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Study on the Diurnal Change of Water Quality in the Pool Managed by the Nature-Friendly River Work (I)

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자연복원하천구간에 있어서 못의 일중 수질변화에 관한 연구

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요 약

자연친화적 하천사업에 있어서 못은 하천환경을 구성하는데 기본단위이나 수환경상의 기능에 대한 평가는 이루어지지 않고 있는 실정이다. 못의 수환경을 평가하기 위하여 측정 자료를 토대로 한 일중 수질모형을 개발하여 적용하였다. 못의 하천환경에 대하여 물리적, 생태학적 관점에서 그 효과를 분석하였다. 못에 있어서 일중 수질은 혼합의 정도에 따라 영향을 크게 받으며 이러한 모의실험 결과는 향후 못의 조성에 따른 자료수집이나 일차 생산력을 이해하는데 유효하게 이용될 수 있을 것이다.

주요어 : Nature-friendly river work, pool, water environment, modelling

I. Introduction

For river management, flood control has been main issue in Japan. Most of river channels have been straightened and widened enough for flood protection. But, recently with new recognition of river front environment, it is gradually becoming a consensus among citizens that sound and sustainable river restoration work based on ecosystem approaches should be emphasized as well. This fact reflects that the conservation and creation of desirable water environment become more important. Lots of works have been carried out in and around rivers to achieve a sound and sustainable water environment. "Nature-friendly river work" is well known as one of these works, and this kind of river work has been used over many places, even though its validity cannot necessarily be assessed(Noguchi, M., *et. al*., 2000).

One of the main issue of nature- friendly river work is to restore biological diversity of ecosystem. The restoration of bio-diversity means to rehabilitate and preserve natural river functions such as habitat for aquatic lives, self-purification of water quality, the field for recreation and so on.

Among them, the function of rapids and pool which become unit shape in river have been focused as a river ecological aspects. Furthermore, this combination has been recognized as not only a unit of benthic communities in the stream but also a unit of geomorphology in the channel morphology(Tanida, K., 1998; Hirose, T., 1997). Thus, in order to restore biodiversity, it is important to estimate their function. For realizing the desirable water environment, river restoration work has often been done, and its effects 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 pool managed by the nature-friendly river work.

II. Data collection

The river chosen for this study is Honmyo river, which is small size urban river having 21km length and about 87km^2 of river basin. The river is well known history of flood disaster. One of the floods broke out in 1957 with rainfall of 1,109 mm/day which resulted in 539 deaths and extensive damage to the area. As a results of flood, the river is classified as class A. Moreover, the importance of river management cannot be neglected because a big project of sea-dyke and the reclamation of Isahaya Bay is now under construction in the downstream of Honmyo River. In this project, a regulation pond for flooding is also planned, so continuous efforts in its watershed is indispensable to prevent the deterioration of water quality such as eutrophication.

In this regard, a part of Honmyo river has been introduced as nature-friendly river work for sound and sustainable river environment as shown in Fig. 1. In order to estimate variation of temporal and spatial water quality, extensive field observation in pool was carried out. In the pool three vertical points of surface, intermediate, and bottom layers are surveyed including inflow and outflow. The depth of each layers is 0.3m,

