京都大学防災研究所年報 第47号 C 平成16年3月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 47 C, 2004

Changing Patterns of Water Quality Associated with Hyporheic Flow of a Gravel Bar in the Kamo River

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Synopsis

Aquatic environmental conditions of the hyporheic zone in a gravel bar were investigated under normal low-flow conditions in the Kamo River, in Kyoto city, Japan. Horizontal distribution and chronological changes in DO concentration, water temperature and electric conductivity in the hyporheic zone were examined in relation to the hyporheic flow as a factor for the changes in water quality. Distribution patterns of the water quality parameters showed that the reduction in DO concentration was strongly related to the hyporheic water temperature, indicating that it was influenced by decomposition process of organic matters as well as the liquidity of the hyporheic flow. Hyporheic water temperature at the area without vegetation cover tended to rise following the increase in the ground surface temperature in the daytime.

Keywords: dissolved oxygen; habitat; hyporheic zone; physicochemical environment

1. Introduction

The interaction area between groundwater and stream water, referred to as hyporheic zone (Orghidan, 1959), has important functions that regulate nutrient cycling (e.g. Pionke et al., 1988; Valett et al. 1996; Wondzell and Swanson, 1999), provide oxygen and habitats for benthic biota (e.g. Bulton et al., 1992; Williams, 1993). In addition, hyporheic zones of sand/gravel bars function to purify water by filtering river water (Fiebig and Lock, 1991). The recent rise in the public's expectations regarding the conservation of lotic environments has prompted the establishment of river management systems by the government. The functions of hyporheic zones have been highlighted as an important composition of lotic environments required for their conservation.

Although some studies have reported hydro chemical functions of the hyporheic zone for river water quality associated with impact of floods and precipitations (Valett et al., 1996; Wondzell and Swanson, 1996), few attempts have been made to clarify the structure and ecological functions of the hyporheic zone from the perspective of the habitat of hyporheos (Bulton et al., 1992; Tanaka et al., 2003). Therefore, the flow and sediment management system had been unaddressed for the maintenance of the functions of the hyporheic zone.

In general, it has been considered that and that enough dissolved oxygen (DO) essential for survival of benthos is supplied by increasing hyporheic flow rate under flood periods. Furthermore, it has been reported that the hyporheic zone functions as a refuge for various benthos or hyporheos (e.g. Bishop, 1973; Poole and Stewart, 1976). In contrast, under normal low-flow periods lacking riverbed disturbance by the flow, less volume of river water penetrates into the hyporheic zone, resulting in the deterioration of the habitat conditions.

The present study focused on the horizontal distribution and chronological changes in DO concentration, an important factor for hyporheos, in the hyporheic zone of a gravel bar under normal low-flow conditions. Possible environmental factors affecting the DO concentration were investigated in relation to the dynamics of hyporheic flow in the gravel bar. Based on the results, functions of hyporheic zone of a gravel bar are discussed as a habitat for hyporheos.

2. Materials and Methods

2.1 Study site

This present study was conducted in the Kurama River, a tributary of the Kamo River, located in central Kyoto city (Fig. 1). Since the Kamo River had often suffered flood and sediment-related disasters in 1930s, a lot of check-dams were constructed after 1940's. The sediment control works have been considered to have changed the landscape of the lower reaches by stabilization of riverbed, resulting in increase in vegetated area on bars and in alteration of habitat quality for hyporheos (Takemon, 2003). We selected a gravel bar of 180m^2 in area for the study site in the Kurana River at 0.6 km from the confluence with the Kamo River (Fig. 2, Photo 1). The bank side terrace and inner parts of the bar were covered by *Phragmites japonica* of ca. 1m in height. Substrates of the bar in the most parts were composed of cobble and gravel with maximum grain size ranging from 10 to 20cm and those in the lower part sand and organic matter.

In this bar, the hyporheic water level, permeability, water temperature and water quality were measured using wells and tubes settled for sampling of hyporheic water. These surveys were conducted on May 4th, May 20th, June 7th, June 22th and July 9th in 2003, every two weeks, during normal low-flow periods so as to avoid flooding effects (Fig. 3). In addition, the topography of riverbed was measured by using level-instrument.

2.2 Hyporheic water level survey

In order to investigate horizontal distribution of the hyporheic water level in the bar, five transects (A, B, C, D, E line) were set up (Fig. 2). On these lines, we selected 31 wells and 4 sites for measuring the hyporheic water level and river water level, respectively. The wells, made of a 4.6cm-diameter PVC pipe (50cm-long) with a strainer of 40 cm-sectional long at the bottom of the pipe, were installed into the bar till the depth of 30-50 cm from ground surfaces. Then, the position coordinate of the sites and the elevation of head of the well were measured with level-instrument. An origin of the position coordinate and the elevation was set up at the A08 site and at the deepest point of pool, respectively. Depth from the head of well to the water head in each well was measured using a water level meter, and then, the depth was converted into the hyporheic water level.

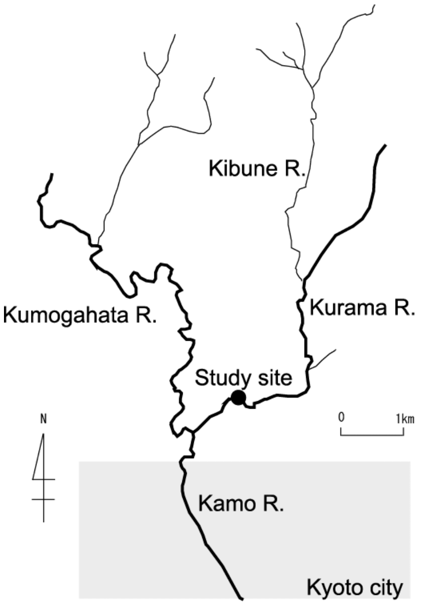

Fig. 1 Location of the Kamo River and the study site in the Kurama River. Solid circle indicates the study site.

