Study on Planning of a Small Hydropower Development under Consideration with the Basin Environment

Kazuki TERADA [(1)], Tetsuya SUMI, Yasuhiro TAKEMON and Motoyuki INOUE

(1) Graduate School of Engineering, Kyoto university

Synopsis

We investigated planning of a small hydropower for development of local community depending on natural resource which conserves natural landscape and basin ecosystem in the Ochiai River, a tributary of the Yoshii River in Okayama Prefecture.

Field surveys were conducted for flow volume measurement at six sites in the basin to predict hydropower potential. At a same time, we surveyed also on geomorphological and physico-chemical environmental factors (micro habitat composition, water quality parameters, canopy openness, etc.), aquatic animal communities and water fall landscapes in the basin.

The benthos and fish fauna of the Ochiai River was characterized by a set of endangered species, such as Nagare-hotoke-loach (*Onychodactylus japonicus*) and Japanese clawed salamander (*Onychodactylus japonicus*) in the upper reaches, indicating the environmental conditions of their habitats should be conserved in a high priority. In addition the EPT and ASPT indices of benthic communities and the waterfall images taken by the interval cameras were used for environmental assessment of a dam impact. .

Based on the results, we proposed the suitable site location of small hydropower in term of both of higher energy gain and nature conservation including habitats of endangered species. We investigated these location in eight cases according with environmental flow pattern considering with aquatic animals, waterfall landscapes in tourism seasons and tributary inflow below the water intake site. The planning procedure shown in this study will benefit local villages in general by sustainable energy of small hydropower generation and by rediscovery of ecosystem services and life styles utilizing original natural resources in the basin.

Keywords: small hydropower planning, flow volume, endangered species, biodiversity, waterfall landscape, environmental flow

1. Introduction

Estimating correct flow regime is very important for anticipating hydropower benefit. It is said 10 years flow regime curves are necessary to predict concisely duration curves. However, most of rivers in local areas where small hydropower projects are planned does not have observatories of flow volume.

When we do environmental assessment before construction of hydropower plant, we use physic and chemical parameter, but we need understanding the structure of river environment for setting more appropriate environmental flow. Benthos animals are reflected to comprehensive river environment. They are thought to be one of more useful methods to assess river environment.

The current hydropower projects are planned to get the lowest energy cost. Based on the plan, environmental methods are conducted as much as possible. Rich and original nature are required to raise the local characteristic, utilizing the value of the local nature for local creation, so it is important for the small hydropower projects to strike a balance between hydropower and environmental benefit (Ministry of the Environment, 2015).

There are many tributary inflows in river stream in local area located in mountains. We need considering the amount of branch inflow in recession area when we set environmental flow. These rivers are not available in all seasons because of the whether, so environmental flow for landscape flexibly needs to change corresponding to tour season.

Therefore, in this paper, this research sets the following four objectives.

1) Evaluation of duration curve at unmeasured point

2) Examination of evaluation of river environment utilizing benthic organisms

3) Combined evaluation of power generation and river ecological environment at each intake point candidate point

4) Establishment of methods to set environmental flow considering tributary inflow in recession area and tour season

In this research, we have created the new small hydropower plan in the Ochiai River at Okayama Prefecture in the Yoshii river system (Fig. 1). Aba village in Tsuyama city in Okayama Prefecture, where the Ochiai River flows, has 563 people and an aging rate in the village is very high (Fig. 2).

This village rapidly declined in population since merged with Tsuyama City in 2005. The village facilities also shrunk. In addition, only a JA gasoline station were withdrawn and the elementary school was closed. In these harsh conditions, management council was established and made "Aba Village Declaration" aiming at establishing a new autonomy (Ministry of Land, Infrastruture and Transport, Tourism, 2015). One of the local creation projects is to revive the gas station for “networking facilities". A small hydropower in the the Ochiai River is planned to produce electricity to operate this gas station and to sell to other areas. In addition, green tourism are considered to made use of the rich nature in Aba Village.

For this reason, this small hydropower project is required not to damage but to utilize effectively the precious natural environment of Aba Village.

2. Methodology

2.1. Duration curve prediction

“Hydro-valley plan guidebook” shows some methods to predict flow duration curves in an area which does not have enough data to do (Ministry of Economy, Trade and Industry, 2005).

A common method is to substitute flow volume data in near sites from the planned intake site and multiply the flow volume by relative ratio of catchment area of the planned intake to that of a substantial site in the observatory.

In this study, we estimate flow duration curves in the Ochiai River using the flow volume data in Osugi observatory (catchment area: 17.5km^2) in the Kamo River adjacent to the Ochiai River and Monomi observatory (catchment area: 38.5km^2) downstream (Fig. 3).

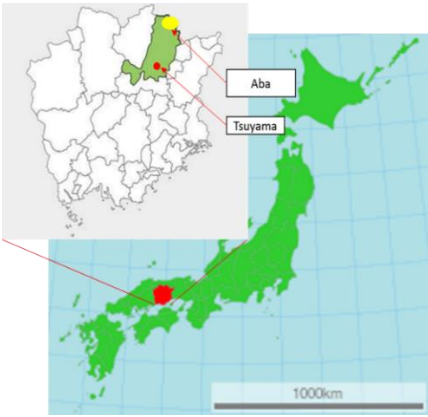


Fig. 1 Location of Aba village

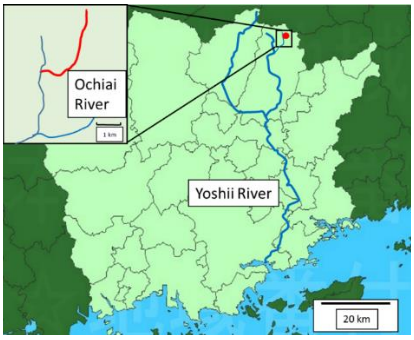


Fig. 2 Location of Ochiai river

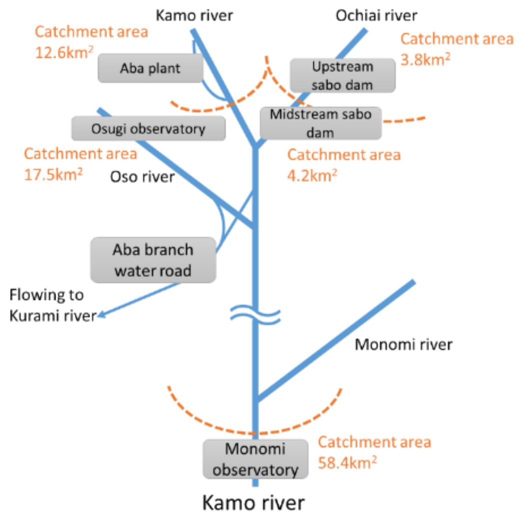


Fig. 3 Simplified Kamo River basin map

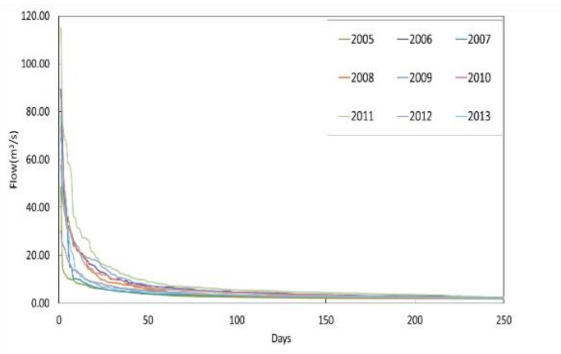


Fig. 4 Duration curves at Monomi observatory from 2005 to 2013

Osugi observatory has annual flow volume data in 2005. Monomi observatory has these data from 2005 to 2013 (Fig. 4).

