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AN IDEA ON NORMAL FLOW DISCHARGE OF A SMALL SIZED RIVER DRAINING A LOW LYING AREA — IN CASE OF THE SHINBORI RIVER, A TRIBUTARY OF THE NAGARA RIVER IN GIFU CITY

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ABSTRACT

It is difficult to determine the normal flow discharge, which must be stated in the basic policy for river improvement and the river improvement plan, even in cases of large-sized rivers, especially in medium to small-sized ones which spread as networks in river basins and have an important part in water environment there. The normal flow discharge covers both of the water use and the maintenance flow discharge, the latter of which satisfies multi-purpose functions required ordinarily for rivers. The maintenance flow discharge of a small-sized river called the Shinborigawa draining a narrow low-lying area including the main campus of Gifu University is discussed in this study from the viewpoints of historical changes of the river and its basin, verifications of the river modification plan, and water quality improvement based on the use of rainfall and a shallow water analysis.

Keywords: normal flow discharge, maintenance flow discharge, small-sized river, river in low lying area, river water quality

1. INTRODUCTION

The normal flow discharge must be stated both in the basic policy for river improvement project and in the river improvement plan in Japan, recently. The normal flow discharge is to be determined to cover both of the water use and the maintenance flow discharges, the latter of which satisfies multi-purpose functions required ordinarily for rivers, such as ecological functions, cleanliness, landscape, navigation use, fishery needs, and so on. It is not easy to determine its definite amount rationally even in cases of large-sized rivers, where hydrological data, such as precipitation, water stage and discharge, have been accumulated for fairly long periods. It becomes especially difficult in cases of medium to small-sized rivers which spread widely in river basins as channel networks and have various, important functions in water environment there, because discharge data are not provided insufficiently and low water flows there are limited in general.

In this study, the maintenance flow discharge of a small-sized river called the Shinborigawa, which drains a narrow low-lying area including the main campus of Gifu University and is supplied a very small discharge at low water stages, is discussed from a viewpoints of historical changes of the river and its basin at first. The latest state of the normal flow discharge in Japan is presented to be compared with case of the Shinborigawa, and a new idea of the normal flow discharge allowing fluctuations and intermittencies is introduced focusing on the function of the discharge, such as maintenance of cleanliness, conservation of preferable habitat conditions.

2. SHINBORI RIVER BASIN SUMMARY

The Shinborigawa is a secondary tribute of the Nagara River, meaning a new river incised artificially and the word of river is not attached here to avoid the redundancy. It flows a northernmost *waju* area in the Nobi alluvial plan. The *waju* is a word denoting a community surrounded by a levee to protect it from floods while Nobi indicates a district consisting of a southern part of Gifu prefecture and a western part of Aichi prefecture being covered with a lot of *waju* areas. The basin area of 8.6km^2 is divided into three subareas reflecting changes in land use since the old *waju* age and river improvement.

One of them is an ordinary drainage area of 5.2km^2 while upper one of 3.4 km^2 as well as the third near the Itaya River are added during high floods which is drained directly into the Ijira River usually.

Originally, Shinborigawa was the a small drainage channel which flowed through a low-lying area in Majito-*waju*, collecting waste water there. It was merged into the class A river system corresponding to the campus unification plan of Gifu University settled in 1970, and a river improvement was planned, including an upper basin. According to the plan, river training began in 1974 and was completed in 2000. About The training works had been continued during 26 years intermittently to produce a provisional channel. The present river channel is that with bed slope lower than 1/2000 and single cross section maintaining a design high water discharge of 65m^3/sec, and at the downstream end, sluice gates and a drainage pump station capable of 20m^3/sec are provided. The river improvement however, have brought low water quality and sludgy bed surface as well as steep river bank protected with concrete blocks, which prevent neighbours from approaching waterside there both physically and mentally. Such a situation is worsened from summer to