Photo 1 Picture of study site.

2.3 Water quality and temperature survey

In order to collect the hyporheic water in the bar, a silicon tube attaching the acrylic fiber at the tip was buried at the depth of 15-20 cm from the hyporheic water surface at each sampling site (Fig. 2). Thus, dissolved oxygen concentration (DO), pH, electric conductivity (EC) and the hyporheic water temperature were measured using DO meter (YSI/Nanotech Inc., YSI Model 95), EC meter (YSI/Nanotech Inc., YSI Model 30) and pH meter (HORIBA Ltd., B-212).

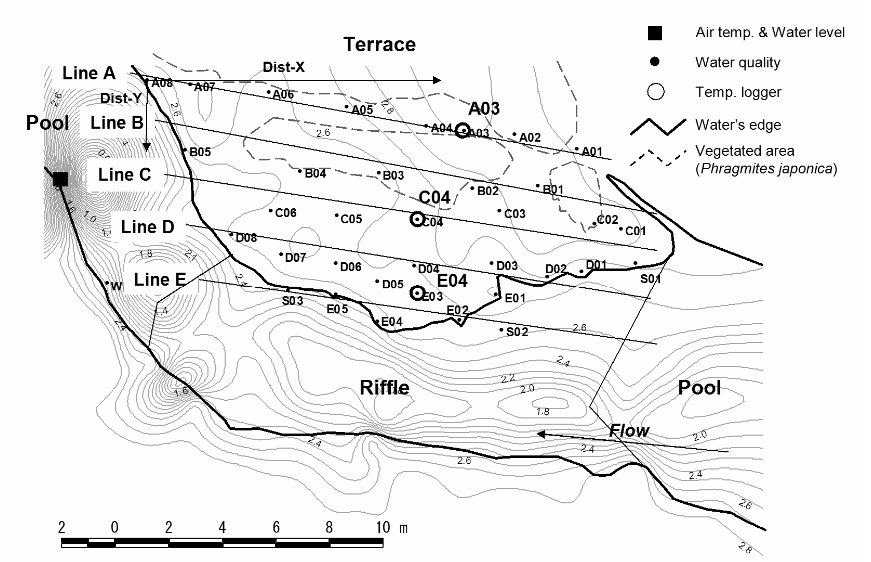

Fig. 2 Location of study site on a bar and sampling sites. Contour interval of ground surface level is 0.1 m.

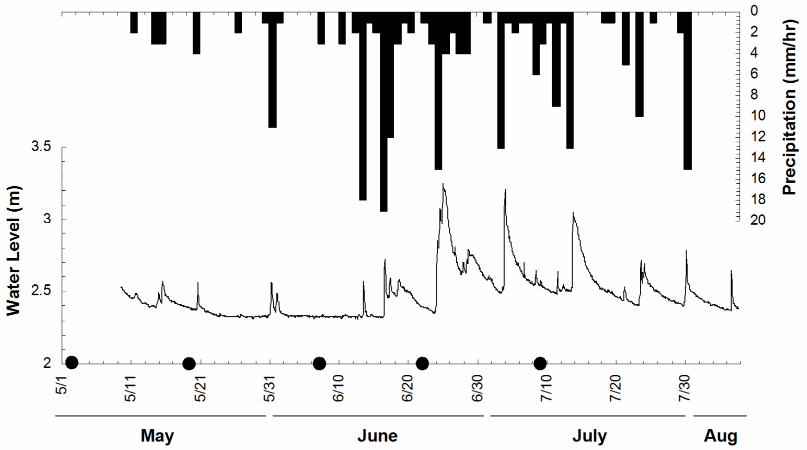

Fig. 3 Fluctuations of water level in data logger site (see Fig. 2) with precipitation from May to Aug. 2003. Solid circles indicate sampling dates.

Moreover, the hyporheic water temperature and ground surface temperature at 3 sites, A03, C04 and E04, the air and river water temperature at one site (Fig. 2), were measured using the sensor and data logger (Onset Computer, StowAway Tidbit Temp Logger) throughout the experimental period. The data loggers for the hyporheic water temperature were buried at same depth of the tubes for water sampling and those for ground surface temperature were settled under gravel of the surface layer to avoid the effect of direct sunlight.

2.4 Permeability test

Permeability of the substrates was measured in the field using methods of the packer test and the piezometers test at 31 sites in the bar in order to obtain the distribution of permeability coefficient. The packer test was conducted in high permeable area, and the piezometers test in low permeable area. Then a steel standpipe of 100cm in length and 4.6cm in diameter with a strainer of 0.5mm in slit width and 5cm-in sectional long was installed into the bar by a hammer to fit the strainer at the depth of 30-50cm from ground surfaces. Water head in the standpipe was measured by a pore pressure meter and a data logger of up to 0.1cm accuracy. These tests were conducted on early May 2003.

In the case of the packer test, the permeability coefficient (k (cm/sec)) can be calculated from the following equation (Murakami et al., 2001; Nishigaki, 1986).

$$k = \frac{Q_p}{2\pi hl}\sinh^{-1}\left(\frac{l}{2r_w}\right) \qquad (1)$$

where Q_p is a discharge pumped into the standpipe (cm^3), l is the sectional length of a strainer (cm), h is the difference between water heads ($h = h_1 - h_2$ (cm)), h_1 is initial water head (cm), h_2 is water head under steady-state condition (cm) and r_w is the inner radius of a standpipe (cm). A pump with its maximum flow rate of 100cm^3/sec was used to raise water head into the standpipe. The flow rates pumped into the well were measured by a flow meter with an accuracy of 0.001cm^3/sec.

