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Purification of river water through a bar sediment of riverbed

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ABSTRACT

Changes in nitrogen components in river water were investigated for one sediment bar over three years. The plane distribution of water quality in the bar was investigated by sampling and measuring the water that lies just below the seepage water table in the bar. It was found that total nitrogen in the seepage water decreased downstream. The observed distribution patterns of nitrogen components are in agreement with the distributions of the dissolved oxygen and the oxidation and reduction potential in the seepage water. The nitrogen distribution patterns match the direction of seepage flow estimated from the seepage water level, indicating that the denitrification process decreased the nitrogen components in the river water as it passed through the bar sediment. A remarkable change in nitrogen components occurs at the shallow and actively flowing part on the upstream side of the bar due to the coexistence of oxidation and reduction around the seepage water table in the bar sediment.

The removal efficiency of nitrogen per unit time is small in the individual bar. However, since several bars are present in the river and since the sediment below the river flow works in the same way as that in the bar, river sediment is thought to contribute greatly to the purification of river water. Thus, the present study has revealed that the natural water purification properties of river sediment, based on river sedimentology, should be used to reduce the pollution in urban and suburban rivers.

INTRODUCTION

Small rivers that have a small flow rate are apt to be polluted by the inflow of fertiliser components that accompany agricultural activities and also by domestic effluents. Among the various types of pollutant in river water, nitrogen components, such as nitrate nitrogen, are known to bring about eutrophication in the downstream areas such as lakes and seas. Some of these nitrogen components are used as qualitative indicators for drinking water. Biochemical oxygen demand (BOD), mainly due to domestic effluents, is decreasing with the development of public sewage systems in watershed areas. In contrast, the decrease in nitrogen components is not significant, due to the increased use of chemical fertilisers in watershed areas. However, all of the nitrogen components introduced upstream into a river are not transferred downstream. Rivers have a natural purification mechanism, which works through aeration of water, adsorption, decomposition by microbes, and absorption through plant roots. Thus, a considerable portion of nitrogen components is fixed in the river sediment or returned to the air.

Riverbed sediment and river channel bars collectively form a system that contributes to the natural purification of rivers. It is considered that the nitrogen components are transformed into each other and are removed or reduced as they flow through the sediment (Montgomery et al. 1997).

In the present study, the increase or decrease in nitrogen components in the seepage water in a bar was investigated, and river sediment is shown to be important in the conservation of the river environment.

BAR SEDIMENT

The lower stream of the Koaze River, which is located in the western part of the Kanto plain in Japan (Fig. 1), contains several channel bars of various sizes, one of which was selected for investigation in the present study. The investigated bar is very small, reaching approximately 30 m in length and is composed of sand and gravel deposits. The shape of this bar has changed from 1996 to 1998 as a result of the deposition and erosion during flooding (Fig. 2). The coefficient of permeability of the bar deposit varied from 2×10^{-2} to 6×10^{-1} cm/s, whereas the sediments deposited along the edges both upstream and downstream had higher permeability values.

The watershed of the Koaze River has an area of 48.5 km^2, and 34% of it is occupied by farmland. In recent years, residential areas have increased and now occupy 23% of the watershed. In this region, the percentage of households that use the public sewage system is 34%, and a part of the domestic effluents is discharged into the river. In addition, the fertiliser from farmland also enters the river. The yearly change in water quality of the river indicates that the amount of NO_3-N in the water has a tendency to increase, whereas BOD is gradually reduced, as the public sewage system is diffused (Fig. 3).

The total nitrogen (T-N) content is stable at about 3–10 mg/l over several years and has not shown any tendency to decrease. The river water, having the above-mentioned water quality, flows through the investigated bar and undergoes a qualitative change.

