SEASONAL COMPARISON OF PREDOMINANT FACTORS IN RIVER TEMPERATURE FORMATION IN AN URBAN RIVER

JUNICHI NISHIMATA
Department of Civil Engineering, Shibaura Institute of Technology, Tokyo, Japan,

and, Department of Water Resources and Waterways, Nippon Koei Co., Ltd., Japan, me18095@shiabura-it.ac.jp

HITOSHI MIYAMOTO
Department of Civil Engineering, Shibaura Institute of Technology, Tokyo, Japan, miyamo@shiabura-it.ac.jp

ABSTRACT

In this paper, predominant factors of river temperature formation in each season were analyzed by using the field observation and heat budget analysis in the middle and lower parts of an urban river. The urban river analyzed was the first-class river, Tama River, flowing through the Tokyo metropolitan area. Treated water with a constant temperature flowed into the Tama River from several water reclamation centers located along with Tama River. Observational data analyses indicated that the influence of convective heat flux from the treated water discharge greatly affected the formation of river temperatures in the middle reach of Tama River in all seasons. On the other hand, in the lower reach, the river temperature flowed downstream with a nearly constant temperature. The heat budget analysis also showed that, in summer and autumn, the river temperature in the middle reach was more influenced by the treated water than that in the downstream reach. Other predominant factors in river temperature formation in each season were further discussed and compared by using the heat budget analysis.

Keywords: urban river, water quality, stream temperature, thermal energy equation, treated wastewater

1. INTRODUCTION

In recent years, there has been a concern that the global climate change and the artificial waste heat from urban rivers will have a significant effect on terrestrial ecosystems at river sites (Robert et al., 2013; Xin and Kinouchi, 2013). River temperature is one of the important indicators that define the river environment. In this paper, the effect of the artificial waste heat of treated water on river water temperature was investigated for the Tama River flowing through the Tokyo metropolitan area. Specifically, seasonal observations of water temperature observation data are compared in the middle and downstream parts of the Tama River, and the water temperature formation factors are analyzed by using the heat transport equation.

2. STUDY FIELD AND RIVER WATER TEMPERATURE MONITORING

The river studied in this paper was Tama River running through the metropolitan Tokyo. Figure 1 shows the land use of the Tama River basin and the locations of river temperature measurement, discharge observatories by MLIT(Ministry of Land, Infrastructure, Transport and Tourism, Japan), and, water treatment facilities. Tama River has an area of 1,240 km^2, a longitudinal and lateral lengths of 115 and 20 km, respectively, and the human

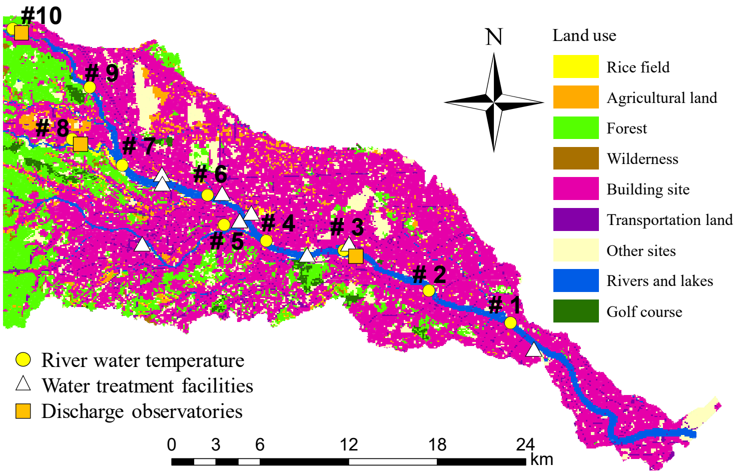

Figure 1. Tama River basin and the locations of river temperature measurements, discharge observatories and, water treatment facilities.

population is 4.46 million people within the river basin. Forests are predominant in the upstream part of the river basin, while, in the middle and downstream parts, the river basin has been heavily urbanized since it has been located in the metropolitan Tokyo. There are 9 water treatment facilities located along the main channel of Tama River, discharging treated sewage water with a constant water temperature of around 23 °C. In this study, from November 2014, hourly monitoring of river water temperatures has been continued at eight locations in the main river and one in each in the Asakawa and Akikawa tributaries.