In the case of the piezometers test, we raised water head in the standpipe and measured a water head (h) per 5 second. The permeability coefficient (k) can be calculated from the following equation (Nishigaki, 1986).

$$k = \frac{r_w^{\ 2}}{2l\left(t_2 - t_1\right)} \ln\left(\frac{l}{r_w}\right) \ln\left(\frac{h_1}{h_2}\right) \tag{2}$$

where l is the sectional length of a strainer (cm), r_w is the inner radius of a standpipe (cm) and h_1 and h_2 are water heads at time of t_1 and t_2, respectively (cm).

2.5 Data analyses

In order to analyze horizontal distribution patterns of water quality measurements in the bar, we measured distance in the Y direction (Dist-Y) and in the X direction (Dist-X) for each sampling site, indicating distance from terrace and from down edge of the bar, respectively (Fig.2).

Interpolation was performed on the hyporheic water level data obtained at sampling time by Inverse Distance Weighting (IDW) to measure the hydraulic gradient (i). Furthermore, the bar was divided by the Voronoi Tessellation (VT) centred on permeability test sites to give the permeability coefficient for each section.

Thus, the hyporheic flow velocity, v (cm/sec) can be calculated using following Darcy law.

$$v = k \cdot i \tag{3}$$

where k (cm/sec) is the permeability coefficient, i is a hydraulic gradient.

For statistical analyses, Pearson's correlation coefficient was used to evaluate the relationships among all variables. In order to improve normality the hyporheic flow velocity (v) and permeability coefficient (k) were transformed to log (x+1) and log (x), respectively (Sokal and Rohlf, 1997). These statistical analyses were conducted using SPSS for Windows Ver.10.1.3J (SPSS Inc., 2001).

Spatio-temporal differences in hyporheic water level and water quality were evaluated based on the mean and standard deviation (SD) of these variables at each site. Interpolation was performed on the data using the Triangulated Irregular Network (TIN). ArcView GIS Ver. 3.2a (Environmental Systems Research Institute, Inc., 1996) was used for these analysis.

3. Results and Discussion

3.1 Fluctuations of the hyporheic water temperature

Figure 4 shows the results of continuous monitoring of the ground surface temperature, the hyporheic water temperature, the river water temperature, and the air temperature at three points on the bar (A03: terrace side, C04: centre, E04: water's edge) during the study periods. Noticeable differences were observed in the fluctuation pattern among the ground surface temperature, the hyporheic water temperature, and the river water temperatures at these points. The ground surface temperature fluctuated markedly; increasing and decreasing quickly according to air temperature changes. The trend was most obvious near the water's edge (E04), where the ground surface temperature was comparatively higher. In contrast, the hyporheic water temperature did not fluctuate as much as the river water temperature, keeping a relatively stable level, although the average value was higher than the river water temperature. The hyporheic water temperature tended to be high near the water's edge (E04).

Relationships among the air temperature, the river water temperature, the ground surface temperature, and the hyporheic water temperature at A08, C04, and E04 showed that the temperature of ground surface, hyporheic water, and river water increased with the air temperature, and their maximum daytime temperature was ranked in order of ground surface>hyporheic water>river water (Fig. 5). In comparison with the river water reached the maximum of 17℃, those of the ground surface and the hyporheic water were as high as 38℃ and 25℃, respectively. It was also found that the changes in the river water temperature were the modest, fluctuating between 10 and 18℃, while marked fluctuations were observed for ground surface (10-40℃) and the hyporheic water (10-25℃) temperatures. The reason for higher temperature of hyporheic water than the river water may relate to the heat stored in the gravel on the ground surface by the sunbeam. The hyporheic water temperature slightly higher at E04 (water's edge) is also attributable to lacking of vegetation cover, where the ground surface will be easily heated by the sunbeam.

3.2 Distributions of permeability, hyporheic water level, water quality variables and water temperature

The permeability test resulted in the permeability coefficients ranging between 0.1e-4 - 0.76cm/sec, showing about one-order higher values in the upstream part of the bar (Fig. 6). This corresponded to relatively large gravels accumulating in this area. The hyporheic water level distribution on May 20 shows that the hyporheic water level gradient corresponds to the distribution of the permeability coefficient; the hydraulic gradient with the high permeability coefficient tend to be steeply (Fig. 6). The figure also shows the river water infiltrating into the bar from

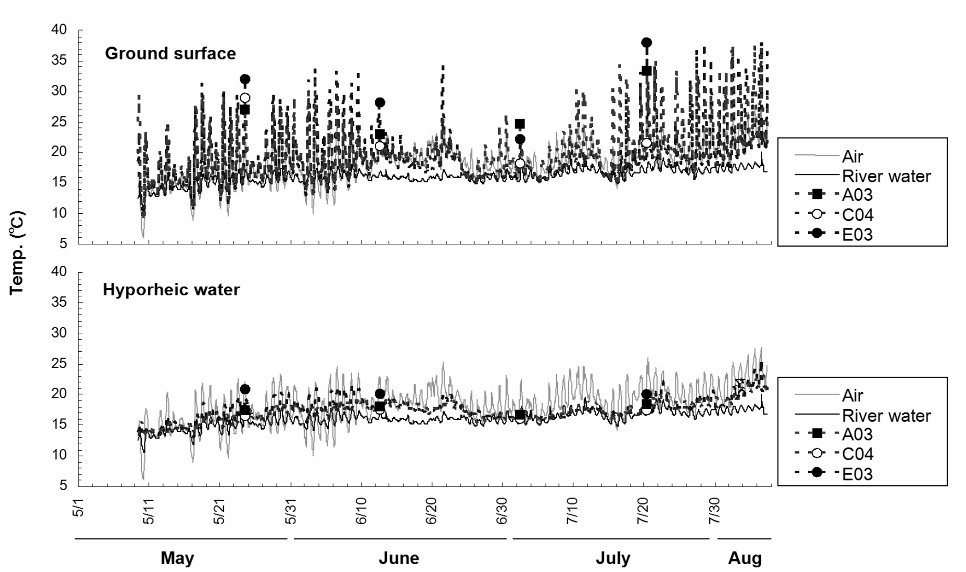

Fig. 4 Fluctuations of ground surface temperatures and hyporheic water temperatures in each data logger site (see Fig. 2) from May to Aug. 2003.

