DIURNAL CHANGE OF WATER QUALITY IN A POOL MANAGED BY THE NATURE-FRIENDLY RIVER WORK

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Aiming at the sound and sustainable water environment, river should be managed taking care of the environment in nature. Also in the Honmyo River, nature-friendly river work has been done from 1991, of which influence on river water should be estimated both on the quantitative and qualitative viewpoints.

In this paper, diurnal change of water quality in a pool has been investigated based on a field observation in the Honmyo River. As one of the results, it makes clear that existence of pool gives lots of influences on river water qualitatively, even if its depth is not so deep. From now on, it seems to be more important that the restoration work will be executed as well as decrease of pollutant runoff from the watershed based on the results which has been and will be obtained through this kind of research.

Key Words : *river environment, water quality, riffle and pool, field observation*

1. INTRODUCTION

The Japanese River Act has newly been changed in 1997, following to a change of 1964 after an establishment of its Act in 1896. This fact reflects that the conservation and creation of desirable water environment become more and more important as well as the protection of our residence from floods and the utilization of water in rivers. From this reason, lots of works have been carried out in and around rivers in order to achieve a sound and sustainable water environment. *"Naturnaher Wasserbau"*, or the nature-friendly river work, is well known as one of these works, and this kind of river work has been used over the many places, even though its validity cannot necessarily be judged.[1)]

Receiving water is enclosed, frequently. Therefore, in order to avoid the degradation of water in such area, it is inevitable to make clear the water in rivers. In Nagasaki, big project called the construction of sea-dyke and reclamation project is now progressing at Isahaya Bay, into which the Honmyo River is flowing.

For realizing the desirable water environment, river restoration work has often been done, and its effect on surroundings should be estimated, quantitatively and qualitatively. In this paper, for an achievement of this purpose, both of the field observation and the mathematical simulation have been carried out related to the prediction of qualitative changes of water in a reach managed by the nature-friendly river work. Finally, some discussion will be done about how to make useful these results for further development of river restoration work.

2. OUTLINE OF THE FIELD OBSERVATION

There is only one A-class river in Nagasaki, that is the Honmyo River, of which catchment area is 87 km^2. Further, its length is 21 km, so it is surely the small-sized river even if considering on an island basis. In spite of its small size, the importance of

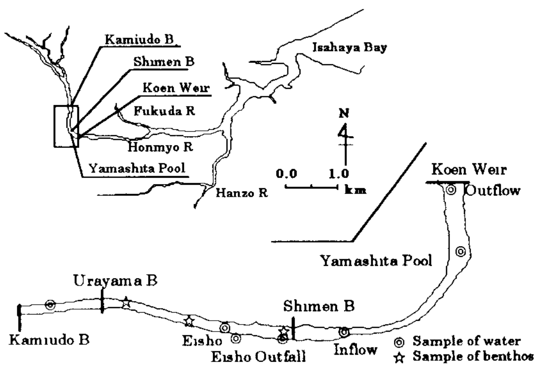

Fig.1 Schematic View of Study Area

river management cannot be neglected because a big project of the construction of sea-dyke and the reclamation of Isahaya Bay is now under construction in the downstream of the Honmyo River. In this project, a regulation pond of floods is also planned to be constructed, so elaborate control of river water cannot be avoided in order to prevent the eutrophication of its pond.

Field observation was carried out in a reach of the Honmyo River on October 15, 21, and 28 in 1997 (Fig. 1). In this reach, located through 5.0 km to 6.2 km from the river mouth, several kinds of nature-friendly river works, such as the willow tree work, the wooden mattress, the concrete crib work, and others, have been constructed since 1991. In addition, no rainfall has been observed throughout a period of field observations, even though it rained on October 14. In 1998, field observation was also carried out under a similar condition on May 18 and 25.

Because of the limited space, detailed explanation of the observation cannot be described. Here, it is shown that several kinds of chemical and biological indices have been measured including water temperature, chlorophyll, turbidity, dissolved oxygen (DO), and insolation using the observation device of CHLOROTECH, ACL1183-PDK. At the same time, total nitrogen (T-N), total phosphorus (T-P), biochemical oxygen demand (BOD_5), and suspended solids (SS) have been observed, measuring the samples by SPECTROPHOTOMETER, HACK DR/2000. Furthermore, aquatic benthos of the river have been collected by the server net and identified with the naked eyes. These data are available when estimating the water quality on a whole aspect.