3. ANALYTIC MODEL

3.1 Basic equation

This paper used the following one-dimensional thermal conservation equation as a basic equation of the river temperature analysis (Miyamoto and Michioku, 2007; Miyamoto et al., 2009).

$$\frac{\partial T_w}{\partial t} = -V\frac{\partial T_w}{\partial x} + \frac{1}{C_w \rho_w h} H_{wb} + \frac{q_x}{A}(T_{wl} - T_w) \quad (1)$$

$$H_{wb} = H_s + H_a - H_{br} - H_{la} - H_{se} + H_{bed} \quad (2)$$

where, T_w: river temperature[°C], V: mean velocity[m/s], A: discharge section area[m^2], C_w: specific heat at constant pressure of water[J/(kg*K)], ρ_w: water density[kg/m^3], h: water depth[m], H_s: short wave radiation[w/m^2], H_a: long wave radiation from air[w/m^2], H_{br}:long wave radiation from water[w/m^2], H_{la}: latent heat transfer[w/m^2], H_{se}: sensitive heat transfer[w/m^2], H_{bed}: thermal flux from the wetted perimeter[w/m^2], x: longitudinal axis, t: time[s], q_x: lateral inflow in unit length[m^2/s], and T_{wl}: water temperature from the lateral inflow[°C].

3.2 Analytical method

The river water temperature change was estimated by using the analytical solution of Eq. (1) obtained by the method of characteristics. In this analytical solution, the river water temperature at the downstream end of the target section was calculated when the water temperature and the flow rate were given as the upstream boundary conditions. The heat fluxes on the water surface and the wetted perimeter were estimated by empirical bulk equations with the weather data from the AMeDAS system of the Japan Meteorological Agency. The water depth and the lateral inflow were determined by the least squares method of the observed and analytic temperatures with model parameters in the governing equations.

3.3 Point-sources treatment as a boundary condition

Regarding the heat inflow from treated waters and tributaries, the analytical section was divided into upper and lower sections at the inflow point, and the analytical solution was applied to each section. The conservation condition (Eq. (3)) of the heat flux before and after the division point was used as the inflow boundary condition of the divided downstream section.

$$T_{wf} = \frac{Q_r T_{wr} + Q_h T_h}{Q_r + Q_h} \quad (3)$$

where, Q_r: river flow rate[m^3/s], Q_h: treated water/tributary flow rate[m^3/s], T_h: treated water temperature (data from the Tokyo Metropolitan Government) or tributary water temperature[°C], T_{wr}: inflow river water temperature in the main river channel at the division point[°C], T_{wf}: river water temperature after the inflow [°C].

4. RESULTS and DISCUSSION

4.1 River temperature observation

Table 1 shows the specifications of the three sections for which the river water temperature was analyzed in this paper.

Table 1. Specifications of the three analytical sections

SECTION	DISTANCE FROM RIVER MOUTH	DATA PERIOD	WATER TREATMENT FACILITY	TRIBUTARY
MIDDLE STREM (#9-#6)	42-54km	12/2017-09/2019	Tama River Upstream, Hachiouji	Akikawa River
DOWN STREAM 1 (#4-#3)	32-37km	12/2014-10/2015	MinamiTama	
DOWN STREAM 2 (#2-#1)	18-24km	12/2017-11/2018		

Figure 2 (a) showed the river water temperature, equilibrium water temperature, treated water temperature, and water temperature change per unit flow distance (water temperature difference / distance) in the middle stream section. It indicated from Fig.2(a) that the (water temperature difference / distance) took a positive value throughout the year. In particular, its value had maximal in winter. This could be due to the large effect of the inflow treated water.

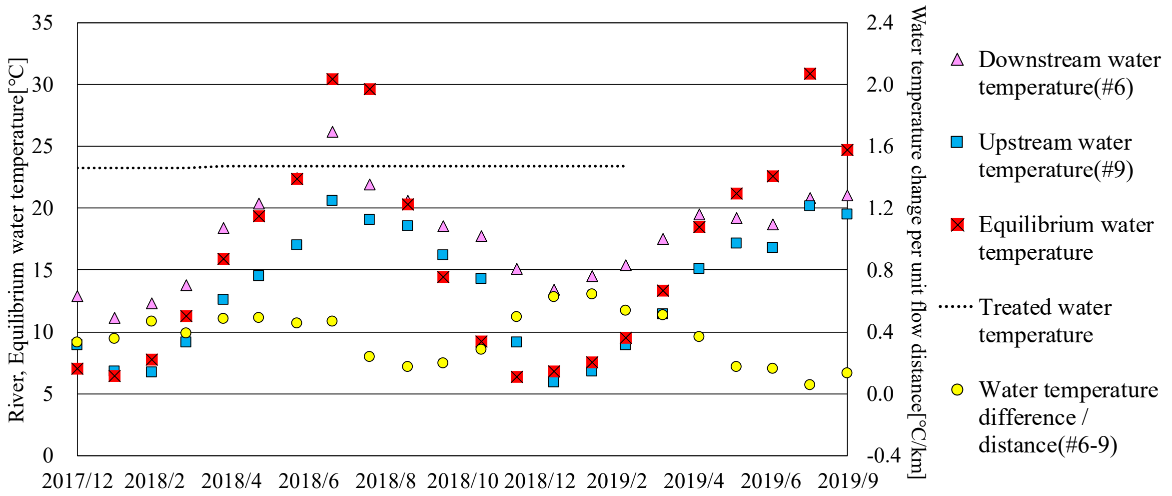

Figure 2. (a) Middle stream section.

