Chapter 70
Changes of River Discharge and Temperature by Using Distributed Runoff Model with the Global Warming Experiments, Frequency Analysis of Drought and Flood

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Abstract In the Yamato River system, it is located in the middle part of the Kinki region of Japan and flows to the south side of Osaka prefecture through the plain of Nara prefecture. This water system has been plagued by drought since ancient times. In modern times, the frequency of droughts has decreased due to the development of water resources such as dam development and water conveyance projects from other basins. On the other hand, the frequency of floods has increased in recent years. Currently, in Japan, we are planning consider measures against not only the increase in flood flow due to climate change by global warming but also the increase in drought frequency. However, no concrete measures have been found yet. In addition, as a scientific basis for formulating these policies, the warming experimental values based on the 4 °C rise reported by the IPCC have been prepared. In this study, we simulated the river flow and river water temperature in the Yamato River basin using global warming data (d4PDF provided by DIAS:). From this result, the frequency of rainfall scale and past observation data are compared, and the basin may be in a critical situation. It was also found that when the river flow rate decreases due to the increase in evapotranspiration in drought, the temperature rise has a very large effect. As a result, we show that there is a possibility of drought that has never been experienced before.

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70.1   Introduction

Predictions regarding climate change due to global warming have shown a four-degree rise by 2100 and a two-degree rise by 2050 [1]. There is also concern that it will occur [2]. So far, changes in Japan as a whole have been expected based on CMIP5 [3]. It is expected that not only will the frequency of heavy rains increase, but also the frequency of floods and sediment-related disasters due to intensifying typhoons and wide-area frontal heavy rains will increase [4]. On the other hand, an increase in evapotranspiration due to an increase in temperature may reduce river flow, and the frequency of depletion of water resources may also increase. The purpose of this study is to predict future changes in river flow and water temperature in the Kinki region in Japan using database for Policy Decision making for Future climate change (d4PDF) [5], and to propose method for crisis management of water resources. In this report, we have predicted precipitation, river flow, and water temperature from 2051 to 2110, especially for the Yamato River basin, which has been suffering from water shortages. First, the suitability is shown by comparing the discharge and water temperature models with past observed data. As a result, extreme drought can occur. Furthermore, it is shown that the increase in evapotranspiration caused by the rise in summer air temperature and water temperature causes water shortage, and the frequency of the phenomenon increases.

70.2   Precipitation, Runoff and Water Temperature Model Overview

70.2.1   Distributed Runoff Model

In this research, the water balance in the basin was calculated using the distributed runoff model [6]. The basin was divided into 250 m square meshes. The basic constants of the distributed runoff model were determined from GIS data such as the strata of the divided mesh, land use, and altitude. Furthermore, the river network connecting each mesh from the altitude was constructed. If there was a cross-sectional survey in the river area, the data was incorporated into the model, and the river discharge and water level were tracked in the river channel with a one-dimensional indefinite flow model. We gave this model the average hourly rainfall of d4PDF. On the other hand, the discharge also changes depending on the temperature. Therefore, the water temperature was tracked by the one-dimensional advection–diffusion equation with the air temperature, solar radiation, and water vapor as inputs. Figure 70.1 shows a conceptual diagram of a model that can track the above discharge and water temperature. Next, for the discharge and water temperature of the artificial system, living drainage, agricultural intake and drainage, and water supplied from the other basin were considered as input data of the model. Details are shown in Table 70.1.
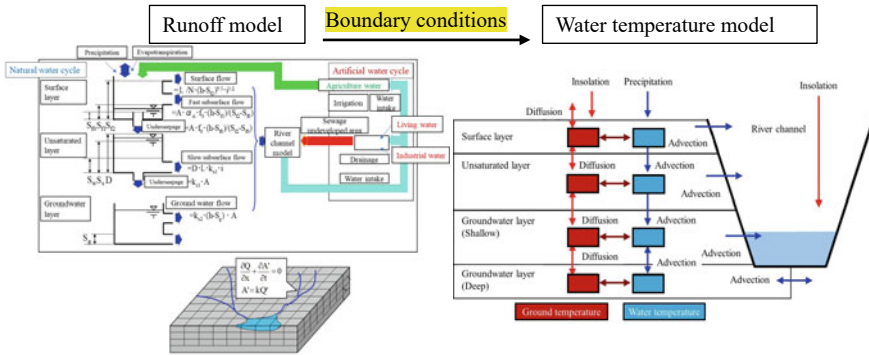
Fig. 70.1 Sketch of runoff and water temperature model

