THE RELATION BETWEEN CHLORINITY AND SILICATE CONCENTRATION OF WATER OBSERVED IN SOME ESTUARIES. II.*

By

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The velocity and amount of currents, the current towards the offing in shallower layers and that towards the coast in deeper layers in bays nourished by many rivers or in the estuarine waters of large rivers, can be calculated by the KNUDSEN's theorem based on the distribution of chlorinity. OKADA tried to estimate the steady surface current along the coast by the KNUDSEN's theorem, supplementarily using silicate concentration besides chlorinity. His method, however, is not applicable to the currents where iso-lines of silicate concentration and chlorinity are parallel or almost parallel to each other. Actually, the universe correlation coefficient, ρ, between chlorinity and silicate concentration may be regarded as -1 near the estuary. This fact means that iso-lines of these two components are parallel, and consequently any current can not be calculated by OKADA's method. According to YOSHIMURA, the amount of dissolved silicate which can be determined easily and exactly, and is considered to be the most suitable indicator to show the mixing ratio of river water with sea water. I tried, in my previous report, to establish a formula showing the influence of the rivers running into Kojima Bay and Yosa-Naikai from YOSHIMURA's point of view and found that the influence of most rivers could be represented by

$$[SiO_2] + A\,[Cl] = B,$$

but when stagnant that relation was represented by the another fomula

$$[Cl] = \text{const.}$$

The seasonal variation of the influence of the same river and the difference between influences of rivers are easily deducible by comparing the two constants A and B of the above-mentioned formula. I have continued to examine the data given by many authors to test whether the above formula is applicable for other rivers, having different amount of flow and the catchment of different soil and pouring into bays different oceanographical conditions, or not and to know the value of the constants A and B, if the formula is available.

Before entering the subject, I must express my sincere thanks to Prof. Dr. D. MIYADI (Zoological Institute), Prof. Dr. M. ISHIBASHI (Institute of Chemistry) and Dr. T. TOKIOKA (Seto Marine Biological Laboratory) of Kyôto University, and Prof. Dr. I. MATSUI of Shimonoseki College of Fisheries for their valuable advices

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and criticisms given on the present work. Also I wish to record my hearty thanks to Mr. H. AMAKAWA who helped me in drawing figures.

METHODS

At first I have calculated the following values : ——

$$\bar{X}=(X_1+X_2+X_3+\cdots\cdots+X_N)/N,$$

$$\bar{Y}=(Y_1+Y_2+Y_3+\cdots\cdots+Y_N)/N,$$

$$S_X=(X_1-\bar{X})^2+(X_2-\bar{X})^2+\cdots\cdots+(X_N-\bar{X})^2,$$

$$S_Y=(Y_1-\bar{Y})^2+(Y_2-\bar{Y})^2+\cdots\cdots+(Y_N-\bar{Y})^2,$$

$$C=(X_1-\bar{X})(Y_1-\bar{Y})+(X_2-\bar{X})(Y_2-\bar{Y})+\cdots\cdots+(X_N-\bar{X})(Y_N-\bar{Y}).$$

Here, X_i and Y_i are the chlorinity and the concentration of silicate each sample respectively. Then the regressioe equation is settled as

$$[SiO_2]=\beta_0+\beta_1[Cl]$$

b_0 and b_1, which are estimates of β_0 and β_1, are calculated by the following formulae:

$$b_0=\bar{Y}-b_1\bar{X},$$

$$b_1=C/S_X.$$

In order to find the significance level of the formula, $\triangle=S_Y-C^2/S_X$ and $F_0=\frac{C^2(N-2)}{S_X\triangle}$ are computed, setting the null hypothesis that the universe correlation coefficient (ρ) is zero. Then F_0 is compared with the value in F-table.

RESULTS

Miho Bay is situated along the southeastern coast of Shimane Peninsula and separated from Nakano-umi by a sand barrier named Yumigahama. Two rivers,

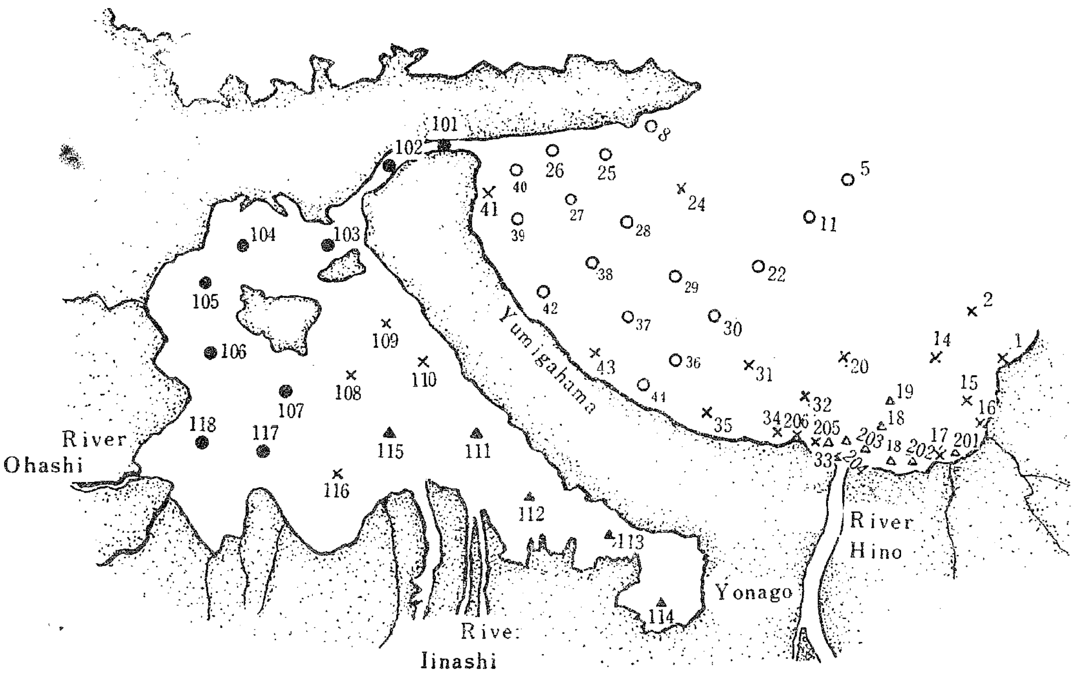

Fig. 1. Map of Miho Bay and Nakano-umi, showing the stations (MIYADI *et al.* :Oct. 24—27, 1951).