To compare with other flow duration curves around the water intake site, we estimated average flow regime in rivers at Setouchi climate district with Mushiake's method. The catchment area of these rivers are 17.5 km^2 to 1730 km^2. His method is to predict maximum, three month, six month, nine month and drought flow, based on geological and climate data not considering snowmelt volume (Katsumi Mushiake et al, 1981)

The Ochiai River is located in Setouchi area and Fig. 5 shows two planned intake catchment area are mostly composed of granitic base rock. We calculate these flow volume using Mushiake's method with parameters of Setouchi climate and granitic sand.

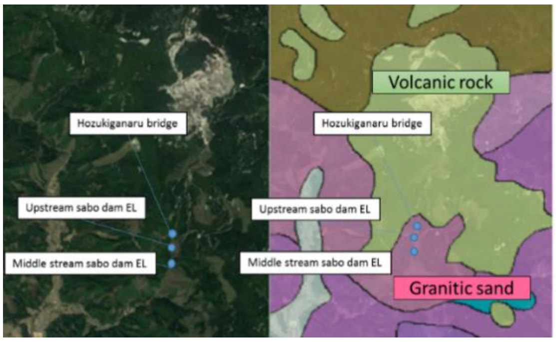


Fig. 5 Geological map at the Ochiai River basin

2.2. Calculation of hydropower potential at different water intake sites

(1) Setting water intake sites and discharge outlet

First, we set discharge outlet at Kanayama bridge in any cases of water intakes. In term of the low construction cost, we selected two sabo weirs as candidate sites of water intake for hydropower plants. In addition, we also choosed Hozukiganaru bridge because of many inflow volume from tributary in the recession area (Fig. 6).

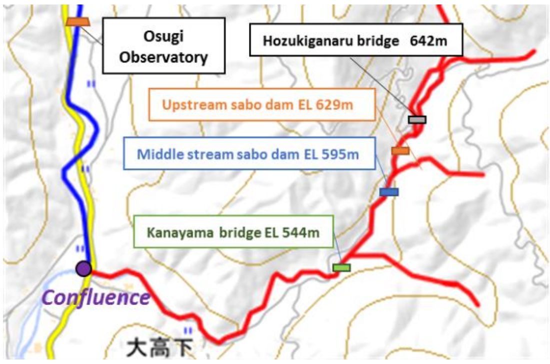


Fig. 6 Elevation of each area at Ochiai River

(2) Loss head

In order to estimate effective head, we calculated loss head from each water intake site to the discharge outlet. We calculated simplified formula used in previous hydropower potential surveys (New energy fundation, 1997).

$$h_l = \frac{1}{1000}L_1 + \frac{1}{200}L_2 + \frac{1}{1000}L_3 + (0.5 + \alpha) \quad [1]$$

$$h_{lf} = \left(\frac{1}{200}L_2 + 0.5 + \alpha\right)\left(\frac{Q_i}{Q_{max}}\right)^2 + \frac{1}{1000}L_3 \quad [2]$$

We did not consider the loss height of intake pipe and drainage tube because these loss impacts were negligible. The length of waterway tube were considered to be equaled to the distance from water intake to discharge sites.

(3) Setting an appropriate water turbine

Appropriate water turbines were decided based on effective height and maximum water intake volume (Fig. 10) (Tanaka Hydropower co., LTD,). The range of effective height from midstream sabo dam to Hozukiganaru bridge is 51m to 95m. A standard maximum water intake in each case is six month flows in each case. The range of maximum water intake volume is from 0.12 m^3/s to 18 m^3/s. Considering these parameter, we selected a pelton water turbine in all cases.

(4) Consideration of cavitation

To avoid cavitation while operating Hydraulic Turbines, the ratio of using water intake volume by maximum water intake volume is set as the parameter. Hydropower operation stops when the parameter is below the criteria of the water turbine. In case of the pelton turbine, the criteria ratio is about 0.08 (Water turbines selection and efficiency)

(5) Environmental flow

According to the guidance of environmental flow in Japan, necessary flow volume for new hydropower plant is about 0.6 $m^3/s/100km^2$. In case of Aba plant at Kamo River adjacent to the Ochiai River, the necessary environmental flow is 0.476 $m^3/s/100km^2$. Environmental flow volume is estimated at each hydropower plant with reference to that in Aba plant.

(6) Setting appropriate water intake volume

We computed annual hydropower energy at each case with each flow duration curve based on Monomi observatory, considering environmental flow and cavitation loss.

In reference to hydropower guidebook, we calculate hydropower construction cost at each powerplant. We calculated energy cost (kWh/yen) dividing hydropower production cost (yen) by hydropower energy (kWh). We set water intake volume at each cases which leads lowest energy cost.

2.3. Environmental evaluation through field survey on basin scale

(1) Term and sites

From September to December in 2016, We conducted a series of field surveys on geomorphology, canopy openness, discharge, water temperature, water quality and aquatic animal communities at a total of 17 sites in Ochiai river basin as shown at Fig. 7.

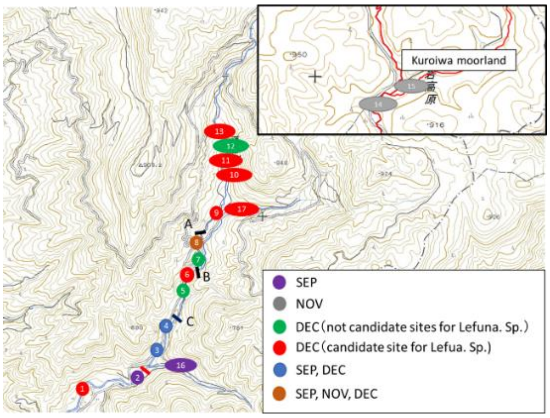


Fig. 7 Field survey sites

(2) Biota survey

Surveys on aquatic animal communities were conducted in the reach of discharge point (Kanyama bridge), recession area (pedestrian walk), an upstream water intake (Hozukiganaru bridge), tributaries (Doshiki River, Shiragataki River) and Kuroiwa moorland. In each sites, aquatic animals were collected separately in riffle pool, small waterfall habitat.