In the living drainage area is shown in Fig. 70.2. Figure 70.3 shows the agricultural intake and drainage area. Figure 70.4 shows the actual value of water supplied from the Kino River basin located on the south side of the Yamato River basin. It is considered only in the summer. Taking these data into consideration, we verified the discharge and water temperature of the Yamato River system using past observation data (discharge and water temperature).

70.2.2 Validation of Distributed Runoff Model

The validation of distributed runoff model was verified by comparing with the observation data from 2003 to 2007 and 2011. Figure 70.5a and b show the daily average discharge from 2003 to 2007 and 2011. Figure 70.6 compares the total yearly discharge. This figure compares each discharge and water temperature observation point of the Yamato River. Table 70.2 shows an evaluation of these results. Percent bias (hereafter PBIAS), Nash–Sutcliffe model efficiency (hereafter NSE) and RMSE-observations standard deviation ratio (hereafter RSR) are shown. According to this, it was shown that the constructed model reproduces the past flow conditions. On the other hand, Fig. 70.7 shows the time-series changes in water temperature. Table 70.3 shows the results of evaluation using the same index as with the discharge. This indicates that the water temperature model reproduces past water temperature change.

Table 70.1 Quantification method of displacement

Data		Quantification method
Population		Use GIS from population data of area mesh (1 km^2) Obtain the value of the area by overlapping with the basin and the municipal bmmdaty
		The area mesh population data was distributed using the architectural area (100 m^2)
Daily life water	Water consumption	Based on the yearbook and water supply statistics issued by prefectures, the annual water supply amount and water supply population were obtained
	Non-feacal wastewater	Based on the sewerage maintenance area map, the amount of living water used for each mesh was allocated to the amount of treated sewage and non-fecal wastewater
	Treated sewage	Obtain treatment results from sewage treatment plant data
Sewage maintenance area map		Convert sewerage maintenance area map to GIS data
Livestock drainage		[250 m mesh] X [Displacement basic unit]
Agriculture water	Quantity of water intake	The amount of water intake based on the actual value and the notification record was used. If there is no actual value, it is estimated by the amount of water right or the water reduction depth method
	Water consumption	The distribution of water consumption in the basin was created by superimposing it on the land use data

70.3 Prediction of Changes in Flow Conditions and Water Temperature Due to Global Warming

70.3.1 Experimental Design of d4PDF

The d4PDF consists of outputs from global warming simulations by a global atmospheric model with horizontal grid spacing of 60 km (hereafter AGCM; Mizuta et al. [7]) and from regional downscaling simulations covering the Japan area by a regional
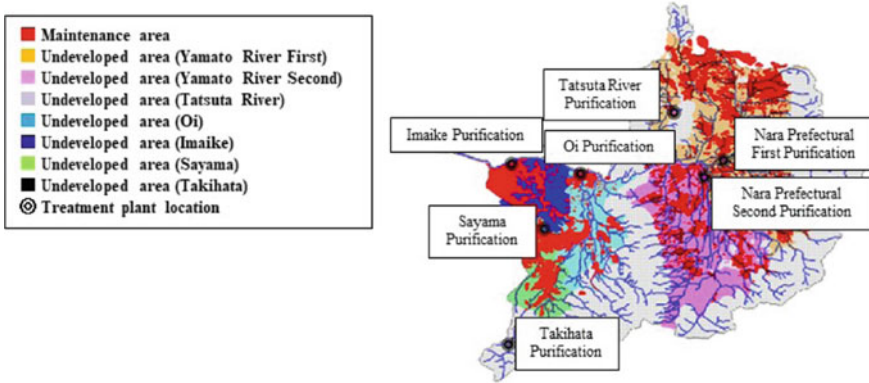
●Living drainage
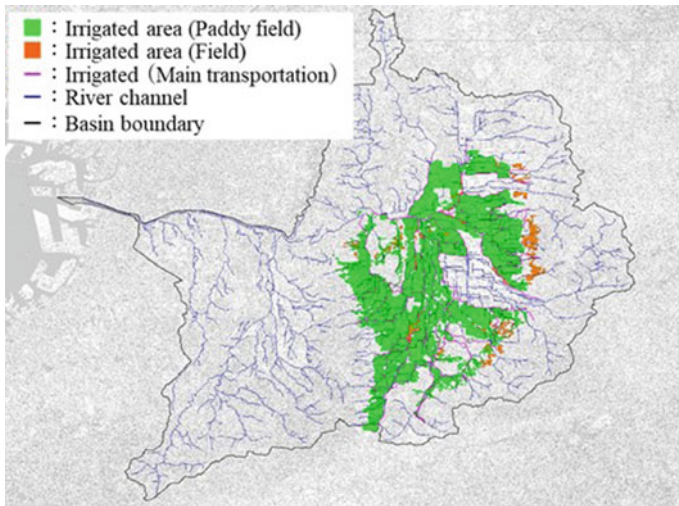