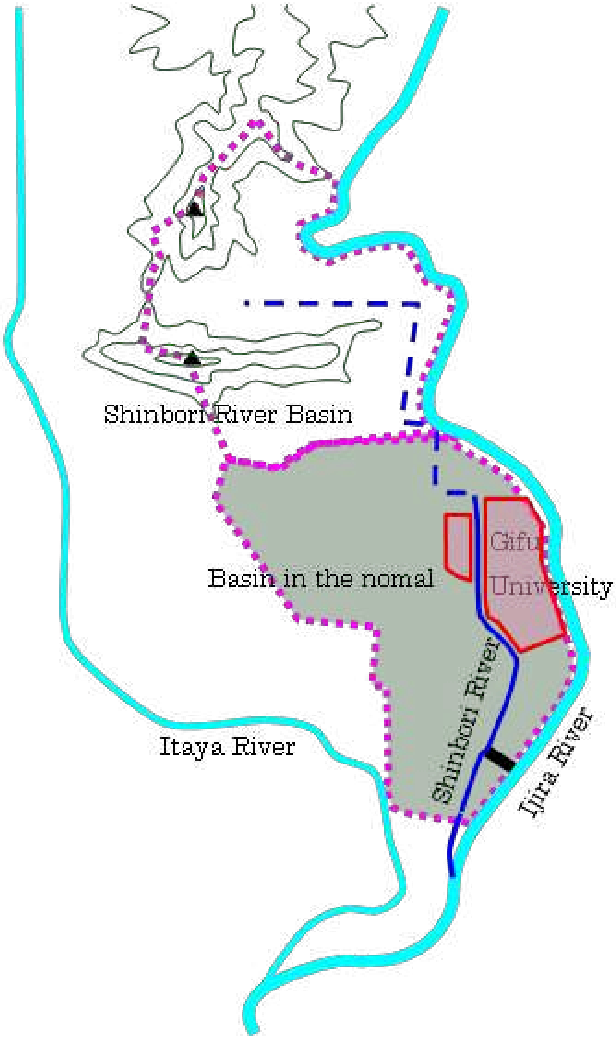

Fig.1. The Shinborigawa river basin

Fig.2. The Shinborigawa's *Egeria densa*

autumn in the downstream reach from the University gate, by scenic deterioration due to rampant Canadian pondweed called *Egeria densa* (Fig-2), a typical naturalized foreign species, which covers whole the water surface thickly, floating garbage here and there. At the upstream reach from the gate, the pondweed does not prevail so much, where surface width is narrowed by introducing a longitudinal mound along the right bank, height of which is about one forth of the bank height. It suggests that increase in flow velocity may suppress the pondweed growth because flow discharge is almost same around the gate and that topographical change may improve environmental conditions of the Shinborigawa.

2.1 Historical changes of the river and its basin

The Shinborigawa, basin of 8.6km^2 of which is located in the northwest part of Gifu city as shown in Fig.3, is a sluggish river flowing though a low-lying area, as mentioned above and 2.45km in length from the northwest edge of the Gifu University to the Ijira River junction. At the upstream end it connects to the Murayama River rising around the foot of Mt. Gomo, 225m above the sea level. Except its outskirts, most areas of the Shinborigawa basin are very flat and the river system acts as a drainage network of neighbouring paddy fields, but there is little vertical drop in the ground level to produce very mild bed slopes and inactive currents, also influenced by back water effects from the junction of the Ijira River. In addition, no usual water supply from the Murayama River to the Shinborigawa, because there is Majito sluice gate discharging the ordinary running water in the Murayama River directly into the Ijira River at a site where the Murayama River approaches most closely to the Ijira. Namely, runoff from the upper sub-basin of 3.4km^2 doses not supply any water to the Shinborigawa except that due to heavy rainfalls which can cause flows over a weir controlling water diversion at the sluice gate or make the gate close. This situation reflects both of the conventional water use, the water right of which is maintained even now in the downstream irrigation ares of the Ijira River, and the flood defence system provided newly in this basin, the latter of which have brought an obvious urbanization, as shown in three topographic maps at 1924, 1970 and 1994 of Geographical Survey Institute, Japan in Fig.3. According to these maps and geographical document of local history, this area was divided clearly into the