We used benthic animals for the semi-quantitative environmental assessment, caught with net of 40 × 30 mouth with a meshsize of 0.5 mm (amount of work; 20~30 min by 3~4 persons).

The reason why benthic organisms were used as a river environment assessment is that large taxes and number of benthic organisms can be captured and they are strongly influenced by the environment at the survey site due to the narrow range of habitats.

Captured benthic organism, preserved in 99% ethanol brought to our observatory, classified and identified into species or genus levels as far as possible using an optical microscope.

(3) Physico-chemical factors

We measured the water temperature, pH and EC at biological surveys and at potential sites where groundwater and hemispheric water spring into main stream. We show research area for latter reason are 1, 3, 4, 5 6, 7, 8, 9, 10, 11, 12, 13,16 (from downstream to upstream and tributary).

(4) Groundwater and spring water

These research sites for groundwater and spring water are selected in term of slope and mountain ridges. Groundwater and spring water are easy to emerge from sites where a slope changes steep into mild and sites where mountain ridges face the river. In order to investigate the slope transition sites, the Ochiai River slope was measured at 50, 100, 200 m intervals from the Ochiai River and Kamo River junction to Kuroiwa moorland (Fig. 8).

For the gradient at 50 m intervals, the site where a gradient gap between an upstream site and a downstream site is 7.5 or more is assumed to be the spring water site (Table 1).

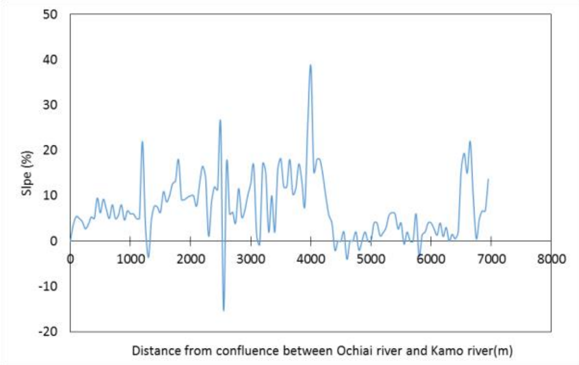


Fig. 8 Relationship between slope and distance from confluence between Kamo River and Ochiai River

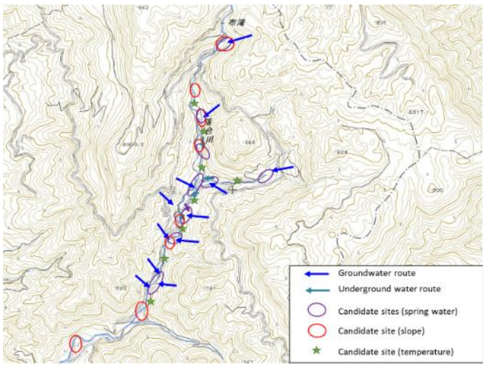


Fig. 9 Candidate sites where groundwater springs

The site facing the ridge and the river of the mountain was judged by eye measure with 1/25,000 scale maps issued by Geographical Survey Institute. 12 candidate spots for spring water from were found (Fig. 9). Of these, the survey was conducted at 1, 3, 4, 5, 6, 7, 8, 9, 10, A, C.

(5) Canopy openness

Canopy openness defined as a value of the area of the river not covered by tree canopies. The tree canopies were measured at several sites at each site by taking pictures upward with a fisheye lens on flat rock, by binarizing the photographs and by analyzing the ratio of the white area to the total area (Fig. 10).

(6) Ephemeroptera-Plecoptera-Trichoptera index and Average Species Per Taxa index

(a) ASPT

Average Species Per Taxa (ASPT) is a value obtained by dividing total environmental score of aquatic animals from 10 to 1 by numbers of discovered aquatic animals. The ASPT value takes a value from 10 to 1. When river environment are oligotrophic condition, ASPT is closer to 10. When river becomes more eutrophic condition, ASPT is closer to 1. Table. 1 shows all scores of benthos animals (Takeo Nozaki, 2012).

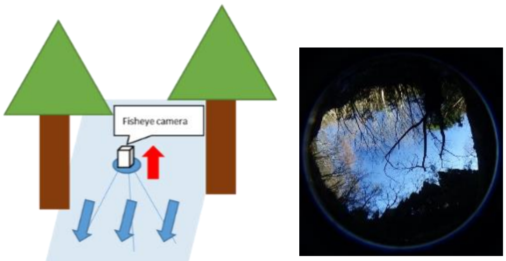


Fig. 10 Image of setting a fisheye camera and pictures taken by a fisheye camera

(b) EPT index

The EPT Index is named for three orders of aquatic insects that are common in benthic macroinvertebrate community: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). The EPT Index is based on the premise that high-quality streams usually have the greatest species richness. We calculated these scores at each habitat survey area.

2.4. Landscape

As the landscape location of the Ochiai River, we selected two waterfalls between Midstream sabo dam and confluence between the Ochiai River and Doshiki river. Time lapse-camera was set at each site and photographing was done at one hour intervals. The

Table 1 ASPT score table

TAXONOMIC GROUP	SCORE	TAXONOMIC GROUP	SCORE
EPHEMEROPTERA		LEPIDOPTERA	
SIPHLONURIDSE	8	CRAMBIDAE	7
DIPTEROMIMIDAE	10	COLEOPTERA	
AMELETIDAE	8	DYTISCIDAE	5
ISONYCHIIDAE	8	GYRINIDAE	8
HEPTAGENIIDAE	9	HYDROPHILIDAE	4
BAETIDAE	6	PSEPHENIDAE	8
LEPTOPHLEBIIDAE	9	DRYOPIDAE	8
EPHEMERELLIDAE	8	ELMIDAE	8
CAENIDAE	7	LAMPYRODAE	6
POTAMANTHIDAE	8	DIPTERA	
EPHEMERIDAE	8	TIPULIDAE	8
POLYMITARCYIDAE	8	BLEPHARICERIDAE	10
ODONATA		PSYCHODIDAE	1
CALOPTERYGIDAE	6	SIMULIIDAE	7
EPIOPHLEBIIDAE	9	CHIRONOMIDAE	2
GOMPHIDAE	7	CHIRONOMIDAE	6
CORDULEGASTRIDAE	3	CERATOPOGONIDAE	7
PLECOPTERA		TABANIDAE	6
NEMOURIDAE	6	ATHERICIDAE	8
PERLODIDAE	9	TRICLADIDA	
PERLIDAE	9	DUGESIIDAE	7
CHLOROPERLIDAE	9	MESOGASTROPODA	
HEMIPTERA		PLEUROCERIDAE	8
APHELOCHEIRIDAE	7	BASOMMATOPHORA	
MEGALOPTERA		LYMNAEIDAE	3
CORYDALIDAE	9	PHYSIDAE	1
TRICHOPTERA		PLANORBIDAE	2
STENOPSYCHIDAE	9	ANCYLIDAE	2
PHILOPOTAMIDAE	9	VENEROIDA	
PSYCHOMYIIDAE	8	CORBICULIDAE	3
POLYCENTROPODIDAE	9	OLIGOCHAETA	
HYDROPSYCHIDAE	7	OLIGOCHAETA	1
RHYACOPHILIDAE	9	OLIGOCHAETA	4
HYDROBIOSIDAE	9	HIRUDINEA	2
GLOSSOSOMATIDAE	9	AMPHIPODA	
HYDROPTILIDAE	4	GAMMARIDAE	8
BRACHYCENTRIDAE	10	ANISOGAMMARIDAE	8
LIMNEPHITIDAE	8	PONTOGENEIIDAE	8
APATANIIDAE	9	ISOPODA	
UENOIDAE	10	ASELLIDAE	2
GOERIDAE	7	DECAPODA	
LEPIDOSTOMATIDAE	9	POTAMIDAE	8
SERICOSTOMATIDAE	9		
LEPTOCERIDAE	8		