Fig. 70.2 Sewage maintenance
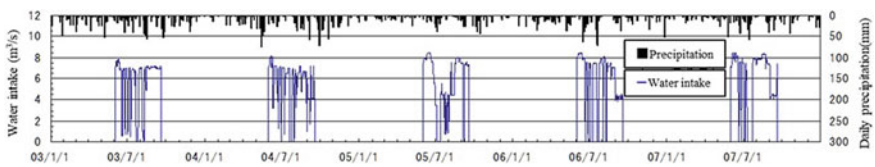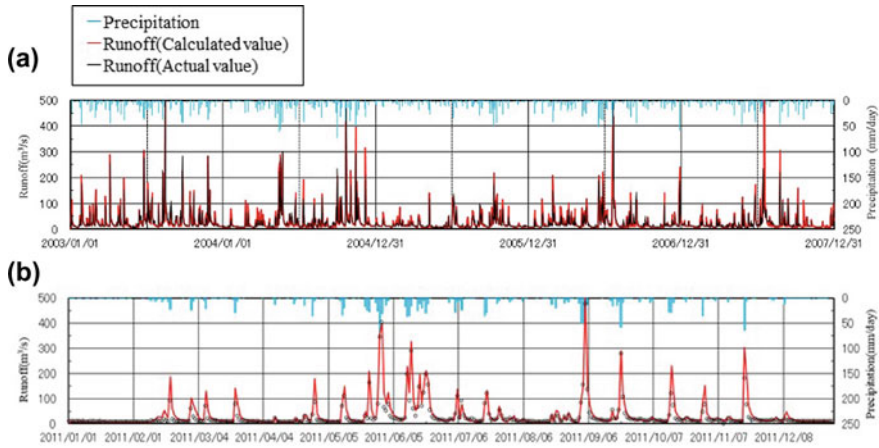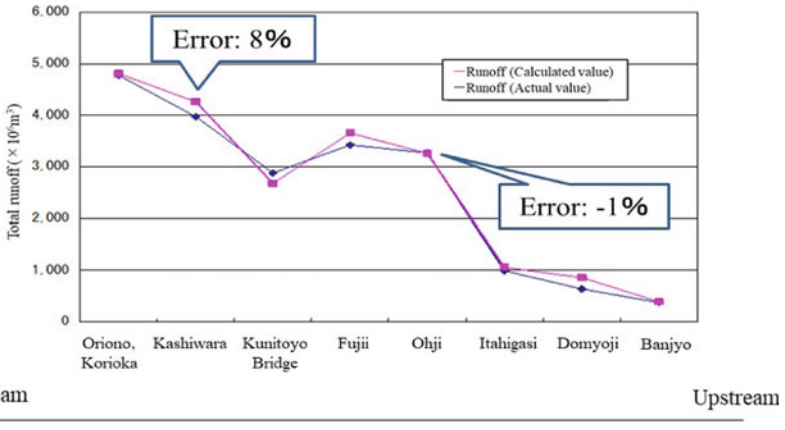