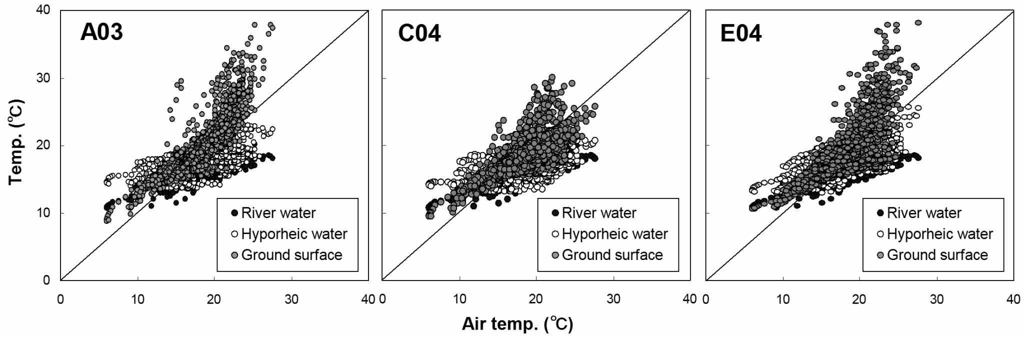

Fig. 5 Relationships between the air temperature and ground surface temperature, hyporheic water temperature, river water temperature in each data logger site (see Fig. 2) from May to Aug. 2003. Line indicates 1 to 1 line.

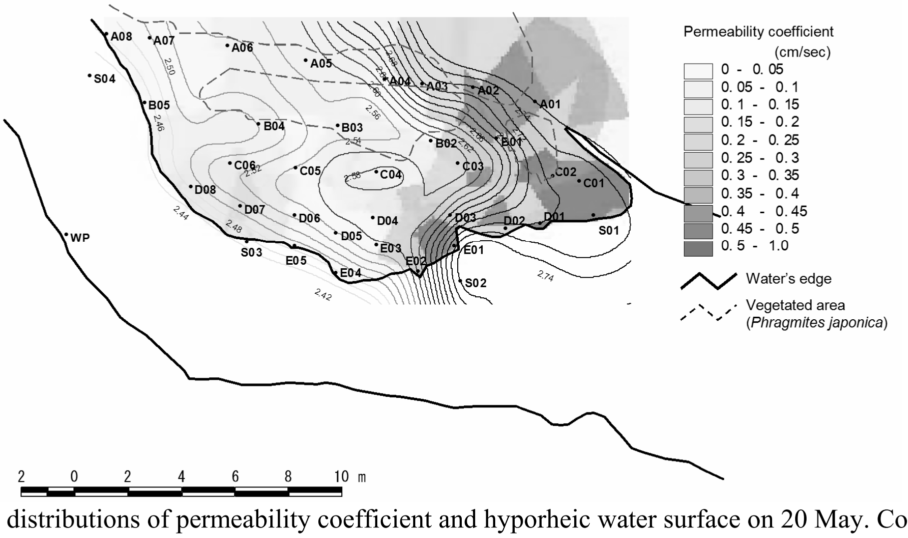

Fig. 6 Spatial distributions of permeability coefficient and hyporheic water surface on 20 May. Contour interval of hyporheic water level is 0.02 m.

the upstream side and the hyporheic water leaching out into the river from the central and downstream part of the bar.

The distribution of the mean values of hyporheic water level within the bar agreed well with the tendency mentioned above (Fig. 7): i.e., they decreased gradually from the upstream to the downstream part of the bar, indicating that the hyporheic water kept flowing through the bar in this way throughout the study period. The mean value of hyporheic flow ve-

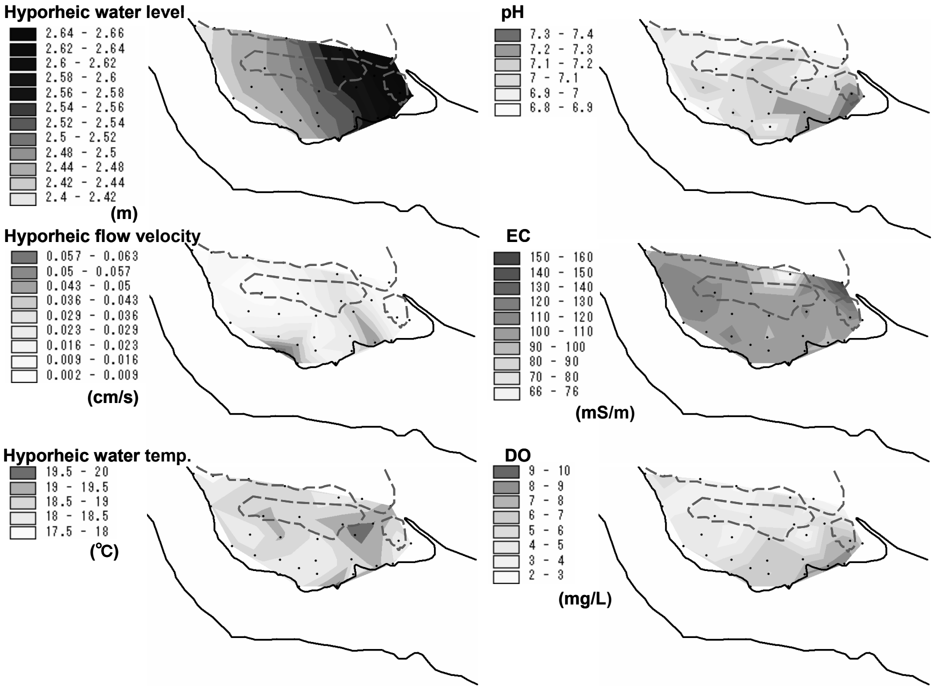

Fig. 7 Spatial distributions of mean values of physicochemical variables of hyporheic water. Solid lines and dashed lines indicate water's edge and vegetated area, respectively.