period is from SEP 18 to DEC 3 in 2016. We considered white water surface of waterfall all surface as area of waterfall (Fig. 11). Taken pictures were cut out with squares including the entire waterfall and the water surface just under the waterfall.

Next, we binarized these images using ImageJ with 256 pixel, divide less pixel than 240 into black and more pixel than 240 and image Processing. The proportion of the white area to the whole area was calculated.

We examined the relationship between this white area ratio and the flow volume measured at Masanotani fall site upstream of the location where we took some pictures. The environmental flow in the Kegon Waterfall is decided based on the flow volume that the waterfall can cut in two (Ministry of Land, infrastructure, transport and Tourism, 2007). Similar evaluation criteria were used for Masanotani falls this time.

Fig. 11 Evaluating site at pictures taken at Masanotani Fall to confirm waterfall landscape

In order to investigate the flow volume at which the waterfall possibly breaks into two as shown in Fig.11, we measured the black and white density of the area where the waterfall became blacker as the flow volume decreases and analyzed the correlation with the flow volume and determined flow volume when the waterfall may break into two.

Since the Ochiai River is a mountain stream, it is difficult to accurately measure the flow velocity and measure the exact cross-sectional geometry, but the upstream site at Masanotani fall is a rock bed with few topographical changes. It was possible to perform a stable flow volume observation. Also, since there is no tributary flow from the midstream sabo dam to the entrance of the boardwalk, the flow volume measured at upstream of Masanotani fall was also used for the landscape evaluation of these waterfall.

3. Result

3.1. Estimation of flow regime prediction

Duration curves at a bridge with midstream, upstream, and Hozukiganaru bridges was created with the duration curve of the observatory from 2005 to 2013. In addition, standard flow duration curves in Setouchi area were calculated by Mushiake method. Comparing the duration curves per unit area at the observatory with flow volume data at the observation, Fig. 12 shows the duration curve at the observatory is more stable than the average duration curve at the Setouchi area. The gap between average flow volume and a drought day (275th day) at the observatory is twice more than that in average rivers at the Setouchi area. This is because Kuroiwa mootland is located upstream of the Ochiai River, so the snow melt gently infiltrates underground. In addition, looking at the geological map of the Ochiai River, it is considered that granitic soil with low penetration rate in the upstream area also contributes to make the duration curve stable.

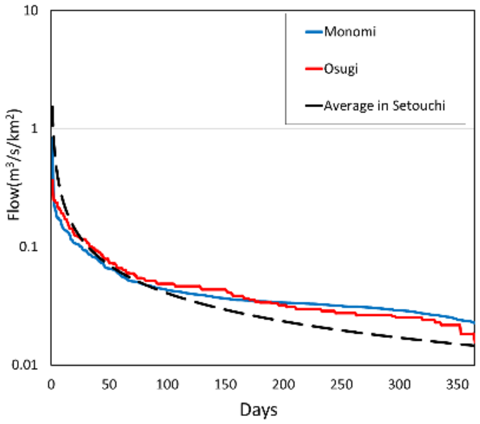
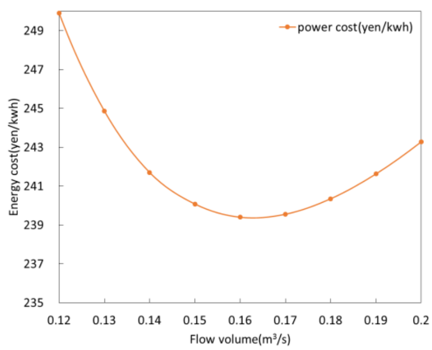


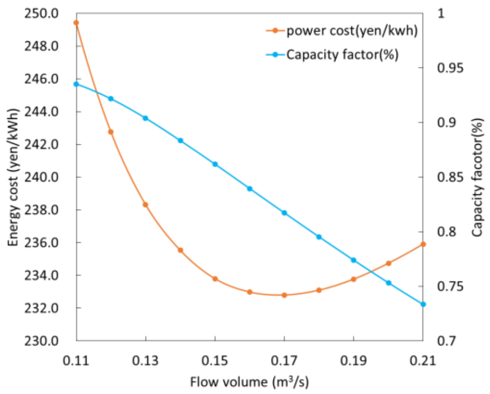
Fig. 12 Comparison of flow regime at the observatory at Kamo river (Monomi and Osugi) and average rivers at Setouchi rivers

3.2. Hydropower potential at each water intake

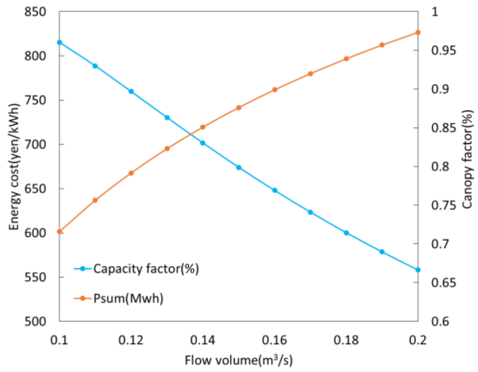
The optimum water intake amount at the midstream sabo dam and the upstream sabo dam was found to be 0.16 m^3/s and 0.17 m^3 / s respectively when we could get the lowest power generation cost (Fig. 13 a,b). In the case of Hozukiganaru bridge, it was set at 0.14 m^3/s, with which we could get the capacity factor close to that of the upstream sabo dam (82%) (Fig. 13 b,c).



a) Midstream sabo dam



b) Upstream sabo dam



c) Hozukiganaru bridge

Fig. 13 Relationship between flow volume and energy cost at midstream (a), at upstream sabo (b) and at Hozukiganaru bridge (c)

3.3. Biota survey

(1) Biota

At the Sasaki Bridge, Onychodactylus japonicus call as Nagarahotoledojyo in Japanese was discovered at SEP 18, 2016 (Fig. 14). This species is designated as endangered species in the Ministry of the Environmental Red Sheet. Onychodactylus japonicus belongs to the carp order Hillstream Loach stone loach subfamily, small freshwater fish living in a trickle of Mountains. It was suggested that it is different from another kind and L.echigonia called as Hotokedojyo. Habitat environment in recent years dramatically changed because of the impacts of human activity which leads to Onychodactylus japonicus is depleted.