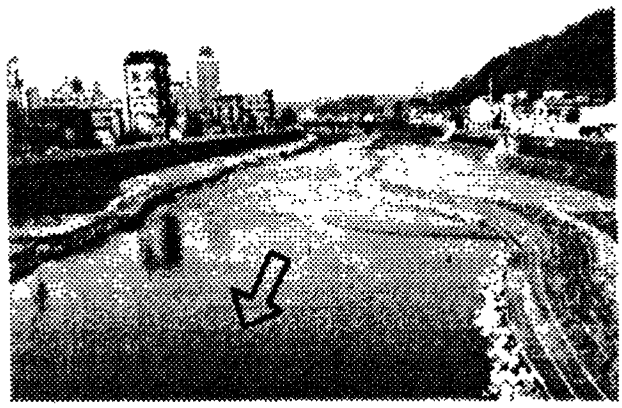

Photo 1 Honmyo River taken at Apr. of 1992

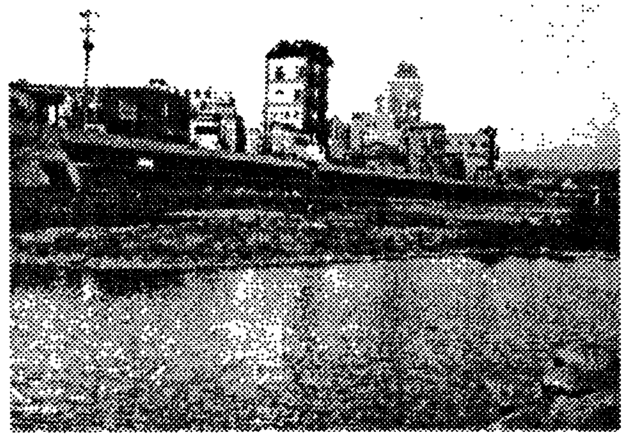

Photo 2 The same place taken at Mar. of 1994

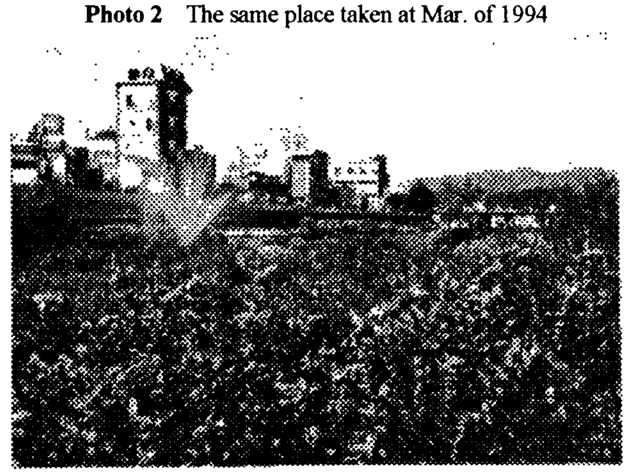

Photo 3 The same place taken at Sep. of 1996

As is well known, river consists of riffle and pool, and they have important roles for formation of water quality. At the same time, it has been recognized that riparian is important to preserve the

