SIMULATED ANALYSIS OF WATER QUALITY TRANSITION IN A SULFURIC-ACID LAKE

HISAO NAGABAYASHI

Professor, Civil Engineering, College of Engineering, Nihon University

YUTAKA FUIJITA[1], YASUTADA OGAWA[2] and VAN-THANH-VAN NGUYEN[3]

[1] *Associate Professor, Department of Civil Engineering, College of Engineering, Nihon University*

[2] *Graduate Student, Department of Civil Engineering, College of Engineering, Nihon University*

[3] *Professor, Department of Civil Engineering and Applied Mechanics, McGill University, Montreal*

nagabaya@civil.ce.nihon-u.ac.jp

Abstract - Long-term transition of the potential of Hydrogen (pH) in a sulfuric-acid lake in mountainous basin was discussed using a simulated model based on inflow and outflow of sulfuric-acid load and flow discharge. When pH reached five or more in 1993, cloudy or black suspended matter was observed around the lakeshore and in the lake. This phenomenon coursed misgivings among residents who warned of the worsening of water environment. The prefectural authorities established guidelines for purification of the lake, and initiated some countermeasures to prevent domestic waste and industrial discharge. However, the tendency toward increased pH was not improved. The simulated analysis suggests that the rising pH trend was based on the regulation of water usage for hydroelectricity in the upper reaches of the basin. Finally, it was indicated by this investigation that, if a objective pH value were proposed, optimal control of water usage could be achieved.

I. OUTLINE OF THE BASIN AND WATER ENVIRONMENT

Outline of the Basin

Integrity of the lake environment is important not only to maintain water resources but also to preserve the irreplaceable ecological balance of the surrounding area. Various activities have been initiated [1] to preserve the favorable water environment, but despite considerable effort, the water quality of lakes in Japan has gradually worsened. Some indications of water pollution were reported even in mountainous lakes, which previously had retained clear water quality. Lake Inawashiro in Bandai Asahi National Park in Japan has an area of 103.3km^2 and maximum depth of 93.5m and is the third largest fresh water lake in Japan. This area is one of the most popular natural tourist sites with almost 8 million people visiting [2] in annually. The outline of the basin is shown in Fig. 1 and the lake profiles in the basin are shown in Table 1. The whole catchments area of this basin is 820km^2 and it is divided into three typical basins. The upper most reach is the Upper-Nagase Basin (274km^2), which has three fresh water lakes, Hibara, Onogawa and Akimoto that continuously stay in reach, and the water used by hydroelectricity. The second is Sukawa Basin, which is in the Lower-Nagase Basin. The area is 101km^2 and the water contains sulfuric acid because of the inflow of strongly acidic effluent from the tributary of this basin. Therefore the pH at this junction of Upper-Nagase Basin and this basin is usually around three. The last is Other–reach Basin, which is the surrounding area of Lake Inawashiro, the area is 342km^2. There are six small rivers in the basin with fresh water inflowing into Lake Inawashiro.

