



Title	Water Quality of Lake Toya and of all the Lake's In- and Outflow Rivers
Author(s)	Sakai, Hiromitsu; Niioka, Tadashi; Urano, Shin-ichi; Kurasaki, Masaaki; Kojima, Yutaka
Citation	Environmental science, Hokkaido : journal of the Graduate School of Environmental Science, Hokkaido University, Sapporo, 8(1), 1-9
Issue Date	1985-07-31
Doc URL	<a href="http://hdl.handle.net/2115/37180">http://hdl.handle.net/2115/37180</a>
Type	bulletin (article)
File Information	8(1)_1-9.pdf



[Instructions for use](#)

## Water Quality of Lake Toya and of all the Lake's In- and Outflow Rivers

Hiromitsu Sakai\*, Tadashi Niioka\*, Shin-ich Urano\*\*  
Masaaki Kurasaki\* and Yutaka Kojima\*

\* Department of Environmental Medicine, Division of Social  
Environment, Graduate School of Environmental Science,  
Hokkaido University, Sapporo 060, Japan

\*\* Laboratory of Fundamental Research, Division of Environmental  
Structure, Graduate School of Environmental Science,  
Hokkaido University, Sapporo 060, Japan

### Abstract

Lake Toya is situated near Mt. Usu, a volcano which erupted on August 7th, 1977, when ash fell on the lake surface and caused an abrupt increase of suspended matter in the lake water.

No significant difference in the concentration of sodium, potassium, calcium, and magnesium ion was reported between the periods before and immediately after the activity of Mt. Usu.

We investigated the water quality (pH, temperature, conductivity and concentration of each metal ion) in order to assess the long-term influence of the eruption of Mt. Usu and the changes on the standing water quality of Lake Toya.

Sampling was carried out on December 8th and 9th, 1983, at the stations beside the basin of Lake Toya and on November 30th, 1983, at sampling points at all the lake's in- and outflow rivers. The pH values and concentrations of sodium and calcium ions were found to be higher than those measured immediately after the eruption. The conductivity and concentration of potassium ion were low as compared with the former data. A significantly positive correlation was detected between the depth from the lake surface and conductivity, while high negative correlations were observed between the depth and the pH and between the depth and water temperature. Nevertheless, the general features of the lake water were considered not to have changed.

**Key Words:** Water quality, Sodium, Potassium, Calcium, Magnesium, Conductivity, pH, Water temperature, Volcano, Mt. Usu.

### 1. Introduction

Lake Toya is situated at the foot of the Mt. Usu volcano (the generic name of Mt. Kousu and Mt. Ōusu) which erupted on August 7th, 1977 (Figure 1). Between August 7th and August 13th, the Mt. Usu volcano erupted 16 times, and brought about great damage to both natural and human activity by the immediate precipitation of volcanic ash or rain. The ash fell on the lake surface and caused an abrupt increase of suspended matter in the lake water. We therefore supposed that the water quality and ecosystem in the Lake and its surroundings would be changed by the eruption of Mt. Usu. During the researches which were carried