In addition, in the Ochiai River. other rare species such as blackfin and salamander have been found.

Fig. 14 Onychodactylus japonicus

(2) pH, EC

Fig. 15 shows results of pH, and electric conductivity at each biological survey site. Although it is low in Kuroiwara Moorland, it can be seen that both PH and electric conductivity increases with the downstream flow due to the inflow of neutral groundwater from the hillside.

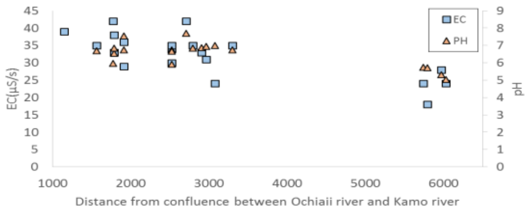
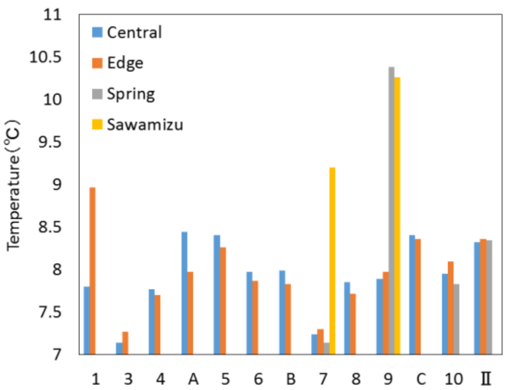


Fig. 15 Relationship between EC and pH and Distance from confluence between Ochiai river and Kamo river

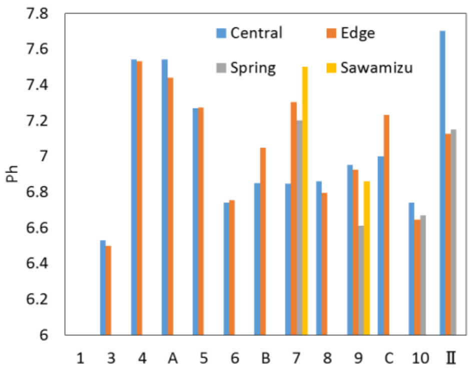
(3) Groundwater, spring water

As shown in Fig. 16, water quality assessment was conducted at the 13 site to evaluate the inflow of spring water and groundwater at the center and at the edge of the river. We also conducted a water quality survey even at the site where spring water could actually be confirmed.

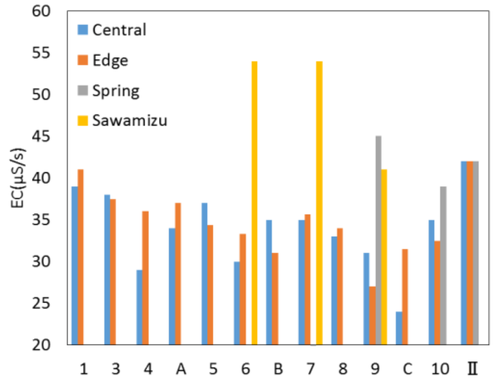
As a result, it was found that these difference between the edge and the median was large at Hozukiganaru bridge.



a) Temperature



b) pH



c) EC

Fig. 16 Temperature (a), pH (b), EC (c) at each field survey sites in December

(4) Canopy openness

The measurement results of openness are shown in Fig. 17 at the Hozukiganaru bridge, the openness became the largest value, and then the value the site between the midstream sabo dam and the pedestrian walk became a large value.

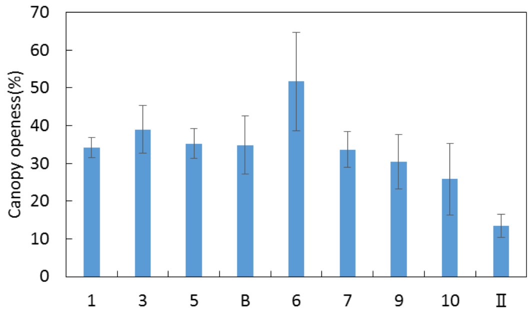


Fig. 17 Canopy openness at each research area

(5) Ecological evaluation

The biodiversity of the river environment was evaluated by using the EPT index and the ASPT index. Different values with EPT and ASPT index are shown at each sites.

The EPT index became a little higher as it went downstream, but the ASPT index are highest at the midstream sabo dam. This means that an increase in flow volume does not necessarily have a big influence on diversity of the biota environment.

There were no significant differences in the ASPT index at four sites of investigation in main rivers in the Ochiai Rivers. On the other hand, it was found that the EPT index has the largest value at the midstream sabo dam. The species targeted by the ASPT index is more than fifteen species, whereas in EPT the target species is only Ephemeroptera, Trichoptera and Plecoptera. Also As Fig. 18 shows, the EPT index shows excessive reaction to turbidity. In addition, the water quality of the Ochiai River was found to be an average value compared to the ASPT and EPT values in other rivers.

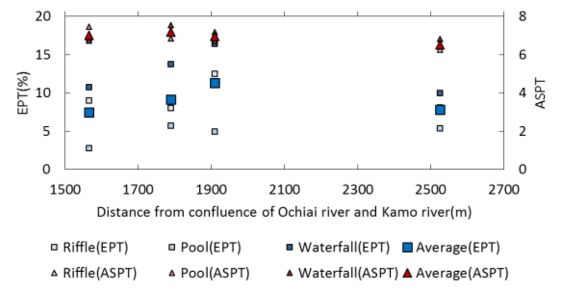


Fig. 18 Relationship between EPT and ASPT and distance from confluence of Ochiai river and Kamo river

3.4. Landscape

In reference to the environmental flow volume at upstream area of Kegon fall, we evaluate waterfall landscape at Masanotani fall. In the Kegon Falls, the environmental flow is set depending on whether the waterfall breaks into two or not. During this survey period, the waterfall hasn't been split into two at any time. Therefore, we paid attention to two places which became black in a part of the waterfall as the flow volume decreased, and the correlation between flow volume and monochrome density was analyzed to calculate the flow volume at which the waterfall was likely to split into two. Average monochrome density of the place where the rock can be seen at the waterfall was 120, when the minimum pixel value in the section was less than 120 pixels (Fig. 19). We assumed the waterfall was split into two and the rocky skin could be seen when the water volume decreased.