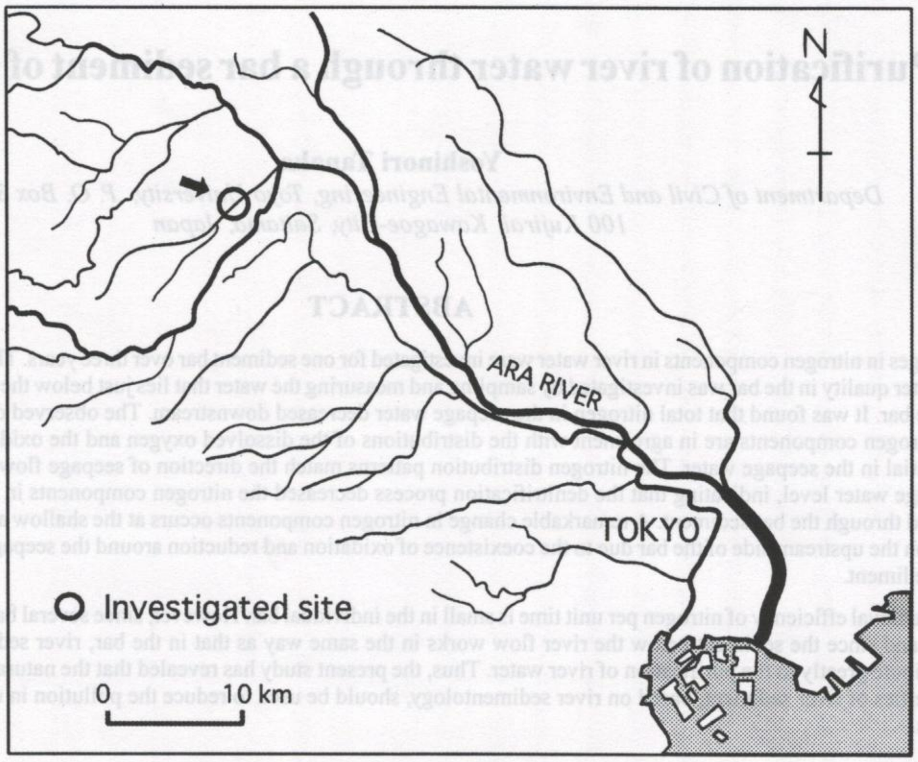

Fig. 1: Location of investigated site

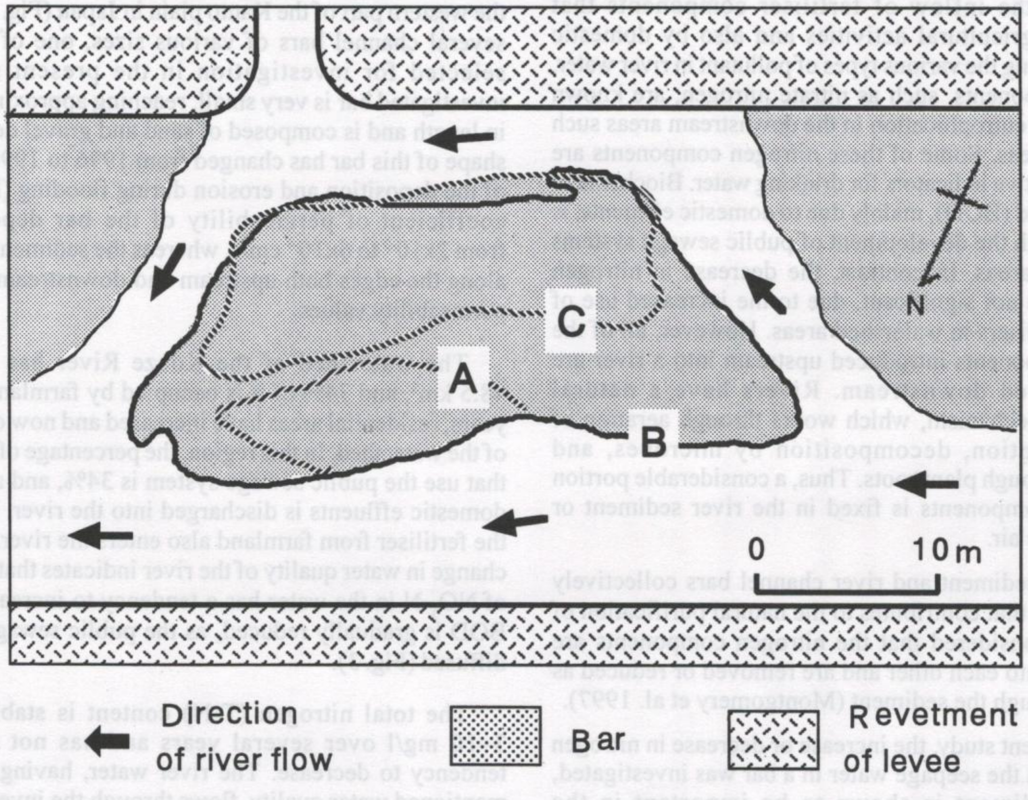

Fig. 2: Changes in the plane shape of the bar with date. A: Aug. 1996, B: Dec. 1996, C: Dec. 1998