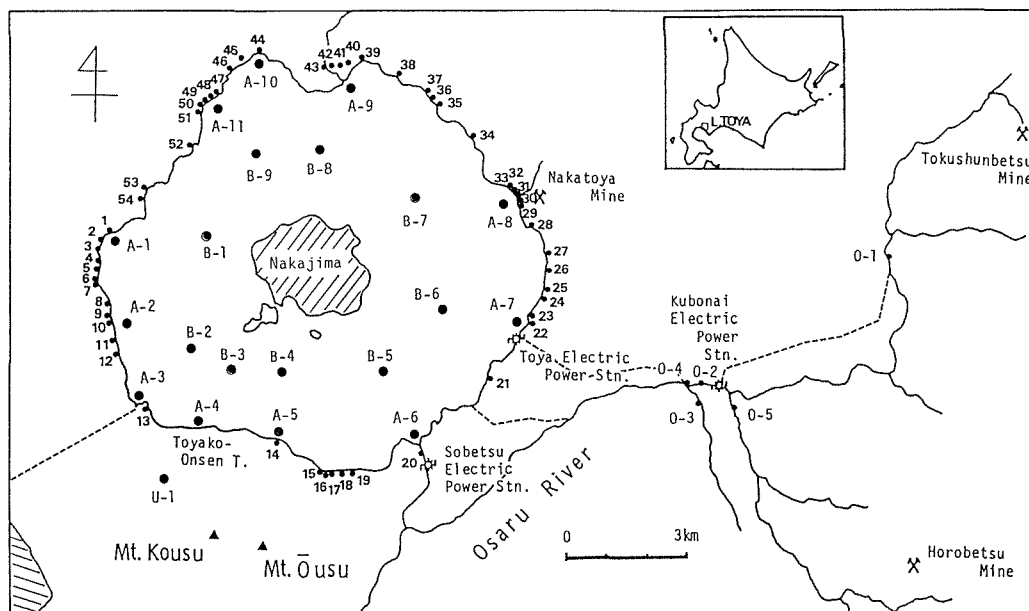


Figure 1. Outline of Lake Toya area and sampling station.

- Sampling station of in- and outflow river
- Sampling station of the surface lake water
- Vertical sampling station of the lake water

out immediately after the eruption, however, it was reported that the water quality had scarcely changed when it was compared with the formerly collected data. No inflow of new substances brought about by the eruptions into the Lake was noticeable (Nagayama and Tamura, 1978).

Earlier studies made of the environment of the ecosystem in the Lake water (Kimura *et al.*, 1978; Kurohagi, 1978), Negishi and Matsunaga (1983), measured organically bounding copper, organic matter concentrations and the molecular weight of the organic matter in the lake water. So far as the investigators have reported, the change of water quality brought about by the eruption is not clear. It is still necessary, however, to continue to research any long-term change of water quality produced by the inflow of the many withered plants and new soil components occasioned by the change of the water run off mechanism.

Lake Toya is located about 3.2 km in-land from the sea (the Uchiura Bay basin area), Mt. Usu lying roughly between the two (Figure 1). The Lake is a big lake in an old caldera, and is 84 m above sea level; the surface area is 69.4 km<sup>2</sup>; the maximum depth is 179 m; the mean depth is 117 m; and the volume is 8.19 km<sup>3</sup> (Ambe, 1984). The human population located around the lake is about 6,000 (as of March 1983). In a southwest corner, especially, where the Toya Spa is located, which is a modest holiday resort. The remaining areas, except for the Spa and a residential area, are devoted almost entirely to farming. Since 1939, an electric power station has supplied increasingly acid effluents to the lake water

through the Osaru River from the Horobetsu and Tokushunbetsu mines in the upper River. This has resulted in decreasing the buffer capacity of the water in the lake (Goto *et al.*, 1969). From 1965 to 1970, it had become heavily acidified, the pH value having changed from 7 to about 5 (Nagayama and Tamura, 1978). After these mines had been closed, however, and the work of purifying the mine effluents from the water had been carried out by a public agency (Soubetsu town and the Hokkaido Prefectural Government), the pH value was restored. Before the eruption, its pH value indicated 6.6-6.8 (Goto and Tanemura, 1971).

## 2. Materials and Methods

### *Sample collection*

Water from the lake's in- and outflow rivers was collected on December 8th, 1983. The sampling sites are also shown in Figure 1. Lake Toya's only outflow stream runs into the Osaru River, and samples were collected from the Osaru River (in the area of the Kubonai Power Station) upstream of the outflow's entry into the main river. A sample was also collected from a spring half way up the southern slope of Mt. Usu. These water samples were stored in deionized polyethylene bottles (500 mℓ). The river water samples were collected at 61 sites and the lake samples were collected at 34 sites. The B-3 site at the center of the lake contained four vertical stages, 0 (water of the surface), 20, 50 and 100 m depth while the B-1 and the B-7 sites contained five stages, 0, 20, 50, 100 and 150 m. The sampling instrument used was a Nanzen water sampler (reversible type, one liter volume).