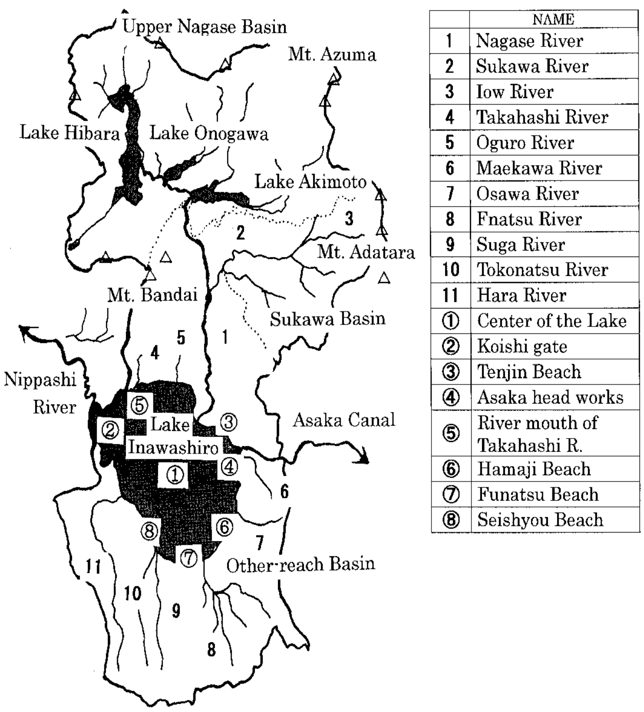


Fig.1. Outline of the Inawashiro Lake Basin

Table 1: The Lake Profiles in Inawashiro Basin

Name	Lake Hibara	Lake Onogawa	Lake Akimoto	Lake Inawashir
Lake type	Mesotrophic	Mesotrophic	Mesotrophic	Sulfuric-acid
Elevation (m)	822	797	736	514
Area (km^2)	10.4	1.4	3.9	103.3
Volume (10^{6}m^3)	127.6	11.8	32.8	3859
Depth (m)	30.5	22	33.2	93.5
Catchments Area (km^2)	106.4	40.5	112.2	820.2

Water environment of the basin

Yearly transition of water quality in the lakes is indicated in Fig.2, water criterion of the lakes in the Upper-Nagase Basin based on chemical oxygen demand (COD) is in category A (COD=3mg/l), and total nitrogen (T-N) and total phosphorus (T-P) is in category II [3] (T-N=0.2mg/l, T-P=0.01mg/l). Lake Akimoto is sometimes recognized to exceed the value of this criterion, whereas Lake Inawashiro shows lower values than the lakes in Upper-Nagase Basin because of sulfuric-acid content. The pH environment of Nagase River is rapidly changed at the Sukawano junction, this is the point of confluence between the Sukawa Basin and the Upper-Nagase Basin, with strong sulfuric-acid inflows from Sukawa Basin. Therefore, phosphorus is removed by the cohesion of metallic-ion downstream of this point in Nagase River, and the phosphorus is transported to the bottom of the Lake. So, the restriction factor on eutrophication of Lake Inawashiro is phosphorus, and the pH of the lake is usually around 4 or 5. Prefectural authorities established a water quality objective [4] under COD=0.5mg/l, T-N=0.2mg/l and T-P=0.003 mg/l for the center of the Lake by 2022.

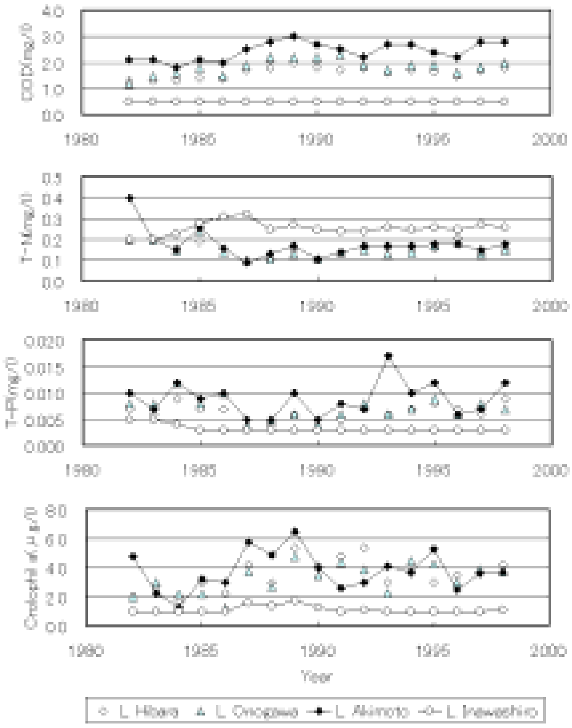


Fig.2.Yearly Transitions of Water quality in the lakes

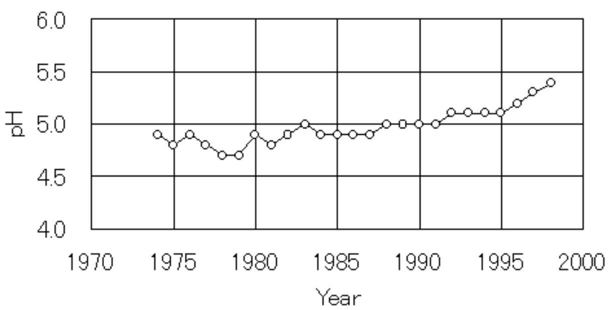


Fig.3. Annual distribution of the pH trend in Lake Inawashiro.