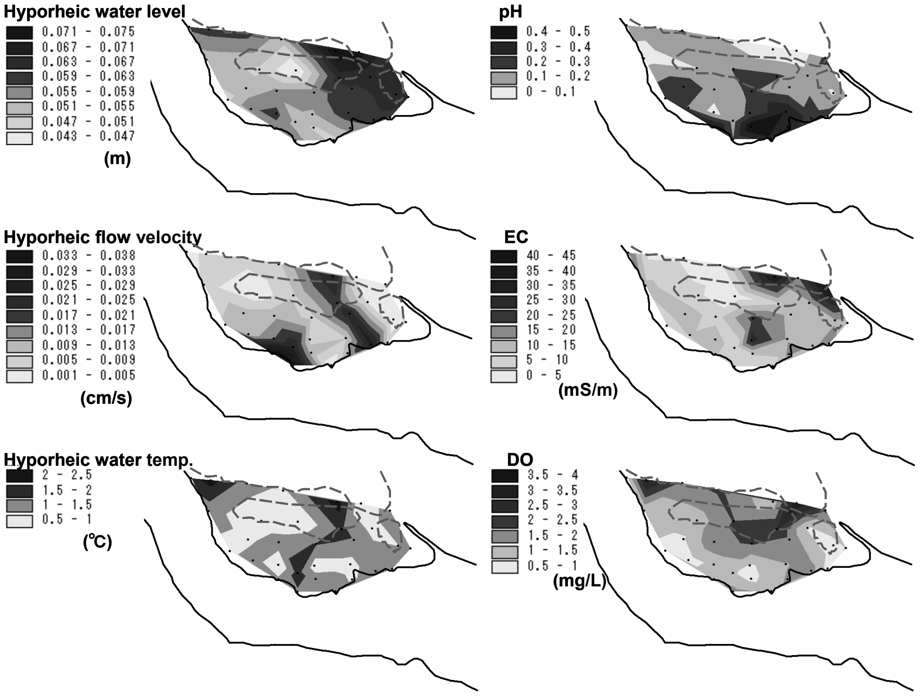

Fig. 8 Spatial distributions of standard deviation of physicochemical variables of hyporheic water. Solid lines and dashed lines indicate water's edge and vegetated area, respectively.

locity was higher at the upstream side of the bar and at the water's edge of the central part of the bar. Furthermore, the mean value of hyporheic water temperature tended to be higher in bare areas without

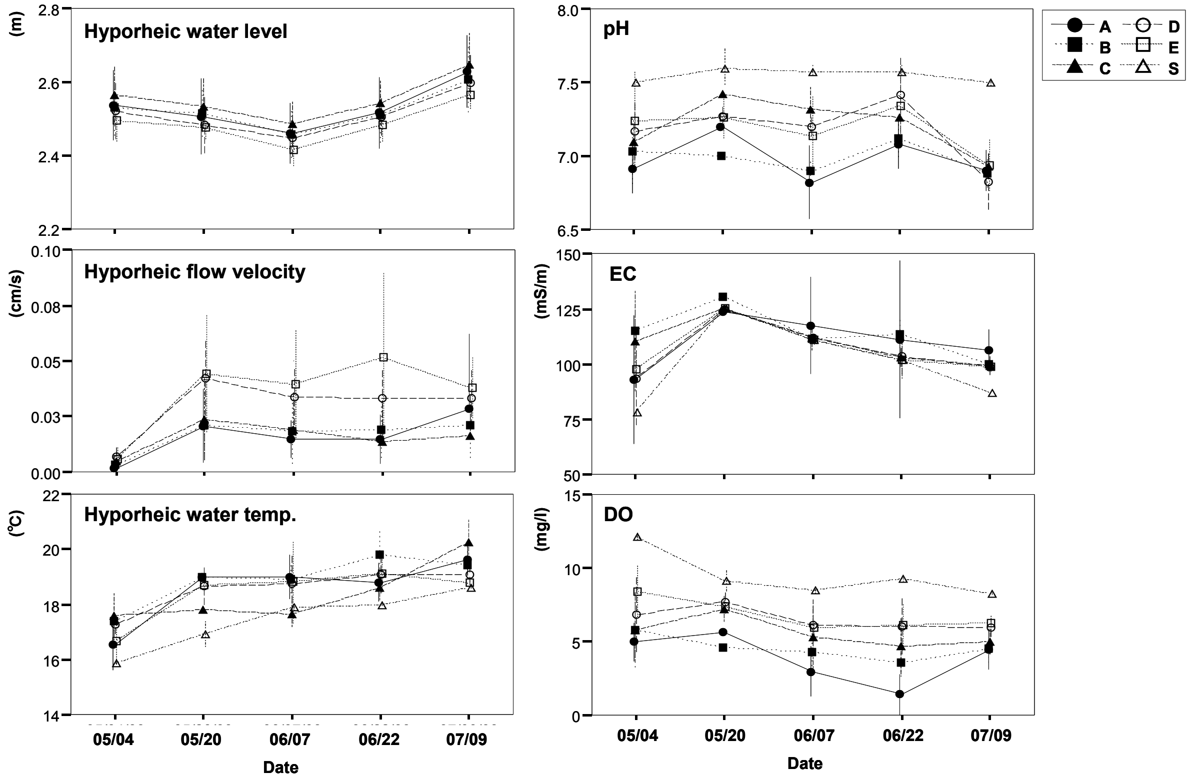

Fig. 9 Chronological changes of hyporheic water level, hyporheic flow velocity, hyporheic water temperature and water quality variables.

vegetation.