### *Sample preparation and analysis*

The water temperature ( $T_w$ ), pH and conductivity were measured immediately after sampling. The water sample was filtered by suction through a 0.45  $\mu\text{m}$  millipore filter, and the metal solutions were analyzed by conventional atomic absorption methods for sodium, potassium, calcium, magnesium and irons, using a Hitachi Atomic Absorption Spectrophotometer (Type 207).

For the surface water of the Lake, our results, measured for five elements of 20 samples, were compared with the previously obtained values (Tachibana and Nasu, 1978), using a *t*-test. We also assessed the vertical distributions of their water temperature, pH and concentrations of sodium, potassium, calcium, magnesium, and iron ions, using a regression test.

## 3. Results and Discussion

### *Chemical properties in the water of Lake Toya*

$T_w$ , pH, conductivity and concentrations of metal ion in the samples taken from Lake Toya are indicated in Table 1. Those in the Osaru River, the spring water from Mt. Usu and the lake's in- and outflow rivers are shown in Table 2. Water quality with regard to the values of pH,  $T_w$ , conductivity and metal ion

**Table 1.** Water temperature (Tw), pH, conductivity (Cond.), and concentrations of metal ion in water of Lake Toya

Station No.	Tw	pH	Cond.	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Fe <sup>2+.3+</sup>
	°C		at 25°C	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ
			μS/cm					
A-1	7.0	7.1	166	13.8	1.8	8.0	2.5	<0.05
A-2	6.9	7.0	166	14.1	1.8	8.1	2.3	<0.05
A-3	6.9	7.0	165	13.9	1.8	8.1	2.3	<0.05
A-4	6.9	7.0	166	14.1	1.8	7.9	2.3	<0.05
A-5	6.9	7.0	164	14.1	1.8	7.9	2.3	<0.05
A-6	6.8	7.1	165	14.0	1.8	7.9	2.3	<0.05
A-7	6.8	7.1	164	13.9	1.8	7.9	2.3	<0.05
A-8	6.8	7.0	165	13.9	1.8	7.8	2.3	<0.05
A-9	6.7	7.1	164	13.3	1.8	7.5	2.2	<0.05
A-10	6.8	7.0	164	13.9	1.9	7.6	2.3	<0.05
A-11	6.8	7.0	165	13.9	1.8	7.7	2.3	<0.05
B-1	6.8	7.0	163	13.9	1.9	8.0	2.4	<0.05
B-1 (20m)	6.9	7.0	165	15.2	1.9	7.9	2.3	<0.05
B-1 (50m)	5.6	6.9	171	14.5	1.9	8.0	2.3	<0.05
B-1 (100m)	4.6	6.9	171	14.6	1.9	8.0	2.3	<0.05
B-1 (150m)	4.4	6.8	171	14.6	1.9	7.8	2.3	<0.05
B-2	6.9	7.1	166	13.9	1.8	7.9	2.3	<0.05
B-3	6.9	7.1	168	13.9	1.8	7.9	2.3	<0.05
B-3 (20m)	6.9	7.0	166	13.9	1.8	8.0	2.3	<0.05
B-3 (50m)	5.6	7.0	171	14.3	1.8	8.0	2.3	<0.05
B-3 (100m)	4.7	6.9	172	14.3	1.9	8.0	2.3	<0.05
B-4	6.9	7.1	165	13.9	1.8	7.8	2.3	<0.05
B-5	6.7	7.0	165	13.9	1.8	8.0	2.3	<0.05
B-6	6.7	7.0	166	13.9	1.8	7.8	2.3	<0.05
B-7	6.8	7.1	164	13.9	1.8	7.9	2.3	<0.05
B-7 (20m)	6.8	7.1	169	14.0	1.8	8.2	2.3	<0.05
B-7 (50m)	4.9	7.0	168	14.3	1.9	8.0	2.3	<0.05
B-7 (100m)	4.5	6.9	172	14.3	1.9	8.1	2.3	<0.05
B-7 (150m)	4.3	6.9	175	14.5	1.9	8.1	2.3	<0.05
B-8	6.9	7.0	167	14.0	1.8	7.9	2.3	<0.05
B-9	6.9	7.0	166	13.9	1.8	7.9	2.3	<0.05