Table. 1.

Name of bay	Name of river	Date	Size of sample	Fo	F	Level of signif.	Constant of formula A	B	C
Miho Bay	Water flowed from Nakano-umi	'51,X,24—26	17	109.00	10.798	0.005	168	3,400	—
	Hino (1)		10	124.84	14.688	0.005	689	13,600	—
	Hino (2) (except St.203)		9	30.27	18.236	0.005	331	7,400	—
Nakanoumi	Iinashi (surface)	'51,X,27	6	—	—	—	—	—	7.4
	Iinashi (bottom)		5	—	—	—	—	—	13.2
	Ôhashi (surface)		9	7.087	5.5914	0.005	294	4,030	—
	Ôhashi (bottom)		7	40.91	22.785	0.005	242	4,870	—
Suruga Bay	Fuji	'34,XI,1	9	197.06	16.236	0.005	590	11,260	—
Lake Hamana	Miyakoda	'34,XI,12—17	14	242.76	11.754	0.005	875	13,730	—
	(except St.16)	〃	13	52.91	12.226	0.005	750	12,260	—
		'35,I,29—II,2	12	21.023	12.826	0.005	880	14,300	—
		'35,IV,18—22	13	72.78	12.226	0.005	1036	15,500	—
		'35,VII,22-28	16	—	—	—	—	—	8.3
		'35,IX,6	12	45.20	12.826	0.005	800	8,080	—
	(except St. 12)	〃	11	9.84	7.209	0.025	460	6,800	—
	Eastern part of the lake	'34,XI,12—17	10	410.67	14.688	0.005	1000	16,000	—
		'35,I,29—II,2	7	106.30	22.785	0.005	865	16,900	—
		'35,IV,18—22	9	22.99	16.236	0.005	355	9,640	—
	(except St.27&29)	〃	7	1.94	1.69	0.25	—	—	—
		'35,VII,22-28	11	15.80	13.614	0.005	1150	20,000	—
	(except St. 40)	〃	10	4.23	3.458	0.10	—	—	—
	Lake Sanaru	'35,I,29—II,2	5	42.59	34.116	0.01	13,200	28,390	—
	Lake Inohana	'35,IV,18—22	5	28.94	17.443	0.025	650	11,530	

Note : $[SiO_2]$: γ/L , [Cl] : ‰

$[SiO_2]$ + A [Cl] = B , [Cl] = C.

Hino and Nakano-umi, pour the land water into the bay. The data of the observations, made by MIYADI and others during the period from 24 to 26 of Oct. 1951 at the estuarine region of the River Hino to examine in detail the influence of the river water, were used as the material to establish the influence-formula. The influence- formula of the water flowed into Miho Bay from Nakano-umi is established from the data obtained at the stations shown in Figs 1 and 2 by the sign ○, while the formula about the influence of the River Hino upon Miho Bay (1) is based on the data obtained at the stations indicated by the sign △. In the latter case, the values obtained at the St. 203, located at just the openning of the river, were so far apart from those obtained at other stations that I tried to make the influence-formula of the River Hino (2) on the data, except that of St. 203. As for myself, I rather prefer to adopt the latter formula as the influence-formula of the River Hino.

Nakano-umi is a shallower lagoon; even the largest depth is only 8.2 m. The channel connecting the lagoon with Miho Bay is long and shallow. Moreover the exchange of the water between the lagoon and the open sea is almost impossible by the existence of two islets, Daikon and Enoshima, near the inner openning of the channel. The Rivers Iinashi and Ôhashi, the latter of which leads to Lake Shinji, pour into Nakano-umi to decrease the chlorinity in the inner part of the bay, where the water is remarkably stagnant.

I used the results of the observations pursued by MIYADI and others on Oct. 27, 1951, to find a influence-formulae of the Rivers Ôhashi and Iinashi; namely the results obtained at the stations indicated by the sign ○(surface) and● (bottom) in Fig. 3(● in Fig. 1), where are regard as lying in the area influenced by the River Ôhashi, were used to make the influence-formulae of the surface and the bottom layer respectively. By these treatments, it is found that not only the influence-formula of the surface water but also that of the bottom water is ascribed to the type [SiO_2] +A [Cl] =B, that is to say the fact the influence of the river water

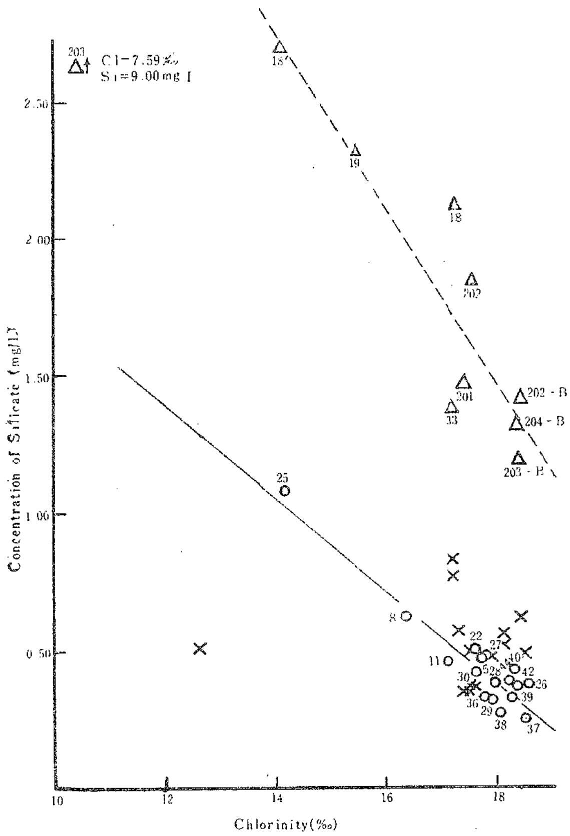

Fig. 2. Silicate-chlorine relation graph drawn on the data of observed by MIYADI *et al.* in Miho Bay (Oct. 24--26, 1951).