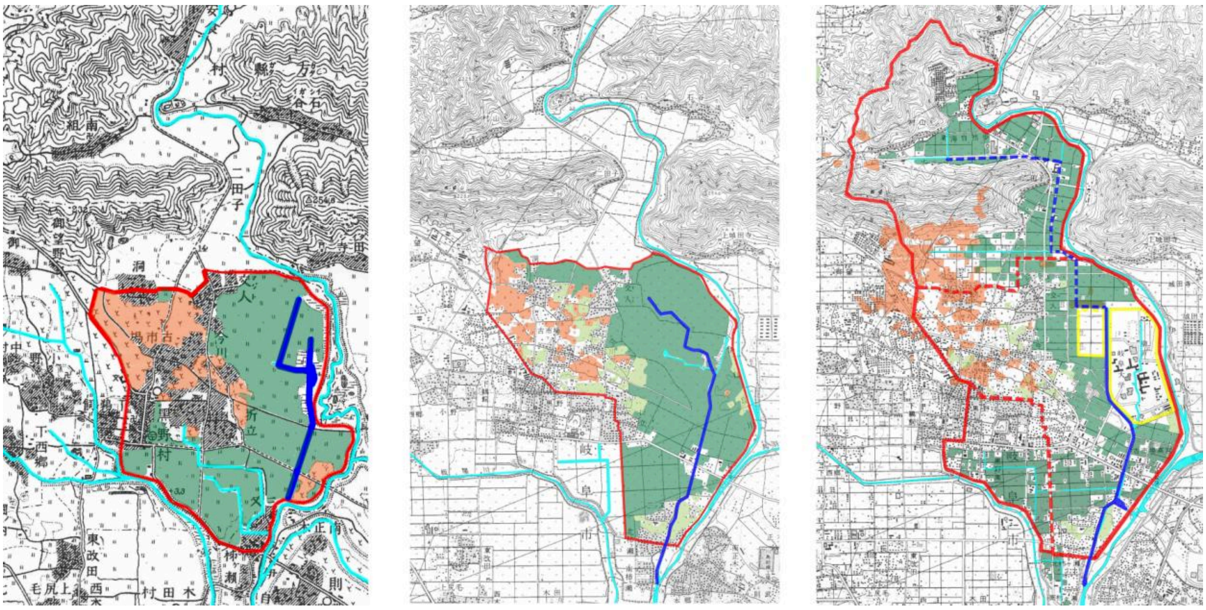

Fig.3. The change and the land use of the basin of Shinborigawa
(1924:left, 1970:center, 1994:right)

drainage area of the Murayama River basin and that of Shinborigawa by a conventional dike protecting Majito-*waju* area.

Along with the relocation of Gifu University and river improvement of the Shinborigawa and the Ijira River, development of the basin have been pushed forward rapidly, and it continues even in the latest years, as is the move here of faculty of medicine and the affiliated hospital of Gifu University as the final stage of the campus unification, a construction plan of a highway interchange and so on. Thus, the water environment of this basin have been and will be subject to the influence of the rapid development, and its conservation and improvement are one of the most important tasks for civil engineers.

3. Inspection of the river design plan by measured rain data

3.1 Inspection of the design flood by measured rain data

The first step of river improvement plan is the determination of design rainfall causing flood, return periods of which are five to thirty years for small to middle sized rivers in Japan. As for the river training works after the very high flood of 1976 it was completed in 1999 under design flood with the return period of five years, which is verified here by rainfall data during recent thirty years shown in Fig.4. This verification has large significances not only to confirm of the validity of the present plan but also to clarify the environmental process during and after river training because precipitation governing water supply to river channels is a dominant factor forming river environment and ecosystem and time series data of the rainfall experienced are examined in the verification procedure.

Gumbel's method was used to examine the experienced recurrence probability of hourly rainfall suitable to estimate the design flood of small rivers such as the Shinborigawa. An empirical formula established by the Gifu prefectural government on the basis of precipitation data from 1887 to 1970 was applied to evaluate the design flood of the improvement plan. Fig.4 shows a comparison of the excess flood probabilities from the empirical formula with that evaluated from rainfall data during 1960-2006 at observatory nearest to the Shinborigawa basin. Two data express different tendency that when values of recurrence year are low, those of hourly rainfalls of the observation are higher while they become lower at larger return periods than forty years on the contrary. Table 1 summarizes the magnitudes of probability hourly rainfalls and the occurrence times exceeding them in the precipitation data. The occurrence times exceeding 48.6mm/hr corresponding to the provisional design probability of 1/5 scale in 46 years of 1960-2006 rainfall record was 11 and it became clear hereby that rains went beyond not only the provisional design scale frequently but also that of the fifty year flood twice.

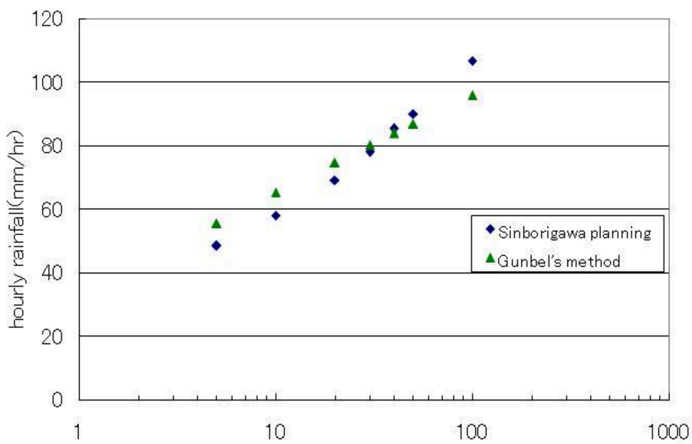

Fig. 4. Verifications of the return periods of the Shinborigawa basin.

Though Shinborigawa experience the rain of the 1/50 scale twice as mentioned above, the flood disaster has not occurred at all.

This river channel seems to have considerable safety margin practically and to be able to introduce various devices for environmental improvement.

Table 1. Comparison of the magnitudes of probability rainfalls and the occurrence times exceeding them in the precipitation data

excess probability	1/5		1/10		1/20		1/30		1/40		1/50		1/100	
	rainfall	times	rainfall	times	rainfall	times	rainfall	times	rainfall	times	rainfall	times	rainfall	times
desigin (1887～1970)	48.6	11	58.1	5	69.2	5	78.2	3	85.5	3	90.1	2	106.9	0.0
Gumbei's method (1960～2006)	55.8	5	65.5	5	74.9	3	80.3	3	84.1	3	87.0	2	96.1	0.0

However, attention must be paid that rainfalls more than 50mm/hr occur only three times after 1988 and that increase in the flood discharge will be caused with the urbanization of the basin and recent climate changes.