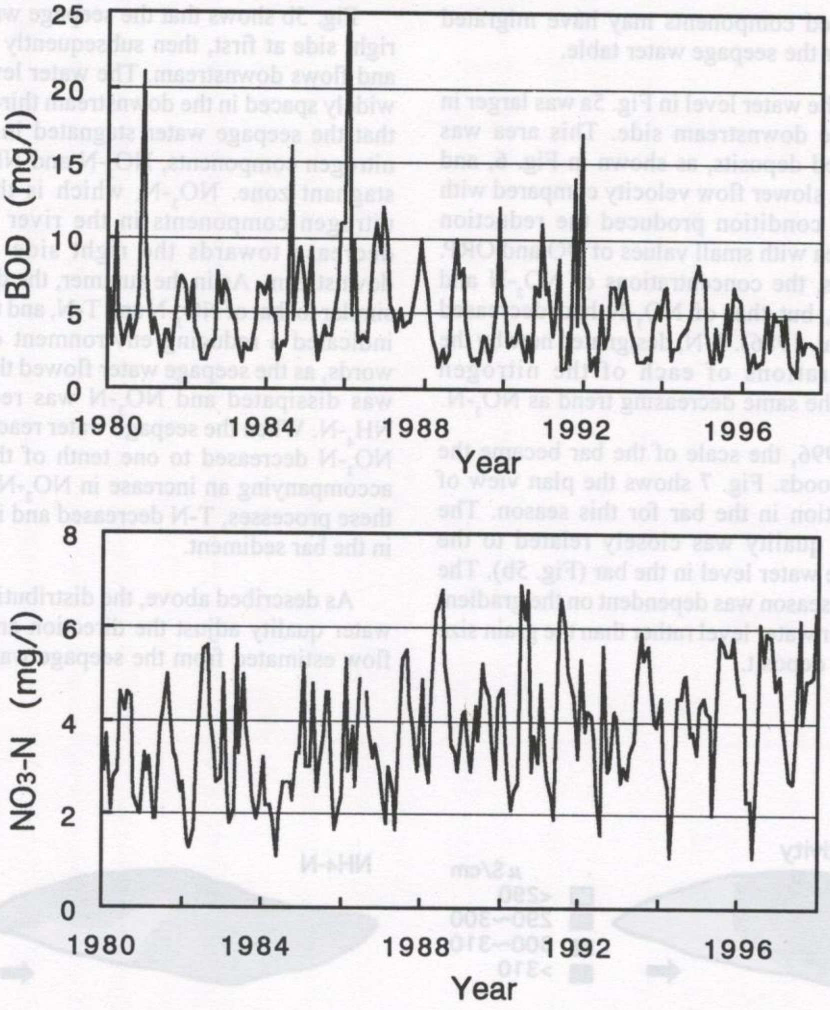

Fig. 3: Yearly change of BOD and NO_3-N in river water

INVESTIGATION METHODS OF WATER QUALITY IN THE BAR SEDIMENT

The quality of the seepage water in the bar was investigated by on-site measurements and laboratory analyses. In the field, temperature, pH, electric conductivity, dissolved oxygen (DO), oxidation and reduction potential (ORP), fluorescent substance, chemical oxygen demand (COD), NO_3-N, NO_2-N, and NH_4-N were measured. The first six qualities were measured using portable or laboratory instruments. COD was obtained by the colorimetric titration method using potassium permanganate. The concentration of nitrogen components was measured by an absorbance photometer after adding a colouring reagent.

The sampling method of seepage water in the bar was different each year. In 1996, many shallow holes were dug in the surface of the bar in order to collect water just under the seepage water table. In 1997 and 1998, collecting pipes were installed. Three pipes of varying lengths were positioned at 11 points along the bar, and the seepage water from the depths of 5, 25, and 45 cm (under the water table) was collected by suction method. In three years, water was sampled from summer to winter, during which time the water quality of the river changed remarkably.