Long-term pH transition of Lake Inawashiro

Annual distribution of the pH trend in Lake Inawashiro is shown in Fig.3. The values ranged from 4.6 to 4.8 in 1980, then the pH gradually increased after 1987, and reached around 5.3 in 1998. Water environments of the lakeshore and surrounding rivers are compared between 1989 and 1998 in Fig.4. Oguro River and Takahashi River, which flow through Inawashiro-Town, are indicating especially high nutrition.

Nagase River is the largest river in this basin, and all indices of water quality have increased. In the surrounding lakeshore, the nutrition has differed slightly over ten years, but the pH has increased in most places. The main reason for increasing pH is the loading of basic oxide and some organic matters from residential waste, industries and farming areas. But specific pollutant matter is not decided in this basin. So the comprehensive measures are demand in this basin.

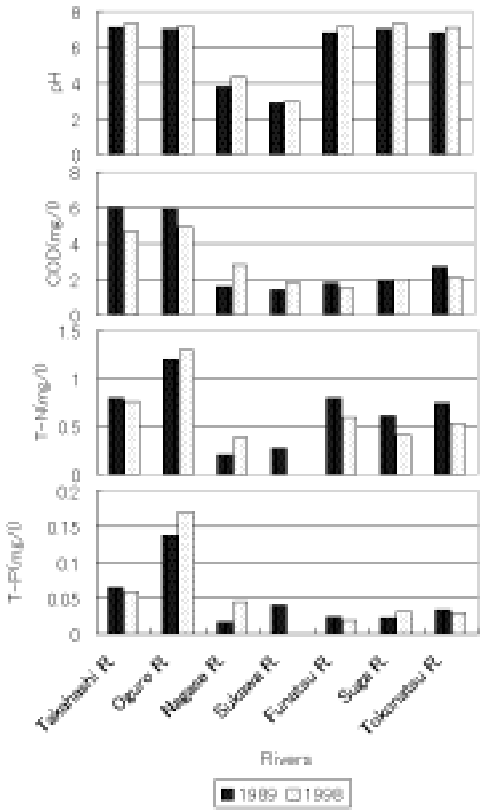


Fig.4(a). Water environments of the surrounding rivers of Inawashiro Lake compared between 1989 and 1998

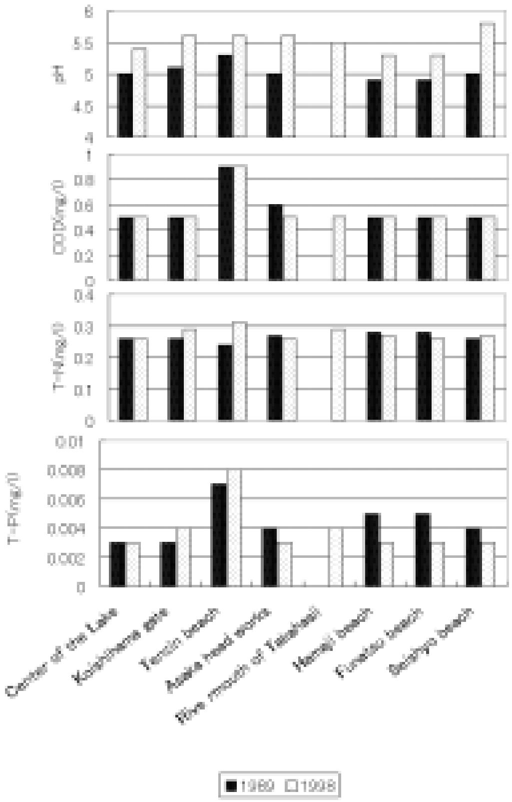


Fig.4(b) Water environments of the lakeshore of Inawashiro Lake compared between 1989 and 1998

II. Discussion

The sulfuric acid load and the dilution characteristics in Nagase River

Relationship pH and electric conductivity (EC) of Nagase River is shown in Fig.5. The pH naturally increased with transportation down stream. The point 20km is the confluence of the highly acidic Iow River in the Sukawa basin, 14km is the Sukawano point at which sulfuric acid load is measured, and the distance is indicated from Nagase River mouth.

Sulfuric ion (SO_4^{2-}) was tested by a highly sensitive ion-chromatography. Main substances with negative ions in Inawashiro Lake and Nagase River are Cl^- and SO_4^{2-} . The SO_4^{2-} is mainly connected with the pH in Lake Inawashiro.

