INTERNATIONAL SYMPOSIUM ON
DAMS FOR A CHANGING WORLD
-Need for Knowledge Transfer across the Generations & the World
Kyoto, Japan June 5, 2012

Preliminary Study of Recent Water Temperature Trends of Dam Reservoirs in Japan

Masayuki Nagao & Atsushi Suzuki
Marine Resources and Environment Research Group, Institute of Geology and Geoinformation (IGG), National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan
nagao-masayuki@aist.go.jp

ABSTRACT:
To investigate the impact of global warming on the inland waters of Japan, we examined the rates of rises in water temperature for nine dam reservoirs that keep long-term records of vertical temperature observations. Water temperatures at the shallowest and deepest layers were selected as being representative for our investigation, and their trend lines were obtained using time-series analysis. Our first expectation was that the deepest water temperatures would be little-affected by meteorological disturbances and may even show clearer temperature rises than the shallowest waters. However, all nine reservoir trend lines from 1993 to 2006 in the shallowest layers showed an upward tendency that can probably be attributed to recent rises in air temperature. In some reservoirs, the ratio of water temperature rises exceeded the ratio of rises in air temperature. In contrast, trend lines for the deepest layers during the same period revealed both upward and downward tendencies. These results suggest that water temperatures in the deepest layers are affected by a reduction in volume due to sand accretion, enhanced stratification, or diminished vertical mixing, rather than by a rise in temperature due to a concomitant rise in air temperature.

Keywords: water temperature, dam reservoir, global warming, trend analysis, seasonal adjustment method

1. INTRODUCTION

There are growing concerns about the negative impact of global warming on inland waters, such as dam reservoirs, lakes, and brackish water. Year-round thermal stratification and inactive vertical mixing in winter cause long-lasting hypoxia and nutrient elution at lake bottoms. Consequent large outbreaks of freshwater red tide and blue-green algae will affect societies and economies due to the rising costs of improving water quality. Accordingly, there is an urgent need to validate the negative impact of global warming on inland waters using observed data.

Working Group II (WGII) of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) described rising water temperatures in reservoirs and lakes due to global warming as causing algae growths (Moulton and Cuthbert, 2000; Robarts et al., 2005) that can contribute to the off-flavor and unpleasant taste of chlorinated tap water. WGII also mentioned that existing technology has difficulties with solving this problem (Charlton et al., 2001).

An example of the above environmental problem of water temperature rise and environment change is the recent gradual increase in chemical oxygen demand (COD) in Lake Kasumigaura, which is the second-largest lake in Japan. Its COD values were 7.6 mg L^{-1} in 2005, 8.2 mg L^{-1} in 2006, 8.8 mg L^{-1} in 2007, and 8.7 mg L^{-1} in 2008 despite efforts made towards nutrient removal (Environmental Policy Division of Ibaraki prefectural government, 2007; 2008; 2009). The Ibaraki prefectural government has stated that the reason for the COD increase from 2005 to 2006 is the excess growth of algae in winter due to higher than average water temperatures (Environmental Policy Division of Ibaraki prefectural government, 2007). In addition, hypoxia persisted in Lake Biwa from January to March of 2007 because the warm winter delayed vertical circulation (Okamoto et al., 2007).

In terms of the response of the inland water temperatures to global warming, Arai (2000) reviewed previous works and found that in general, the degree of water temperature rise is smaller than that of the air temperature, the circulation pattern of lakes may change, and thermal stratification is strengthened. Meanwhile, Arai (2000) pointed out that future forecasts are very difficult because of insufficient observation data, which are the basis to the studies on rise in inland water temperatures. Hayami and Fujiwara (1999) reported that the water temperature rise rate in Lake Biwa (Japan's largest lake) was 0.40 °C (10 years)$^{-1}$ from 1964 to 1997 and that this rise rate was higher than the 0.30 °C (10 years)$^{-1}$ rate of rise in air temperature observed at Hikone City, which is located on the banks of Lake Biwa.

