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Variations of Calcium, Bicarbonate, and Cation in the Lacustrine Zone by Interannual Differences in Up-River Discharge

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Monthly up-river discharge in the riverine zone analysis resulted in large interannual variations and differences in calcium (Ca^{2+}), bicarbonate (HCO_3^-), and cations in the lacustrine zone (*Lz*) of Daecheong Reservoir during the wet year (*Wy*, 1993) vs. dry year (*Dy*, 1994). Total up-river discharge in the *Wy* was four times that of the *Dy*, and the up-river discharge in July~August of the *Wy* was eight times greater than that of same period of *Dy*. Annual water retention time in the *Lz* showed large difference between the two years. Water residence time (WRT) was minimum when the up-river discharge peaked, whereas the WRT was maximum when the up-river discharge was at minimal condition. This peak discharge from the up-river on early July reduced residence time in the *Lz* on mid-July~late July. Monthly pattern, based on data of May~November, was similar between the two years, but, but mean retention time in the *Wy* was 50 days shorter than in the *Dy*. Such hydrology, up-river discharge, and WRT reduced Ca^{2+}, HCO_3^-, and cations in the *Lz*. At low up-river discharge in *Wy* during April~May, the cation content of Ca+Mg+Na+K averaged 1.17 meq L^{-1} (range= 1.09−1.26 meq L^{-1}), but as the up-river discharge increased suddenly, the values decreased. Seasonal fluctuations of Ca^{2+} showed exactly same pattern with bicarbonate ion of HCO_3^-. The minimum Ca^{2+} (0.03 meq L^{-1}) was occurred in the early August of wet year and coincided with the minimum HCO_3^-. These results suggest that the magnitude of variation in Ca^{2+}, bicarbonate, and cations in the lacustrine zone is directly determined by the peak magnitude of up-river discharge. The magnitude of up-river discharge determined water retention time and the magnitude of ionic dilution in the lacustrine zone, resulting in functional changes of the ecosystem.

Key words : lacustrine zone, ion content, flood, wet year, calcium, bicarbonate

INTRODUCTION

Artificial dendritic-shape reservoir ecosystem is generally consisted of three different zones of riverine zone, transition zone, and lacustrine zone and each zone is largely influenced by the transport processes of river water (Ford, 1990). Water quality shows typical longitudinal gradients along the main axis of the riverine-to lacustrine zone. Thus, the lacustrine zone of reservoir show lower nutrients (N, P), higher transparency, lower suspended solids, higher influences of autochthonous organic matter, and lower primary productivity than in the transition and riverine zone. For this reason, seasonal river input may directly influence the water quality in the lacustrine zone (Vincent *et al.*, 1991). These evidences are well studied

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in North American and European waterbodies (Straskraba *et al.*, 1993), but little is known about ionic variations of Asian reservoirs which are influenced by seasonal monsoon.

Previous some studies reported that ionic dilutions (An, 2001a), changes of hydrological and thermal structures (An, 2001b), and nutrient dynamics of nitrogen and phosphorus and biological dynamics, based on algal chlorophyll (An *et al.*, 2001) were function of the interannual flow in the reservoirs influenced by the Asian monsoon. Some evidences of hydrological, nutrients, and ionic dynamics are shown in Japan (Ohtake *et al.*, 1982), Sri Lanka (Silva and Davies, 1987) and Bangladesh (Khondker and Kabir, 1995) as well as Korean waterbodies (An, 2001b). All these studies pointed out that monsoon seasonality is one of the most important key factor regulating the system structure (depth, water level, morphology) and functions such as relations of algal productivity to nutrients, light regime and inorganic solids.

Such studies, however, were mainly based on once or twice a month observations or monitoring in the waterbodies rather than an intensive monitoring (1~3 day interval observations). Nutrient dynamics, primary productivity variations, trophic changes in Korea (Choi *et al.*, 1988; Cho *et al.*, 1989; Choi and Lee, 1991; Kim *et al.*, 1997; Kong, 1997; An, 2001a, b) conducted over the past several decades have not directly addressed how the flood seasonality influences the ionic contents and the dilutions of lake water dilutions by up-river peak or high discharges, especially in the lacustrine zone. Even if previous study of hydrological significance on interannual variability of cations, anions, and conductivity in reservoir ecosystem (An, 2001a) is present, it is based on regular sampling of once per month rather than a study, based on intensive sampling. This situation is also similar in the North American and European waterbodies.