Sulfuric-acid load measured in Nagase River is shown in Fig.6, owing to this relation, the SO_4^{2-} remains almost the same annually and is recognized as constantly.

The relationship of sulfuric-ion between the pH in Nagase River and Lake Inawashiro is indicated in Fig.7. The round marks are data from a prefectural investigation and the other data were obtained this project. The regression line (1) indicates these relations.

$$pH = 9.29(SO4 - 22)^{-0.3303} + 22 \qquad (1)$$

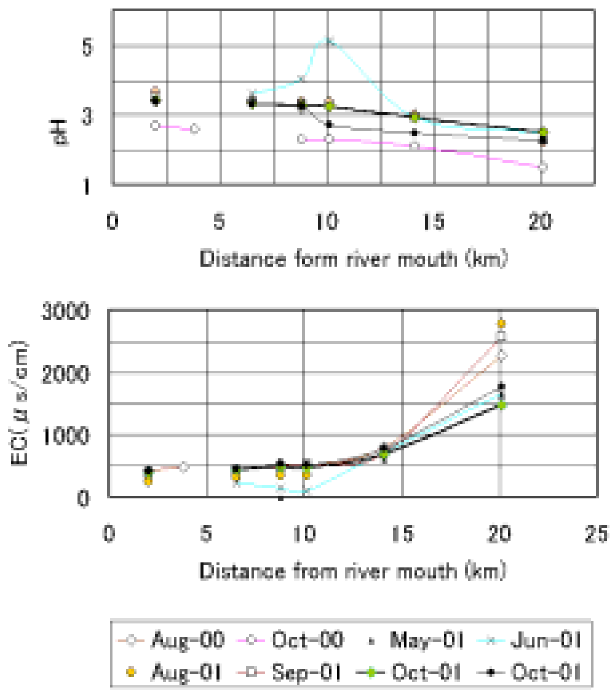


Fig. 5. Distribution of pH and EC in Nagase River

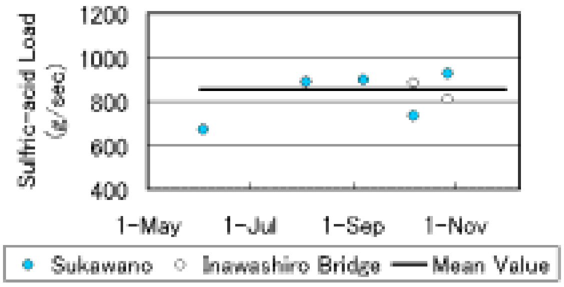


Fig. 6. Sulfuric-acid load measured in Nagase River

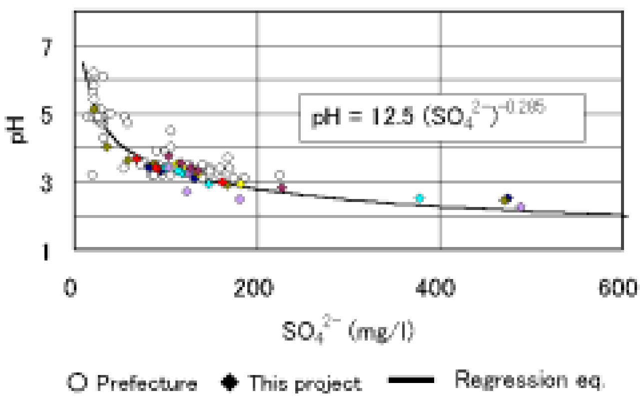


Fig.7. The relationship between sulfuric-ion and pH on Nagase River

pH estimation for Lake Inawashiro

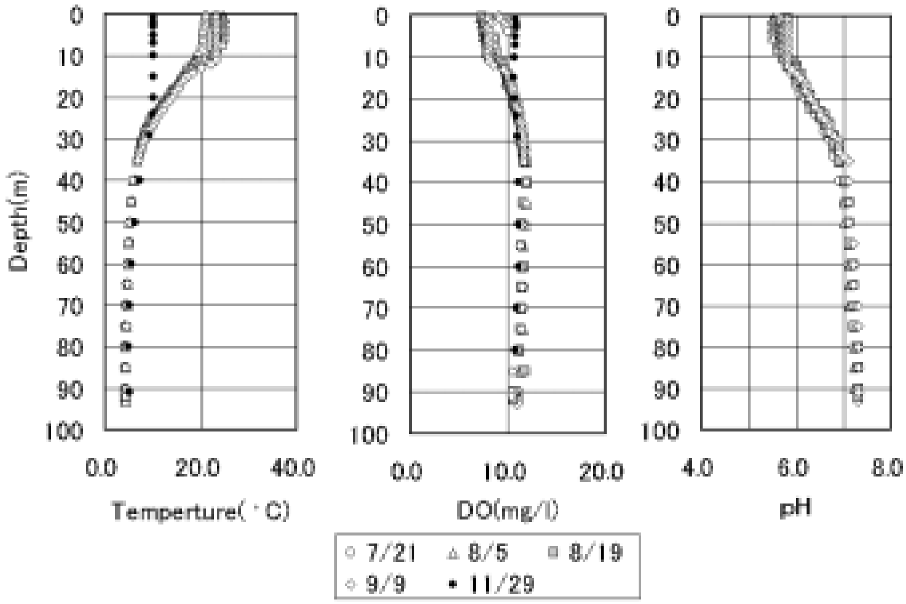
A completely mixed horizontally simulation model developed based on inflow and outflow of the sulfuric acid load and water volumes in this basin. Vertical distributions of temperature(◦C), dissolved oxygen (DO) and pH in the center of the lake are shown in Fig.8. The stratification of water temperature is clearly indicated in this figure. The depth of the epilimnion layer is about 30m from the water surface, so the conversion of the sulfuric acid load occurs in this layer, and the vertical mixing connection with the hypolimnion is not considered here. If the sulfuric-acid load W (g/day) flowing in from the Nagase