The water temperatures in Japan's main dam reservoirs are observed periodically, and the results are published in the *Management Annual Report of Multipurpose Dams* (River Bureau of Ministry of Construction, Transport and Tourism, 1959-1992) and *Database of Dams* (Ministry of Land, Infrastructure, Transport and Tourism). For example, Ikeura et al. (2008) studied the water temperature trends of Hyugami Dam Reservoir from January 1962 to February 2008 and concluded that the rise rate of its bottom water temperature was 0.88 °C (10 years)$^{-1}$, which was higher than the 0.32 °C (10 years)$^{-1}$ rise rate of the annual average air temperature. This result implies that in some dam reservoirs, the rise rate of the water temperature may potentially be higher than that of the air temperature. The same trend was found by Hayami and Fujiwara (1999) despite there being differences between the two studies in terms of water area and period of analysis.

Investigating water temperature trends of Japan's dam reservoirs in a manner similar to that of Ikeura et al. (2008) was feasible for us. However, to the best of our knowledge, Ikeura et al.'s (2008) study is the only one of its kind. The study of water temperature trends of Japan's dam reservoirs is probably limited because of difficulties in accounting for the reduction in a dam's volume due to sand accretion. Large water level changes in dam reservoirs due to artificial manipulation are another possible reason.

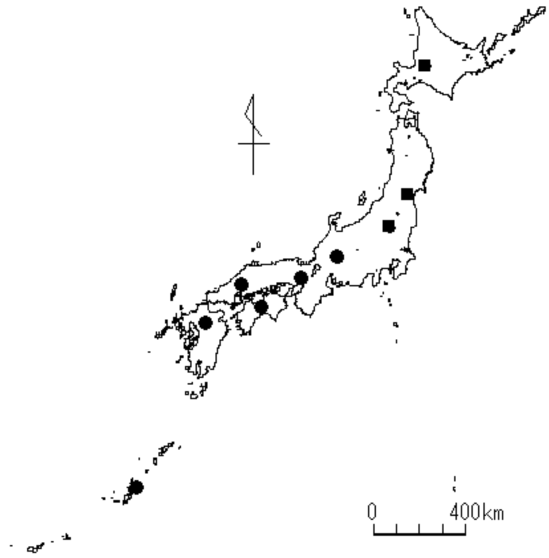

Figure 1. Locations of analyzed dam reservoirs. Squares (■) denote reservoirs utilized for long/short-term trend analyses. Circles (●) denote reservoirs utilized only for short-term trend analyses. Locations are quoted from *Dam Handbook* (*Damu Binran*) (Japan Dam Association) (adopted from Nagao and Suzuki (2010)).

Our eventual aim is to reveal the water temperature trends of Japan's main dam reservoirs. This paper

Table 1. Specifications of analyzed dam reservoirs (adopted from Nagao and Suzuki (2010) with minor alterations).

Dam Name	(1)Gross capacity (10^3m^3)	(2)Surface Area(ha)	(3)Depth (m)*	(4)Latitude	(5)Longitude	(6)Elevation of dam crest(m)	(7)Basin Area(km^2)	(8)Gross capacity of annual flow(10^6m^3)**	(9)Exchange rate(y^{-1})	(10)Residence time(mon)
Katsurazawa	92,700	499	19	43° 14′ 23″ N	142° 00′ 09″ E	192	446	286	3.1	3.9
Kamafusa	45,300	390	12	38° 12′ 08″ N	140° 41′ 51″ E	153	195	297	6.6	1.8
Ikari	55,000	310	18	36° 54′ 11″ N	139° 42′ 20″ E	594	271	359	6.5	1.8
Iwaya	173,500	426	41	35° 45′ 39″ N	137° 09′ 25″ E	428	1,735	556	3.2	3.7
Hitokura	33,300	140	24	34° 54′ 19″ N	135° 24′ 42″ E	154	115	89	2.7	4.5
Haji	47,300	280	17	34° 38′ 37″ N	132° 37′ 16″ E	259	308	378	8.0	1.5
Sameura	316,000	750	42	33° 45′ 24″ N	133° 33′ 02″ E	345	472	952	3.0	4.0
Matsubara	54,600	190	29	33° 11′ 39″ N	130° 59′ 38″ E	275	491	977	17.9	0.7
Aha	18,600	83	22	26° 42′ 38″ N	128° 16′ 09″ E	114	40	63	3.4	3.6
Hyugami	27,900	112	25	33° 10′ 34″ N	130° 46′ 49″ E	146	84	124***	4.4	2.7

(1) and (2) were quoted from *Dams Yearbook 2008* (*Damu Nenkan 2008*) (Japan Dam Foundation, 2008). (4)–(7) were quoted from *Dam Handbook* (*Damu Binran*) (Japan Dam Association).