DISTRIBUTION OF WATER QUALITY IN THE BAR

In the summer of 1996, the scale of the bar was the smallest. Fig. 4 shows the plan view of water quality distribution in the bar for this condition. Each distribution shows a continuous change from upstream to downstream. The water level shown in Fig. 5a indicates that the seepage water flowed towards the right side of the bar, which resulted in a higher electric conductivity and a higher concentration of fluorescent substances in the right side of the bar. Therefore, electrolytes and components of synthetic detergents accumulated in this side of the bar. Furthermore, some of these dissolved components may have migrated from the sediment over the seepage water table.

The inclination of the water level in Fig. 5a was larger in the central part of the downstream side. This area was covered by fine-grained deposits, as shown in Fig. 6, and is considered to have a slower flow velocity compared with the other areas. This condition produced the reduction environment in this area with small values of DO and ORP. Under such conditions, the concentrations of NO_2-N and NH_4-N had increased, but that of NO_3-N had decreased with flow (Trundell et al. 1986). T-N, designated here by the sum of the concentrations of each of the nitrogen components, showed the same decreasing trend as NO_3-N.

In the winter of 1996, the scale of the bar became the largest after several floods. Fig. 7 shows the plan view of water quality distribution in the bar for this season. The distribution of water quality was closely related to the distribution of seepage water level in the bar (Fig. 5b). The water level during this season was dependent on the gradient of the surrounding river water level rather than the grain size distribution of the bar deposit.

Fig. 5b shows that the seepage water flows towards the right side at first, then subsequently changes the direction and flows downstream. The water level contour lines were widely spaced in the downstream third of the bar, indicating that the seepage water stagnated in the area. Among the nitrogen components, NO_2-N and NH_4-N increased in this stagnant zone. NO_3-N, which is the richest among the nitrogen components in the river water, was found to decrease towards the right side of the bar and then downstream. As in the summer, the distribution of DO was similar to that of NO_3-N and T-N, and the distribution of ORP indicated a reducing environment downstream. In other words, as the seepage water flowed through the bar, oxygen was dissipated and NO_3-N was reduced to NO_2-N and NH_4-N. When the seepage water reached the stagnant zone, NO_3-N decreased to one tenth of that in the river water, accompanying an increase in NO_2-N and NH_4-N. Through these processes, T-N decreased and identification occurred in the bar sediment.

As described above, the distribution patterns of seepage water quality adjust the direction and velocity of seepage flow estimated from the seepage water level and the grain

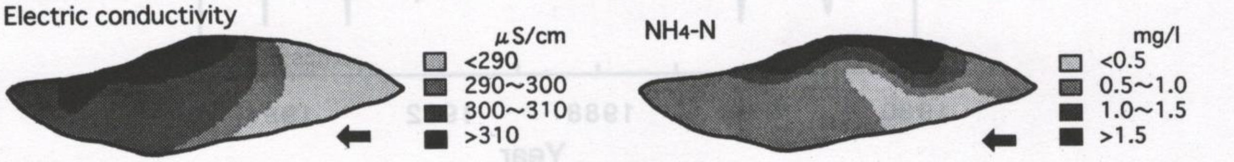

Fig. 4: Plan view of water quality distribution in the bar (August 1996). Each arrow shows the direction of river flow.

size of the deposit. Thus, the distribution patterns were formed along with the seepage of river water. This result indicates that the nitrogen components, which cause eutrophication of river water, are removed in the bar, and that water having a low concentration of nitrogen components is returned to the river.

THREE-DIMENSIONAL VIEW OF WATER QUALITY IN THE BAR

Fig. 8 shows the three-dimensional view of concentrations of nitrogen components in the bar for the summer of 1998. The distribution patterns of water quality on the upper surface were basically similar to those of Fig. 7, with the exception of NO_2-N concentration, which was very low. NH_4-N had a tendency to increase with depth, whereas NO_3-N decreased with depth. T-N decreased downstream and in the depth. These results indicate that the nitrogen components were transformed to each other at shallow depths under the seepage water table.

Fig. 9 indicates that DO and ORP decreased greatly in the shallow regions, which resulted in the transformation among the nitrogen components and denitrification near the water level.