Figure 2 (b) showed the same items as Fig.2 (a) for the down stream sections 1 and 2. The (water temperature difference /distance) was quite small throughout the year in the downstream section 1. On the other hand, for the downstream section 2, positive and negative values were switched seasonally. It was considered that the formation mechanism of river water temperature had a great influence on the presence or absence of treated water inflows. In other words, it could infer that high temperature conditions were maintained continuously by the treated water inflow in the down stream section 1, while the river water temperature was naturally changed due mainly to the thermal balance on the water surface in the down stream section 2.

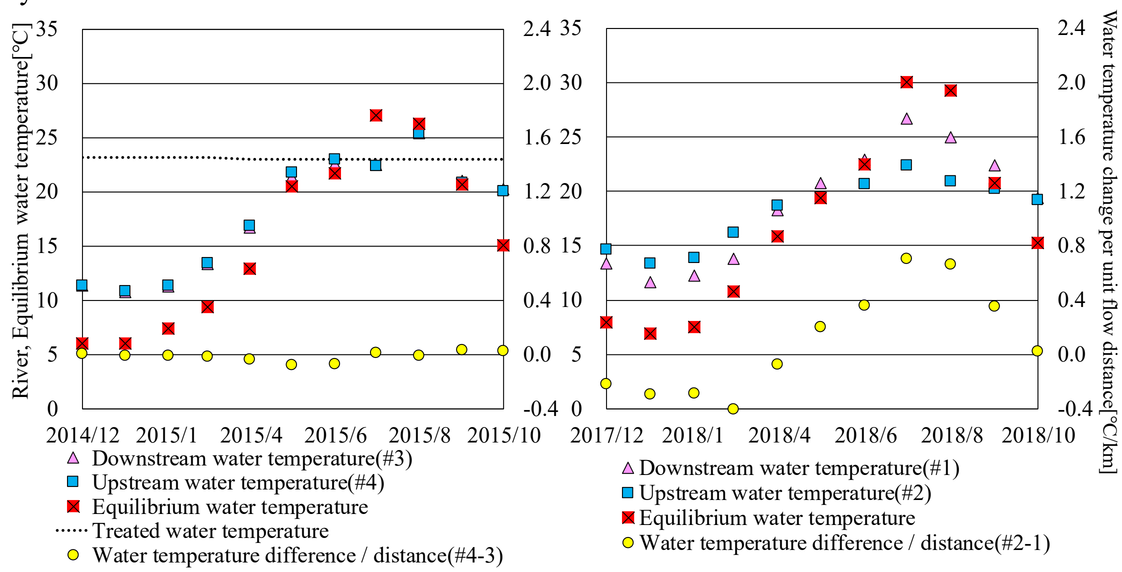

Figure 2. (b) Down stream sections (left: down stream 1, right: down stream 2).
Figure 2. Time series of various water temperature quantities in the tree analytical sections.

4.2 Model analysis

Figure 3 showed the distributions of the total heat flux, the heat flux from the water surface, wetted perimeter and lateral inflow, that from the treated water, and that from tributaries for the middle and down stream section 1. The values of the fluxes in Fig. 3 were devided by unit downstream distance. In Fig. 3, the values during the period of fine weather were collected and calculated for discussion. It was revealed from Fig. 3 that the total heat flux was larger in the middle section than that in the downstream section 1. It corresponded to the characteristics found in the (water temperature difference / distance) relationship in Fig. 2. The heat flux of the treated water in winter was the largest in the middle section, while that in spring was the largest in the down stream section 1. It could suggest that the season in which the effect of treated water was predominant differed largely in each section. Furthermore, it also indicated in Fig. 3 that the heat flux of the water surface, wetted perimeter, and lateral inflow had negative or nearly zero in summer and autumn in the down stream section, meaning that the treated water inflow was only contributed to the temperature formation.