Fig. 70.3 Irrigated area in Yamato Plain

Fig. 70.4 Water supplied from the Yoshino River (2003–2007)

Fig. 70.5 a Reproduction result of river discharge at Kashiwara (2003–2007). **b** Reproduction result of river discharge at Kashiwara (2011)

Fig. 70.6 Comparison of reproduction result of total runoff (Total of 5 years from 2003 to 2007)

Table 70.2 Evaluation of runoff model at Kashiwara

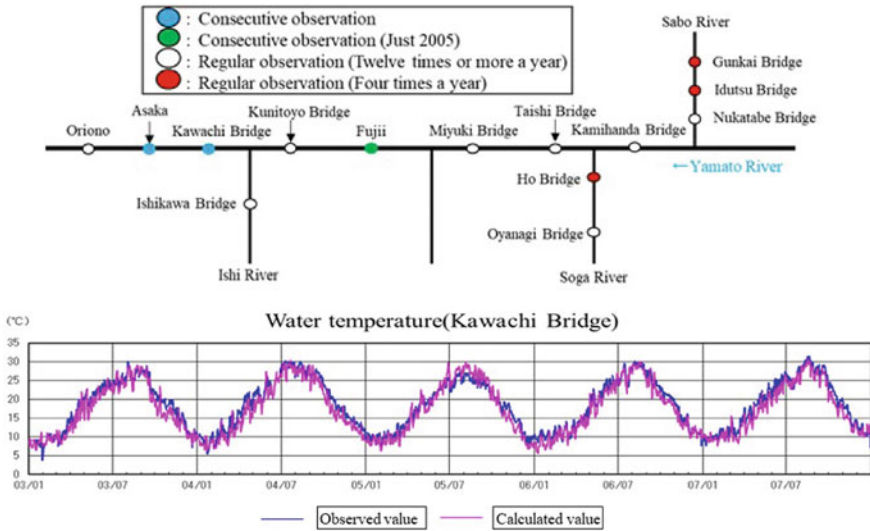|	2003	2004	2005	2006	2007	2011
NSE	0.94	0.90	0.82	0.89	0.87	0.85
PBIAS	−4.48	−7.33	−8.04	−10.56	−2.85	−2.77
RSR	0.25	0.31	0.42	0.33	0.36	0.36

Fig. 70.7 Reproduction result of water temperature at Kawachi Bridge (2003 –2007)

Table 70.3 Evaluation of water temperature model at Kunitoyo Bridge

	2003	2004	2005	2006	2007	2011
NSE	0.97	0.98	0.98	0.98	0.98	0.96
PBIAS	–2.00	1.43	0.80	1.34	1.41	1.41
RSR	0.18	0.14	0.16	0.14	0.15	0.15

climate model with 20 km grid spacing (hereafter RCM; Sasaki et al. [8], Murata et al. [9]). The future climate in which the global-mean surface air temperature becomes 4 K warmer than the pre-industrial climate is simulated in the +4 K simulation. For the use of the +4 K simulations, climatological SST warming patterns (ΔSSTs) are added to the observational SST after removing the long-term trend component. Six CMIP5 models were selected, and 15-member ensemble experiments are conducted for each of the six ΔSSTs, giving a total of 90 members. The greenhouse gases are set to the value in 2090 of the RCP8.5 scenario. In this simulation, the amplitude of the warming is kept constant throughout the 60-year integration of the years labeled from "2051" to "2110". The dynamical downscaling simulations by the RCM are conducted from AGCM; historical climate simulation: Jan 1981–Dec 2010, 50 members. +4 K future climate simulation: Jan 2051–Dec 2110, 90 members. In our research, above two simulations were used (Fig. 70.8).
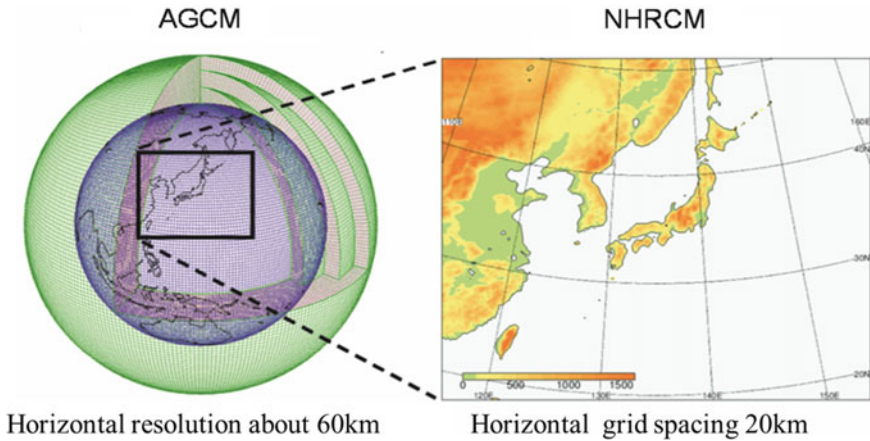
Fig. 70.8 Range of data obtained from Dias (horizontal grid spacing 20 km)