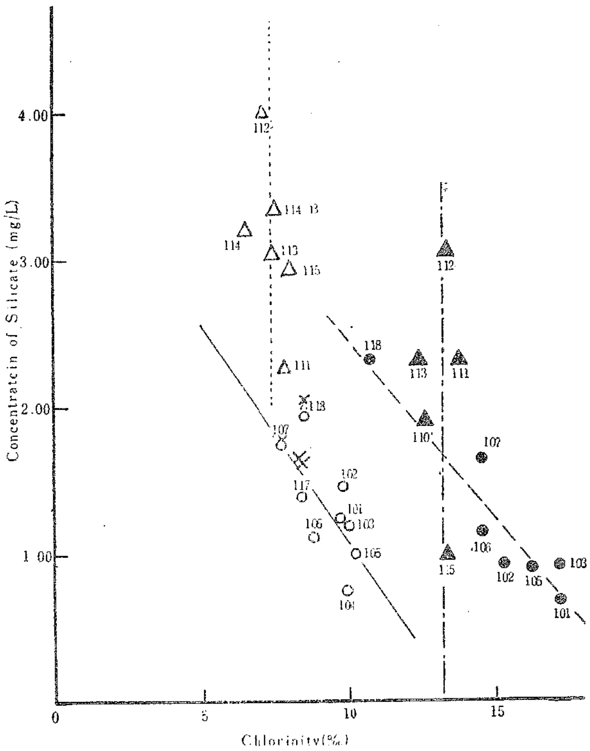

Fig. 3. Silicate-chlorine relation graph drawn on the data ef observed by MIYADI *et al.* in Nakano-umi (Oct. 27, 1951).

extends to the bottom in a considerable degree. Against to this fact, F_0 of both surface and bottom layers calculated by the above-mentioned treatment from the results obtained at the stations indicated by the sign △ (surface) and ▲ (bottom) in Fig. 3 (▲ in Fig. 1), where are regarded as lying in the area influenced by the River Iinashi, can not be regarded as significant (at 0.05 level of significance).

The variation of silicate concentration is far larger than that of chlorinity in both the surface and bottom layers. Therefore, the formulae showing the influence by the river water in the surface and bottom layers may be represented by [Cl] = const. which is the type of the formula available in the stagnant water. Thus, it is clear that in this region the influence of the stagnation is far stronger even in the surface layer than that of the River Iinashi, the influence of which is almost negligible. The data obtained at the stations represented by the sign X in Figs. 1 and 3, which are located along the expected boundary between the areas influenced by the Rivers Ôhashi and Iinashi (Fig. 1), are actually plotted in the graph around the crossing-point of the influence-formulae of the Rivers Ôhashi and Iinashi.

Suruga Bay is a large bay situated to the south of Mt. Fuji and is influenced strongly by the oceanic water. The River Fuji pours into the bay at the inner-most part and the river water is carried away from the estuary in the direction of SW along the coast by the anticlockwise stream in the bay, forming the main fishing grounds of *Sergestes lucens* HANSEN. I derived the influence-formula of the River Fuji upon Suruga Bay based on the results of observations pursued by Shizuoka Prefectural Fisheries Laboratory on Nov. 1, 1934, and found that silicate-chlorine relation in this case is represented with considerable accuracy by the formula—type $[SiO_2] + A\ [Cl] = B$, and the influence of the river becomes weaker in the order of St. E→St.D→St.H→St.G→St. B, St. I, St. A, St.F, St.C.

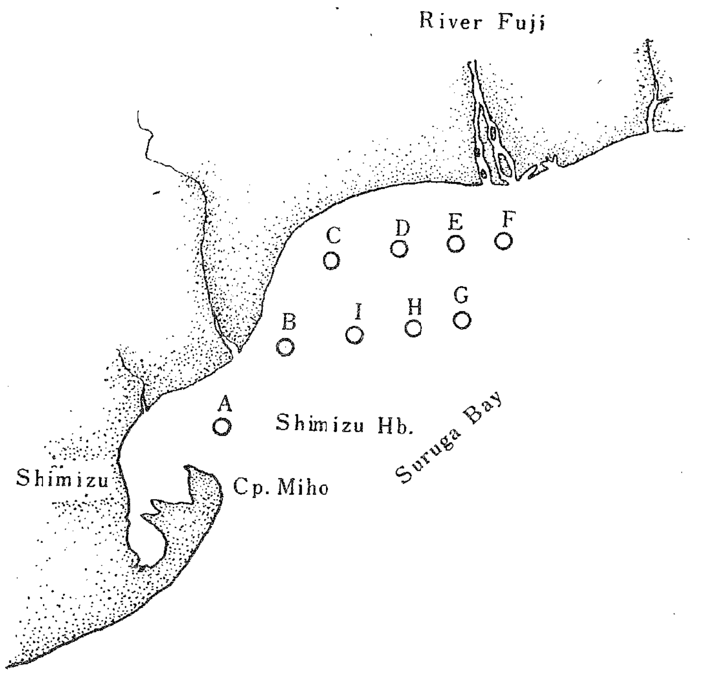

Fig 4. Map of the estuarine region of the River Fuji, showing the stations (Shizuoka Prefectual Fisheries Laboratory : Nov. 1, 1934).

Lake Hamana is a large and sha-llow brackish lake situated about 100 km east of Nagoya. The lake is a little wider than 27km² in area, while the breadth of the channel communicating with the outer sea is only *ca.* 500 m and is shallow. Consequently the exchange of the water is quite inconspicuous and the lake is