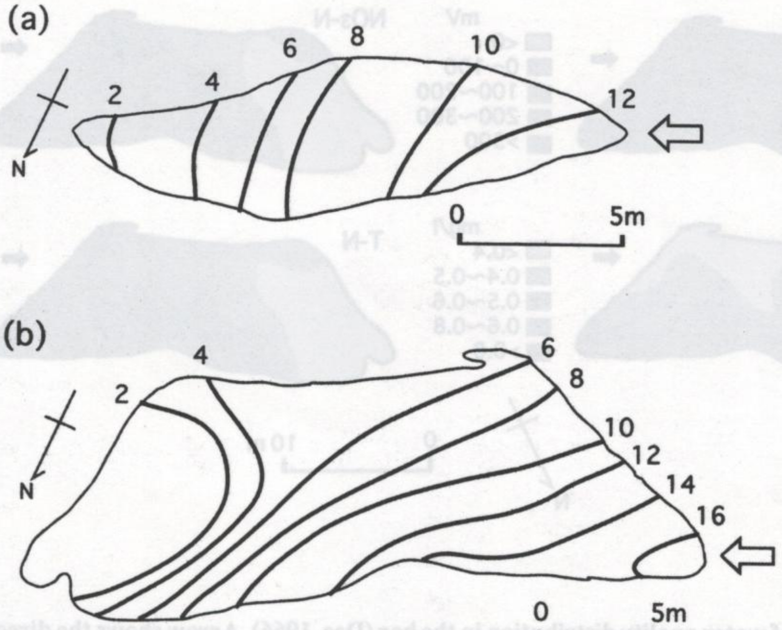

Fig. 5: Contour map of seepage water level. a: Aug. 1966 b: Dec. 1966 Arrow shows the direction of river flow.

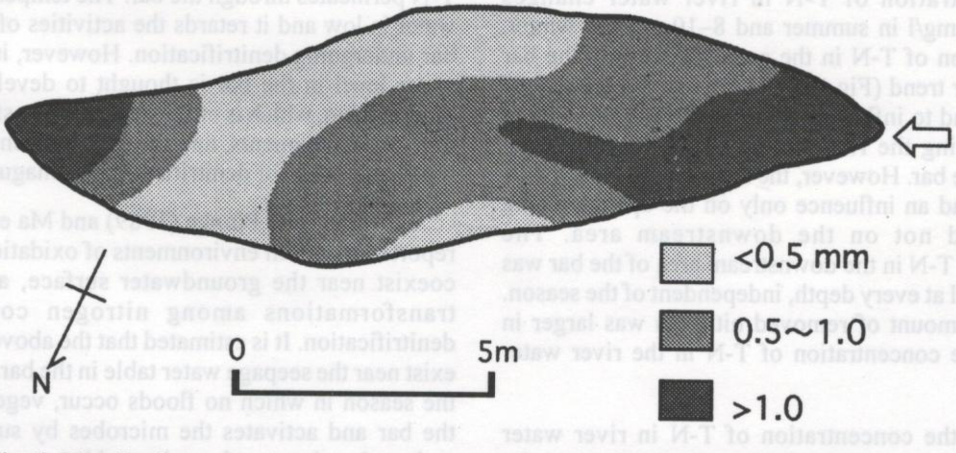

Fig. 6: Distributions of grain size D10 of bar deposit (Aug. 1996). Arrow shows the direction of river flow.