In this study, we measured seasonal and interannual variations in detail at the lacustrine zone of the reservoir, so surface samples were collected 2~3 times a week at the dam wall of the lacustrine zone during the two study years. The purpose of the research was to determine how the up-river discharge influences water residence time, calcium, bicarbonate ions, and cation contents in the lacustrine zone by intensive sampling strategy. These outcomes may provide an efficient reservoir management strategy on water quality response on the peak discharge from the up-river.

MATERIALS AND METHODS

1. Descriptions of sampling sites and water sampling

This study was conducted in lacustrine zone near the dam, transition zone (Whenam Bridge) and up-river site (Janggae Bridge) of Daecheong Reservoir. The reservoir and has a surface area of 6.8×10^7 m^2, a volume of 14.3×10^8 m^3, with a mean depth of 21.2 m and maximum depth of 69 m at an elevation of 80 m above mean sea level. However, the dimensions are varied depending on the flow and rainfall distribution annually. Hydropower release from the dam is located at 49 m at the sea level and outflow from the mainly occur in the summer season. Near the dam, discharge points having 6 weirs are located at 64.5 m to allow epilimnetic discharge during floods. Surface water samples were collected from once per month three sites of riverine zone (up-river, Janggae Bridge), transition zone (mid-lake, Whenam Bridge) and lacustrine zone (near the dam) during May 1993 to November 1994. Also, we measured seasonal and interannual fluctuations in detail at the lacustrine zone surface samples within 0.5 m were collected 2~3 times a week at the dam wall during the two study years.

2. Water quality parameters and analytical methods

Water samples collected from three different sites were covered to prevent exposure to direct sunlight, stored in ice, and either preserved or analyzed in the laboratory within 12~36 hours. Specific conductivity (at 25°C; YSI Model 33) were measured in the laboratory and bicarbonate ion of HCO_3^- was analyzed by sulfuric acid titration (Orion pH meter 501). Calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+) were determined on acid-preserved samples by using an atomic absorption spectrophotometer (Varian AA-20, APHA., 1985). Each cation and anion sample were analyzed in duplicate. Total cations were estimated from the sum of Ca+Mg+Na+K ions. Also, we estimated water retention time in the lacustrine zone. Water residence time (TWR as day) was estimated using total reservoir surface area of the reservoir, volume and the discharge volume from the up-river on each sampling date in the study system. For the estimation, we used the contour map of depth profile. In this analysis, we assumed that water retention time equals the length of presampling time required for inflow to equal the volume upriver from the sampling site. In this calculation of residence time, we did not add water inputs from precipitation and evaporation, so the values are considered as more theoretical values.

RESULTS AND DISCUSSION

Monthly rainfall and up-river discharge data analysis showed large interannual variations and the difference was mainly attributed to summer rainfall and flow in the system. We analyzed river up-river discharge data (Fig. 1). Major mainstream river flow come from the up-river, so we got the flow data from Jangge Bridge. During 14 years, large inflows occurred during the summer period of July ~ August and accounted for more than half of total annual up-river discharge. Total up-river discharge in wet year was four times that of dry year, and the up-river discharge in July ~ August of the wet year was eight times greater than that of same period of dry year. Mean annual rainfall at the system averaged 1,100 mm during long-term period over 14 years (1981 ~ 1994), even if we did not include in the Fig. 1 (previous paper is available). The major difference in precipitations between wet year and dry year occurred during the summer period of July ~ August (Fig. 1). Total precipitation during July ~ August of wet year was 660 mm which comprised 43% of the annual total, but in the same period in dry year precipitation was only 251 mm. During the summer period, rainfall in wet year was 164% of the mean value during the summer in 14 years, whereas in dry year, it was 50% less than this long-term mean. Overall, our precipitation and up-river discharge dataset suggest that lake flow is a function of rainfall and flow from the summer periods.