**Table 2.** Water temperature (Tw), pH, conductivity (Cond.), and concentrations of metal ion in water of all the lake's in- and outflow rivers and the spring

Station No.	Tw	pH	Cond. at 25°C	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Fe <sup>2+,3+</sup>
	°C		μS/cm	mg/l	mg/l	mg/l	mg/l	mg/l
1	9.0	7.2	150	8.8	1.1	12.0	4.0	<0.05
2	4.0	7.1	151	8.0	1.1	8.5	2.7	<0.05
3	—	7.0	272	11.4	1.8	18.8	7.8	0.13
4	4.4	7.1	228	9.8	2.2	18.5	5.8	<0.05
5	4.0	5.1	152	6.7	1.0	5.0	2.3	0.22
6	6.0	6.5	204	10.2	1.7	17.2	4.0	<0.05
7	3.8	7.0	251	10.0	1.2	22.3	5.6	<0.05
8	4.3	4.5	243	8.7	1.0	7.6	4.1	0.06
9	4.8	6.1	416	11.2	1.0	47.5	8.1	<0.05
10	7.7	4.6	397	15.6	1.3	21.8	9.0	<0.05
11	3.6	3.9	465	10.3	1.3	15.3	10.0	0.70
12	4.9	5.8	247	10.0	0.9	15.6	6.0	<0.05
13	5.0	6.7	220	13.3	2.4	13.5	5.8	<0.05
14	15.8	7.2	2050	258.9	17.4	87.7	16.8	<0.05
15	29.0	7.9	4000	739.6	59.9	94.6	49.0	0.08
16	35.0	7.7	3870	758.1	64.7	108.2	51.4	0.12
17	35.2	7.0	4150	570.7	55.1	109.3	50.9	0.12
18	4.5	7.3	309	17.2	3.5	35.5	2.9	<0.05
19	22.0	8.0	4020	417.0	68.3	107.0	54.5	0.07
20	8.4	7.6	175	12.0	1.5	9.6	2.4	<0.05
21	6.1	7.4	161	12.1	2.1	6.6	3.9	<0.05
22	7.9	7.4	175	9.9	1.2	14.5	3.5	<0.05
23	6.4	6.8	205	7.8	3.6	10.3	5.5	<0.05
24	6.4	7.0	193	7.7	1.3	13.8	4.5	<0.05
25	7.8	7.1	182	8.3	1.4	11.2	4.4	<0.05
26	5.6	7.1	248	10.4	1.5	13.8	8.0	<0.05
27	4.9	5.1	151	5.9	1.2	4.9	3.5	<0.05
28	5.5	5.7	95.9	5.6	0.9	4.5	1.6	<0.05
29	5.7	6.3	106	6.6	1.0	5.9	2.3	<0.05
30	5.7	6.2	75.3	5.5	1.0	3.7	1.3	<0.05
31	5.7	6.5	80.8	5.5	0.9	4.2	1.7	<0.05
32	6.8	3.2	517	5.1	1.5	0.3	0.8	7.913
33	5.1	5.6	93.3	5.6	1.0	3.9	2.1	<0.05
34	5.7	6.8	120	7.1	1.1	5.8	2.9	<0.05
35	6.2	6.9	107	7.3	1.1	6.9	2.5	<0.05
36	5.0	6.6	104	6.9	1.3	5.0	2.2	<0.05
37	6.2	6.7	166	8.1	1.2	8.0	4.5	<0.05

Table 2. (Continued)