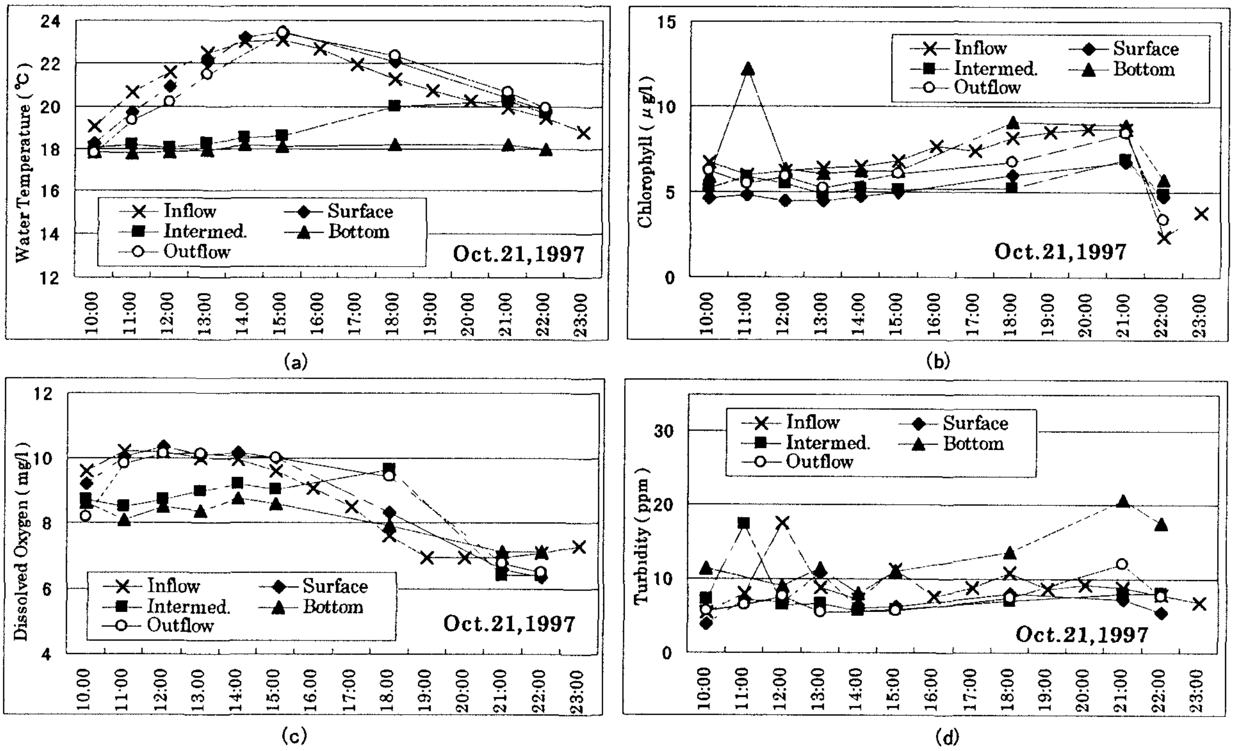

Fig.2 Temporal variation of water quality in Yamashita Pool (observed data)

clear water, and lots of restoration works have been executed over the many places. This situation is also similar in the Honmyo River, as illustrated in Photos 1 to 3. The present field observation has been carried out in this reach. In addition, in this reach, there is a pool called *"Yamashita-buchi"*. Here, the above photos were taken from the *Shimen Bridge*, overviewing the upstream side. In Figs. 2 (a)-(d), the temporal variation of water temperature, chloro-phyll, DO, and turbidity is also shown. Here, the water quality of inflow into and outflow from the pool has been observed at each point illustrated in Fig. 1. Furthermore, the water quality has also been observed vertically in the surface, intermediate, and bottom layers in the Yamashita Pool. The depth of each layer is 0.6m, 1.0m, and 1.0m, respectively. Referring to Fig. 2 (a), it is clear that thermal stratification diurnally develops and is disappeared in the pool. It is easily supposed that this kind of stratification restricts the water movement, and that the water quality of that pool, so also in the downstream, is strongly influenced by its effects. Regarding these observed results, further discussion will be shown in the following sections.

3. PREDICTION OF WATER QUALITY IN STREAM

It is well known that mathematical model is frequently available for making clear the flows in a pool. At the same time, it should be understood that structure of the model must have some kind of simplicity. As is well known, water quality in a pool changes due to lots of reasons. Then, in order to analyze its mechanism, parameters included in the model should be identified as well as pursuing to develop the highly sophisticated model. In this section, prediction of water quality in streams is explained using the mathematical model.