Annual water retention time in the lacustrine zone showed large difference between the two years. Up-river discharge showed a reverse function of water residence time. As shown in Fig. 2, water residence time was minimum when the up-river discharge peaked, whereas water residence time was maximum when the up-river discharge was at minimal condition. But, time-lag phenomenon was evident in the response of water residence time on the up-river discharge due to arrival time of water from the up-rivers to the lacustrine zone. This is shown in the July peak of the rainfall. This peak discharge from the up-river on early July reduced water residence in the lacustrine on mid-July ~ late July. Monthly pattern, based on data of May ~ November, was similar between the two years, but, but mean retention time in wet year was 50 days shorter than in the dry year (Fig. 2). Such difference in water retention time between the wet and dry year was maximized in July ~ August and in other seasons the patterns were similar between the two years. Thus, mean retention time in the July ~ August of dry year was >70 days longer than in the July ~ August of wet year. We found that long retention time of >100 days was observed in the period of low precipitation period of dry year.

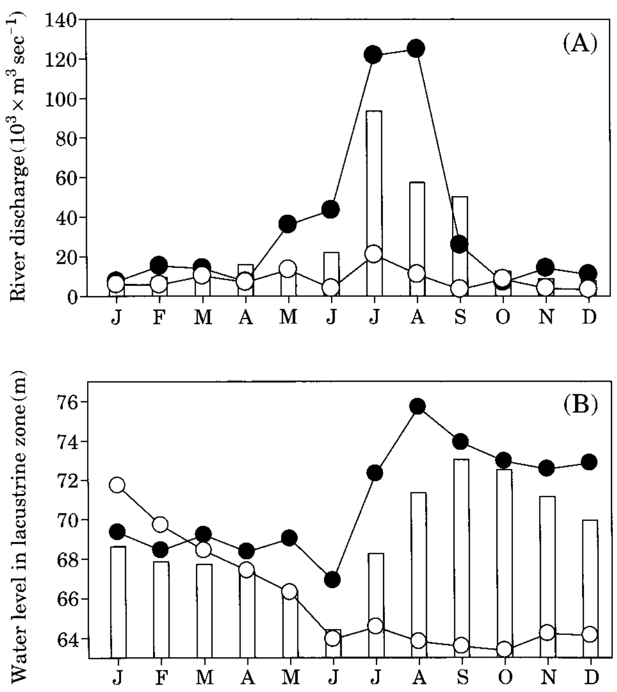

Fig. 1. Monthly fluctuations of river discharge and water level in the lacustrine zone. The dark circle indicates a wet year (1993) and open circle indicates a dry year (1994).

Intensive monitoring data of calcium, bicarbonate, and Ca+Mg+Na+K at the lacustrine zone suggested that ionic contents were a function of the hydrograph of the up-river discharge (Fig. 3). At low flow in wet year ($< 10^7 m^3 d^{-1}$ during April ~ May), cation content of Ca+Mg+Na+K averaged

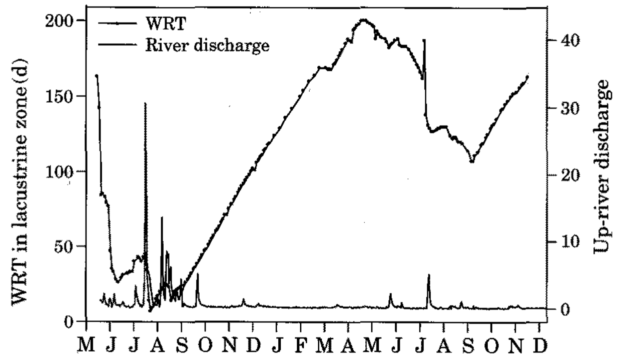

Fig. 2. Water retention time (as a day) in the lacustrine zone of the reservoir in the response of up-river discharge. In the x-axis, M, J, J, A, S, O, N, and D indicate the month of March~December of the wet year, respectively and J, F, M, A, M, J, J, A, S, O, N, and D indicate the month of January~December of the dry year, respectively.