70.3.2 Changes in Flow Conditions

The water supplied from the Kino River affects the current discharge. Therefore, the future flow of the Yamato River. When grasping the future flow condition of the Yamato River, it is necessary to consider water supplied from the other basin and non-water supplied from the other basin. In other words, discharge only Yamato River. Figure 70.9 shows the yearly flow conditions in each ensemble sorted by ranking the daily average discharge. The flow condition curve at the time of drought in 1994 is added to this figure, and only the flow condition curve below the low water flow
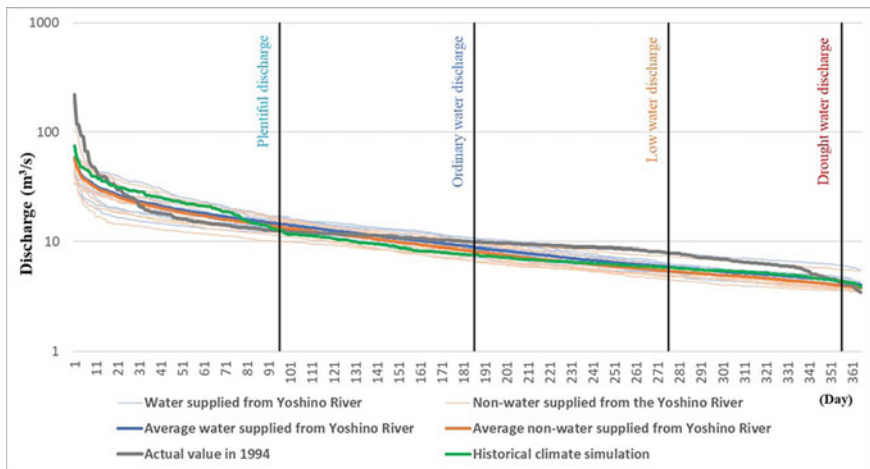