Conservation equations of heat, mass, and momentum are well known as those governing the quantitative and qualitative mechanism of water. These kinds of equations can be written as follows:

$$\frac{\partial S}{\partial t}+\frac{\partial (u_j S)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\varepsilon_{(j)}\frac{\partial S}{x_j}\right)+source \quad (1)$$

Of course, S should be understood as ρcT, s, and ρu_i corresponding to each conservation law. Here, ρ is the density of water, c the specific heat, T the water temperature, s the concentration of dissolved or suspended matters, u_i the x_i component of velocity, $\varepsilon_{(j)}$ the coefficient of turbulent diffusion, and t and x_j the time and space variables, respectively. In addition, Eq. (1) is expressed by the tensor using the Einstein's summation convention, and i and j are chosen through 1 to 3.

For practical purpose, Eq. (1) is transformed into the another form, integrating it in a control volume. For example, the following eqvation can be used in order to study thermal stratification, which develops vertically. [2)]

$$\frac{\partial T}{\partial t}=\frac{q_i\cdot T_i-q_0\cdot T_0}{A}-\frac{1}{A}\frac{\partial(AwT)}{\partial z}+\frac{1}{A}\frac{\partial}{\partial z}\left(A\cdot\varepsilon_z\frac{\partial T}{\partial z}\right)+\frac{Q_h}{\rho\cdot c} \quad (2)$$

Here, suffix i and o show the quantities of inflow and outflow, respectively, and z is the vertical axis. Furthermore, q is the discharge per unit depth, ε_z the dispersion coefficient of z direction ,w the vertical component of the velocity, A the horizontal area, and Q_h the thermal source of unit volume per unit time.

Even though integrated form of the fundamental equation has been explained using the heat balance equation, another equation can be transformed into the integrated form, similarly. The source term included in Eq. (1) should be estimated for each equation.

$$Source_T=\frac{\phi_s}{\rho c}\cdot\left(e^{-k(z+dz)}-e^{-kz}\right) \quad (3)$$

$$Source_D=K_{air}\cdot(D_{sat}-D)+\left(\alpha_1\cdot\mu_{max}\cdot f_{(T)}\cdot f_{(I)}-\alpha_2\cdot\gamma\right)\cdot C-K_{org}\cdot L \quad (4)$$

$$Source_{C_j}=\left(\mu_{max}\cdot f_{(T)}\cdot f_{(I)}-\gamma-w_0/d_l\right)\cdot C \quad (5)$$

$$f_{(T)}=\left\{\frac{T}{T_{opt}}\cdot exp(1-\frac{T}{T_{opt}})\right\}^2 \quad (6)$$

$f_{(I)}=1$ (for daytime), $=0$ (at night) (7)

Here, D , C , and L are the concentration of DO, chlorophyll, and BOD, respectively. Conservation equations of heat and mass are directly solved, while momentum one is solved estimating the water movement related to the Richardson number. Eqs. (3) to (5) show the source terms for water temperature, DO, and chlorophyll, respectively. Of course, many other quantities are correlated to the formation of water quality in a pool. In this study, their effects have been intended to estimate through the parameters included in the model. Eqs. (6) and (7) correspond to them. Furthermore, k is the extinction coefficient of insolation into the water, which is strongly influenced by turbidity of water. In Eq. (5), the algal growth rate is estimated considering the effects by water temperature and rate of insolation. Here, μ_{max} is the maximum value of its rate. Regarding the source term, typical phenomena are considered when estimating its value. Namely, the extinction of insolation for water temperature, and the reaeration, the photosynthesis and the respiration, and the deoxgenation by the organic matters for DO are considered. w_0 is the velocity of deposition, and d_l the depth of each layer.

Furthermore, algal growth and death, and deposition are also considered for chlorophyll.