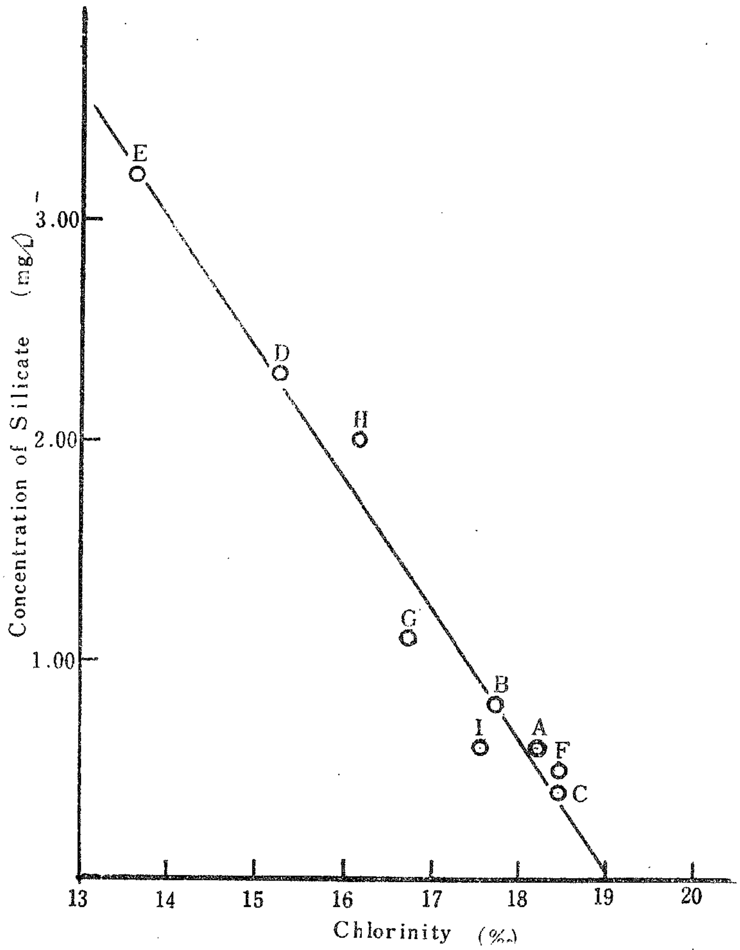

Fig. 5. Silicate-chlorine relation graph drawn on the data of observed by Shizuoka Prefectual Fisheries Laboratory in the estuarine region of the River Fuji (Nov. 1, 1934).

affected strongly by the land water. Thus the cultivations of the oyster, the laver and the eel all of which are adapted for the brackish environment are prosperous in this lake. I derived the influence-formulae in each season. Using the data of five series of observations held by the Hamamatsu Meteorological Observatory and the Shizuoka Prefectual Fisheries Laboratory.

I have derived the influence-formulae of the River Miyakoda from the data at the stations indicated by the sign ○ in Figs. 6−15 and found that A is 1,040−800 and B is 15,500−8,100 (8,100 is the value observed a little after the heavy rain, when the silicate concentration in the river water probably decreased or besides the river water the rain water having no silicate dilute the chlorinity). Among these 5 cases, the influence of the river was the strongest during the period April 18−22, 1935 and weakest during the period July 22−28, 1935 when it was almost negligible. The degree of the influence is constant in other cases.

I derived the influence-formulae available in the eastern part of the lake (=Kotôbu) using the data obtained from the stations indicated by the sign △ in Figs. 6−15, where are regarded as lying in the area influenced by small streams

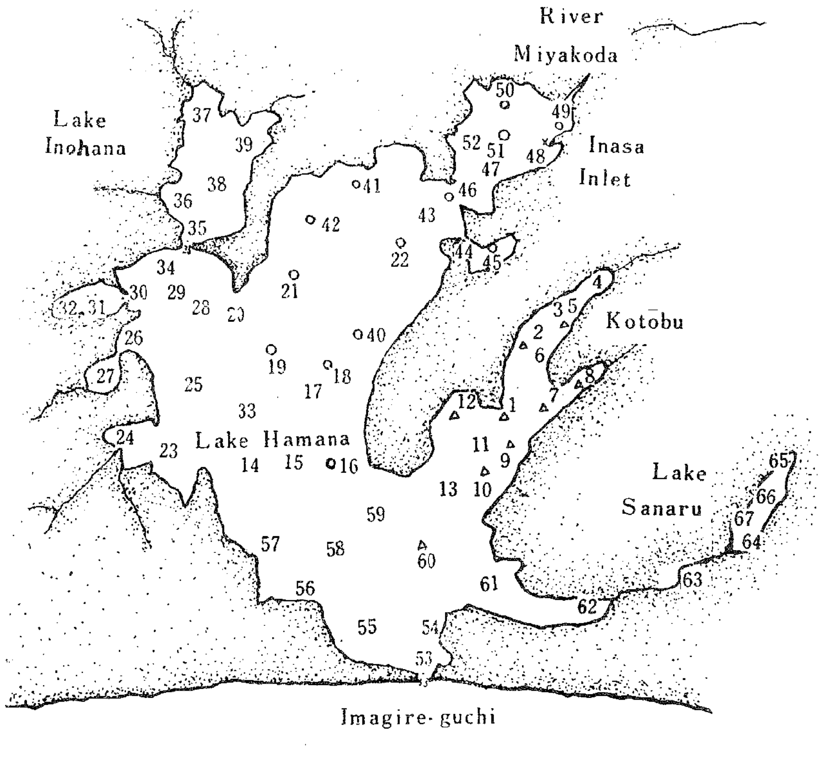

Fig. 6. Map of Lake Hamana, showing the stations.
(Hamamatsu Meteorological Observatory : Nov. 12–17, 1934).