4. The requirement items for the normal flow discharge and its trends

4.1 The requirement items to set the normal flow discharge

Flow discharge necessary to secure normal functions satisfied by river current is called "normal flow discharge" in Japan. Its settlement requires to grasps sufficiently the use of river water, the present states of river environment from the standpoint on natural and social environments of the basin and their historical process. As is known generally, it must satisfies both flow for water use and the maintenance flow, after the examination of many relating items as the following.

(1)navigability, (2)fishery, (3)maintenance of the cleanliness of current, (4) prevention of damage by salt water intrusion, (5)the prevention of river mouth blockade, (6)the maintenance of administrative facilities for river, maintenance of ground water,scenery and sightseeing, the locality and the situation of the habitation of animals and plants.

It is also said to consider rich contact between people and rivers generally, and it must be established.

4.2 The latest trend of the normal flow discharge in class A river systems

The normal flow discharge is decided for 169 rivers in 109 class A river system in Japan by the end of March, 2008, almost all values of which are determined mainly on three items among the nine listed above *i.e.* (9)the locality and the situation of the habitation of animals and plants, (8)scenery and sightseeing and (3)maintenance of the cleanliness of current. Though the normal flow discharge has different values for irrigation seasons and for non-irrigation seasons corresponding to water use, according to the three items of the determination basis mentioned above, the normal flow discharges are classified into three groups and compared with basin areas as specific discharges (discharge per unit basin area)=as shown in Fig.5. Even if a basin area is quite large, specific

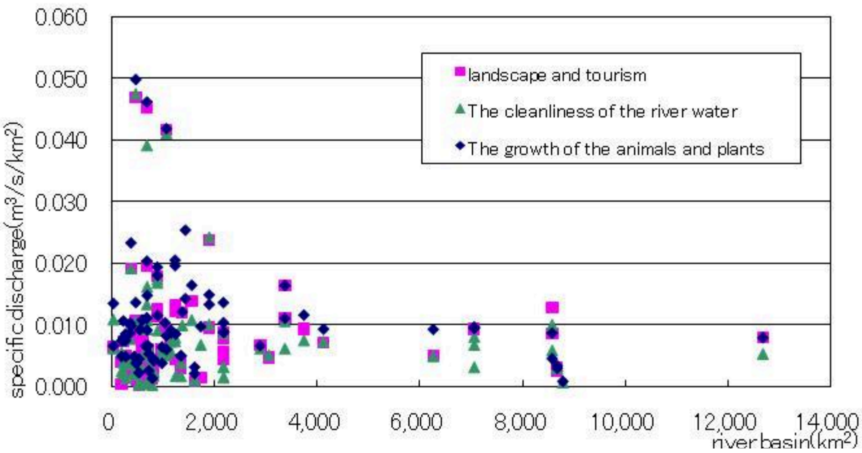

Fig.5. Specific discharge in the threshold of the normal flow discharge of the first-grade river water system

discharge is not large, and=values gather mostly in 0.01m^3/s/km^2, showing no tendency corresponding to setting reasons.

5. A survey of water quality and river bed conditions of the Shinborigawa

5.1 A survey of water quality on existing observation data

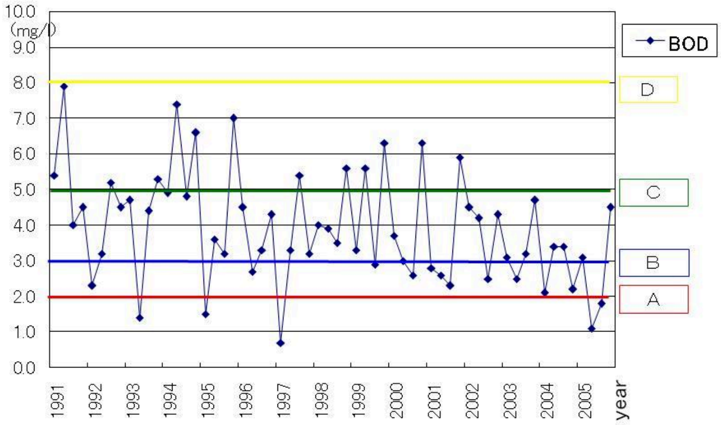

Fig.6. The BOD concentration of the Shinborigawa

Observations of water quality in the Shinborigawa conducted four times a year since 1991 Environmental Quality Standards for Conservation of the Living Environment (pH, DO, BOD, COD, SS) at a site in the downstream reach by an environmental division of Gifu municipal office. Although the class B criteria of the water quality standard almost has been satisfied for the items except BOD, but only the BOD values indicate class C or class D as shown in Fig.6. They varied very much from high values more than 7 mg/L to low values less than 2 mg/L, especially in 1990s, but they present a falling tendency as a whole in recent several years. It is a result of the development of sewer systems pushed forward slowly in this basin which has completed in 2004 and it contribute to reduce pollution load from the whole basin such as domestic sewage.