Simulating the diurnal variation of water quality in the Yamashita Pool, above described equations have been solved numerically, considering the convection terms in the longitudinal and the vertical directions, the diffusion term, and the source term. Making clear the whole mechanism of water quality, it should be discussed on physical, chemical and biological viewpoints. It is well known that stratification and destratification of thermal layer strongly affect the physical feature of flows. At the same time, it can be easily supposed that these kinds of characteristics influence the ecosystem including the movement of phytoplankton. In order to predict the water quality in streams, above mentioned parameters have to be identified appropriately. Referring to the observed data described below, the following values of parameter have been used in a present computation. Namely, ε_z is estimated as a function of Richardson number, and $\varepsilon_{z,0}$=5X10^{-5}m^2/s, i.e. maximum value of ε_z. ϕ_s is evaluated considering a diurnal change of insolation as $\phi_{s,0}$=145J/m^{2}s. Here, k=1.23m^{-1}, α_1 =1.7mgO/mgChl, α_2=2.0mgO/mgChl, w_0=2.6 m/d, and T_{opt}=25℃. Furthermore, μ_{max}=1.73d^{-1} and γ =1.04 d^{-1} as a rate of algal growth and death, respectively. In addition, K_{air} is calculated by K_{air} =3.3x $u/h^{1.33}$• 2.31(d^{-1}), and K_{org}=0.23d^{-1}. Obtaining the appropriate value of parameter, field observations of water quality must be done, especially observing the detailed manner of living things such as several kinds of algae. In order to carry out the exact simulation of water quality in a pool, it becomes important to realize how to know their movement. From this kind of viewpoint, some discussions will be done in the following section.

4. COMPARATIVE DISCUSSION ABOUT THE OBSERVED AND CALCULATED RESULTS OF THE WATER QUALITY

Next, qualitative changes of river water are investigated based on a field observation. After this, their quantitative estimation has been done through a mathematical simulation. Figs. 3 (a)-(c) show the temporal variation of water temperature, chlorophyll, and DO obtained by a numerical computation, respectively, including the field data observed on October 21, 1997. From these Figures, it becomes clear that the thermal stratification of the Yamashita Pool has numerically been simulated fairly well. This means that flows in the pool can exactly be anticipated, though equation of motion has not been solved directly. As is easily supposed, river water flows near the surface during the daytime, while dives to the deep layer at night. On the other hand, agreement of calculated data with observed ones is fairly well also for chlorophyll and DO, even though accuracy of agreement decreases in an intermediate layer for chlorophyll. This fact also denotes the difficulties of precise prediction of water quality, influenced by the living things. As described in the former section, source terms of the matters are estimated considering the mutual effects with others. However, self-movement of the living things has been ignored in the present calculation. For further calculation, biological and/or ecological behaviors should be included in the model.

Referring to Fig. 3, it becomes apparent that the accordance of the observed and the calculated results of DO is fairly well as one of water temperature. But accordance of DO becomes less acculate at night. This is due to a fact, such that inflow dived into the bottom layer with small value of DO at night. Correlation of DO and chlorophyll has been illustrated in Fig.4. This figure shows the typical feature of DO throughout a day, and also a close relationship between both of them. This reflects a fact such that the photosynthesis and the respiration are strongly related to the formation of the spatial distribution of the water quality, as is easily predicted.