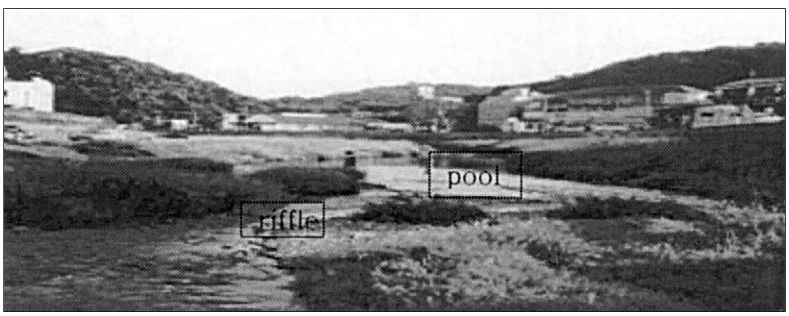

Fig. 1. Riffle and pool in the area of nature-friendly river work

1.0m, and 2.0m, respectively. In these observation, water temperature, chlorophyll-a, turbidity, dissolved oxygen (DO), and insolation were observed using the observation device of CHLOROTECH, ACL1183-PDK. At the same time, total nitrogen (T-N), total phosphorus (T-P), biochemical oxygen demand (BOD5), and suspended solids (SS) have been measured for the samples collected by SPECTROPHOTO-METER, 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. It is well known that river consists of riffle and pool, and they play important roles for formation of water quality (Morishita, E., 1996). It has been recognized that riparian is important to preserve water quality. For simulation of water quality in pool, extensive field surveying has been carried out from 1998 to 2001. These data will be used to simulate water quality in the pool.

III. Equations for the prediction of water quality

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:

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

Of course, S should be understood as ρcT, corresponding to the above-mentioned quantity. Here, ρ is the density of water, c is the specific heat, T is the water temperature, u_j and x_j are component of velocity, $\varepsilon(j)$ is the coefficient of turbulent diffusion, and t is the time, respectively. In addition, Eq. (1) is expressed by the tensor using the Einstein's summation convention, and $_j$ is chosen through 1 to 3.

For thermal stratification in pool, the vertical variation of water temperature, dissolved oxygen and chlorophyll-a should be considered in calculation. Thus, proposed model is designed under some assumption ; 1) the system can be divided into layers, 2) outflow is calculated using the concept of selected withdraw and, 3) vertical transport of mass though diffusion are varied with the intensity of thermal stratification.

In a practical case study, Eq. (1) will be transformed into the another form, integrating it in a control volume. For example, the following equation can be used in order to investigate the thermal stratification developed vertically.

$$\frac{\partial T}{\partial t} + \frac{q_i \bullet T_i - q_o \bullet T_o}{A} - \frac{1}{A}\frac{\partial (AwT)}{\partial z} + \frac{1}{A}\frac{\partial}{\partial z}\left(A \bullet \varepsilon_z \frac{\partial T}{\partial z}\right) + \frac{Q_h}{\rho \bullet C} \qquad (2)$$

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 width, z the dispersion coefficient of εz 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, anther equation can be transformed into the integrated form, similarly. The source term included in Eq. (1) should be estimated for each equation.

$$Source_T = \frac{\phi_s}{\rho C} \bullet (e^{-k(z+dz)} - e^{-kz}) \qquad (3)$$

$$Source_D = K_{air} \cdot (D_{sat} - D) + (\alpha_1 \cdot \mu_{max} \cdot f_{(T)} \cdot f_{(1)} - \alpha_2 \cdot \gamma) \cdot C - K_{org} \cdot L \quad (4)$$