However, Ijira River is clearly almost higher for there being an class A, Itaya River in the range of the class A - class B than the outskirts, and the water is still in condition not to be able to be said to be good when I compare Shinborigawa with a neighborhood river. Because bed slope is slow, and this river does regular filling, attached algae is produced and becomes suspended solid and can judge it to subside. I compare the water of this river with a neighborhood river as above and do this with an index of the improvement because BOD value in particular is high.

5.2 Properties of bed material in the Shinborigawa

Shinborigawa is so stagnant with very mild riverbed slopes that a lot of fine grains would deposit easily and accumulate thickly on the riverbed. In order to confirm this, bed materials are sampled and analysed at six points near both side banks in three sections, representing typical conditions of the upper, middle and lower reaches of the Shinborigawa. The sampling was carried out manually, inserting a pipe of transparent acrylic material of 1m in length into riverbed from water surface at each point, inside and outside diameter of which are 18mm and 21mm, respectively. After insertion to resistant base of the bed, putting a stopper on its top opening made it easy to extract rather soft bed materials.

Apparent properties of sampled bed materials are sketched in Fig.7, showing sedimentation thicknesses of 10-20cm or more.

As a result, only thin top layers proved to contain organic matters on the riverbed and a clayey substratum is found in the upper reach only while those in the middle and lower reaches consists mainly of silt and fine sand sometimes including comparatively coarse materials as gravel size. Fig. 8 shows grain size distribution curves of middle layers of the bed material measured by a laser diffraction-type of grain size distribution analyzing device

(SALD-3000 made by Shimazu Corporation).

Values of their mean diameters vary widely from 0.005 to 0.05mm implying rather high to little cohesion of bed materials. However, as the physical significance of a trend that all curves are raised more or less at around 0.0004-0.0005mm is not clear, the trend is neglected, and then clayey fractions smaller than 0.005mm hardly exceed 10% except two samples and sedimentation has been caused mostly with silt component transported in suspension from the basin. It is also recognized that since the silt component is less cohesive to be washed away easily the possibility to make the riverbed clean and improve water quality by utilizing flows during small floods which frequently happen. Through the discharge fluctuations corresponding to such frequent floods, one of main functions of normal flow discharge, maintenance of river flow cleanliness, can be satisfied, especially with river channel rearrangement to promote effective currents aspirating sediment motion on the bed.

