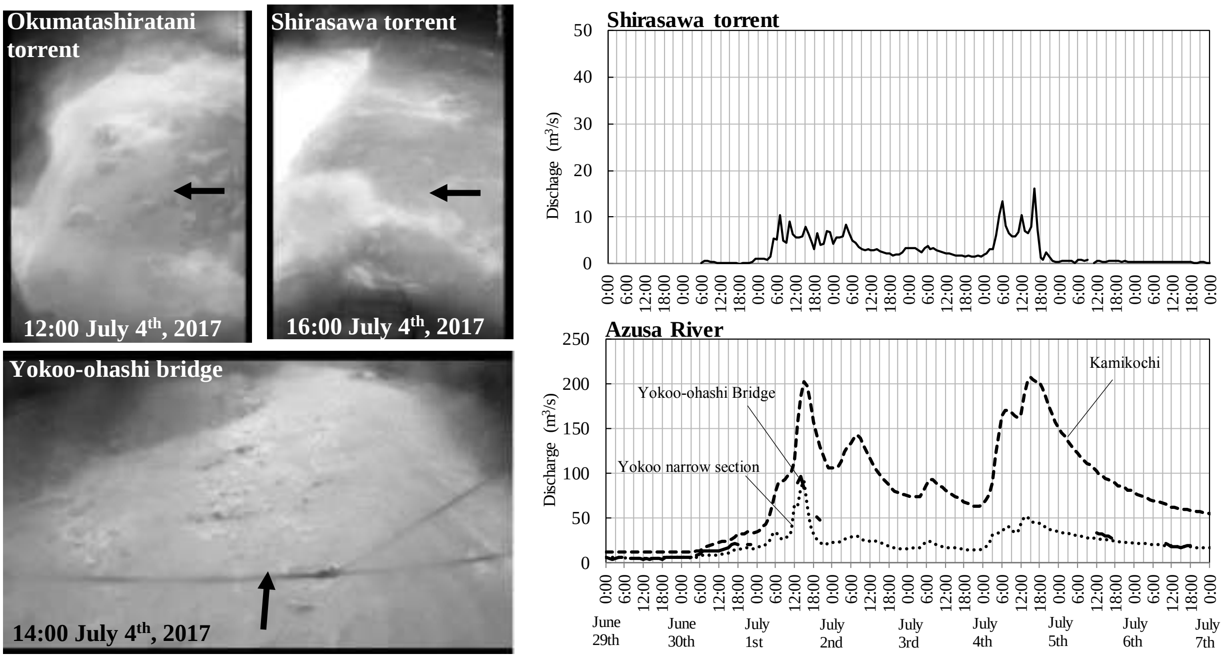

Fig.5 Time changes of discharge and flow condition during the flood on July 1st to 4th in 2017