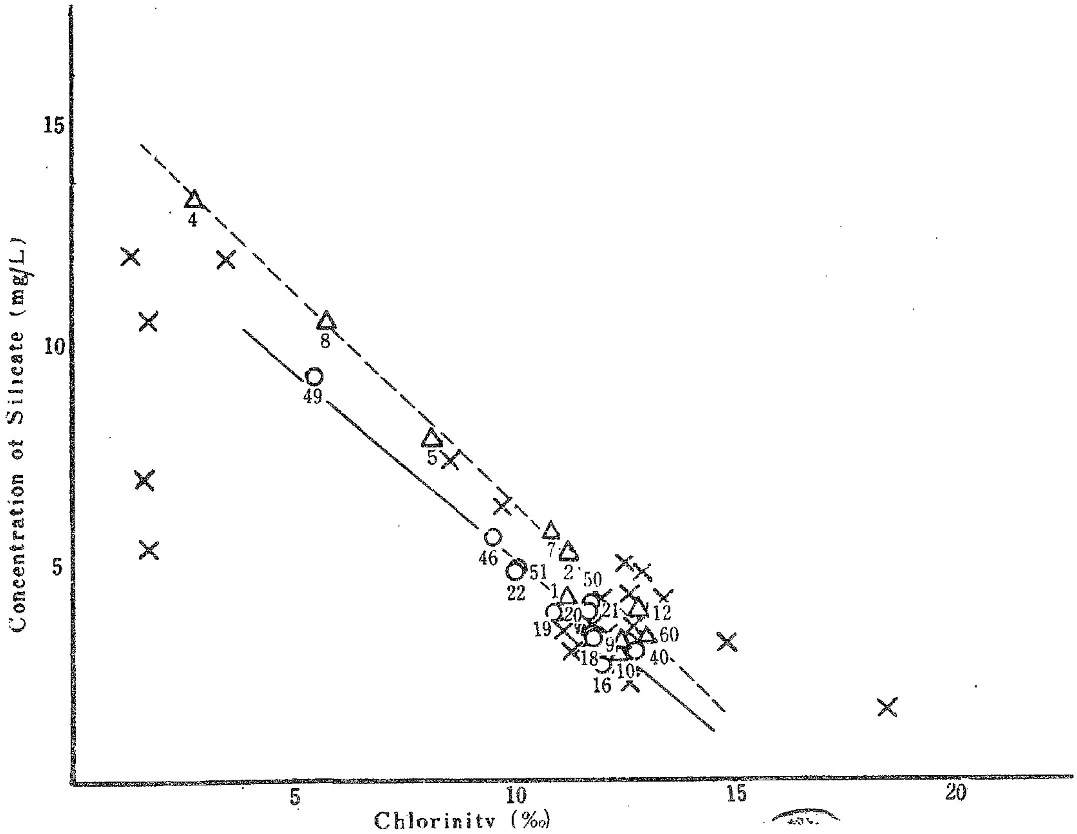

Fig. 7. Silicate-chlorine relation graph drawn on the data of observed by Hamamatsu Meteorological Observatory in Lake Hamana (Nov. 1, 1934).

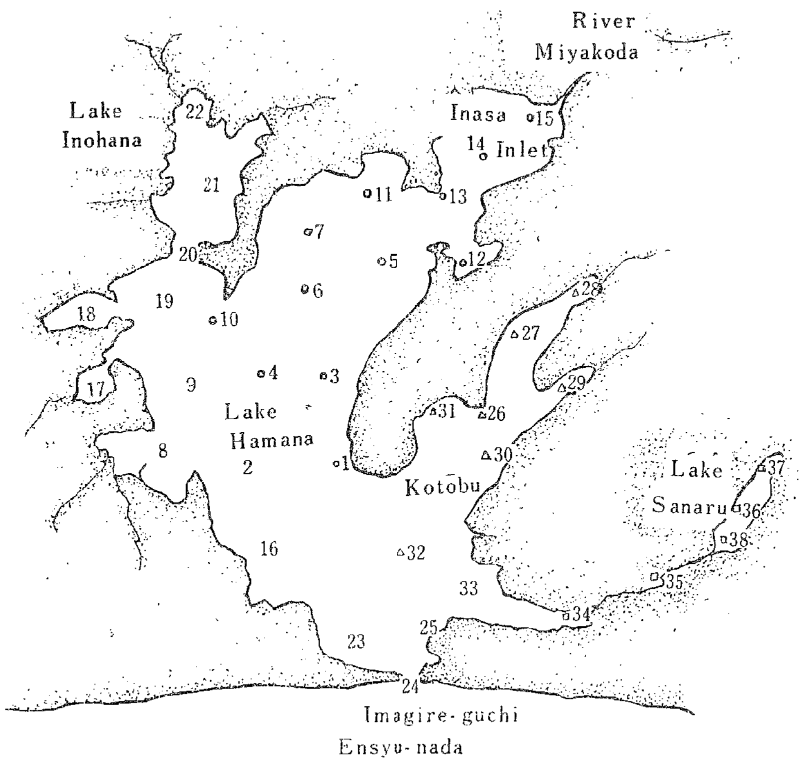

Fig. 8. Map of Lake Hamana, showing the stations.
(Hamamatsu Meteorological Observatory : Jan.29—Feb. 2, 1935).

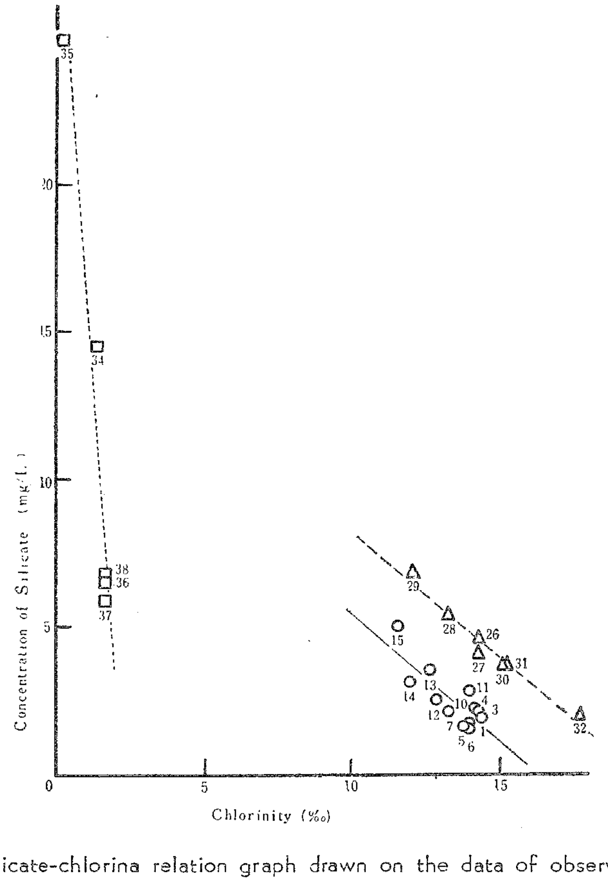

Fig. 9. Silicate-chlorina relation graph drawn on the data of observed by Hamamatsu Meteorological Observatory in Lake Hamana (Jan. 29—Feb. 2,1935).