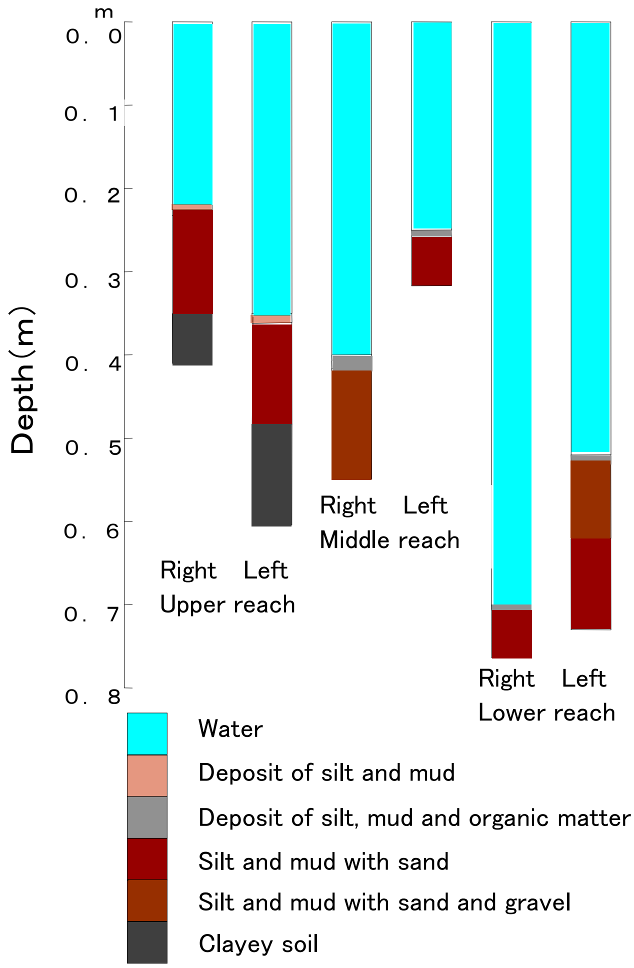

Fig.7. Deposition properties on the bottom

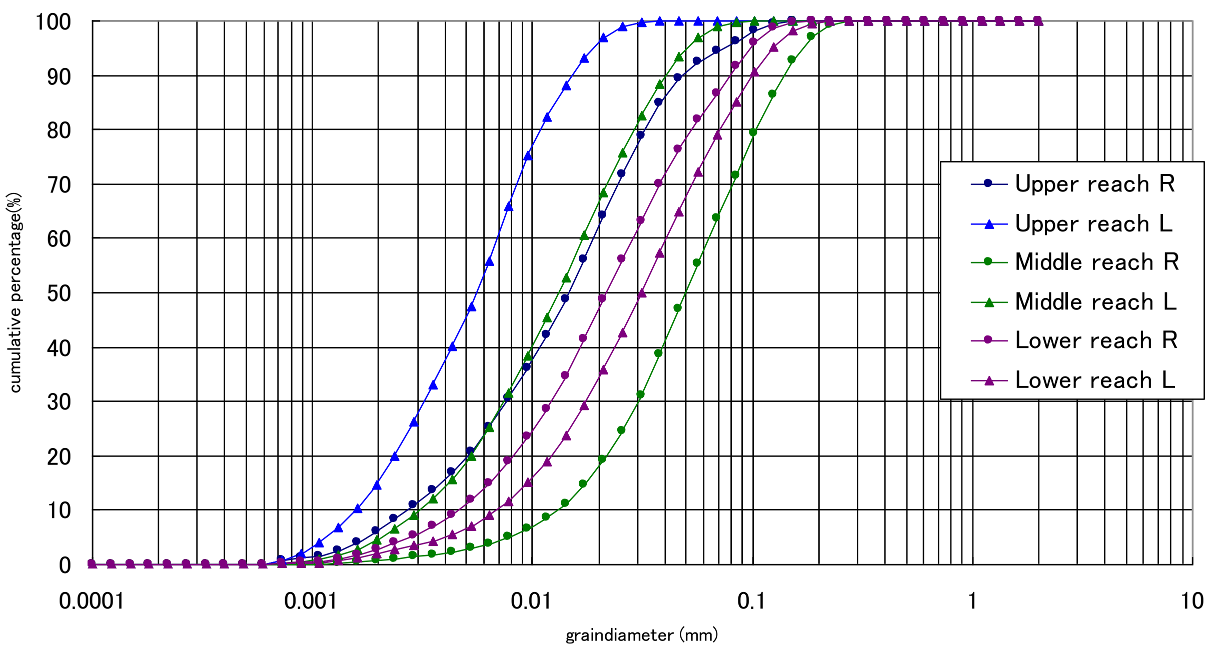

Fig.8. Grain size accumulation curves of bed material

6. An improvement idea of water environment in the Shinborigawa

6.1 Production of effective velocity fields with sandbar like bed topography

The contaminant materials are diluted and flushed away with eutrophicated substrata by flood flows, so that water environment is somewhat improved after floods in rivers. Shinborigawa is affected by the backwater of the main Ijira River and the inflows from the upper basin are very little in the ordinary states, which make it difficult not only to expect maintenance and improvement of water cleanliness but also to settle the normal flow discharge as a constant value. Even though the constant normal flow discharge could be settled the river environmental conditions would not be raised if the river channel topography will remain flat and monotonous as present situations because flowing water spreading all over the riverbed can produce very low values of averaged velocity that cannot remove contaminant materials in the ordinary states. Therefore, more or less high flow discharge during rainfall runoff is the only option to be expected to improve the water and substrate quality, which is one of main functions of the normal flow discharge. Actually, in this river, the water quality had been raised during and after medium or small scale of floods, such that the BOD values of around 2.0-3.0 (class B)have been attained rather frequently, and this improvement ascribes partly to the effect of the sewerage system installation decreasing pollutant load such as domestic waste water. However, more improvement by the sewerage system cannot be expected from now because its installation has been completed though it was pushed forward slowly in this basin as already mentioned, and new ideas are requested to enable to raise the water environment of the Shinborigawa.

As also pointed out already, the luxuriant growth of the naturalized alga, Brazilian waterweed *Egeria densa*, which is seen in general at the middle and lower reaches, summer to early autumn in particular, is hardly found at the upper reach where riverbed under the ordinary water stage is narrowed by introducing the longitudinal mound. The narrowing of the ordinary stream channel is regarded to result in generating a fairly high velocity field there and to prevent the waterweed from growing thick.

Accordingly, if the channel bed topography I can be changed adequately it is considered possible to generate a velocity field creating desirable river conditions without harmful increase in flow resistance even from the midstream to the downstream reaches. At the same time, such an elaborated investigation on channel topography must be useful for scenery improvement of the Shinborigawa. Therefore, as a tentative approach to effectiveness of channel topographical changes for the environmental improvement, velocity fields are examined for flood flows caused by comparably high intensity rainfall occurring around three times a year, imposing sandbar like undulations on the riverbed topography. Especially in case of the Shinborigawa, cross sections corresponding to the wide drainage area during high floods are too wide for flow discharge supplied from the ordinary drainage basin to produce stream currents sufficient to move sediment motions on the flat riverbed channel, and it results in the monotonous pool like scenery as the present situation (see Fig. 9).