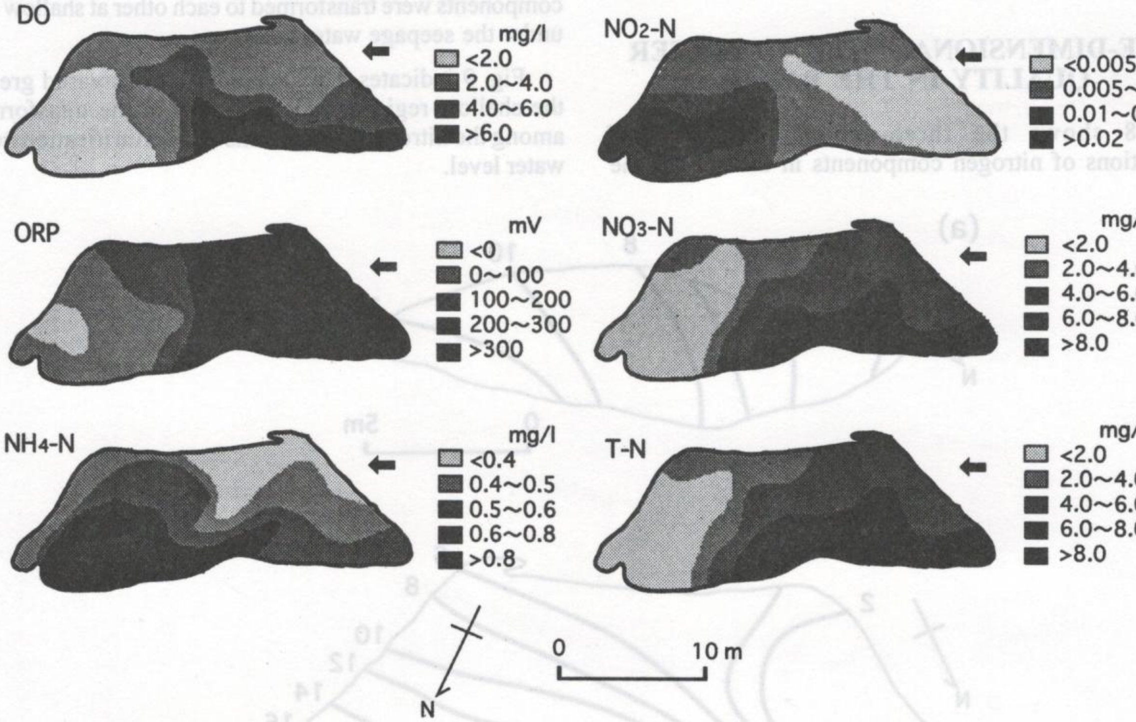

Fig. 7: Plan views of water quality distribution in the bar (Dec. 1966). Arrow shows the direction of river flow.

PURIFICATION CAPACITY OF THE BAR

The concentration of T-N in river water changes seasonally: 3–4 mg/l in summer and 8–10 mg/l in winter. The concentration of T-N in the seepage water in the bar showed a similar trend (Fig. 10). Moreover, the amount of rainfall was found to influence the concentration of T-N in the bar by diluting the river water and infiltrating from the surface of the bar. However, the seasonal change in T-N in river water had an influence only on the upstream area of the bar and not on the downstream area. The concentration of T-N in the downstream area of the bar was lower than 1 mg/l at every depth, independent of the season. Therefore, the amount of removed nitrogen was larger in winter, when the concentration of T-N in the river water was high.

In summer, the concentration of T-N in river water decreases due to the high activities of microbes on the surface of the riverbed.

In contrast, in winter, the activities of microbes are reduced, and river water having a higher concentration of T-N permeates through the bar. The temperature of seepage water is low and it retards the activities of microbes in the bar undergoing denitrification. However, in winter, the low water level in the bar is thought to develop the reducing environment, which is efficient for the transformation among nitrogen components, and the high concentration of T-N is highly effective for denitrification (Yamaguchi et al. 1990).

Lowrance and Pionke (1989) and Ma et al. (1999) have reported that both environments of oxidation and reduction coexist near the groundwater surface, and induce both transformations among nitrogen components and denitrification. It is estimated that the above conditions also exist near the seepage water table in the bar. Furthermore, in the season in which no floods occur, vegetation grows on the bar and activates the microbes by supplying organic carbon. In other words, a channel bar promotes the process of denitrification.