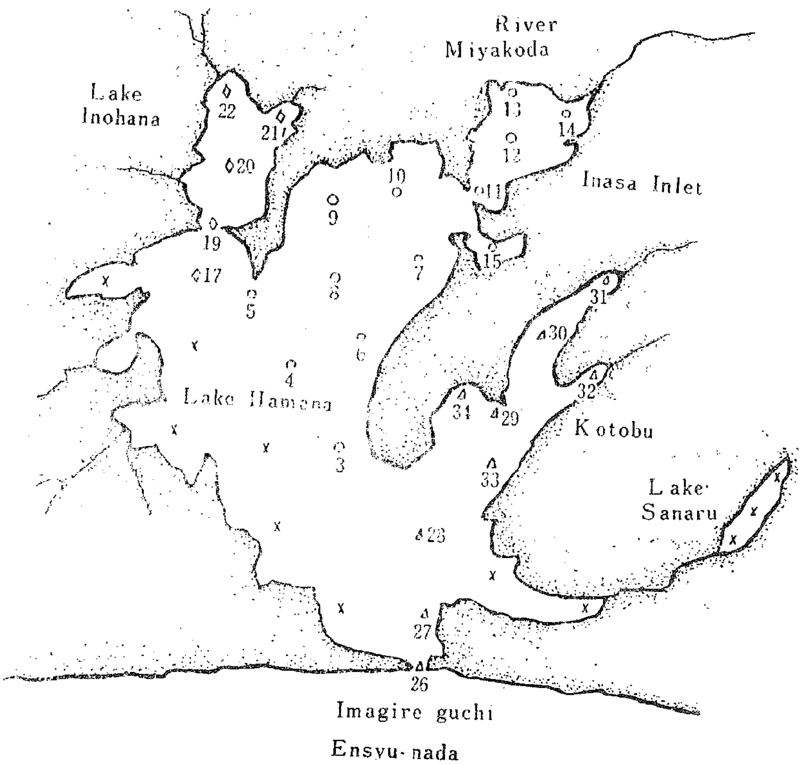

Fig. 10. Map of Lake Hamana, showing the stations.
(Hamamatsu Meteorological Observatory : April 18—22, 1935).

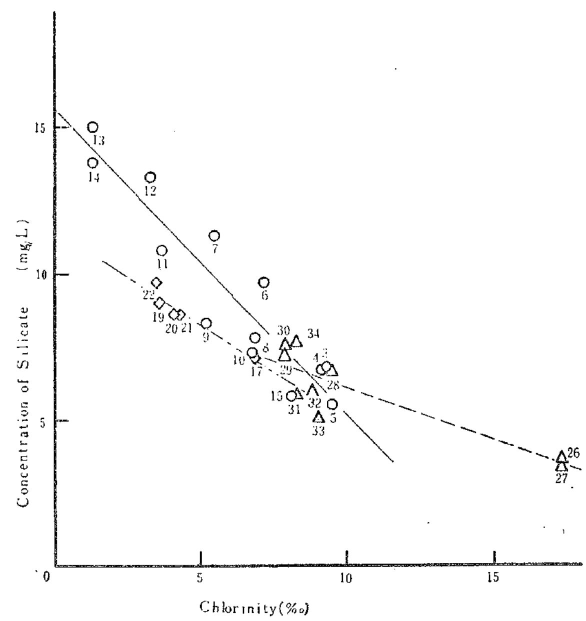

Fig. 11. Silicate-chlorine relation graph drawn on the data of observed by Hamamatsu Meteorological Observatory in Lake Hamana. (April 18—22, 1935).

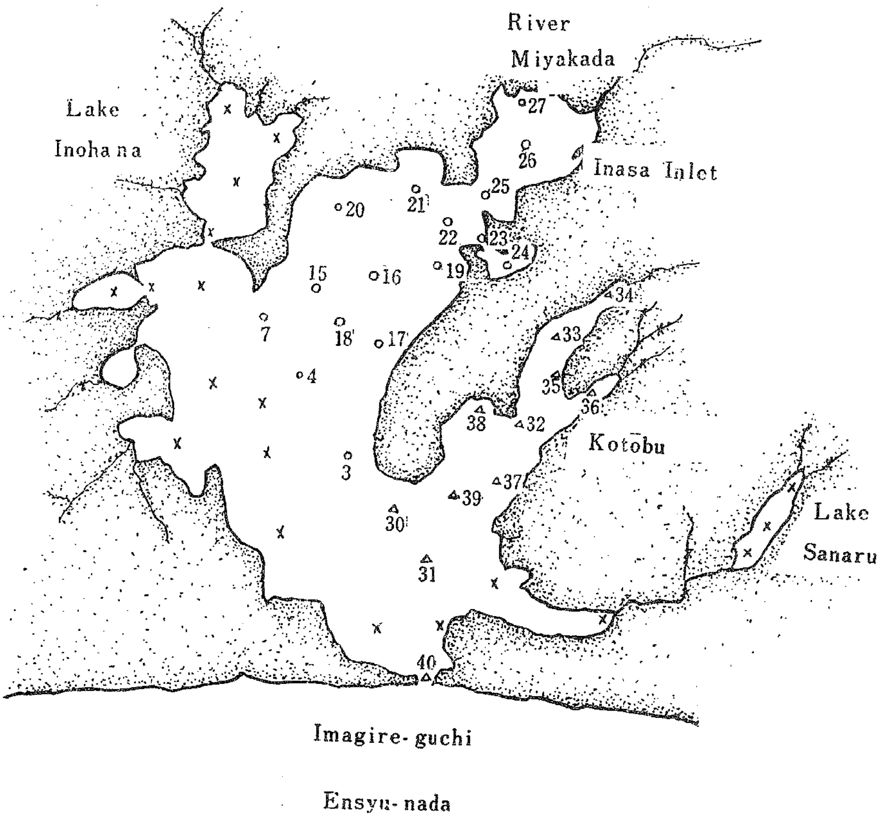

Fig. 12. Map of Lake Hamana, showing the stations.
(Hamamatsu Meteorological Observatory : July 22–28, 1935).