6.2 Effectiveness of the introduction of sandbar like undulations

A sandbar like bed topography is introduced onto the conventionally improved river channel as follows: top heights of the undulations are just above the ordinary water stage and its width is 3.0m from the side bank while bed levels near the opposite bank are degraded to compensated the reduction of cross sectional areas like as sandbars. This flat top of each mound of the undulations is 10m in length and has longitudinal slopes of 30m on both up- and down-stream sides, and the mounds are placed at intervals of=80m on both side banks alternately.

According to the statistical analysis of rainfall data, the mean value of the hourly rainfall occurring three times a year, the third greatest rainfall intensity (the third record of a year) is 26.5mm/hr. From this hourly rainfall, a peak flow discharge of 25m^3/s is estimated by the Mononobe's rational formula for the middle reach.

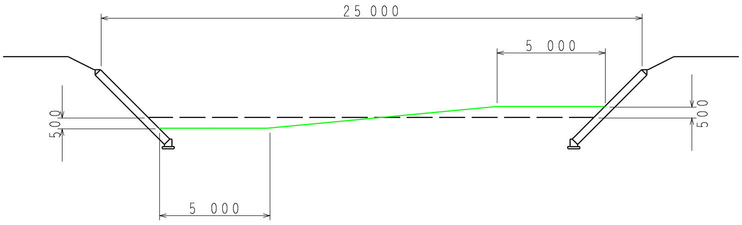

Fig. 9. Modification of riverbed topography in the conventionally improved river channel.

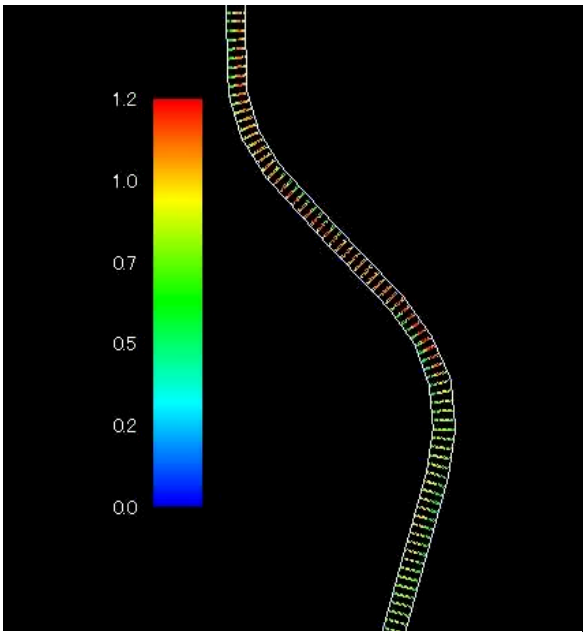

Fig. 10(a). Velocity fields in case with sandbar like undulations produced by a middle scaled flood

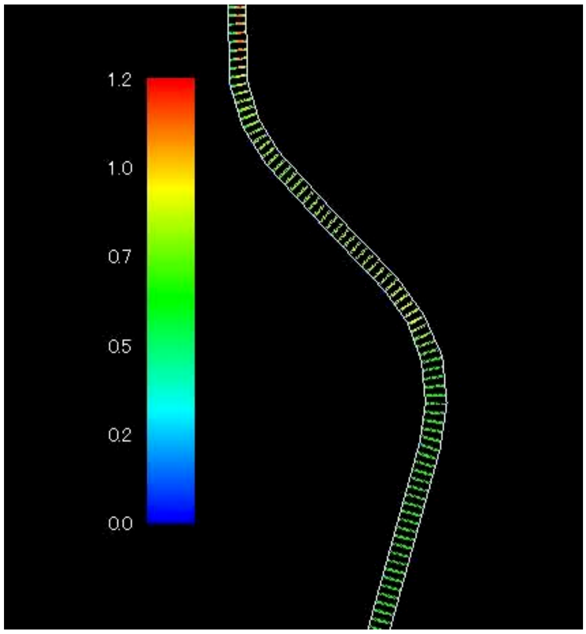

Fig. 10(b). Velocity fields in case of the present state produced by a middle scaled flood