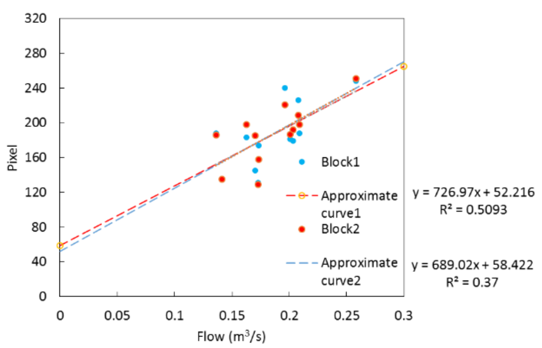


Fig. 19 Relationship flow and pixcel at block1 and block2

The results of the relation between the white area ratio of the waterfall and the flow volume are shown below. Although it showed a linear relationship at the falling site of the waterfall, the surface of the waterfall showed a nonlinear relationship. When the waterfall breaks into two, the white area of the waterfall is 8%. During the photo shooting period from October to November, the day when the flow volume became the smallest is 11/3. The white area ratio at that time was 10% (Fig. 20). This indicates that there is a possibility that when the waterfall breaks into two, the landscape of the entire waterfall has not changed significantly.

4. Proposal of small hydropower projects considering environmental conservation

4.1 Assessment of hydropower potential and river environmental impacts at each water intake

The water intake site in the conventional hydroelectric power plan was decided as the site where the power generation cost becomes minimum. Environmental preservation are conducted at recession area, adjusting environmental flow. However, hydropower generation at rural area are required to preserve the distinctive environment. Therefore, from the stage of the planning, we should make the plan more harmony with hydropower energy cost and environment impacts.

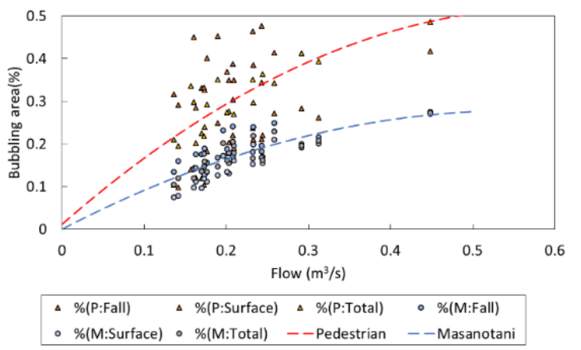


Fig. 20 Relationship between flow and bubbling area at Masanotani fall

We calculated minimum energy cost at midstream and upstream sabo dam to set optimum water intake. At Hozukiganaru bridge, we set optimum water intake when the capacity factor at Hozukiganaru bridge is equal to that at upstream sabo dam because we cannot estimate the construction cost of the weir at Hozukiganaru bridge.

We evaluated two kinds of environmental flow. One is set with reference to average environmental flow volume in Japan; 0.3 $m^3/s/km^2$ to 0.6 $m^3/s/100km^2$. In this study, we used the environmental flow in case of Aba plant in Kamo river: 0.47 $m^3/s/100$ km^2. Another is set to conserve Masanotani waterfall scenery; 0.09 m^3/s. Fig.21 shows the results of hydropower energy at each water intake in two cases of environmental flow. We found these 50% decrease of hydropower energy at midstream and upstream intake. The cause of about 80 % decrease of hydropower energy at Hozukiganaru bridge is the increase of the number of the day when water intake stopped to prevent cavitation.

Environmental impacts of flow volume depends on water intake volume and environmental flow volume. Considering the influence on the environment in case of each intake site and environmental flow, we selected three high valuable area in the Ochiai river in term of biodiversity and rare species and landscape (Fig. 22).

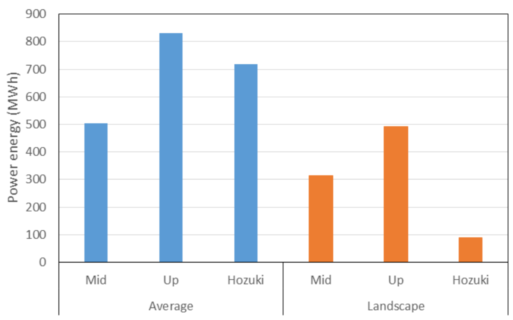


Fig. 21 Comparing power production in each water intake in case of average environmental flow and environmental flow for landscape

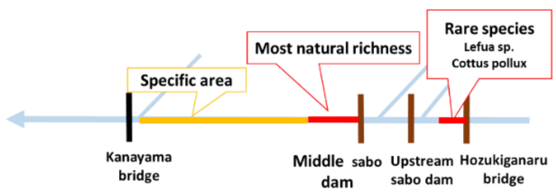


Fig. 22 Characteristic at each section in the Ochiai River

The impacts on three valuable sites was evaluated for the amount of water. When considering the decrease of flow volume at each site, we considered the increase due to the inflow amount of the tributary flow. These tributaries inflow amount was determined by multiplying the duration curve at Monomi observatory by the ratio of the catchment area of these tributary to that of the observatory site (Fig. 23).

At each intake site, ranking evaluation was conducted in five terms of power generation cost, generated electric energy, biodiversity / rarity and landscape. As a result, in case of average environmental flow, the upstream sabo dam was ranked first in terms of power generation cost, generated electric energy, biological scarcity, but the annual flow volume just under the midstream sabo dam became the smallest value (Fig. 24). This means that it has the greatest influence on the biodiversity and landscape downstream of the midstream sabo dam. In case of environmental flow for the waterfall scenery, we found upstream dam are most optimum. The reason why impacts on environment and landscape in upstream dam is less than in midstream is that environmental discharges are same at each intakes and the impacts depends on the amount of inflow in the tributatries.

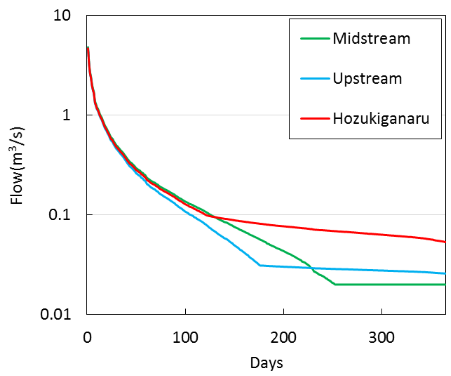


Fig. 23 Duration curves at downstream of midstream sabo dam in each case of midstream sabo dam, upstream sabo dam and Hozukiganaru bridge; average environmental flow

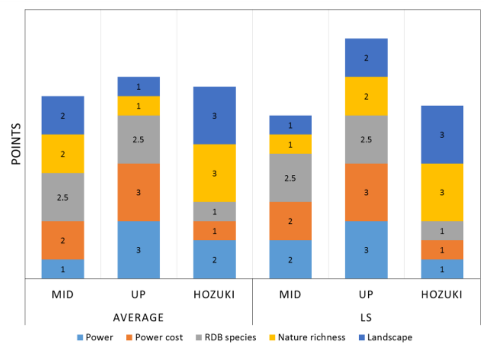


Fig. 24 Comparison of total evaluation in case of average environmental flow and environmental flow for landscape

4.2 Evaluation of hydropower potential and river environmental impacts with new environmental flow methods

In the process to decide conventional environmental flow, the tributary inflow in the water recession section has not been considered. However, in mountain stream rivers where many small hydropower projects are carried out, there are many confluence between main rivers and tributary rivers. We should set the environmental flow volume considering the tributary inflow amount in the water reduction section. In addition, one of the purposes of river use is to see the landscape. When river is not accessible because of snow, environmental flow for landscape is not necessary.