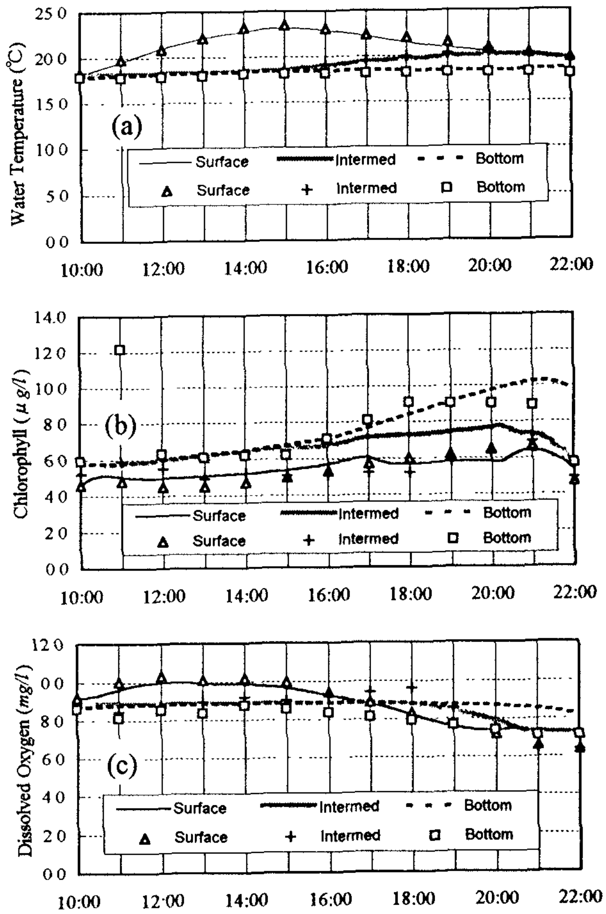

Fig.3 Temporal variation of water quality in Yamashita Pool with field data observed on Oct. 15, 1997.

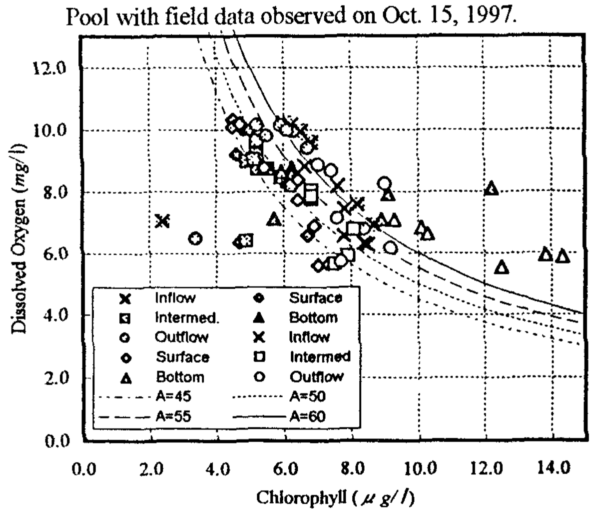

Fig.4 Relationship between DO and Chlorophyll.

5. QUALITATIVE CHANGE OF WATER IN A POOL

In the previous section, brief discussion about both of the results has been carried out. Further, it should be noted that the ecological model might become a powerful tool for predicting the temporal and spatial variations of water quality, if exactly estimating the lots of coefficients included in the model. In order to investigate the diurnal change of water quality in a pool, field observation should be performed under the several conditions.

As mentioned above, thermal stratification was observed in Yamashita Pool on a field observation

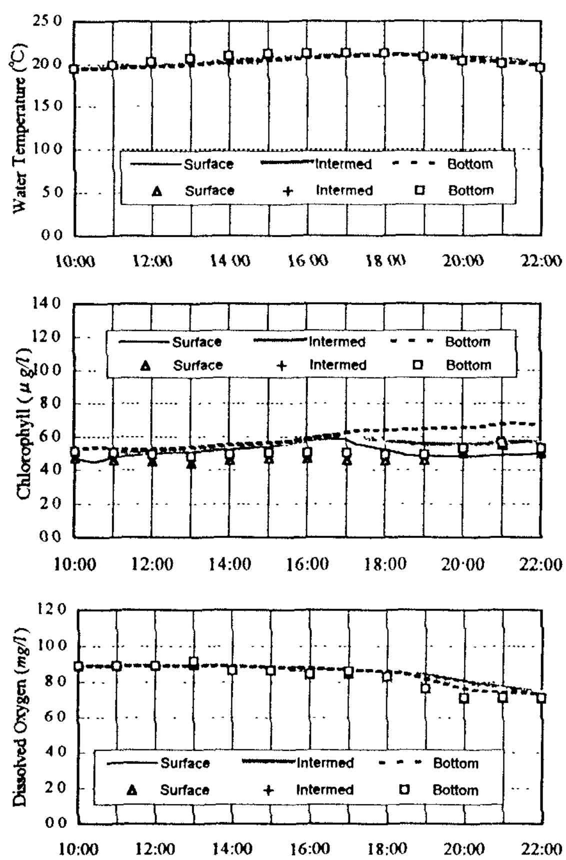

Fig.5 Temporal variation of water quality in Yamashita Pool with field data observed on May 18, 1998.