$$Source_{CJ} = (\mu_{max} \cdot f_{(T)} - \gamma - W_o/d_l) \cdot C \quad (5)$$

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

$$f_{(1)} = 1 \text{ (for day time)}, = 0 \text{(at night time)} \quad (7)$$

Where, D, C, and L are the concentration of DO, chlorophyll-a, and BOD, respectively. Conservation equation of heat and mass are directly solved, while momentum one is solved to estimate water movement related to the Richardson number. Eqs. (3) to (5) show the source terms for water temperature, DO, and chlorophyll-a, respectively. Of course other quantities are correlated to the formation of water quality in a pool. In this study their effects have been intended to estimate model parameters by using Eq. (6) and (7). 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 by considering the effects of water temperature and insolation rate. Where, μ_{max} is the maximum rate. Regarding the source term, typical phenomena are considered when we estimate its value. Namely, the extinction of insolation for water temperature and reaeration, photosynthesis and respiration, and deoxydation by the organic matters for DO are considered. The value of w_o is the velocity of deposition and d_l is the depth of each layer. Furthermore, algal growth, death, and deposition are also considered for chlorophyll-a. Simulating the diurnal variation of water quality in the pool, described Eqs. have been solved numerically, considering the convection terms in the longitudinal and the vertical directions, the diffusion term, and the production term by the insolation. Making clear the mechanism of water quality changes, it should be discussed on physical, chemical and biological viewpoints. It is well known that stratification and de-stratification of thermal layer strongly affect the physical feature of flows.(Gu, R., 1998) At the same time, it can be easily supposed that these kinds of characteristics influence the ecosystem including a movement of phytoplankton. In order to predict the water quality in streams, above mentioned parameters have to be identified. For the water quality simulation, ε_z is estimated as a function of Richardson number and $\varepsilon_{z,0}=5\times10^{-5}\text{m}^2/\text{s}$, i.e. maximum value of ε_z. ϕ_s is evaluated considering a diurnal change of insolation as $\phi_{s,0}=145J/\text{m}^2 \cdot S$.

Here, $k=1.23\text{m}^{-1}$, $\alpha_1=1.7\text{mg}\,O_2/\text{mg}Chl$, $\alpha_2=2.0\text{mg}\,O_2/\text{mg}Chl$, $w_0=2.6\text{m}/d$, and $Topt=25°\text{C}$. Furthermore, $\mu_{max}=1.73\ d^{-1}$ and $\gamma=1.04\ d^{-1}$ as a rate of algal growth and death, respectively. In addition, K_{air} is calculated by $K_{air}=3.3\times u/h^{1.33} \cdot 2.31\ d^{-1}$, and $K_{org}=0.23\ d^{-1}$(Gu, R., 1998).

IV. The water quality observed and calculated

Qualitative changes of river water are investigated based on a field observation. Their quantitative simulation has been carried out based on field surveying. Figs. 2 show the temporal variation of water temperature, chlorophyll-a, and DO obtained by a numerical computation, respectively, including the observed data. From these Figures, it becomes clear that the thermal stratification of the Pool has numerically been simulated fairly well. This means that flows in the pool can exactly be anticipated, though equation of

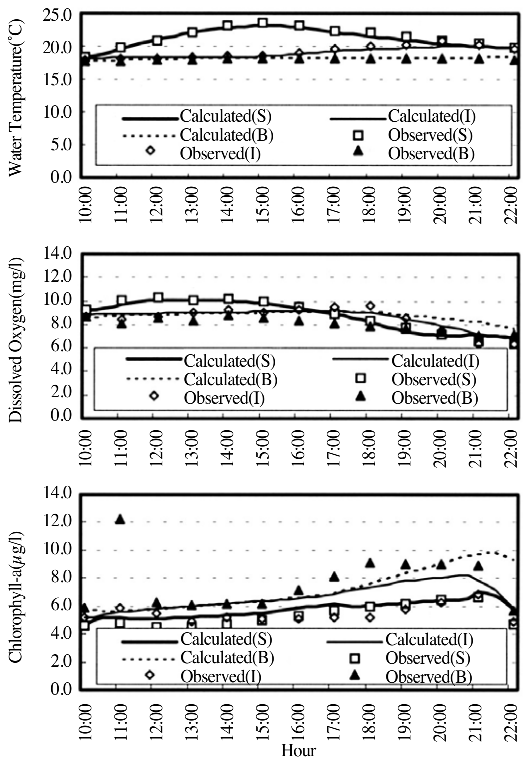

Fig. 2. Simulated results of water quality under thermal stratification in the pool(S; surface, I; intermediate, B; bottom, respectively)

motion has not been solved directly. We can suppose that river water flows near the surface during the daytime, while dives to the deep layer at night time. On the other hand, fitness of calculated data with observed ones is fairly good also for DO and chlorophyll-a, even though accuracy of fitness decreases in an intermediate layer for chlorophyll-a. This fact also denotes the difficulties of precise prediction of water quality influenced by the living organism. As mentioned in former section, source terms of the matters are estimated considering the mutual effects with others. However, self-movement of the living organism has been ignored in the calculation.