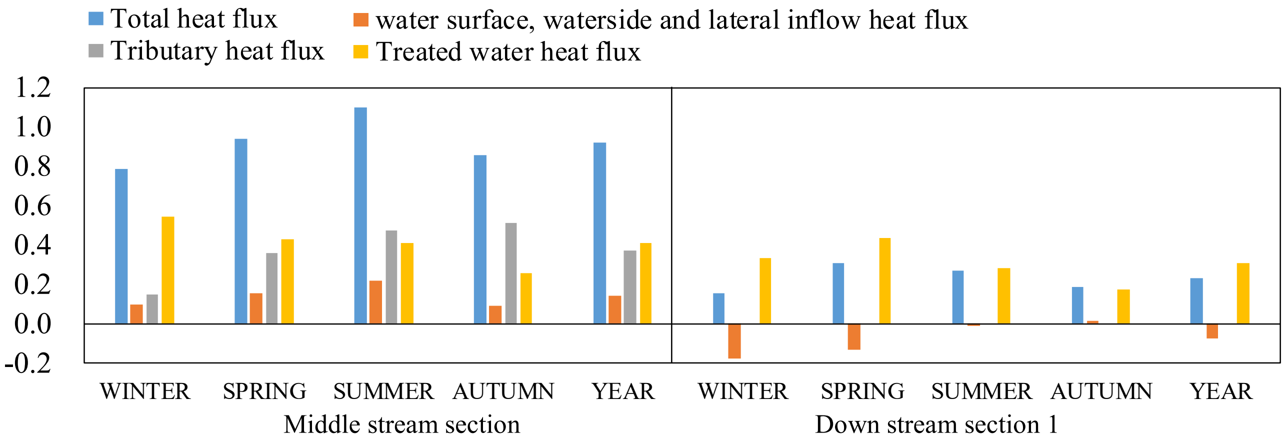

Figure 3. Seasonal distributions of heat fluxes in the middle and down stream sections.

Figure 4 showed the ratios of each heat flux in the middle stream section and the down stream section 1. In the middle stream section, the effect of treated water on the river water temperature became most predominant in winter, and its ratio was reached to 70%. This result was also confirmed in the water temperature analysis in Fig. 2 (a). On the other hand, in the down stream section 1, the model analysis revealed that the formation mechanism of the river water temperature was completely different in each season, though the river temperature change was quite small as shown in Fig. 2 (b). Namely, in winter and spring, the river water temperature was kept constant by the balance between a warming effect of the treated water and a cooling effect of the heat fluxes from the water surface, wetted perimeter, and lateral inflow.

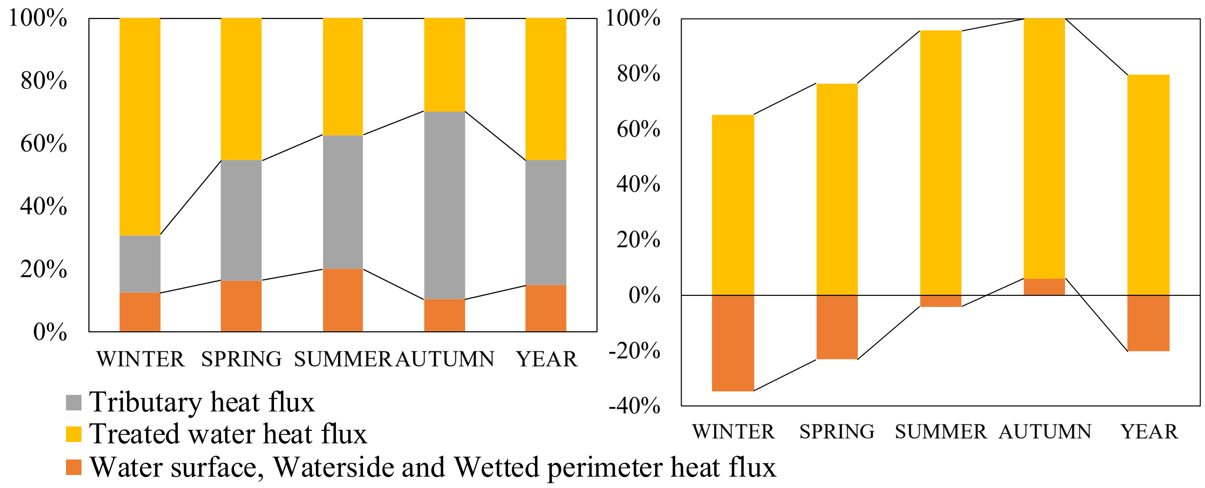

Figure 4. Ratios of heat fluxes (left: the middle stream, right: down stream section 1).

5. CONCLUDING REMARKS

This paper examined the temporal characteristics of river water temperature, and analyzed the dominant factors of water temperature formation by using the heat transport equation in the middle and down stream sections of the Tama River, Japan. The results indicated that the influence of the treated water inflow extended to the entire river course of the Tama River. In particular, it revealed that the influence became larger in the middle stream section than in the down stream sections, and most predominant in winter.

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