*(3)=(1)/(2). **(8) is based on average annual flows from 1993 to 2007 taken from *Database of Dams* (*Damu Shoryou De-tabe-su*) (Ministry of Land, Infrastructure, Transport and Tourism).

*** Estimated from the following equation: [Total annual volume of Yabe River's flow] × [Hyugami Dam Reservoir's catchment area]/[Yabe River's catchment area]. Yabe River flows into Hyugami Dam Reservoir. The total annual volume of Yabe River's flow and its cachment area were obtained from *Rivers in Japan* (*Nihon Kasenzu*) (Japan River Association).

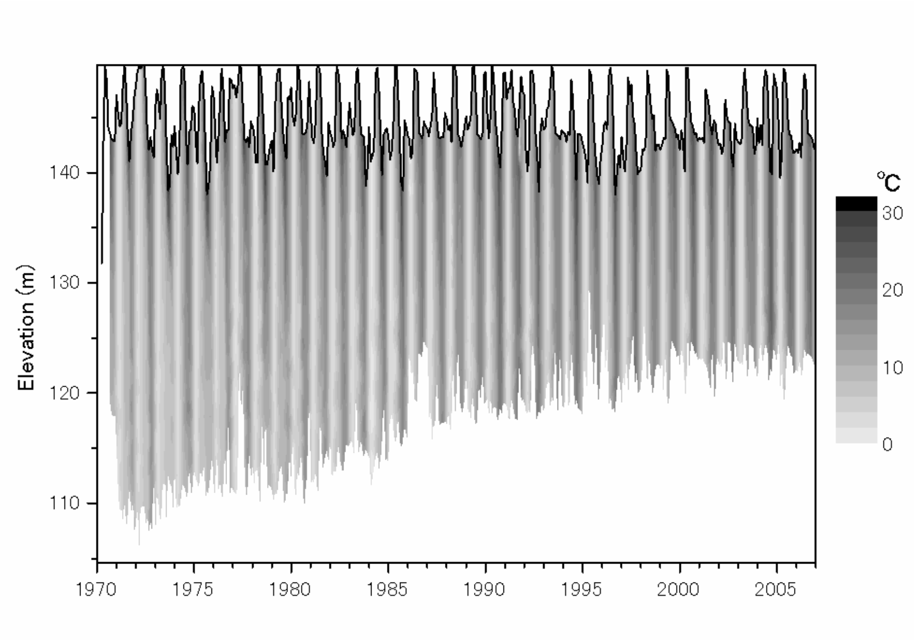

Figure 2. Isothermal plot of Kamafusa Dam Reservoir. Data were obtained from *Management Annual Report of Multipurpose Dams* (*Tamokuteki Damu Kanri Nenpou*) (River Bureau of Ministry of Construction, 1961–1997) and *Database of Dams* (*Damu Shoryou De-tabe-su*) (Ministry of Land, Infrastructure, Transport and Tourism) (adopted from Nagao and Suzuki (2010)).