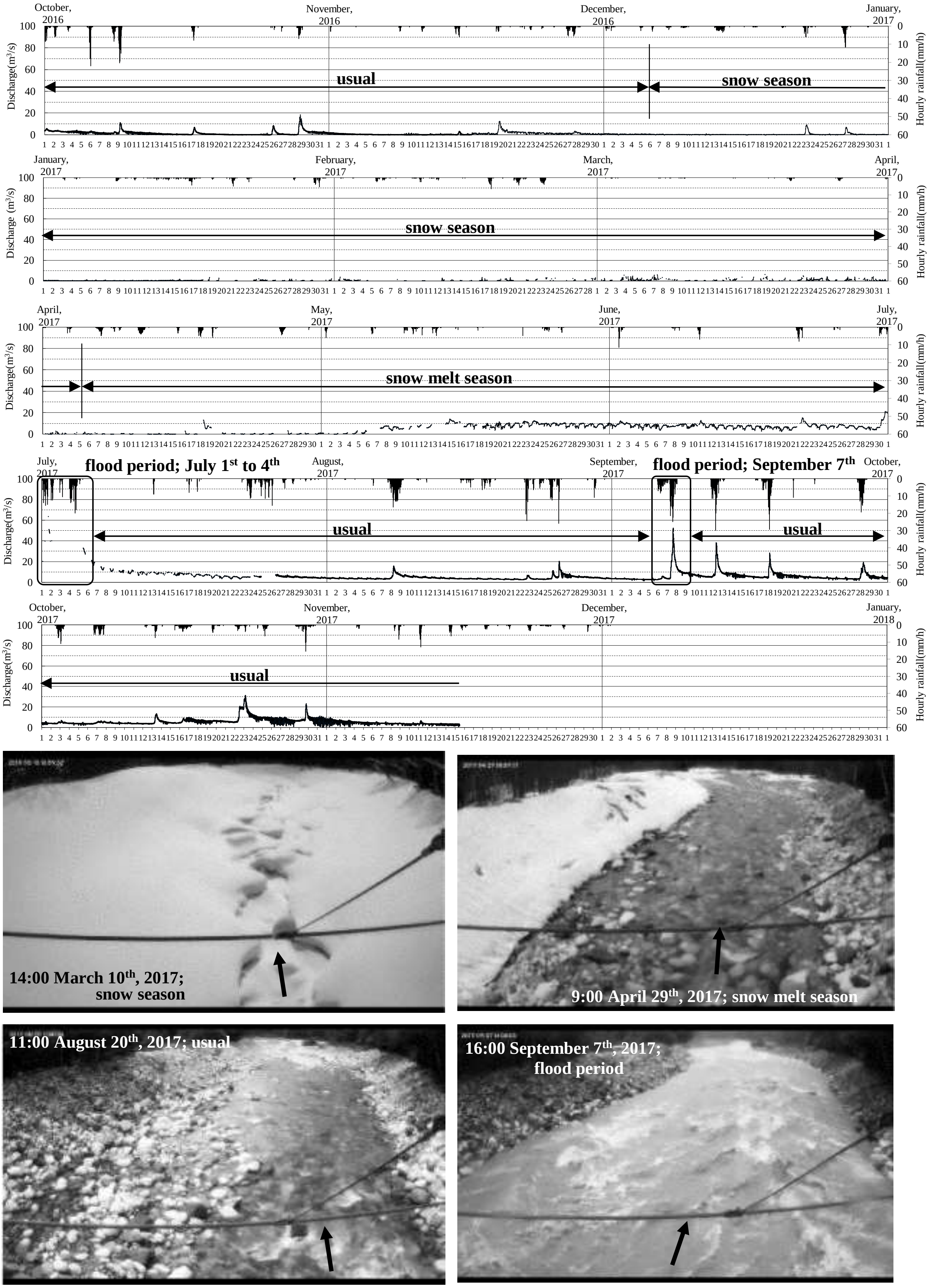

Fig.6 Time changes of discharge and flow condition during October, 2016 to November, 2017 at Yokoo-ohashi bridge

change causes since then. In the section of Tokusawa torrent to Shirasawa torrent that is the contraction section, 1979 flood flushed out the riverbed deposit that has been stored gradually since 1975 flood, and no major change causes since then. In the section of Shirasawa torrent to Kappa-bashi bridge riverbed aggradation causes gradually until 2006 while no major change causes in the next decade.

4. PROPERTY OF RAINFALL-RUNOFF PROCESS

4.1 Property of rainfall-runoff process during flood

Table 1 shows the outline of flood events that occurred in 2015 to 2017, after the installation of the rainfall gauges at the ridge line and water level gauges in the tributary (**Figure 3**). The flood is defined that more than 20mm of hourly rainfall, 80mm of continuous rainfall, 50m^3/s of discharge at Yokoo-ohashi bridge and 100m^3/s of discharge at Kamikochi water level gauging station. In Kamikochi, the movement of heavy rain area during the flood tends to move west to east or southwest to northeast in the past floods influence of the movement of the seasonal rain front or typhoon. We focused on the flood occurred on July 1st, 2017 (hereinafter called 2017 flood) that the largest peak discharge in the past and significant sediment movement has been confirmed.

Figure 4 shows the rainfall condition during the 2017 flood at Yokoo and Kamikochi rainfall gauge that locates in the upstream and downstream along the main stream because of that rainfall gauges of the ridge line has not been installed because of the snow cover during the flood. Both of the maximum hourly rainfall precipitation is approximately 20mm/hr and rainfall waveform is similar, while continuous rainfall precipitation of Yokoo (583mm) is 1.6 times that of Kamikochi (362mm). Incidentally, hourly and continuous rainfall precipitation of the ridge line is almost 2 or 3 times that of the main stream in the grand valley is confirmed at the past flood events.

Figure 5 shows the time changes of discharge at main stream of Azusa River from upstream to downstream and Shirasawa torrent, with the images of flow condition in Okumatashiratani torrent, Shirasawa torrent and Yokoo-ohashi bridge. It was not clear by the waveform of rainfall, but two clear peaks of discharge were confirmed on July 1st (first peak) and July 4th (second peak). As for the first peak, the discharge and turbidity started to increase simultaneously and rapidly 3 hours later after beginning of rainfall, that the waveform shape is similar to rainfall with good responsiveness at Shirasawa torrent. On the other hand, the discharge started to increase gradually 2 hours later after beginning of rainfall at Yokoo-ohashi bridge and Yokoo narrow section, while 4 hours later at Kamikochi water level gauging station. After that the discharge stared to increase rapidly with the rainfall, while the waveform shape differs after the peak from the rainfall that influence of the subsurface runoff. The peak discharge of Yokoo-ohashi bridge, Yokoo narrow section and Kamikochi water level gauging station that locates upstream to downstream of the main stream is 96m^3/s, 92m^3/s and 202m^3/s, and the specific discharge is 3.13m^3/s/km^2, 1.94m^3/s/km^2 and 2.49m^3/s/km^2 (**Table 1**). Kamikochi water level gauging station has a discharge almost twice that of Yokoo-ohashi bridge, and that of the peak appearance time delayed for 2 hours. In spite of Yokoo narrow section locates downstream and watershed area is larger than Yokoo-ohashi bridge, the peak discharge and specific discharge is smaller than Yokoo-ohashi bridge.