Horizontal distributions of the mean values of water quality variables in the bar were shown in Figure 7. The mean values of EC were high throughout all over the bar. Those of pH and DO varied significantly among sites of the bar, and areas with high pH values tended to have high DO concentrations. Low pH values less than 7 and low DO concentration less than 5mg/L were detected at the downstream side of the bar. Relatively high values of DO concentration were observed only at the water's edge of the bar. The downstream areas with low pH values corresponded to the substrates of sand and silt mixed with organic matters. It was confirmed that the distribution of the pH and DO levels and the distribution of the average hyporheic water temperature had negative correlations each other.

Horizontal distribution of the standard deviations (SD) of the hyporheic water level in the bar (Fig. 8) shows high values in the areas with high permeability coefficient (Fig. 6), suggesting that the interchange between river water and hyporheic water occurs more in such areas with a high permeability coefficient. The SD of the hyporheic water temperature were more near the water's edge and the terrace side reflecting a wide range of fluctuation but those of vegetated area were less in values. This may be because the ground surface with vegetation receives less amount of sunbeam. It is therefore suggested, based on the results, that the magnitude of fluctuation of the hyporheic water level will be influenced by water permeability and that the changing patterns of the hyporheic water temperature by the vegetation cover. It was also found that the SD of pH values was less near the terrace and downstream side of the bar, whereas those of DO concentration were less near the water's edge.

3.3 Factors controlling dissolved oxygen concentration of hyporheic water

Figure 9 shows the chronological changes in the average hyporheic water level, the hyporheic flow velocity, and water quality variables in each transect. The closer the transect lines located to the water's edge, the more similar values of each variable to those of the river water (Fig. 9). The chronological changes in these values revealed that the hyporheic water temperature increased with decreasing DO concentration in the later half of the study periods. On line A, in particular, located near the terrace, DO concentration reduced to almost 0mg/L at one point, producing anaerobic conditions. The hyporheic water level tended to rise in the later half of the study periods and the changes in the hyporheic water temperature and DO concentration did not correspond to the rise of the water level.

A series of correlation analyses were conducted between DO concentration and other water-quality variables or physical factors of the hyporheic water for each date (Table 1). The DO concentration showed significant positive correlations with Dist-Y, pH and permeability coefficient throughout the study

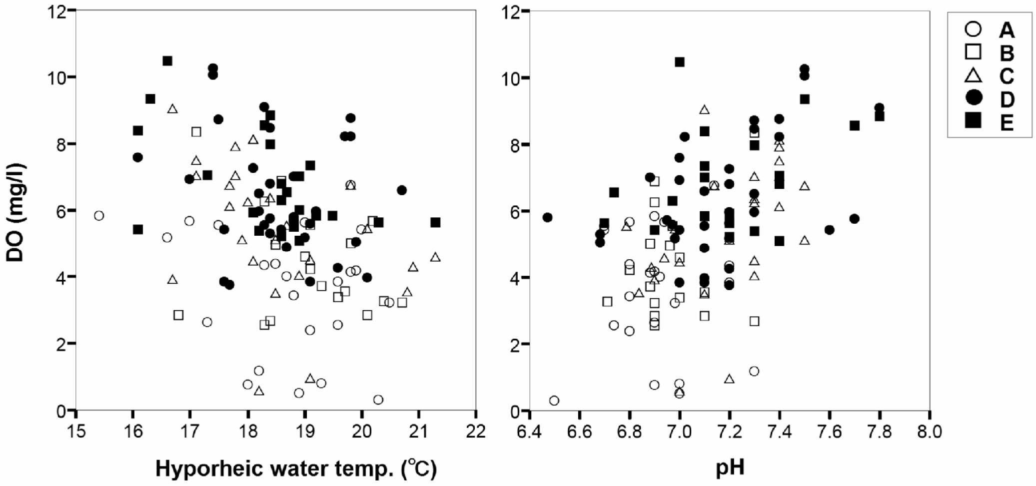

Fig. 10 Relationships between DO concentration and hyporheic water temperature, pH, respectively.

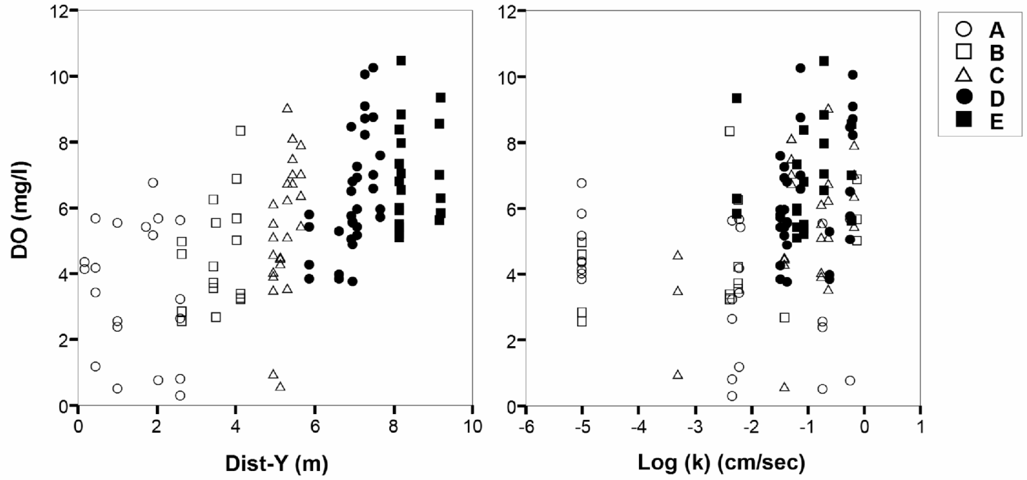

Fig. 11 Relationships between DO concentration and distance from terrace (Dist-Y), permeability coefficient (log (k)), respectively.