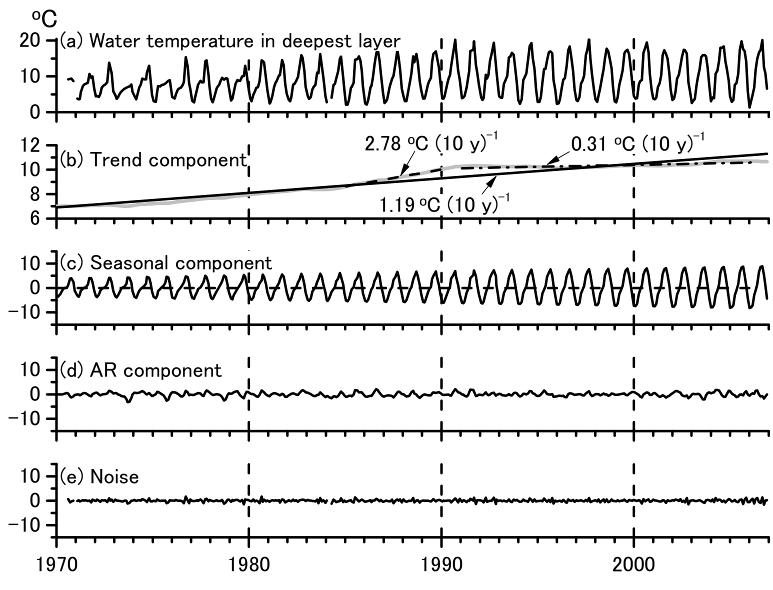

Figure 3. Decomposition of water temperature time series at the deepest layer of Kamafusa Dam Reservoir. (a) Monthly water temperature, (b) trend line (gray line), (c) seasonal component, (d) steady autoregressive (AR) component, and (e) noise. Solid, broken, and dashed-dotted lines denote regression lines for 1970–2006, 1985–1990 and 1991–2006, respectively (adopted from Nagao and Suzuki (2010)).

presents a short summary of our preliminary study (Nagao and Suzuki, 2010).

2. MATERIAL AND METHOD

2.1. Data Source and Analyzed Dam Reservoirs

We selected the water temperature records of dam reservoirs in Japan that were observed monthly at multiple depths from 1959 to 2006. The cited records are from the *Management Annual Report of Multipurpose*

Dams (River Bureau of Ministry of Construction, Transport and Tourism, 1959-1992) and *Database of Dams* (Ministry of Land, Infrastructure, Transport and Tourism).

We investigated both long-term and short-term trends to evaluate the water temperature rise rate. For the long-term trend, we selected dams with water temperature records from their completion year in the 1970s to the present. For the short-term trend, we fixed the period of analysis as 1993 to 2006 (fourteen years) in order to compare water temperature rise rate among different dam reservoirs. Water temperatures at the shallowest and deepest layers were selected as being representative for our investigation.

We investigated short-term trends of dam reservoirs from the following regions of Japan: Hokkaido, Tohoku, Kanto, Chubu, Kansai, Chugoku, and Kyushu. Okinawa was also selected and considered as a part of Kyusyu (Fig. 1). Long-term trends were investigated at the Katsurazawa (Hokkaido), Kamafusa (Miyagi prefecture) and Ikari (Gunma prefecture) dam reservoirs. Specifications of the analyzed dam reservoirs are shown in Table 1. All of the measurement points of water temperatures used for this research were located near bodies of the dams.

2.2. Method of Determination of Water Temperature Rise Rate

The trend lines were obtained using the TIMSAC for R package (Institute of Statistical Mathematics), which includes a seasonal adjustment method named “decomp” (Akaike et al., 1985). Decomp can remove seasonality and short-term fluctuation from monthly data and extract long-term trends (Eq. 1).

$$y(t) = T(t;k) + S(t;l) + AR(t;m) + W(t) \qquad (1)$$

where t: time (month), $T(t;k)$: trend expressed by the k-th order difference model, $S(t;l)$: seasonality expressed by the l-th order seasonal variation model, $AR(t;m)$: stationary autoregressive (AR) component expressed by the m-th order AR model, and $W(t)$: noise. Detailed explanations of each model in Eq. 1 are given by Akaike et al. (1985).

The best seasonal adjustment model in Eq. 1 can be selected by referring to the minimum Akaike information criteria (AIC) value. The water temperature rise rate can then be determined from the gradient value of the regression line fitted to the trend.

Note that $S(t;l)$ includes seasonality due to water level changes caused by artificial manipulation as well as the common seasonality due to the heat budget. Also, $T(t;k)$ has the potential to include cycles with periodicities longer than one year as well as the trend due to global warming. Some studies have separated the cycle and the trend from the time-series environment data and evaluated the connection between the separated cycle and El Nino. For example, Arpe et al. (2000) showed that the annual mean sea level of Caspian Sea correlates highly with the Southern Oscillation Index (SOI). Lough (2000) discussed the specificity of the high water temperature caused by El Nino in 1997–1998 on the basis of the long -term time series of sea surface temperatures from 1903 to 1999. Both Arpe et al. (2000) and Lough (2000) used long-term observation data to evaluate the correlation between an observed event and El Nino. For Japan’s main dam reservoir, however, the question of whether the correlations with El Nino drawn from the time series data is valid requires further discussion, because the time series data only covers a period of fifty years even in the best possible case.