Fig. 70.9 Comparison of flow conditions curves

rate in 1994 is extracted from the flow condition for 5400 years. According to this, in the case of the future forecast below 1994, the yearly fluctuation of the discharge is large as a whole. Furthermore, historical climate simulation value have a similar tendency. This is considered to be due to the characteristics of the input data of d4PDF. However, not only the decrease in precipitation due to global warming, but also changes in temperature are considered to affect the flow conditions. Therefore, Fig. 70.10 shows comparison of the discharge and the evapotranspiration. The yearly discharge data extracted in Fig. 70.9 is created below. According to this, from April to June, the outflow of historical climate simulation is larger than that of future climate simulation, and the evapotranspiration is low. On the other hand, in future climate simulation, evapotranspiration is increasing compared to the river discharge. From January to March, the temperature is low and precipitation is increasing. Heavy rainfall caused by typhoon from August to October shows unpredictable results in this extracted data. It is considered that this is because the tendency that typhoons are less likely to occur affects the flow condition of the Yamato River while the amount of frontal rainfall from April to June is increasing. Figure 70.11 shows the frequency of yearly precipitation assuming historical climate simulation and +4 K simulation. While it is possible that precipitation exceeding 2600 mm, which is extremely large, may occur, there are also years when the yearly precipitation is lower than in historical climate simulation. From this result, we think that the rise in temperature also affects the flow conditions.
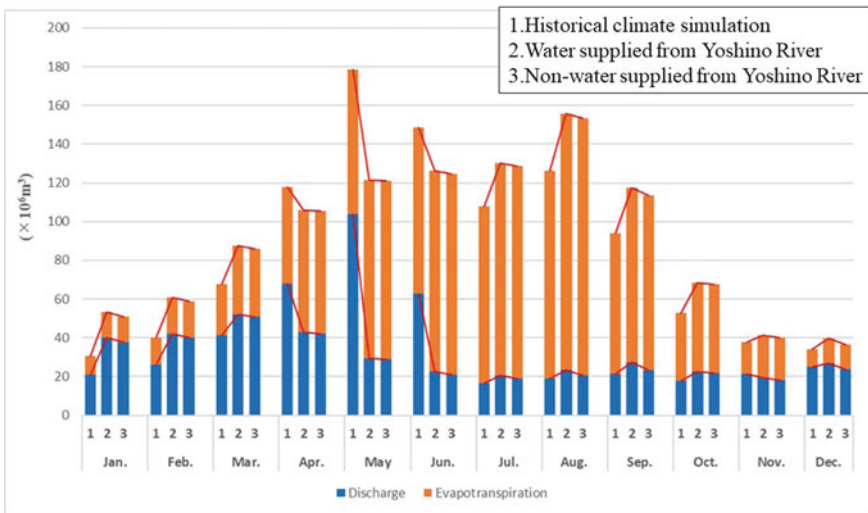

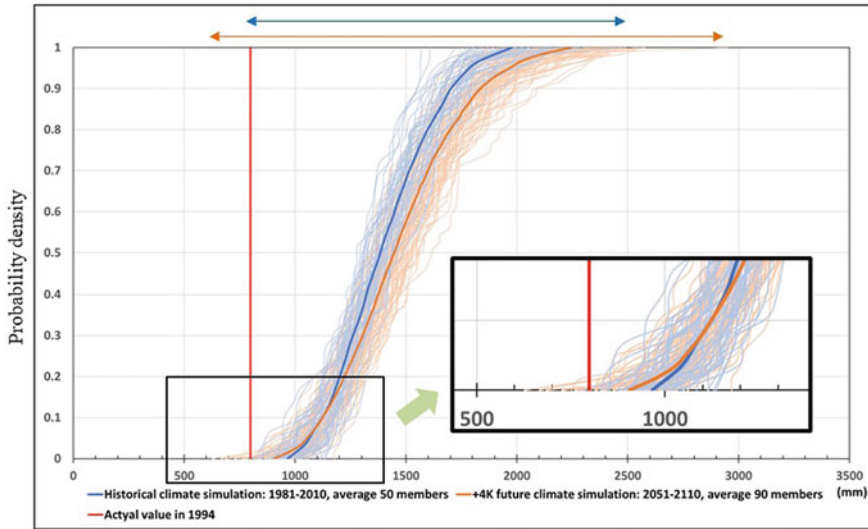**Fig. 70.10**   Relationship between discharge and evapotranspiration

Fig. 70.11 Probability density function of total yearly precipitation

70.3.3 Effect on Water Temperature

It is possible that the decrease in flow conditions also affects the water temperature. Figure 70.12 shows the change only in the case where the water discharge is lower than the low water flow in 1994. The figure shows the yearly average daily fluctuation of the water temperature from the upstream observation point to the downstream observation point. There is a sewage treatment plant directly upstream of Miyuki Bridge and multiple rivers merge. As a result, the water temperature fluctuates. If non-water supplied from Kino River basin, the discharge would decrease. As a result, the influence of the sewage treatment plant has come out in Oriono although not directly upstream. At other observation points, it almost follows the temperature change in summer. The change in winter is affected by the high water temperature of the sewage treatment plant.

70.4 Conclusions

The results obtained in this study are shown below.