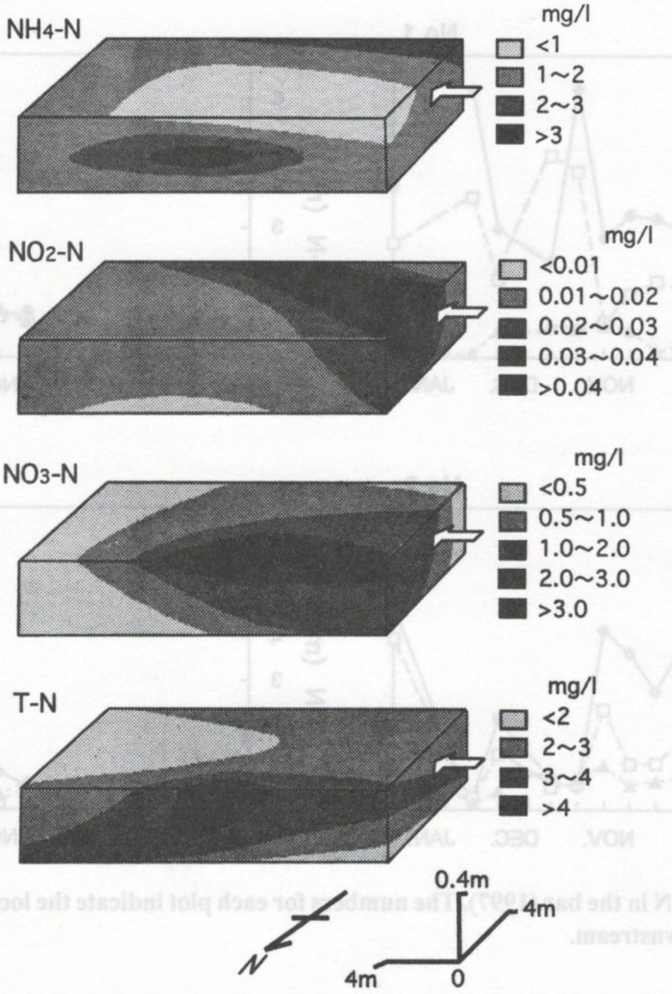

Fig. 8: Three-dimensional view of nitrogen components in the bar (Aug. 1998). Each arrow shows the direction of river flow.

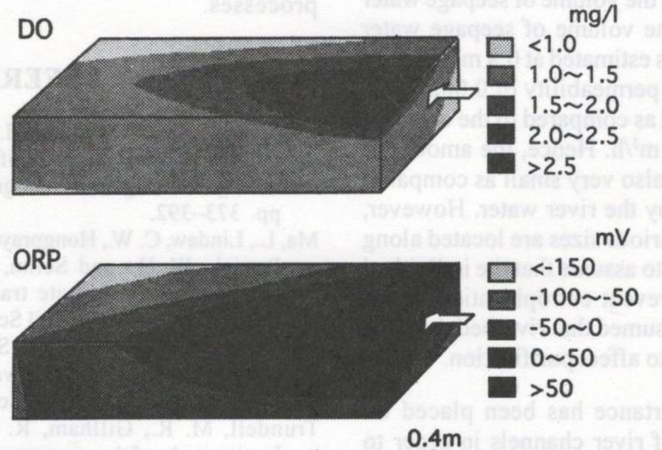

Fig. 9: Three-dimensional views of DO and ORP in the bar (Aug. 1998). Each arrow shows the direction of river flow.