3. RESULT AND DISCUSSION

3.1. Kamafusa Dam Reservoir

A time-series for the isothermal chart of Kafusa Dam Reservoir was constructed from its monthly water temperature data observed from 1970 to 2006 (Fig. 2). The elevation of the bottom is not uniform because of sand accretion. The isothermal chart clearly shows that since 1985, the summer water temperature has been on rising.

The water temperature time series (Fig. 3a) at the deepest layer of Kamafusa Dam Reservoir was decomposed by decomp. The decomposed factors were the trend (Fig. 3b), seasonality (Fig. 3c), steady AR component (Fig. 3d), and noise (Fig. 3e). The overall water temperature rise rate showed a high value of +1.19 °C (10 years)$^{-1}$.

The advantage of using a trend line derived from the seasonal adjustment method is that it is easy to compare the rise rate of a certain time series of the water temperature for different observation periods (Fig. 3b). The rise rate for 1970–1984 is equal to that for 1970–2006, while that for 1985–1990 is 2.78 °C (10 years)$^{-1}$, which is 2.3 times of the overall rise rate. Additionally, the rise rate for 1991–2006 is 0.31 °C (10 years)$^{-1}$, which is one-third of the overall rise rate.

Table 2. Trends of water temperature for each dam reservoir (adopted from Nagao and Suzuki (2010)).

Dam Name	Prefecture	Analyzed period	Shallowest layer Average					Deepest layer Average					Rate of air–temperature rise****
			Average	Rate of rise	Order			Average	Rate of rise	Order			
			°C	°C (10 y)$^{-1}$	k	l	m	°C	°C (10 y)$^{-1}$	k	l	m	°C (10 y)$^{-1}$
Katsurazawa	Hokkaido	1970–2006*	10.2	+0.30	1	1	2	5.9	+0.01	1	1	1	+0.106
		1993–2006**	10.6	+0.73	–	–	–	5.9	+0.02	–	–	–	
Kamafusa	Miyagi	1970–2006	13.5	−0.06	1	1	2	9.1	+1.19	1	2	2	
		1993–2006	13.3	+0.03	1	1	1	10.4	+0.03	1	1	1	
Ikari	Gunma	1970–2006*	12.5	−0.03	1	1	2	5.2	−0.04	1	1	2	+0.110
		1993–2006	12.4	+0.35	1	1	0	5.0	+0.01	1	1	3	
Iwaya	Gifu	1993–2006	15.1	+0.02	1	1	1	8.7	−1.09	1	1	2	
Hitokura	Hyougo	1993–2006	17.9	+0.01	1	1	1	9.0	−0.00	1	1	4	+0.115
Haji	Hiroshima	1993–2006	16.5	+0.04	1	1	1	10.5	+2.36	1	1	2	
Sameura	Kouchi	1993–2006	17.2	+0.77	1	1	0	7.1	+0.62	1	1	2	
Matsubara	Ooita	1993–2006	17.5	+0.01	1	1	1	14.1	−0.02	1	1	1	
Aha	Okinawa	1993–2006	23.4	+0.67	1	1	0	16.0	+0.48	1	1	0	+0.103
Hyugami***	Fukuoka	1962–2008	–	+0.21	–			–	+0.88	–			0.115 (0.32)#
										Whole of Japan			+0.106

* For Katsurazawa and Ikari Dam Reservoirs, rise rates and averages were determined using trend only from 1970 to 2006.

** Rise rate and average temperature of Katsurazawa Dam Reservoir from 1993 to 2006 were obtained using trend line from 1959 to 2006.
*** By Ikeura et al. (2008) with linear regression analysis.
**** Cited from Table 2.1.3 in *Extreme Weather Report 2005* (*Ijou Kishou Report 2005*) (Japan Meteorological Agency, 2005).
# At dam site of Hyugami Dam Reservoir (Ikeura et al., 2008).