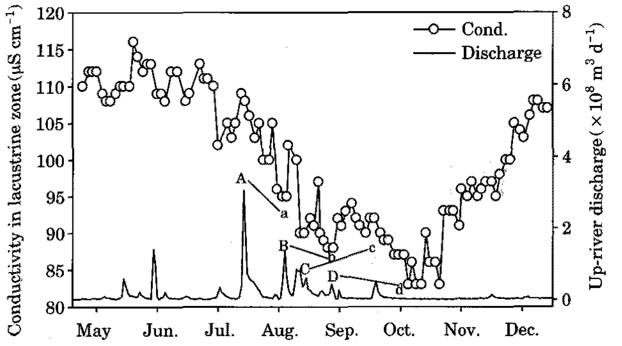

Fig. 4. Conductivity in the lacustrine zone and river discharge during the wet year. Capital letters of "A"~"D" indicate four major up-river discharges, respectively and small letters of "a"~"d", indicate the responses of cation on each peak up-river discharges.

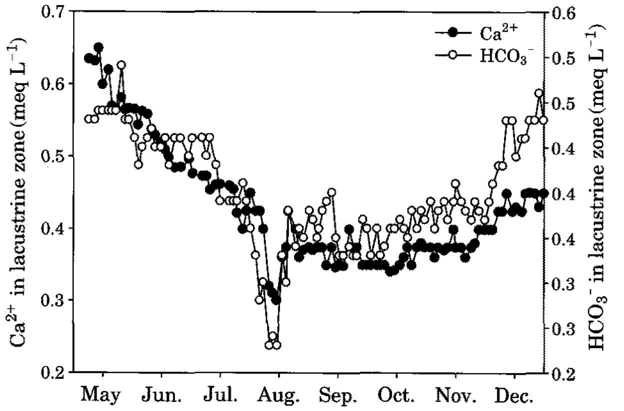

Fig. 3. Calcium and bicarbonate ion contents in the lacustrine zone during the wet year.

1.17 meq L^{-1} (range=1.09~1.26 meq L^{-1}), but as the up-river discharge increased abruptedly, the values decreased. At base flow in wet year ($<10^7$ m^3 d^{-1} during April~early May), the sum of Ca+Mg+Na+K was 1.17 meq L^{-1} (range=1.09~1.26 meq L^{-1}, Fig. 3). As shown in Fig. 3, four major peak up-river discharges (A, B, C, and D in Fig. 3) occurred on 3 July, 13 July, 5 August, 12 August, respectively. And these peaks occurred in wet year. During the summer of the wet year, four major rainfalls resulted in abrupt increases in up-river discharge peaks. And the maximum flushing rate was $>3\times10^8$ m^3 d^{-1} and this occurred in the mid-July period (Fig. 3). When we calculated water residence time, these four up-river discharges ($>5\times10^7$ m^3 d^{-1}) arrived in the riverine zone 12 to 20 days later (denoted as a, b, c, and d , Fig. 3), resulting in >25% decreases in total cations of Ca+Mg+Na+K. This is shown in small letters of "a", "b", "c", and "d", in Fig. 3, respectively. These peaks resulted in dramatic decreases of Ca+Mg+Na+K.

Seasonal fluctuations of calcium (Ca^{2+}) showed exactly same pattern with bicarbonate ion of HCO_3^- (Fig. 4). The minimum Ca^{2+} (0.03 meq L^{-1}) was occurred in the early August of wet year and coincided with the minimum HCO_3^-. Thus, calcium co-varied with water retention time in response to up-river discharge in the riverine zone. Similar pattern is shown in calcium and bicarbonate ions (Fig. 4), even if the peak is not corresponded to the peak up-river discharge. Thus, minimum calcium values in the lacustrine zone were <0.27 meq L^{-1} on late July, and minimum bicarbonate values were in the lacustrine zone were <0.35 meq L^{-1} on late July. Thus, minimum cation content of Ca+Mg+Na+K was 0.70 meq L^{-1} and this was occurred in early October. The low values in the October, except for July~August, were attributed to continued large up-river discharges and heavy rainfall in the summer period (Fig. 4). Thus, minimum ionic contents showed a time lag of one and half months compared to the minimum in the riverine zone of up-river location. During wet year, the ionic dilution of four major ions in lacustrine zone was accompanied by a change in ionic composition (Fig. 4). The proportion of Ca^{2+} (expressed as % of total cations equivalents) decreased