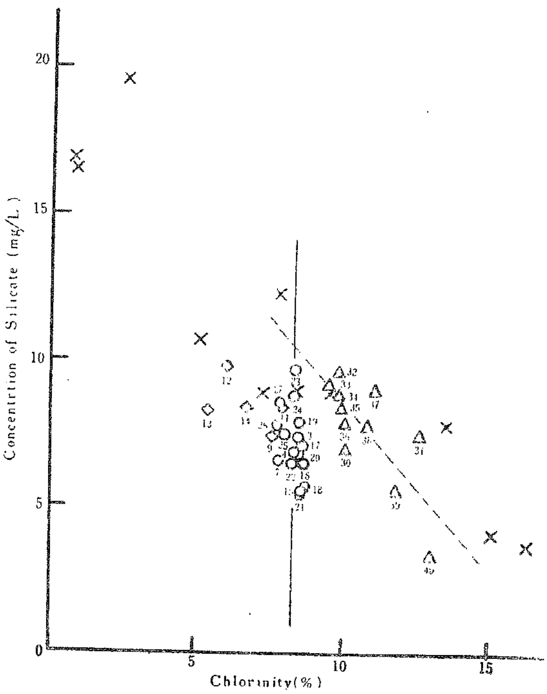

Fig. 13. Silicate-chlorine relation graph drawn on the data of observed by Hamamatsu Meteorological Observatory in Lake Hamana (July 22–28, 1935).

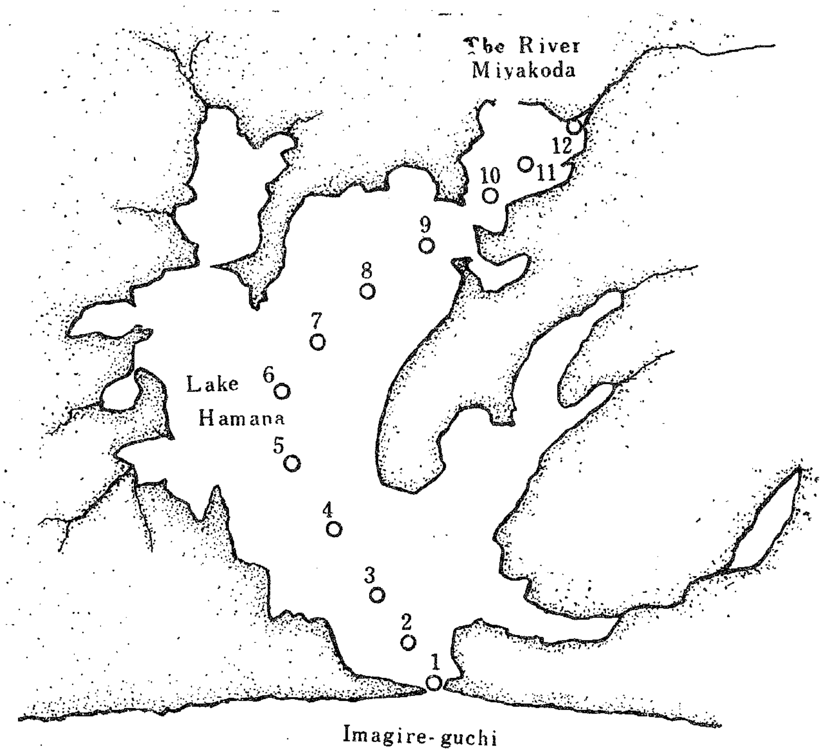

Fig. 14. Map of Lake Hamana, showing the stations.
(Shizuoka Prefectual Fisheries Laboratory : Sept. 6, 1935).

pouring into the eastern part of the lake. In the third observation, F_0 calculated from the data obtained at all stations can be considered as significant at 0.005 level of significance, while F_0 calculated from the stations except St. 27 and St. 29 (April 18–22, 1935) or St. 40 (July 22–28, 1935), the values at these stations being far apart from the distribution of those at other stations in the graph, can not be regarded as significant even at 0.05 level of significance. Therefore, A and B of the formula in the third observation seem to be different from those in other cases, but I rather think that these values are not so important for the considerations upon the seasonal change of the influence. It may be said safely that A and B in the eastern part of the lake are a little higher than those of the River Miyakoda.

F_0 of Lake Sanaru obtained from the results of the second observation may be regarded as significant at 0.01 level of significance; A and B in this case are far larger than those of other rivers. F_0 of Lake Inohana in the third observation, estimated from the data at all stations indicated by the sign ◇ in Figs. 10 and 11, may be regarded as significant at 0.05 level of significance, but that estimated from the data at stations except St. 17, the value at which is far apart from those of other stations, is insignificant at 0.05 level of significance. Both A and B in the former treatment resemble to the values of other rivers pouring into Hamanako. F_0 of Lake Sanaru and Inohana estimated from the data in other cases can not be regarded as significant, because the influence of the sea water is far weaker than that of other factors affecting the silicate concentration and chlorinity.

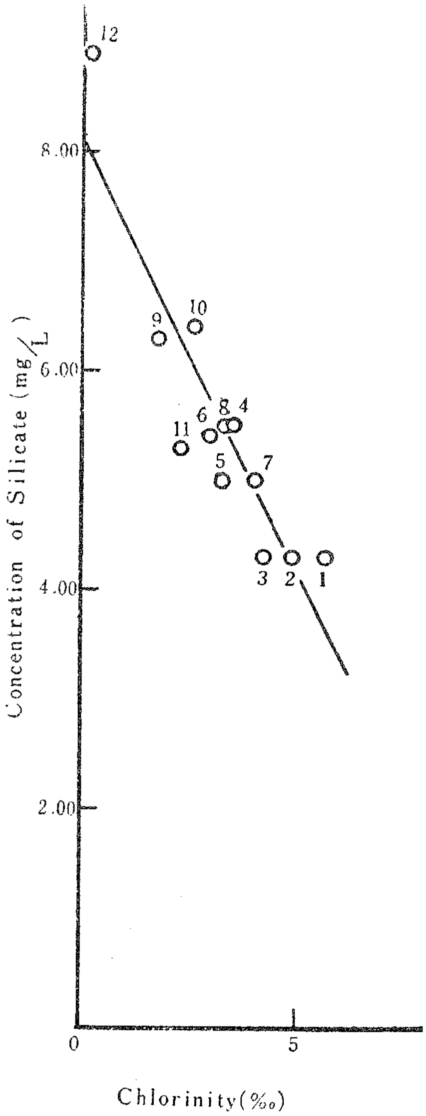

Fig. 15. Silicate-chlorine relation graph drawn on tho data of observed Shizuoka Prefectual Fisheries Laboratory in Lake Hamana (Sept. 6, 1935).