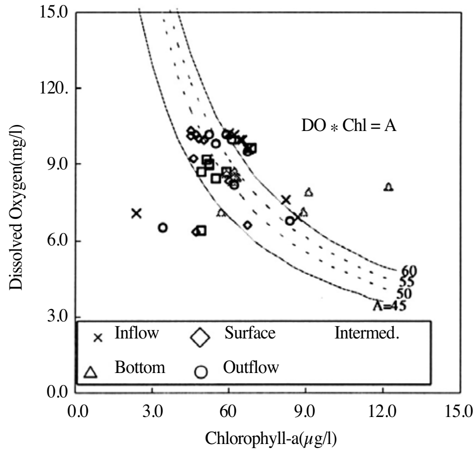

Fig. 3. Relationship between DO and Chlorophyll-a in the pool

Referring to Fig. 2, it becomes apparent that the accordance of the observed and the calculated results of water temperature is good fitness as one of water temperature. But, at night time the simulation results of DO become out of accordance with observed ones. This is due to a fact that inflow dived into the bottom layer with small value of DO at night time. Correlation of DO and chlorophyll-a has been illustrated in Fig. 3. Fig. 3 shows the typical feature of DO throughout a day, and also a close relationship between DO and chlorophyll-a. This reflects that the photosynthesis and the respiration are strongly related to the formation of the spatial distribution of the water quality. Dissolved Oxygen would be produced by the phytoplankton at day time and consumed by the respiration at night time. However, its distributions of concentration may be different vertically due to the difference of water density. Their relationship can be represented by following equation.

$$DO = A/Chl \tag{8}$$

Where, DO(mg/l): concentration of dissolved oxygen, Chl($\mu g/l$) : concentration of chlorophyll-a and A : constant value. Calculated values of A obtained by equation 8 were estimated, when A takes 45, 50, 55, and 60, respectively.

V. Water quality change in the 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, when we estimate various coefficients exactly included in the model. The thermal stratificaion was observed on a field survey in fall period, while it was not observed in spring season. Even though both of the observations were carried out under the similar weather condition, amounts of heat stored in a pool are different. Fig. 4 shows the comparison of the calculated and the observed data for temporal variation of water temperature, chlorophyll-a, and DO. Under the condition of uniform density, river water flows through a whole depth. Therefore, concentrations of considered matters are almost uniform vertically. Also, on the case of 1998 data, concentration of DO decreases at night, even though both conditions are remarkably different from one anther. Fig. 5 illustrated the temporal distribution of inflow and outflow in each layer. Referring to these figures, it is quite apparent that river water flows differently under stratified and non-stratified conditions. This kind of difference also affects lots of water quality.