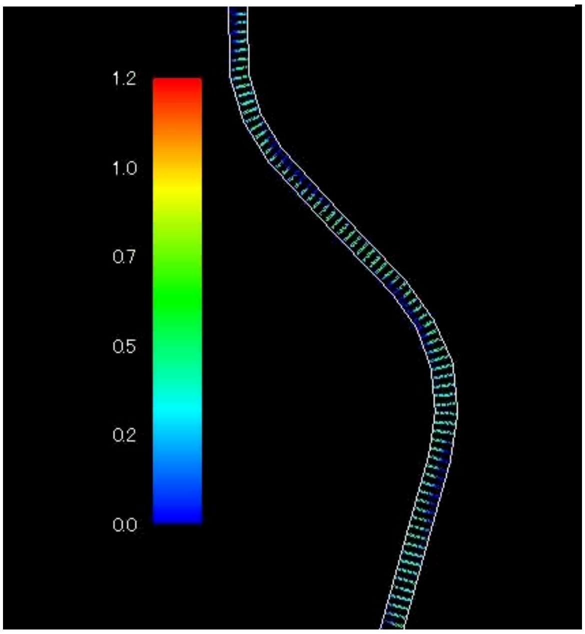

Fig. 11(a). Velocity fields in case with sandbar like undulations produced by the ordinary discharge

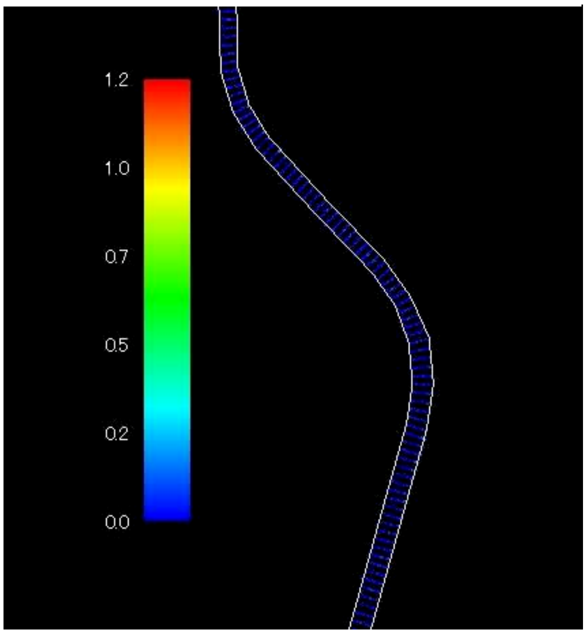

Fig. 11(b). Velocity fields in case of the present state produced by the ordinary discharge

Fig. 10(a) shows 2 dimensional velocity field computed by using a shallow water model for the riverbed introduced the sandbar like undulations under flow discharge of $25m^3/s$ while Fig. 10(b) for the present river channel shape under the same discharge condition. In the former, higher velocity areas than 1m/s appear widely along the thalweg connecting the lowest bed levels implying a favorable feature for river environment, such as fairly high ability to activate bed material exchange. On the other hand, velocity values are very low except uppermost area in the latter, suggesting sedimentation at the downstream reach.

Results of the same calculation are depicted in Figs. 11(a) and (b) with flow discharge of $0.1m^3/s$ representing the order of those at the ordinary states. As shown in Fig. 11(a), fairly high velocities at around 0.3m/s are anticipated in case that the sandbar like undulations are introduced even in the ordinary states. In addition, slight meandering of this flow and emerged mounds from water surface will improve the present monotonous scenery as imagined easily from Fig. 11(b) where all the channel bed is covered with lower velocities than 0.05m/s. Probably, flow velocity higher than 0.3m/s may suppress luxuriant growth of Brazilian waterweed *Egeria densa*. Thus, river environment must be improved with a little flow discharge caused by usual rainfalls by introducing some riverbed modifications.

6.3 An introduction effect of the riverbed transformation and a future problem

The scene as of a thing of Shinborigawa is the monotonous state that the area of the sea of the same depth of the water spread through between the concrete building a breakwater of both sides. I am in condition the surface of the water that sludge accumulates in the riverbed as for it, and was covered with a waterweed opens, and to be hard to allow a person to come near. On this account the eco-tone is poor, but is connected for the creation of a good eco-tone if I divide area of the sea by assuming a sandbar river channel the riverbed shape that I imitated. In addition, the movement of the bed material is promoted, and it seems that the quality of the biotope such as fish improves.

The habitation population had abundant the fish seeds when I carried out fish investigation although there was little it. Fish classes increase so that good biotope spreads by installing an eco-tone of the sandbar shape and think that people are easy to come to approach it.

I comparatively examined a big flood and the flow quantity in the normal of the scale for the examination of the foregoing paragraph. Even if it was velocity in the normal, the settlement was broken off, and it was recognized that I could anticipate velocity by having installed a sandbar. Examination whether or not the movement of the bottom quality is enabled in this velocity will be necessary in future.

ACKNOWLEDGMENT

We are grateful to the Gifu Construction Office, Gifu Prefecture for the courtesy to provide documents of the river improvement planning of the Shinborigawa. We thank Mr. S. Mizukami as well as under graduate students of Laboratory of River Engineering, Gifu University, Mr. T. Shiozawa in particular, for their cooperation to carry out the observations.

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