- A distributed runoff / water temperature model was constructed considering the natural runoff system and the artificial runoff system. As a result, actual value from 2003 to 2007 and 2011 are reproduced.
- Using the predicted value of d4PDF, the calculation results of the flow conditions and water temperature of the Yamato River, which is below the 1994 drought, are
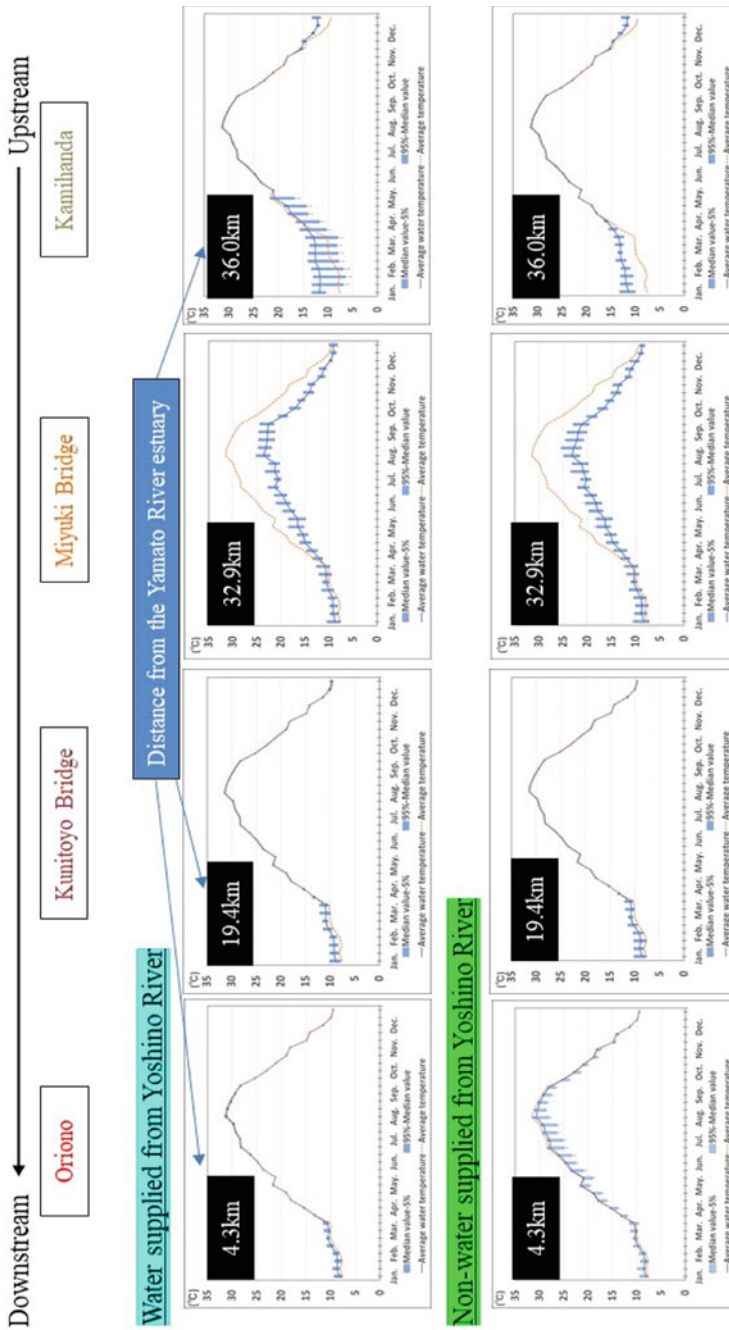
Fig. 70.12 Comparison of water temperature from upstream to downstream in Yamato River

shown. As a result, it is not only low precipitation, but evapotranspiration also increases, which might be worse the flow conditions.

- As the discharge decreases, the water temperature approaches the air temperature in summer.
- The water temperature will rise more than the past results.

From the above, the depletion of water resources may occur rarely, and also the rise in water temperature may affect the river discharge. Based on these results, it is necessary to consider a river crisis management system related to the decrease in sewage treatment capacity due to population changes, dam operation and biological habitat.

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