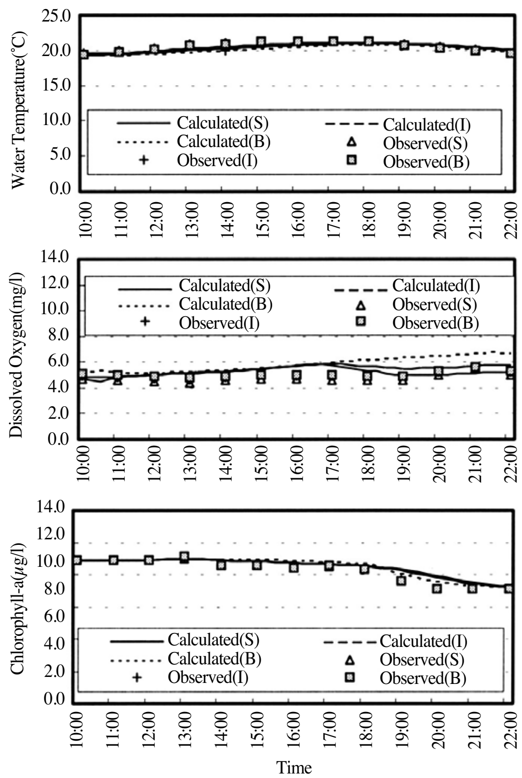

Fig. 4. Simulated results of water quality under non-thermal stratification in the pool(S; surface, I; intermediate, B; bottom, respectively)

VI. Conclusions

In relation to nature-friendly river work, rapids and pool have been focused on biological aspect to enhance primary production and self purification of river. In order to investigate the diurnal change of water quality in the pool managed by nature friendly river work, both of the field observation and mathematical simulation have been carried out and the following results ware obtained. Under the stratified and non-stratified conditions, influence of pool on water quality becomes different from one anther. The simulated results show that inflowing DO level is main item of distribution of DO level in

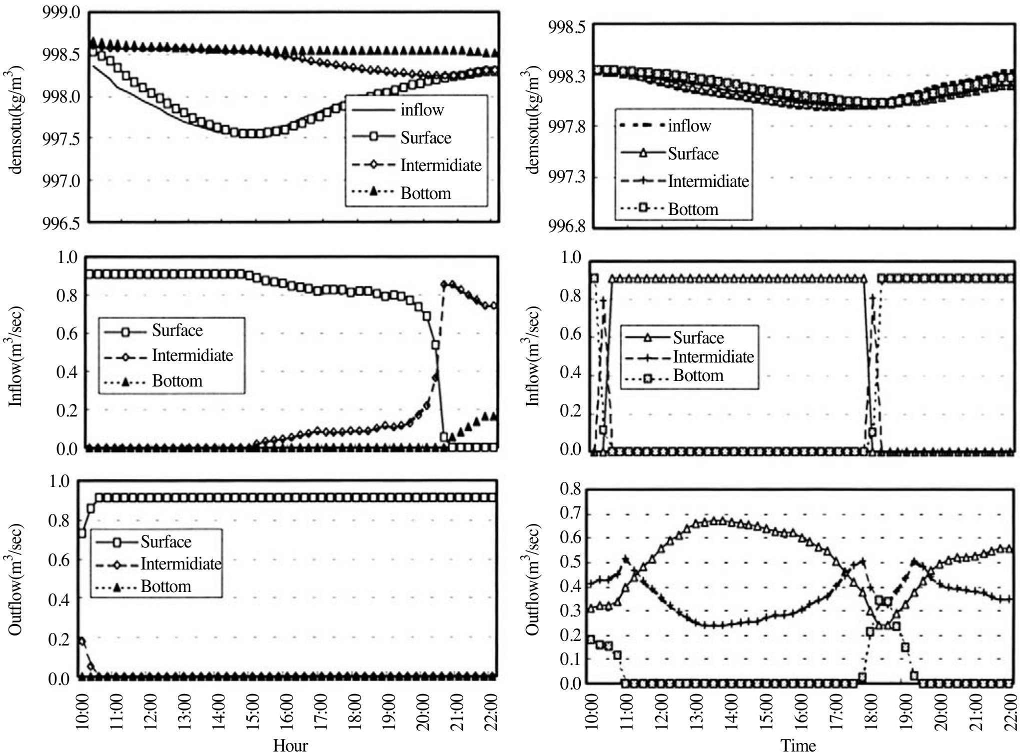

Fig. 5. Temporal and spatial distribution of flows in inlet and outlet in the pool

closed water body. This is mainly due to the existence of vertical different distribution of flow in pool. The water temperature, DO, and chlorophyll-a concentration change throughout a whole day, affected by the rate of insolation. The proposed model is useful to guide field data collection work and to understand primary production.

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