We proposed two environmental flow setting concepts in term of space and time. One concept is that tributary inflow volume in recession area is substracted by amount of environmental flow. Another concept is that environmental flow is stopped during water season when the Ochiai river is not available because of snow. In the Ochiai river, we introduce this method to set environmental flow into water intakes at upstream sabo dam and Hozukiganaru bridge.

We simulated three cases to confirm the effects of the new method to determine environmental flow volume. One case is that discharge at upstream sabo dam and Hozukiganaru bridges are decided considering the increase of the tributary inflow at these recession area. Second case is that environmental flow stops during the winter season (TO). In third case, we combined two above cases (TO + TR).

(1) Tributary; TR

The energy cost was calculated when the environmental flow volume was 0.09 m^3/s. As a result, the cost was the smallest at 0.12 m^3/s at the midstream sabo dam and 0.13 m^3/s at the upstream sabo dam (Fig. 25, 26). The amount of power generation at this time is 315 MWh at the midstream sabo dam and 492 MWh at the upstream sabo dam.

Compared with the conventional environmental flow volume, the generated electric power amount decreased by about 37 to 40%.

At Hozukiganaru Bridge, when the water intake volume was determined with the same facility utilization rate as that of the upstream sabo dam, the intake amount is 0.02 m^3/s (Fig. 26), and the power generation was only 90 MWh. This is because **75** days of the year when the intake flow volume is below 0.1 m^3/s. This makes more number of the days when the water intake is 0 m^3/s to prevent cavitation.

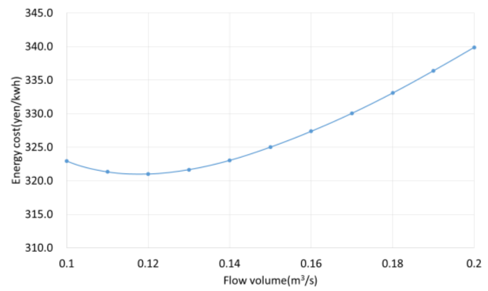
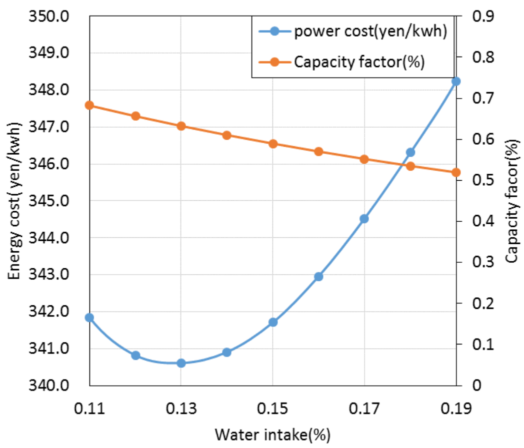
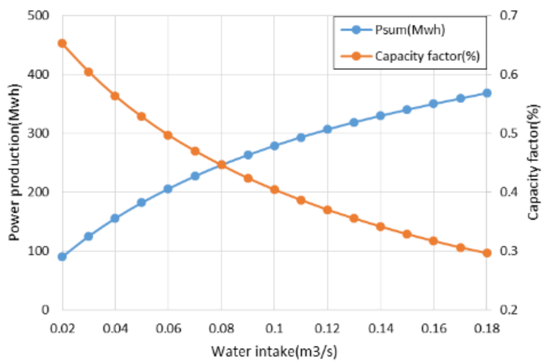


Fig. 25 Relationship between flow volume and energy cost at midstream sabo dam



a) Upstream sabo dam



b) Hozukiganaru bridge

Fig. 26 Relationship between water intake and energy cost and a capacity factor at upstream sabo dam (a) and a capacity factor at Hozukiganaru bridge (b)

(2) Tour season; TO

The power generations are calculated without environmental flow during winter when waterfall downstream of the midstream sabo dam cannot be seen

Table 2 Environmental flow at each intakes in each case

	Average (m^3/s)			Landscape (m^3/s)		
	Mid	Up	Hozuki	Mid	Up	Hozuki
Normal	0.020	0.018	0.012	0.090	0.090	0.090
Tributary (TR)	0.020	0.005	0.000	0.090	0.077	0.022
Tour season (TO)	0.020	0.018	0.012	0.090	0.090	0.090
TR+TO	0.020	0.005	0.000	0.090	0.077	0.022

due to snowfall. In this case, annual change of the snow height at Uenagata in 2005 is calculated by AMeDAS observatory near the Ochiai river.

The period during which sightseeing is impossible in the the Ochiai River is generally from December to April. The number of days when it falls below 0.09 m^3/s was calculated from the duration curve at each water intake site, it was found that the day when the flow volume is less than 0.09 m^3/s is 113th days at the upstream sabo dam, 135th days in the midstream sabo dam and 144th days in the Hozukiganaru Bridge (Fig. 26).

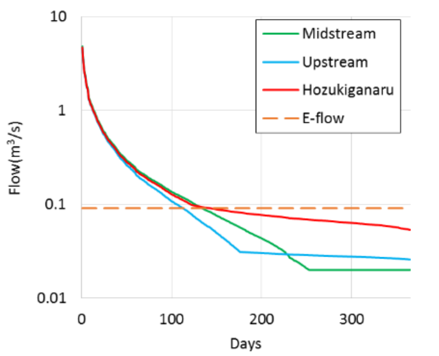


Fig. 27 Relationship between environmental flow (E-flow) duration curves at downstream of midstream sabo dam in each cases

Judging from the duration curve at Monomi observatory from 2005 to 2013, we calculated the ratio of the number of days from December to April to the total number of days when flow volume is less than 0.09 m^3/ s.

The ratio at each intake site is 39.9% out of 253 days in the upper sabo dam, 36.3% out of 231 days in the midstream sabo dam, 35.1% out of 221 days in the Hozukiganaru bridge.

The loss of power generation by maintaining 0.09 m^3/s at downstream of midstream sabo dam is computed using the gap between total flow volume which are under 0.09 m^3/s and the value which 0.09 m^3/s multiplied by the number of the days when flow volume are under 0.09 m^3/s.