4.2 Property of annual runoff process

In Kamikochi it begins to snow from around December and covered with snow until May, while that start to melt around April, so that it is covered by snow through the half of year. **Figure 6** shows the time changes of discharge and flow condition during October, 2016 to November, 2017 at Yokoo-ohashi bridge. The time changes of discharge roughly divided into 4 periods according to the season, such as usual, flood period, snow season (December to April) and snow melt season (April to June). The average discharge at Yokoo-ohashi bridge is approximately 2-5m^3/s as usual, less than 3m^3/s in the snow season, and 2-3m^3/s during the early snow melt season with 10m^3/s in late period. During the snow melt season, as the temperature changes, the discharge is changing in the day. Such a trend is confirmed at Kamikochi water level gauging station, Tokusawa torrent and Shirasawa torrent. At Kamikochi water level gauging station downstream end of the main stream, the average discharge is approximately 5-10m^3/s as usual, 3-4m^3/s in the snow season, and approximately 5m^3/s during the early snow melt season with 10-25m^3/s in late period.

5. CONCLUSIONS

The upstream region of the Azusa River (Kamikochi) is an aggrading braided river that is characterized by the significant changes of the riverbed width that forms the contraction and expansion section, and the meandering. Based on the actual condition of the long-term sediment movement including the flood event and results of monitoring data, property of the sediment movement, rainfall-runoff process during flood and annual runoff process became clear as follows:

(1) Main active sediment production and discharge source in upstream region of the Azusa River is the riverbed deposit in the main stream, and tributaryies such as Yokoodani torrent, Okumatashiratani torrent, Shimomatashiratani torrent, Tokusawa torrent, Shirasawa torrent, Shimoshirasawa torrent and Hachiemonzawa torrent.

(2) Yokoodani torrent, Okumatashiratani torrent and Hachiemonzawa torrent are characterized by huge amount of sediment discharge flow into the main stream as debris flow forming a wide debris fan that causes the expansion or blockage.

(3) Significant riverbed changes (aggradation and degradation) has confirmed at the contraction and expansion that the riverbed width changes and the meandering, especially at the junction of the tributary. It is estimated that one of the reason of riverbed changes due to the riverbed width and meandering because of almost no changes in the riverbed gradient in the main stream.

(4) Rainfall precipitation is different between upstream and downstream, and also in the grand valley and ridge line. It tends to be larger at the ridge line that depends on the elevation.

(5) Along the main stream, peak discharge tends to be large at the downstream, while the specific discharge is small. It is estimate that one reason of the loss of discharge is the influence of the infiltration to the riverbed deposit.

(6) Based on the monitoring data during April 2015 to November 2017, sediment movement that causes the riverbed change tends to occur during the flood time, and the sediment movement increases significantly according to the discharge.

On the other hand, because of the monitoring period is short and the scale of observed floods was relatively small, there are challenges to be addressed that to monitoring continually, examining the H-Q formula and the property of the sediment movement during large-scale flood as the design scale of sabo works. In addition, we are now preparing the numerical simulation model that can predict the future riverbed changes and sediment discharge, and also evaluate the effect of sediment movement, so that it is necessary to calculate the quantity of sediment yield and production in the tributaries throughout the year including flood period.

ACKNOWLEDGEMENT: Authors should be thankful for the kind advices provided by Prof. Masaharu FUJITA, Prof. Shinya HIRAMATSU, Prof. Keisuke SUZUKI and Dr. Hikaru KITAHARA as the member of study committee for discussing the mechanism of sediment movement in the upstream region of the Azusa River (Kamikochi).

REFERENCES

Rees, D.G.T. (1967): A Study of the Movements of Bed-sediment along Azusa River, Japan, Geographical Reports of Tokyo Metropolitan University, 2, pp.29-40.

Shin, N., Ishikawa, S. and Iwata, S. (1999): The mosaic structure of riparian forest and its formation pattern along the Azusa River, Kamikochi, Central Japan, Japanese Journal of Ecology, 49, pp.71-81 (in Japanese with English Abstract).

Shimazu, H. (2013): Interannual Landform Changes and Formation of Environmental Diversity in the Riverbed at the Upper Reaches of the Azusa River, Central Japan, Journal of Geography, Vol.122, No.4, pp.709-722 (in Japanese with English Abstract).

Takahashi, T. (1977): A Mechanism of Occurrence of Mud-Debris Flows and their Characteristics in Motion, Annuals of Disaster Prevention Research Institute, Kyoto University, 20B-2, pp.405-435 (in Japanese).

Suwa, H. and Okunishi, K. (1990): Motion, Debris Size and Scale of Debris Flows in a valley on Mount Yakedake Japan, Annuals of Disaster Prevention Research Institute, Kyoto University, 33B-1, pp.191-203 (in Japanese with English Abstract).

Ikeda, A. and Hara, Y. (2003): Flow properties of debris flows on the Kitamata Valley of the Name River, Japan, Debris-Flow Hazards and Mitigation: Mechanics, Prediction and Assessment, Rickenmann & Chen (eds), pp.101-112.