Station No.	Tw	pH	Cond.	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Fe <sup>2+.3+</sup>
	°C		at 25°C					
38	6.3	6.9	104	6.9	1.2	5.5	2.1	<0.05
39	8.1	6.8	185	8.5	2.7	14.6	3.9	<0.05
40	5.1	6.9	121	6.5	2.4	9.6	2.3	<0.05
41	4.7	7.1	106	6.9	1.9	7.9	2.1	<0.05
42	4.6	7.0	83.6	5.3	1.1	5.4	1.7	<0.05
43	4.6	7.2	83.3	5.3	0.9	5.2	1.7	<0.05
44	6.2	7.1	155	9.9	2.6	10.6	3.7	<0.05
45	6.0	7.0	186	11.8	4.0	12.0	4.3	<0.05
46	6.3	7.1	194	10.5	3.8	15.1	3.6	<0.05
47	4.5	7.2	155	10.5	2.5	8.4	4.2	<0.05
48	3.6	7.0	77.8	4.6	5.0	4.1	1.0	0.161
49	7.1	7.2	209	19.2	2.0	9.5	4.6	<0.05
50	6.1	7.0	186	10.4	3.8	12.3	4.8	<0.05
51	5.6	6.7	251	13.1	14.2	12.1	5.9	<0.05
52	5.5	7.0	143	9.9	3.3	8.6	3.7	<0.05
53	6.9	6.9	151	10.1	1.9	9.9	3.7	<0.05
54	7.0	6.9	166	10.3	4.1	12.1	3.6	<0.05
(Osaru River)								
0-1	4.2	7.3	100	8.5	1.0	4.1	1.2	<0.05
0-2	4.1	6.9	172	9.3	1.2	13.2	1.9	<0.05
0-3	3.0	7.4	69.6	5.2	0.7	3.1	1.3	<0.05
0-4	—	6.9	164	9.0	1.2	11.9	1.9	<0.05
0-5	3.1	4.8	505	8.3	1.8	81.0	4.4	0.697
U-1	11.8	6.7	642	48.8	4.5	74.4	12.6	<0.05

Table 3. Comparison of water quality (Mean±S.D.)

	Sample (n)	pH	Cond. at 25°C (μS/cm)	Na <sup>+</sup> (mg/ℓ)	K <sup>+</sup> (mg/ℓ)	Ca <sup>2+</sup> (mg/ℓ)	Mg <sup>2+</sup> (mg/ℓ)
This study (1983)	n=20	7.04±0.05	165.2±1.2	13.91±0.16	1.81±0.03	7.89±0.15	2.31±0.05
Tachibana and Nasu (1978)	n=18	6.54±0.12	168.6±1.9	11.56±0.41	1.38±0.05	12.76±0.25	2.22±0.26
Significance		p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	N.S.

N.S.: Not significant.

concentrations in the lake was not significantly different for any of the sampling sites. It was therefore confirmed that the water quality was homogeneous. The mean values of each item are shown in Table 3. In the comparison of the results of this study and the report of Tachibana and Nasu (1978) after the eruption of

Mt. Usu, we found that the pH has slightly increased, that sodium and potassium ions concentrations have clearly increased, while calcium ion concentrations were observed to be markedly lower in our study than in the earlier one ( $p < 0.001$ ).