We calculated the increasing amount of power generation by not discharging environmental flow in winter by multiplying the loss of power generation with the above ratio.

(3) Tributary inflow + Tour season; TR + TO

Finally, we combined two above cases: environmental flow is set with consideration of the increase of tributary inflow and the off season of environmental flow. Based on the above, we summarized environmental flow at each intakes in each case (Table 2).

The power generation at Hozukiganaru bridge is more than that at other two water intakes. On the other hand, when we evaluate which hydropower plant site is appropriate in case to consider waterfall scenery, tributary inflow and winter season, upstream sabo dam is the best same as in case of a conventional method.

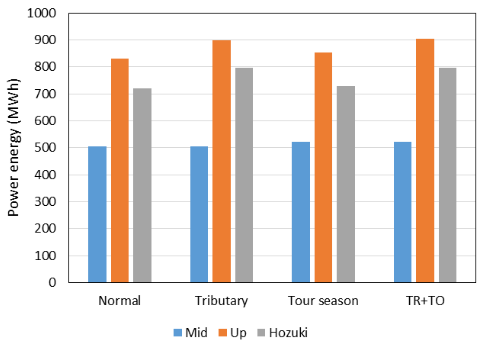
Conclusion

We found The gap between average flow volume and a drought day (275^{th} day) at the observatory is twice more than that in average rivers at the Setouchi area which shows the flow regime in the Ochiai river is more stable than other rivers in Setouchi climate regions because moorland on upper the river has high water retention and a lot of snow.

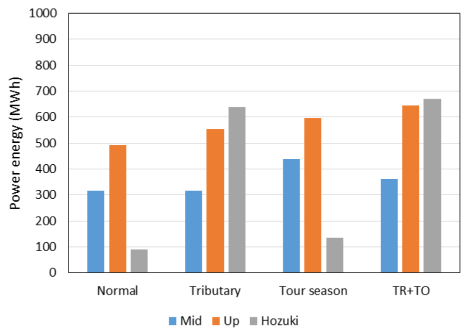
In term of hydropower generation, Fig. 28 shows Upper stream dam is the most appropriate site, comparing midstream sabo dam and Hozukiganaru bridge. In the site, about 800 MWh can be produced in all cases of average environmental flow and about 500 to 600 MWh can be produced in some cases of environmental flow for landscape.

On the other hand, Fig.29 shows there is a possibility that the location to build small hydropower plant will change by setting integrated evaluation methods considering power generation cost, ecology and landscape.

However, there are two problems in the ranking methods. One is that this ranking system does not show how much differences there are among each site in each item. Another is that the number of evaluation items (hydropower generation, ecology and landscape) are different, so, we should compare some evaluation methods.

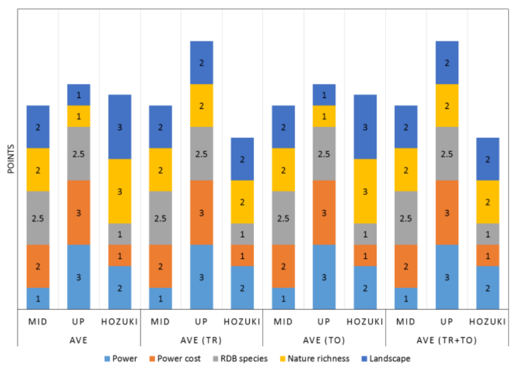


a) Average environmental flow

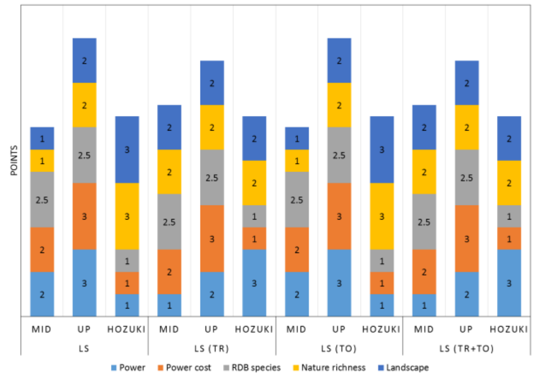


b) Environmental flow for landscape

Fig. 28 Comparing power generation in each water intakes in case of average environmental flow (a) and environmental flow for landscape (b)



a) Average environmental flow



b) Environmental flow for landscape

Fig. 29 Comparing total evaluation in case of average environmental flow (a) and environmental flow for landscape (b)

Acknowledgment

I wish to thank Hazime Goto, belonging to Bizen clea energy company, Kensuke Tanaka working as Community-Reactivating Cooperator Squad, and Masamichi Nanto belonging to Aba village office who help me do field surveys at the Ochiai river many times.

References

環境省(2015)：「低炭素・循環・自然共生」地域創生実現プラン策定事業.

経済産業省: 再生可能エネルギーを巡る情勢について, http://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/003/pdf/003_000.pdf

経済産業省(2005)：ハイドロバレー計画ガイドブック, pp5-2-9.

経済産業省資源エネルギー庁 (2014): エネルギー基本計画, pp20.

経済産業省資源エネルギー庁 (2015): エネルギーコストの状況, 平成 26 年度エネルギーに関する年次報告, pp 180-182.

国土交通省(2015) ：あば村宣言と「小さな拠点」づくり,「小さな拠点づくりフォーラム」資料, pp5-16

国土交通省河川局河川環境課(2007)：正常流量検討の手引, pp28-30..

国土交通省(2015): 国土形成計画, pp86,87.

新エネルギー財団: 水力本部中小水力発電ガイドブック(1997):. pp81.

鈴木達也,・石原鞠絵・ 橋本北斗・眞木優一 (2012)：

中小水力発電と再生可能エネルギー導入の地域経済波及効果, 早稲田社会科学総合研究. 別冊, 2012 年度学生論文集, pp 183-198.

全国小水力利用推進協議会(2014)：中小水力発電の現状と見通し, pp5.

全国地球温暖化防止活動推進センター: 日本の二酸化炭素の排出量の推移（1990-2014 年度）, http://www.jccca.org/chart/chart04_03.html.

田中水力株式会社: Tanaka Hydropower Turbine Selection Chart, http://www.tanasui.co.jp/productsChartsEn.html.

諸富 徹 (2015)：「エネルギー自治」で地域再生!——飯田モデルに学ぶ , 岩波ブックレット, pp7.

Katumi Mushiake., Yutaka TAKAHASI and Yoshihisa ANDO(1981): Effects of basin geology on river-flow regime in mountainous areas of Japan. Journal of Japan Society of Civil Engineering 309, pp 51-62.

Takeo Nozaki. (2012) : Biological assessment based on macroinvertebrate communities -Average Score System for Japanese rivers, Journal of Japan Society on Water Environment 35, pp 118-121.

Water turbines selection and efficiency: ttp://waterturbines.wikidot.com/system:join.

(Received June 13, 2017)