period (Table 1). Significant negative correlations were found between hyporheic water temperature and EC (Table 1). Thus, DO concentration decreased with increasing the hyporheic water temperature, and increased with increasing pH values (Fig. 10). Low

pH values were observed more on line A, B, and C, located at inner part of the bar. In addition, DO concentration decreased with decreasing Dist-Y (Fig. 11), reflecting the tendency of DO concentration gradually decreasing toward the terrace. The permeability coefficient and DO concentration concurrently increased (Fig. 11).

These results suggested that DO concentration in the hyporheic zone was influenced by the permeability coefficient, the hyporheic water temperature, and pH. Plausible reasons for the low DO concentration in the inner part of the bar may be, firstly, the dilution by the groundwater with low DO concentration infiltrated from the terrace, and secondly, the poor permeability and increased water temperature which promoted dissolved oxygen consumption by micro organisms decomposing organic matter in the riverbed. It is also likely that the presence/absence of vegetation on the bar and the amount of organic matters in the riverbed influence the temperature, pH, and DO concentration of the hyporheic zone.

3.4 Ecological functions of hyporheic zone on a gravel bar

Considerably high species diversity of hyporheos have been reported from the hyporheic zone of gravel bars in Japanese mountain streams (Takemon et al., 1999), and the presence of such biota has been considered to be linked with high water velocity, high DO concentration, and less amount of accumulated organic matter (Takemon, 2003b).

Some studies argued that the hyporheic zone of sand bars would function as a refuge and/or habitat

Table 1 Correlation coefficients between DO concentration and other variables

Variables	DO														
	4-May			20-May			7-Jun			22-Jun			9-Jul		
	r	*p*	n	*r*	*p*	n	*r*	*p*	n	*r*	*p*	n	*r*	*p*	n
Dist-X	0.297		(29)	0.394		(17)	0.348		(30)	0.239		(32)	0.231		(36)
Dist-Y	0.443	*	(29)	0.474		(17)	0.511	**	(30)	0.621	**	(32)	0.535	**	(36)
HW level	0.281		(25)	0.458		(13)	0.319		(26)	0.191		(28)	0.189		(32)
EC	-0.550	**	(28)	-0.464		(17)	-0.372	*	(30)	-0.424	*	(31)	-0.746	**	(36)
pH	0.723	**	(29)	0.752	**	(17)	0.765	**	(30)	0.756	**	(32)	0.660	**	(34)
HW Temp.	-0.450	*	(29)	-0.481		(17)	-0.433	*	(30)	-0.324		(32)	-0.516	**	(36)
k†	0.418	*	(25)	0.817	**	(13)	0.474	*	(26)	0.386	*	(28)	0.257		(32)
HFV†	0.428	*	(25)	0.059		(13)	0.167		(26)	0.197		(28)	0.263		(32)

* and ** indicate significant levels at $p<0.05$ and $p<0.01$, respectively. Variables with † were transformed to log (x+1). HW indicate hyporheic water, and HFV is hyporheic flow velocity.

for aquatic insects (e.g. Bishop, 1973; Poole and Stewart, 1976). Others, however, suggested that the zone did not function as a refuge and most of them were merely infiltrated in a flood period (Matthaei et al., 1997 a b; Dole-Olivier et al., 1997). Our results showed a clear inclination of low hyporheic water temperature and high DO concentration near the water's edge, suggesting that such an area can function as a suitable habitat for hyporheos particularly for aerobic inhabitants. The hyporheic zone in the inner parts of the bar, however, was characterized by the low DO concentration and the strong fluctuation in water temperature, suggesting that the inner parts of the bar would be a harsh habitat for hyporheos and might be less important as a refuge and/or habitat for usual aquatic insects. However, it should be noted that the present study was conducted in early summer under high temperature conditions and did not show any data on the biota in the bar. Furthermore, it is also probable that functions of the hyporheic zone of bars would be strongly influenced by the makeup of riverbed materials, and hence, highlighting the need for detailed future studies taking into account differences in both seasons and riverbed materials.

4. Conclusions

The present investigation on physicochemical environments of the hyporheic zone in a gravel bar under normal low-flow conditions revealed that 1) the chronological changes in DO concentration in the hyporheic zone were characterized by decrease with increasing the hyporheic water temperature, 2) low DO concentration of the hyporheic zone in the inner parts of the bar and high DO concentration near the water's edge could be explained not only by water permeability but also by the hyporheic water temperature, 3) vegetation cover could affect the environments of the hyporheic zone via temperature reduction and producing the organic matter. The wider ranges of temporal fluctuation in the physicochemical parameters indicated that the hyporheic zone in a bar structure would be more harsh environment for hyporheos in comparison with for those in the stream channel.

A series of field experiments for rearing eggs of the mayfly *Ephemera strigata* under various conditions in the hyporheic zones were carried out in the same sites of the bar in order to examine relations of their survivability to the physicochemical conditions shown in the present paper. Hence, the combination of these works in the future would be helpful to further understanding of the ecological functions of the hyporheic zone and to establish target images for the optimum flow and sediment management system aiming at maintenance of the functions.