The water temperature at the deepest layer is possibly influenced by sand accretion, although this issue requires further investigation.

3.2. Water Temperature Rise Rate of Nine Dam Reservoirs

The long-term and short-term water temperature rise rates of the shallowest and deepest layers are shown in Table 2 for each dam reservoir in Fig. 1.

3.2.1 *Water temperature rise rate according to long-term trend*
The rise rate of Katsurazawa Dam Reservoir derived from the shallowest layers according to the long-term trend was positive (uptrend) and higher than the rise rate of the air temperature, while the rise rates of the shallowest layers of Kamafusa and Ikari dam reservoirs were negative (downtrend).

The rise rates of Katsurazawa and Kamafusa dam reservoirs derived from the deepest layers according to the long-term trend were positive (uptrend). In particular, the rise rate of Kamafusa Dam Reservoir was much higher than that of the air temperature. Meanwhile, the rise rates for the deepest layer of the shallowest layer of Ikari Dam Reservoir were negative (downtrend).

3.2.2 *Water temperature rise rate according to short-term trend*
The long-term rise rates of Katsurazawa, Kamafusa, and Ikari dam reservoirs imply that the trends have changed since the 1980s or 1990s. Thus, we investigated the water temperature rise rate of the nine dam reservoirs (Fig. 1) according to short-term trends derived from the data for 1993–2006 (Table 2**)**.

For all nine reservoirs, the water temperature rise rates for the shallowest layers were positive (uptrend); this is probably because of the recent rises in the air temperature. For Katsurazawa, Ikari, Sameura, and Aha dam reservoirs, the rise rates the water temperature exceeded those of the air temperatures. The reason of this result remains to be determined.

In contrast, the rise rates of the deepest layers, where the deepest water temperatures are little-affected by meteorological disturbances, were both positive (uptrend) and negative (downtrend). These results suggest that water temperatures in the deepest layers were affected by a reduction in volume due to sand accretion, enhanced stratification, or diminished vertical mixing, rather than by a rise in temperature due to a concomitant rise in air temperature. Determining the impacts of these effects will be an important issue in future investigations.

4. CONCLUSION

From FY2009, we started collecting of observed data on dam reservoirs in Japan and investigated the rising trends of water temperature, thermal stratifications, and inactive vertical mixing in winter. In particular, we examined the rates of rises in water temperature for nine representative Japanese dam reservoirs that keep long-term records of vertical temperature observations. Water temperatures at the shallowest and deepest layers were selected as being representative for our investigation, and their trend lines were obtained using time-series analysis. Our first expectation was that the deepest water temperatures would be little-affected by meteorological disturbances and may even show clearer temperature rises than the shallowest waters. However, all nine reservoir trend lines from 1993 to 2006 for the shallowest layers showed an upward tendency that can probably be attributed to recent rises in the air temperature. In some reservoirs, the ratio of water temperature rises exceeded the ratio of rises in air temperature. In contrast, trend lines for the deepest layers during the same period revealed both upward and downward tendencies. The results suggest that water temperatures in the deepest layers were affected by a reduction in volume due to sand accretion, enhanced stratification, or diminished vertical mixing, rather than by a rise in temperature due to a concomitant rise in air temperature. Determining the impacts of these effects will be an important issue in future investigations.

ACKNOWLEDGEMENT

We thank the libraries of the following Japanese organizations for their permission to access the Management Annual Report of Multipurpose Dams: Ministry of Land, Infrastructure, Transport (MLIT), National Institute for Land and Infrastructure Management (NILIM), Japan Society of Civil engineers (JSCE), and Engineering and Information Science and Technology of the University of Tokyo. Part of this research was supported by the Research Funds for the National Organizations for Pollution Prevention and the Japan Society for the Promotion of Science (JSPS), Grant-in-Aid for Scientific Research (C) (No.23560616).

REFERENCES

Akaike, H., Ozasaki, T., Ishiguro, M., Ogata, Y., Kitagawa, G., Tamura, Y.-H., Arahata, E., Katsura, K. and Tamura, Y. (1985): TIMSAC-84 Part 1 & Part 2. Computer Science Monographs, The Institute of Statistical Mathematics, Tokyo,. No.22 & 23.