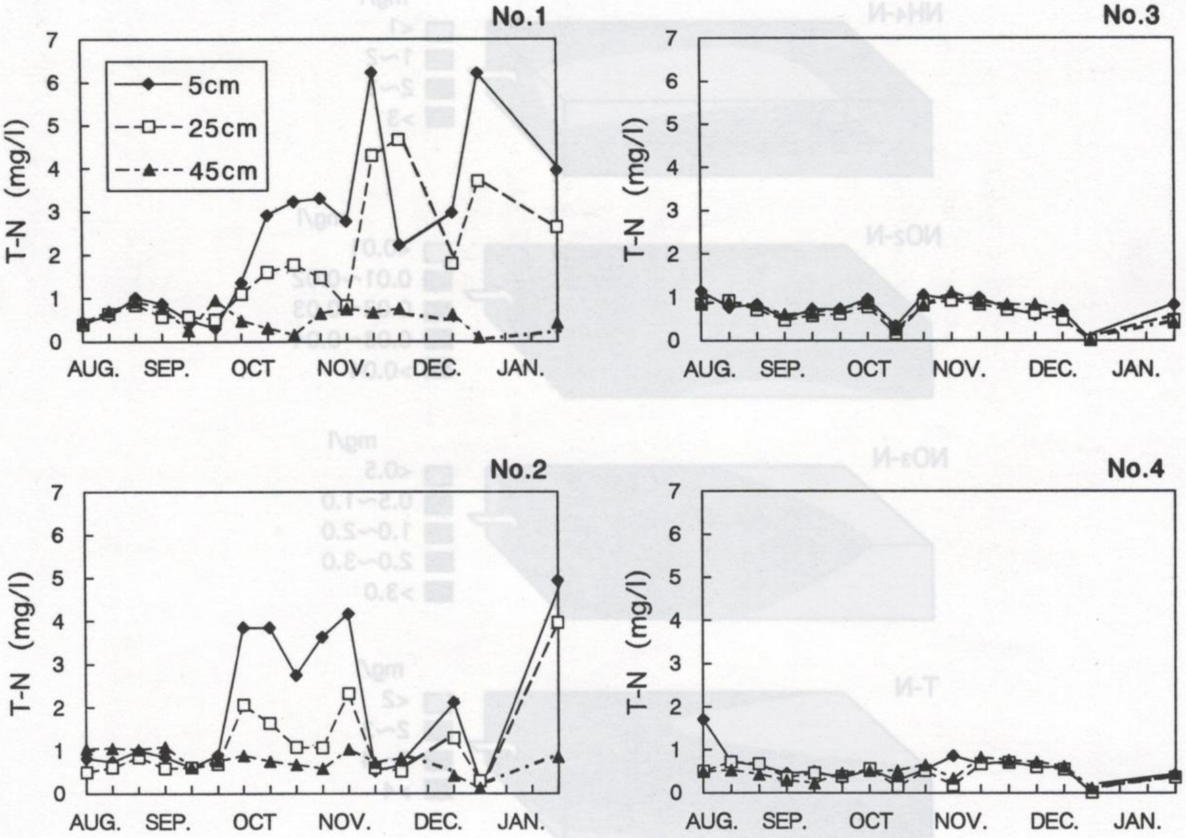

Fig. 10: Seasonal change of T-N in the bar (1997). The numbers for each plot indicate the location of sampling points in sequence from upstream to downstream.

CONCLUSIONS

The purification capacity of a bar with respect to nitrogen components is very small, since the volume of seepage water passing through it is small. The volume of seepage water through the investigated bar was estimated at 0.8 m^3/h, based on the measured coefficient of permeability of 0.0025 m/s. This volume is extremely small as compared to the ordinary discharge of the river of 3100 m^3/h. Hence, the amount of removed nitrogen in the bar is also very small as compared to that which is carried away by the river water. However, since several channel bars of various sizes are located along a river channel, it is reasonable to assume that the individual bars function as a whole to prevent eutrophication of the river. At the same time, it is presumed that riverbed deposits below the river flow also work to affect purification.

Until recently, great importance has been placed on increasing the flow capacity of river channels in order to prevent floods. As a result, river channels in urban and suburban areas have been shortened and covered with concrete. In several cases, riverbed deposits were also covered or removed, and the formation of bars was restricted. Such artificial manipulation of river channels causes the nitrogen components to flow unchanged downstream, which in turn causes eutrophication. Hence, in order to preserve the river environment, river channels must be maintained with consideration for the natural sedimentological processes.

REFERENCES

Lowrance, R. R. and Pionke, H. B., 1989, Transformations and movement of nitrate in aquifer systems, In Follett R. F. (ed.) Nitrogen management and groundwater protection, Elsevier. pp. 373–392.

Ma, L., Lindaw, C. W., Hongprayoon, C., Burhan, W., Jang, B. C., Patrick, W. H., and Selim, H. M., 1999, Modeling urea, ammonium, and nitrate transport and transformations in flooded soil columns, Soil Science, v. 164(2), pp. 123–132.

Montgomery, E., Cayne, M. S., and Thomas, G. W., 1997, Denitrification can cause variable NO_3^- concentrations in shallow groundwater, Soil Science, v. 162(2), pp. 148–157.

Trundell, M. R., Gillham, R. W., and Cherry, J. A., 1986, In-site study of the occurrence and rate of denitrification in a shallow unconfined sand aquifer. Jour. Hydrology, v. 83, pp. 251–268.

Yamaguchi, T., Moldrup P., Teranishi, S., and Rolston, D. E., 1990, Denitrification in porous media during rapid, continuous leaching of synthetic wastewater at saturated water flow. Jour. Environ. Quality, v. 19, pp. 676–683.