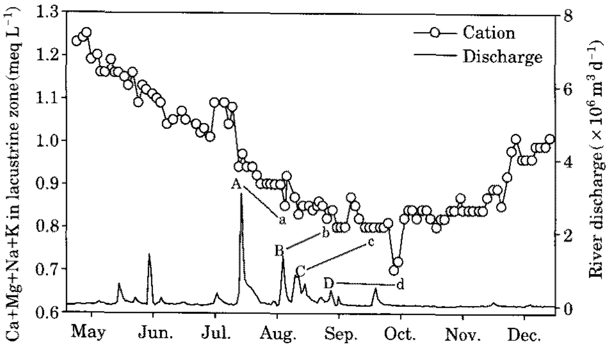

Fig. 5. Cation contents of Ca+Mg+Na+K in the lacustrine zone and river discharge during the wet year. Capital letters of "A"~"D" indicate four major up-river discharges, respectively and small letters of "a"~"d", indicate the responses of cation on each peak up-river discharges.

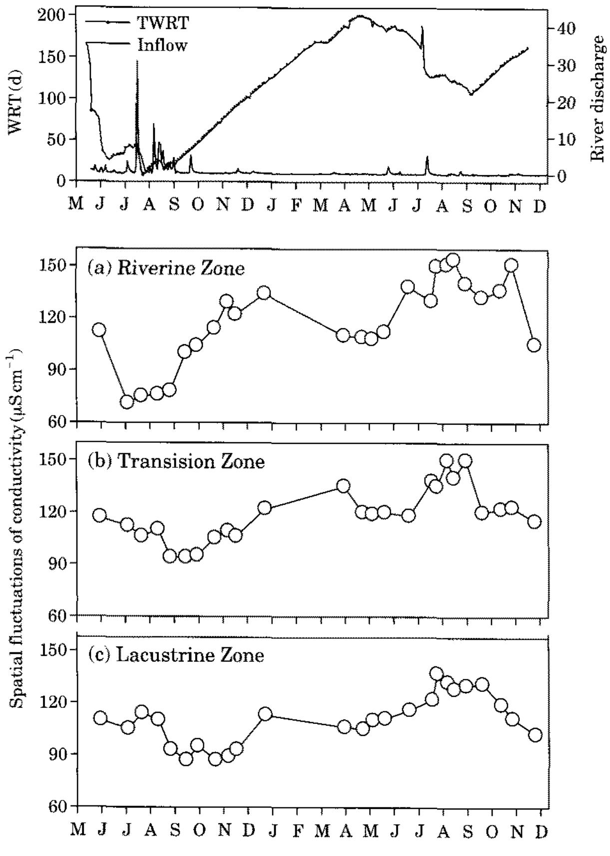

Fig. 6. Spatial conductivity fluctuations in the riverine zone, transition zone, and lacustrine zone, respectively. In the x-axis, M, J, J, A, S, O, N, and D indicate the month of March~December of the wet year, respectively and J, F, M, A, M, J, J, A, S, O, N, and D indicate the month of January~December of the dry year, respectively.

18% during July~September relative to period of May~June. This result suggests that the magnitude of variation in Ca^{2+}, bicarbonate, and cation in the lacustrine zone is directly determined by the peak magnitude of up-river discharge. Fig. 5 also suggests that conductivity in the riverine zone declined by the river discharge in the July~August, but conductivity values in the transition and lacustrine zones declined in early October, indicating a time-lag phenomenon. Thus, daily conductivity in the riverine zone had reverse relation with the river discharge, but not in transition and lacustrine zones.

Our study suggests that up-river discharge of the summer rainfall is a major source of variation in the cations such as calcium and bicarbonate. The magnitude of rainfall in the July~August accounted for most of the up-river discharge and determined water retention time in the riverine zone. These hydrological factors directly influence the reservoir water level, and ions such as cations and anions (bicarbonate), thereby determining patterns of these variables at time scales corresponding to hydrological patterns (Fig. 6). This variations in the lacustrine zone probably influenced ionic dilutions (An, 2001a), thermal structures (An, 2001b), and nutrients of nitrogen and phosphorus, and biological conditions (based on algal chlorophyll, An *et al.*, 2001) in the system as shown in previous studies, resulting in functional changes of the lacustrine zone of the reservoir ecosystem.

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