On the other hand, in making this comparison we weren't able to take into account the variations between our data and that of Tachibana and Nasu (1978), because we had not been able to observe the seasonal changes during the five years between 1978 and 1983, when we made our first collection, so that these years are a blank. The pH in the Lake was about 7.0 before 1955 (Nagayama and Tamura, 1969). Thereafter, there was increased acidification until 1968, when the pH showed its lowest values, pH 4.9-6.3 (Goto *et al.*, 1969). This phenomenon indicated the presence of the Horobetsu and the Tokushunbetsu mine effluents recorded by Goto and Tanemura (1971). The Tokushunbetsu mine closed in 1971, however, and the Horobetsu mine closed in 1973. The mine effluents rapidly decreased and a neutralising treatment of the sewage was carried out step by step as a co-operative venture between Soubetsu town and the Hokkaido Prefectural Government (Sasaki *et al.*, 1976; Hokkaido Prefectural Government, 1983). In 1977, Tachibana and Nasu (1978) reported a mean pH value in the lake water of 6.5 in the lake water. In our study, the mean pH value was 7.0. We thought that this pH change showed that the lake had clearly been restored to its 1955 state. We considered that with regard to the increase of sodium and potassium ion in the water, the effluents of the hot springs and the Horobetsu and the other rivers have always supplied these to in the lake. However we have not concluded that this is definitely so because we have also considered the influence of groundwater and so on. Since 1955, there has been a tendency for the calcium ion concentration to decrease (Nagayama and Tamura, 1978). Our study observes the phenomenon of a markedly decreased calcium ion concentration since 1978. We have supposed that by supplying  $\text{HCO}_3^-$  from the effluents of the hot springs and the polluted rivers, the solution of calcium precipitates more easily. The buffer capacity of the lake water has so far been very small owing to the prolonged supply of acidic water from the ion sulfide mines; this was indicated by the water's small alkalinity value. We suggest that the ash does not contain any soluble components, or that these dissolve extremely slowly (Nagayama and Tamura, 1978). Any changes of metal concentration in the water were not recognized immediately before or after the eruption. We believe that there was no direct influence from the falling ash or the flowing lava and mud, but that the high soluble sodium and potassium contained in the ash may have an indirect influence over a long-term from the soil that contains the ash (Okajima *et al.*, 1978). The iron ion concentration was, anyway, less than  $0.05 \text{ mg}/\ell$ . The conductivity was  $163\text{-}168 \mu\text{S}/\text{cm}$ . This value was significantly lower than the results produced by Tachibana and Nasu (1978) (see Table 3).

#### *The relationship of the depth and water quality in Lake Toya*

At sites B-1, B-3 and B-7, we looked into the relationship between the depth and  $T_w$ , conductivity, pH, sodium, potassium, calcium and magnesium ion con-



**Table 4.** Correlation coefficient between the depth of the lake and each element

	vs Tw	vs pH	vs Cond.	vs Na <sup>+</sup>	vs K <sup>+</sup>	vs Ca <sup>2+</sup>	vs Mg <sup>2+</sup>
This study (1983)	-0.9264 (p<0.001)	-0.8674 (p<0.001)	0.8332 (p<0.001)	0.4622 (p<0.10)	0.5791 (p<0.05)	0.0400 (N.S.)	0.3129 (N.S.)
Tachibana and Nasu (1978)	-0.7095 (p<0.01)	0.2296 (N.S.)	0.3787 (N.S.)	0.4958 (p<0.10)	0.1910 (N.S.)	0.0200 (N.S.)	0.0060 (N.S.)

N.S.: Not significant.

centrations. As for the depth versus Tw and pH, we recognized as having a negative correlation ( $p < 0.001$ ) and there was a positive correlation between the potassium ion concentration and conductivity ( $p < 0.001$ ), as we show in Table 4. We have observed no tendency for a leap with regard to Tw, considering that our sampling date was December 8th. The pH value was 6.9–7.1, and the potassium ion concentration changed only within a small range, so that it may not be significant as for the depth. We supposed that the high correlation with conductivity had been influenced by the sodium ion because a sodium ion concentration has a correlation with the depth ( $p < 0.1$ ) but has no significance as to depth for the other elements. A positive correlation between sodium and the depth was consistent with the reports of Tachibana and Nasu (1978).

Ambe (1984) reported on the measured results of the main vertical element concentrations of sodium, calcium, magnesium and potassium in the water of Lake Mashu as a monitoring station for a limnol background. Lake Mashu is a most beautiful as well as an unpolluted lake. In a comparison of these elements, Lake Toya possesses very poor nutrition and may be influenced hardly at all by water and fly ash pollution. Yasuda *et al.* (1984) also reported that the Lake was non-nutrient in vitamin B<sub>1</sub> when compared with Lake Biwa. These conclusions may be taken to show that Lake Toya is a non nutrient and unpolluted lake.