DISCUSSION AND CONCLUSION

In my previous paper I reported that the formula for silicate-chlorine relation for the bottom stagnant water differes from the surface water and is represented by other type of the formula generally shown by [Cl] = const. But at this time, I found that the silicate-chlorine relation can be represented by this type of formula even in the surface water, when the water is stagnant and the river water can be regarded as being nearly dried up.

To find the relation between the two constants, A and B, in each case listed in table 1, including also the results reported in the previous paper, I tried to derive the relation-formula on these constants by the same methods as adopted in the case of deriving the influence-formula. At this time, X_i and Y_i is replaced by A and B of each formula respectively, and it is found that the relation is represented by the following formula with considerable accuracy.

$$B = 807 + 15.9A,$$

$$F_o = 406.7, \qquad (n_1 = 1,\ n_2 = 21)$$

The relation-formula, $[SiO_2] + A[Cl] = B$, can be determined by only one of the constants, A or B. Thus, the general formula may be transformed into the following form,

$$[Si\,O_2] + A[Cl] = B = 807 + 15.9A,$$

$$\therefore [Si\,O_2] + A([Cl] - 15.9) = 807.$$

The formula becomes $[SiO_2] = 807$, if we set $[Cl] = 15.9$. This means that all relation-formulae pass the point ($[Cl] = 15.9$, $[Si\,O_2] = 807$) or thereabout. Therefore, the difference of the formula can be represented simply by the difference of the inclination, and finally we may be able to make a rough estimation of the influence-formula of a certain river from any one arbitrary sample.

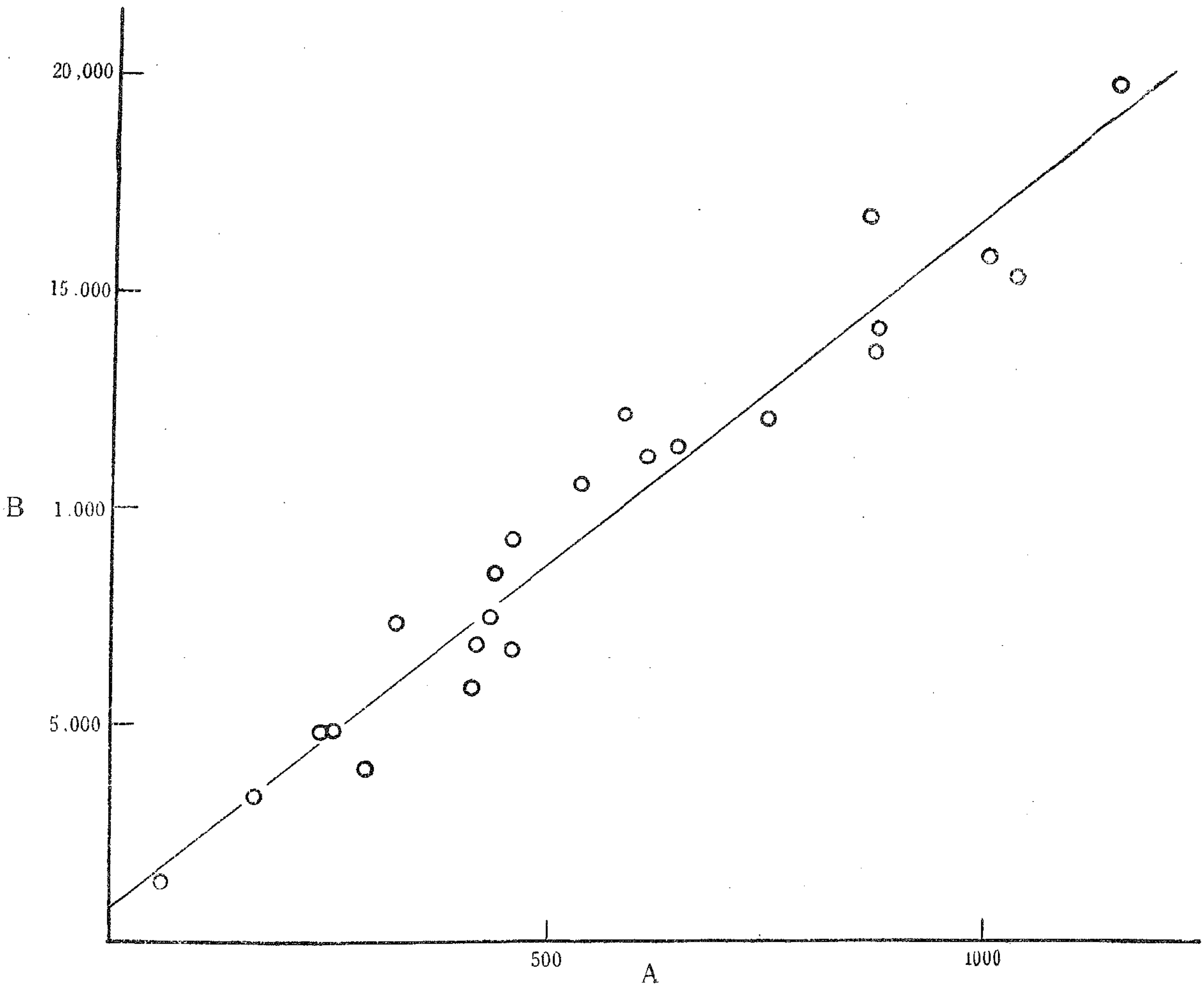

Fig. 16. Relation graph of both constants A and B.
Remarks : The point, (A=800, B=8,080), which seems to be apart from regression line, is obtained from the influence formula of the River Miyakoda upon Lake Hamana in Sept. 6, 1935, after heavy rain.

SUMMARY

1) Many influence-formulae are shown in table 1.

2) Silicate-chlorine relation can be represented even in surface water by the formula [Cl] = const. prevailing in bottom stagnant water, when the water is stagnant and the river can be regarded as being nearly dried up.

3) The relation between two constants, A and B, is represented by the formula: $B=807+15.9A$.

4) All relation-formulae pass through the point ([Cl] =15.9, $[SiO_2]$ =807) or thereabout.

5) The difference of the formulae can be represented simply by the difference of the inclination, thus we may be able to make a rough estimation of the influence of a certain river from any one arbitrary sample.

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