River is assumed to be constant, the mass balance for the lake is given by (2). Here, s (g/m^3) is the concentration of sulfuric acid in the lake and Q_{out} (m^3/day) is the outflow discharge. The water volume V_{i+1} (m^3) is obtained from the volume of over conversion layer V_i, inflow discharge Q_{in}(m^3/day), direct rainfall of the lake surface RA_s (m^3/day) and outflow discharge Q_{out} (m^3/day). The newly established concentration of the lake s_{i+1} is given by (4), and the pH is converted from (1).

$$\frac{dVs}{dt} = W - Q_{out}s \qquad (2)$$

$$V_{i+1} = V_i + Q_{in} + RA_s - Q_{out} \qquad (3)$$

$$s_{i+1} = (V_i s_i + W(t) - Q_{out\,i} s_i)/V_{i+1} \qquad (4)$$

Fig.9 shows the comparison of calculated value with the measured one over twenty years. Depths of the exchange layer used were estimated as 20m, 40m and 60m. Despite the simplicity of estimation, the long-term pH transition of the lake is well explained. The typical distributions of pH seasonal change are compared in Fig.10. Differences between the calculation and observed value mainly occurred between September and December in 1995 and 1998, when the decrease in the calculated value was less than that in the observed value. This estimation is based on a completely mixed process, and greater accounting of the many processes involved in the water temperature variation is needed. Yearly mean value profiles are potted in Fig.11. The upward tendency was well fitted by this calculation.