Arai, T. (2000): Global warming and the temperature of inland waters, Japanese Journal of Limnology, 61:1, pp.25-34 (in Japanese with English abstract).

Arpe, K., Bengtsson,, L., Golitsyn, G., Mokhov, I., Semenov,V. and Sporyshev, P. (2000): Connection between Caspian sea level variability and ENSO, Geophysical Research Letters, 27, pp.2693-2696.

Charlton, M., Giddings, M., Holmes, C., Carmichael, W. and Ridal, J. (2001): Algal toxins and taste and odour. In Threats to sources of drinking water and aquatic ecosystems health in Canada, NWRI Scientific Assessment Report Series Report No.1., Environment Canada (ed.), National Water Resources Research Institute, Burlington, pp.5-8.

Environmental Policy Division of Ibaraki prefectural government (2007)：Summary of water quality of Lake Kasumigaura in 2006 (in Japanese).

Environmental Policy Division of Ibaraki prefectural government (2008)：Summary of water quality of Lake Kasumigaura in 2007 (in Japanese).

Environmental Policy Division of Ibaraki prefectural government (2009)：Summary of water quality of Lake Kasumigaura in 2008 (in Japanese).

Hayami, Y. and Fujuwara, T. (1999): Recent Warming of the Deep Water in Lake Biwa, Oceanography in Japan, 8, pp.197-202 (in Japanese with English abstract).

Ikeura, T., Ichiki, K. and Takeda, T. (2008): Cyclical Fluctuation of water temperature in Hyugami-dam lake, Annual report of the Fukuoka Environmental Research Center, 35, pp.83-89 (in Japanese).

Institute of Statistical Mathematics: TIMSAC for R package, http://cran.r-project.org/web/packages/timsac/index.html (last access date: November 2, 2009).

Japan Dam Foundation: Dams Yearbook 2008 (*Damu Nenkan 2008*), Japan Dam Foundation, Tokyo.

Japan Dam Foundation: Dam Handbook (*Damu Binran*), http://wwwsoc.nii.ac.jp/jdf/Dambinran/binran/TopIndex.html (last access date: November 2, 2009).

Japan Meteorological Agency (2005): Extreme Weather Report 2005 (*Ijou Kishou Report 2005*), Japan Meteorological Business Support Center, Tokyo.

Japan River Association: Rivers in Japan, http://www.japanriver.or.jp/river_law/map.htm (in Japanese. last access date: November 2, 2009).

Lough, J. M. (2000): 1997-1998: Unprecedented thermal stress to coral reefs?, Geophysical Research Letters, 27, pp.3901-3904.

Ministry of Land, Infrastructure, Transport and Tourism: Database of Dams (*Damu Shoryou De-tabe-su*), http://www2.river.go.jp/dam/index.html (in Japanese. last access date: November 2, 2009).

Moulton, R. and Cuthbert, D. (2000): Cumulative impacts/risk assessment of water removal or loss from the Great Lakes–St. Lawrence River system, Canadian Water Resources Journal, 25, pp.181-208.

Nagao, M. and Suzuki A. (2010): Preliminary study of recent water temperature trends of nine dam reservoirs in Japan, Japanese Journal of Limnology, 71:1, pp.27-36 (in Japanese with English abstract).

Okamoto, T., Okuda, K., Kobayashi, H., Yada, M., Hara, R., Ishikawa, T. and Nakamura, T. (2007): Water quality variation of the north coast of Lake Biwa in the winter of 2007 (*Heisei 19 nen (2007 nen) touki ni okeru biwako hokko no suishitsu hendou ni tsuite*), Proceedings of the 72nd annual conference of the Japanese Society of limnology, P35 (in Japanese).

River Bureau of Ministry of Construction, Transport and Tourism (1961-1997): Management Annual Report of Multipurpose Dams (*Tamokuteki DamuKanri Nenpou*), no.34-36 (in Japanese).

Robarts, R., Kumagai, M. and Magadza, C.H. (2005): Climate change impacts on lakes: technical report of the session ‘Ecosystem Approach to Water Monitoring and Management’ organized at the World Water Forum II in Kyoto, Climatic Change Ecosystem Approach to Water Monitoring and Management, UNEP Publication, Nairobi.