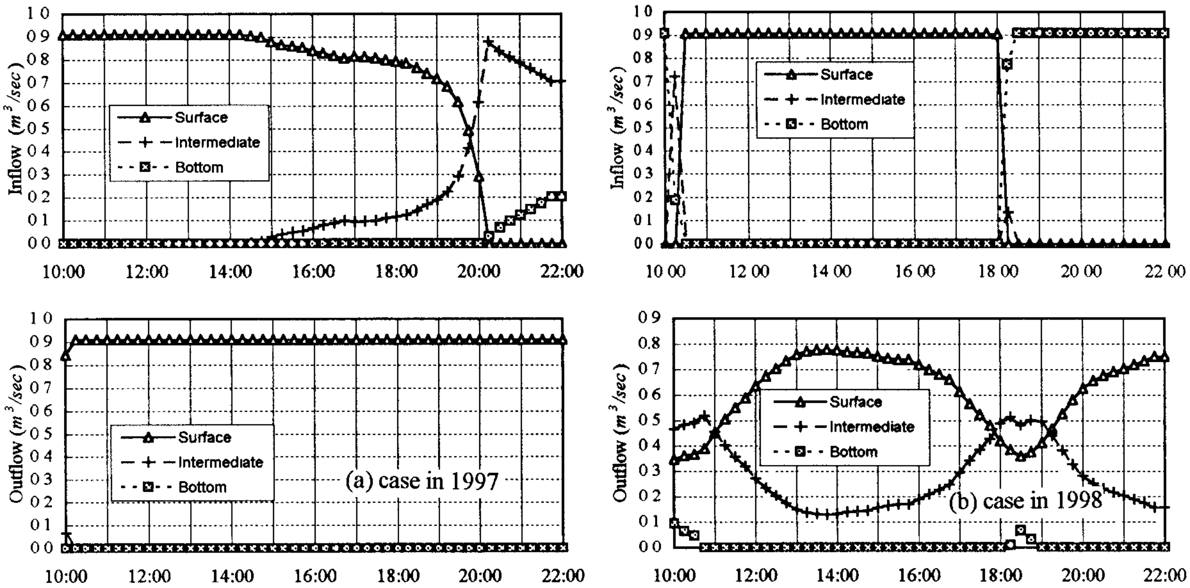

Fig.6 Temporal and spatial distribution of flows in an inlet and an outlet in the pool (calculated results).

in 1997, while it was not in spring of 1998 (Fig.5). Even though both of the observations were carried out under the similar weather condition, amounts of heat stored in a pool are different from each other. Fig.5 shows the comparison of the calculated and the observed data for temporal variation of water temperature, chlorophyll, and DO, in a similar form with Fig.3. Under the condition of uniform density, river water flows through a whole depth. Therefore, concentration of the considered matters is almost uniform, vertically. Also on the case in 1998, DO decreases at night, even though both conditions are remarkably different from one another. In Fig.6, temporal distribution of discharge calculated for inflow and outflow is illustrated in each layer, on both cases. Referring to these figures, it is quite apparent that river water flows in a different manner under the stratified and non-stratified conditions. This kind of difference also affects lots of water quality, as already explained about DO and chlorophyll.

6. CONCLUSIONS

In order to investigate the diurnal change of water quality in a pool managed by the nature-friendly river work, both of the field observation and the mathematical simulation have been carried out. Through these procedures, the following conclusions can be derived.

1) Comparing both of the field observations under the similar weather condition, flow of river water is not necessarily the same, because there exist some differences anywhere.

2) Under the stratified and non-stratified conditions, influence of a pool on the water quality at downstream becomes different from one another. This is mainly due to the existence of difference in the vertical distribution of flow in a pool.

3) Water quality in a pool changes diurnally. Water temperature, DO, and chlorophyll, mainly discussed in this paper, change throughout a whole day, affected by the rates of insolation. In order to estimate its effect, correlation of the matters has been investigated, using the mathematical model. For practical purpose, dominant parameters included in the model should be identified appropriately.

4) Effects of the nature-friendly river work on water quality seem to be small, at least for short period. Therefore, in order to make them clear, ecological model which can predict the movement of algae rationally must be developed. For an accomplishment of this purpose, further discussion based on field observation and mathematical simulation is recommended.

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