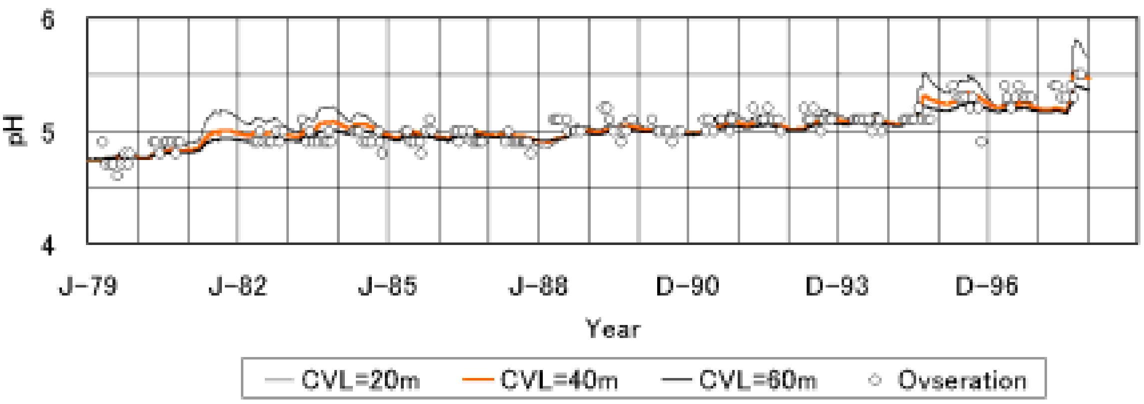


Fig.9. Comparison between calculated pH and the observations in Lake Inawashiro

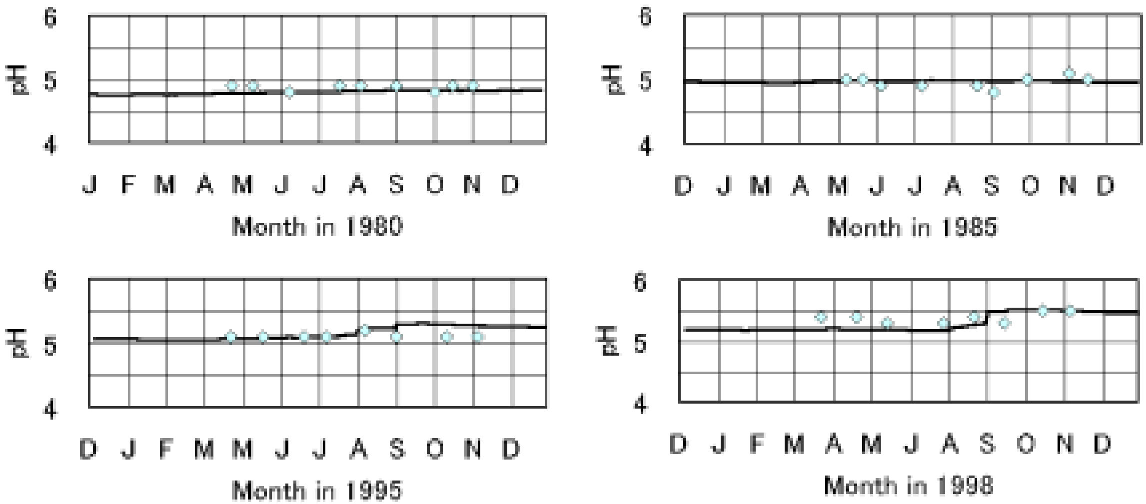
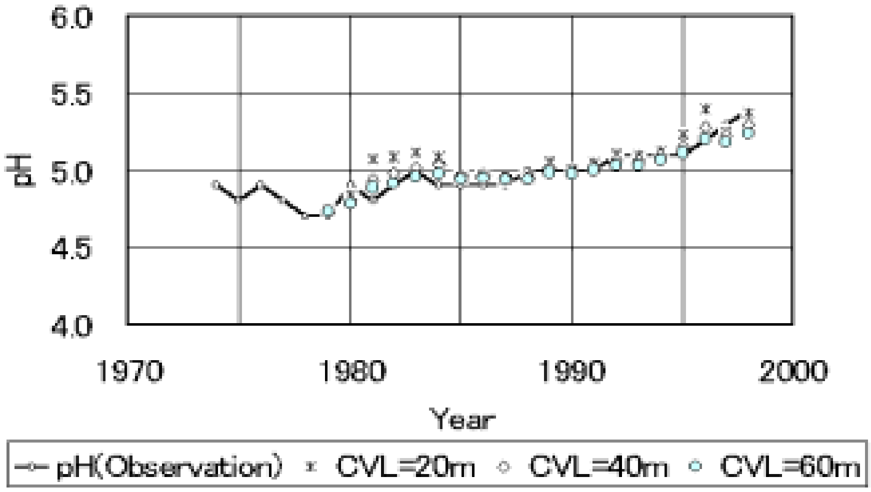


Fig.10. The typical distributions of pH seasonal change



III. SUMMARY AND CONCLUSIONS

Long-term pH transition of Lake Inawashiro was investigated by a completely mixed model analysis. The main factor in pH transition is based on the balance between water discharge and sulfuric-acid load in the lake. If the optimum pH value is proposed, it is possible to calculate flow regulation of upper lakes in Upper Nagase Basin, if this analysis is inversely applied.

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