#### *The water of all the lake's in- and outflow rivers*

We sampled the water of the lake and all the in- and outflow rivers on November 29th and 30th (the only natural outflow river is the Soubetsu River). Most of rivers which flow into the lake from the north contain the same level or a lower level of metals as the lake, with the same conductivity and pH value. The south end of the lake, where several hot springs enter it, contained high levels of sodium and potassium ion (sites Nos. 14, 15, 16, 17 and 19), while the west end of the lake was influenced by drainage (pH 3.2 and high contained iron in the site No. 23) from the closed Nakatoya mine. Nevertheless, the lake water from sites A-4, A-5 and A-8 in the south and west had almost the same levels as that from the center of the lake (see Table 1). This result indicates the rapid spread and dilution of every element that flowed into the surface water.

#### *The water of the Osaru River*

We investigated the five points, illustrated as in Figure 1, and show the results in Table 2. The conductivity and calcium ion concentration were of a comparably

high level and, moreover, the pH value was low at the upper basin; they all had the same levels at the center of the lake. This result clearly shows that at present no pollution has been brought about by the Tokushunbetsu mine effluents.

### Acknowledgements

The authors gratefully appreciate the helpful advice and sampling of water of Dr. Takashi Kurohagi and Hiroyuki Haruna.

The authors also thanks our colleagues for much discussion and assistance in the design, conduct, and analysis of the research reported here. They include Kazuo Hasegawa, Yasuo Takahashi, Hideko Yasuda, Yasunori Okamoto, Tadao Makizuka, Yoshiro Shibasaki, Masaho Ishino, Minoru Nakamura, Mika Suzuki, Shoko Nishimae, Mineo Kato and Takahiro Ichinose.

Furthermore, the authors are greatly indebted to Miss Tomoko Ohma for her devoted effort in the preparation of the manuscript and the secretarial assistance during while research period.

### References

- Ambe, Y. (1984): Studies of the method for long term environmental monitoring. *Research report from the National Institute for Environmental Studies, Japan*, 58: 22-30. (in Japanese).
- Okajima, H., Sakuma, T., Imai, H., Iizuka, F., Kiso, S. and Taniyama, I. (1978): Preliminary studies on the Pedological aspects of new tephra erupted from Usu volcano. *Usu Eruption and Its Impact on Environment, Hokkaido University*, 335-347. (in Japanese with English abstract).
- Goto, K. (1973): Effect of a hermetically sealed dam for antipollution of the closed mine. *Water Purification and Liquid Wastes Treatment*, 14: 453-456. (in Japanese).
- Goto, K., Yotsuyanagi, T., Tanemura, T. and Watanabe, H. (1969): Effect of acid mine drainage in Lake Toya. *Water Purification and Liquid Wastes Treatment*, 10: 25-30. (in Japanese).
- Goto, K. and Tanemura, T. (1971): Changes of the water quality in Lake Toya. *Report of Studies on Water Pollution*, 5: 1-11. (in Japanese).
- Hokkaido Prefectural Government (1983): 'An Environmental White Paper on Hokkaido', 213-215. (in Japanese).
- Nagayama, M. and Tamura, H. (1978): Effect of the volcanic ash fall from Mt. Usu on the quality of water in Lake Toya. *Usu Eruption and Its Impact on Environment, Hokkaido University*, 289-292. (in Japanese with English abstract).
- Sasaki, S., Tanemura, T., Yamasaki, K., Uno, T., Terai, T., Iwasaki, T. and Goto, K. (1976): Studies on changes of water acidification and effects of water neutralization. *Report of Studies on Water Pollution*, 9: 1-15. (in Japanese).
- Tachibana, H. and Nasu, Y. (1978): Studies on the water quality of Lake Toya. *Usu Eruption and Its Impact on Environment, Hokkaido University*, 275-287. (in Japanese with English abstract).
- Yasuda, H., Inoue, K., Sakai, H., Makizuka, T., Kurasaki, M., Niioka, T., Kojima, Y., Kato, M., Mitsutake, M., Urano, S. and Kurohagi, T. (1984): Vitamin B<sub>1</sub> in water in Lake Toya. *A Follow-Up Survey of Environmental Changes Caused by the 1977-1978 Eruptions of Mt. Usu and Related Events, Graduate School of Environmental Science, Hokkaido University*, 101-109. (in Japanese with English abstract).

(Received 29 December 1984)