Acknowledgments

We thank Y. Ishida, K. Hatano, K. Yamamoto and students in the Graduate School of Engineering, Kyoto University for assistance. This research was supported in part by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) 21st Century COE Program for DPRI, Kyoto University (No.14219301, Program Leader: Prof. Y. Kawata), and the Grant-in-Aid for Scientific Research (A2) (No.15206058, Principal Investigator: S. Ikebuchi, Kyoto University).

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要　旨

本研究は，平水時の砂州間隙水域の水質環境のうち，とくに間隙生物にとって重要な溶存酸素の分布様式や時系列変化に着目し，それらに影響を及ぼす要因について，間隙水の動態と関連付けて検討した．その結果，平水時における砂州間隙水域の溶存酸素濃度分布には，間隙水流動性そのものよりもむしろ，間隙水温の上昇に伴う酸素溶解度の低下，生物による有機物の分解の影響が強く働いていることが示唆された．また，間隙水の溶存酸素濃度の高い場所は，水際近傍に限られており，砂州内の大半で低かった．さらに，晴天時，上空が開けた裸地下では，地温の上昇に伴い間隙水温も上昇しやすいことから，平水時の砂州間隙水域は，生物にとって変動の激しい過酷な生息環境であると考えられた．

キーワード：河床間隙水域，生物生息場，物理化学的特性，溶存酸素

COE-19

賀茂川中流域における砂州間隙水の動態と水質変化機構

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1．はじめに

河床内部の斜面由来の地下水と河川水が混ざり合う場所は河床間隙水域と呼ばれ，河川生態系における物質の滞留や分解の場，水生昆虫などの生息場となるなど，その様々な生態学的機能が注目を集めている．また，砂州の間隙水域には，河川水が濾過されることによる水質浄化作用にも社会的な期待が寄せられている．こうした間隙水域の機能については，降雨･増水イベントと関連付けて，河川の水質形成に及ぼす影響を調べた事例は多いが，間隙生物の生息場機能に着目した研究は少ない．一般に，増水時には，間隙水域の流量が増大し，多くの間隙生物の生存に不可欠な溶存酸素が供給されると考えられる．いっぽう，河床の攪乱が起こらず平水状態が続くと，河川水が浸入しにくくなり間隙水域の環境が悪化すると考えられる．

そこで，本研究では，平水時の砂州間隙水域の水質環境のうち，とくに溶存酸素の分布様式や時系列変化に着目し，それらに影響を及ぼす要因について，間隙水の動態と関連付けて検討した．

2．研究方法

賀茂川(京都市)の支流である鞍馬川において，比較的植生が繁茂せず，裸地の多い寄り州(約 $180\mathrm{m}^2$)を調査地とした．斜面側から水際にかけて 5 本のトランセクト(A～E ライン)を設け，各ライン上に採水管･間隙水位観測孔(計 31 地点)を設置し，間隙水の水質･水温ならびに間隙水域の水位標高(間隙水位)を測定した．水質測定は，現地にて溶存酸素濃度(DO)･pH･電気伝導度･水温をポータブル水質計で測定した．調査は，2003 年 5 月 4 日から 7 月 9 日までの約 2 週間毎に実施した．また，データロガーを用いて，調査期間中の河川水温･河川水位ならびに間隙水温･地表面温度を計測した．さらに，地形測量･現地透水試験を行い，透水係数と動水勾配より間隙水(平均)流速を求めた．

3．結果および考察

調査期間中の地表面･間隙水･河川水の温度は，気温の上昇とともに上昇し，日中の最大温度は，地表面＞間隙水＞河川水の順に高く，河川水温の最大値は 17℃程度であるのに対し，地表面温度･間隙水温の最大値はそれぞれ 38℃，25℃と高い値を示した．これは，砂礫に蓄積された熱が，間隙水に伝導しているためと考えられる．

各調査時における間隙水位分布を示した結果，河川水位の上昇によって間隙水位分布も変化するものの，砂州の上流部や斜面から浸入した河川水･地下水が，砂州の中央･下流部で河川に向かって浸出する傾向がみられた．また，間隙水位勾配は透水係数の分布と対応しており，透水係数の高い場所で勾配が急になる傾向があった．さらに，間隙水域の DO は，砂州内部の大半では低く，比較的高い部分は，水際近傍に限られている分布様式が確認された．

いっぽう，各ラインにおける水位･間隙水流速･水質成分平均値の時系列変化を分析した結果，水際に近いラインほど河川の値に近づき，水位は低く，流速･pH･DO は高くなる傾向が認められた．また，斜面に近いラインの DO は 5mg/L よりも低くなる傾向があった．時系列変化に着目すると，調査時後半になるにしたがって，間隙水温が高くなり，これに対応して，DO が低下する傾向がみられた．間隙水位についても，調査時後半に上昇する傾向があったが，間隙水温･DO の変化は，間隙水位の変化と対応していなかった．これらの結果から，間隙水域における DO の低下の原因として，DO の低い斜面由来の間隙水の影響とともに，水温の上昇に伴って酸素溶解度の低下や河床内部の有機物の分解(硝化)による溶存酸素の消費が進行した可能性が考えられる．

4．おわりに

平水時における砂州間隙水域の溶存酸素濃度分布には，間隙水流動性そのものよりもむしろ，間隙水温の上昇に伴う酸素溶解度の低下，生物による分解の影響が強く働いていることが示唆された．また，間隙水の溶存酸素濃度の高い場所は，水際近傍に限られており，砂州内の大半で低かった．さらに，晴天時には，地温の上昇に伴い間隙水温も上昇しやすいことから，平水時の砂州間隙水域は，生物にとって変動の激しい過酷な生息環境であると考えられた．