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Author(s)	Fukushima, Hisao; Yakuwa, Isao
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On the Photo-Electric Measurement of the Concentration of Suspended Load.

By

Hisao FUKUSHIMA and Isao YAKUWA

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A turbidimeter which employs a photo-cell and a lamp mounted in brass tubes has been constructed and adjusted by the authors. With this apparatus, an attempt was made to determine the concentration of suspended load by measuring the transmission of light through the water. In this paper, a description of the apparatus and the results obtained between September, 1951 and November, 1952 on the Ishikari River are reported with some discussion on the relative sizes of silt particles. The apparatus has been ascertained to be useful for the quantitative study of sediment transportation in a river.

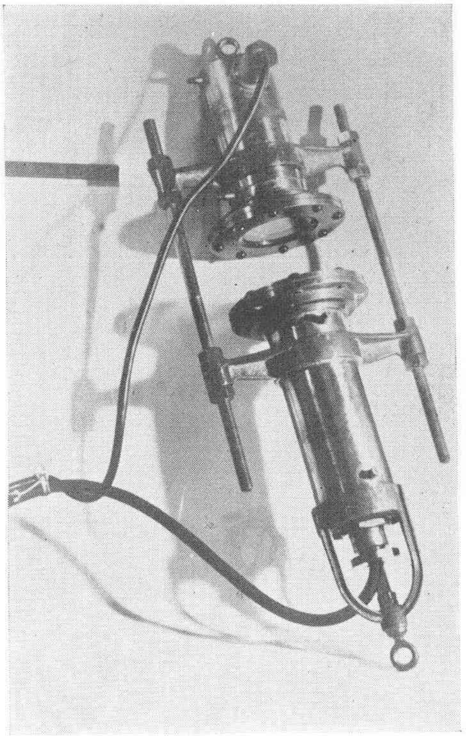


Fig. 1.

On the study of the transmission of light in the sea or lake by the photo-electric method, some works have already been published. But so far as the present writers know, in the case of river few investigations have been made either on turbidity due to suspended materials, or on the relation between the turbidity and the silt concentration. An apparatus emloying a photo-cell was constructed by the writers for the study of transmission of light through the suspension. It was designed for use in the field too. If the relation of turbidity to the mass of suspension for one river or stream is obtained, it will be possible to determine the concentration of suspended load without any sampling of water. By making use of this apparatus observations were made of the seasonal variation of the extinction of light in the water of the Ishikari River. The experiments were carried out with waters having the original concentrations and also with diluted water. These observations were made from September, 1951 to November, 1952. The water samples were collected at Ishikari at the mouth of the Ishikari River, and sometimes at Ebetsu, which is situated 25km up the river from the estuary.

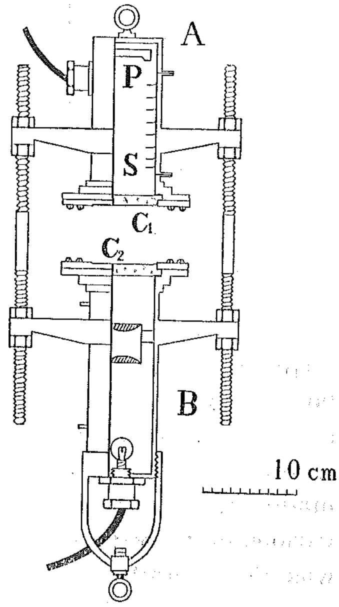


Fig. 2.

Apparatus and Measurement.

The apparatus consists mainly of two brass cylindrical tubes as shown in Figures 1 and 2. Tube B contains an automobile tail lamp as light source and a couple of convex lenses to make light beam from the lamp parallel. Stop S is furnished in the cylinder A, lest stray light should arrive at the photo-cell P, which is attached to the bottom of tube A. Circular glass plates C_1 and C_2 are set in brass frames and rubber packings. These two tubes are coupled by means of two rods as shown, so that the distance between C_1 and C_2 can be adjusted to the desired value. When the set of these tubes is immersed into water of lower temperature than the air the glass plates are fogged due to the condensation of water vapour. So dry air is blown into the tubes and tightly sealed.

On a boat a storage battery (6 volts, 60 ampere-hours), a slide resistance of 1 ohm, and an ammeter were connected in series to both ends of a captire cord from the lamp. The microammeter connected to the photo-cell, which was also on the boat, could be used for the current up to 150μA in full scale. The whole system of the apparatus is schematically shown in Fig. 3.

In the case of the actual use in measurement, firstly before the photo-cell was immersed into the water, the variable resistance R was

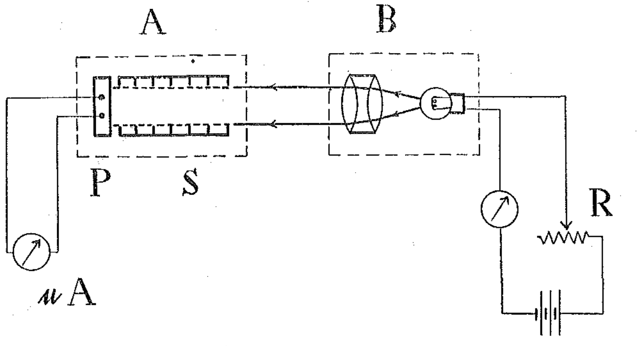


Fig. 3.

adjusted so that the reading of the microammeter was 100 μA or 90 μA. Then the tubes were sunk into the water whose transmissibility was to be measured. The length of the path of light in the water was always 6.0 cm. The observations of transmissibility were made two or three times a month at Ishikari together with observations of velocity of flow. The vertical distribution of transmissibility was almost uniform in the river. But when the saline water appeared at the depth under the fresh water, in the dearth period in summer and winter, the "Sprungschicht" was clearly observed between the saline and fresh water strata. Several experiments were added to study the extinction of the diluted samples. The water from the river was poured into a tank whose inside walls were blackened, and was mixed with a certain quantity of pure water in succession after each reading was finished, being stirred up lest sedimentation should occur.

The water whose transmissibility was to be measured was sampled to the amount of 2 litres by a water sampler. These samples were filtrated at the laboratory. They were desiccated and weighed carefully, Though the size distribution of the suspended materials generally varied with the phase of the river, the total mass of them was measured in this experiment.

Results and Discussion.

In Table 1, the silt concentration, m and the coefficient of extinction, k are given together with the date of observations and the velocity of flow v. The value of k is obtained by the formula

$$k = -\frac{1}{x} \ln \frac{i}{i_0} \qquad \cdots\cdots (1)$$

where x represents the length of the path of light through water in cm, i and i_0 are the photo-electric currents for turbid water and air respectively. The difference between pure water and air was almost negligibly small in this case.

In Fig. 4, are plotted k of ecah water sample against the silt concentration, and to compare with them several values for Ebetsu and

TABLE 1.

	No.	Date		m (g/l)	k (1/cm)	v (m/sec.)
Curve I.	1	Mar.	14, 1952	0.037	0.173	0.42
	2	”	27	0.056	0.231	0.29
	26	May	16	0.037	0.174	0.45
	30	June	6	0.055	0.219	0.78
	38	July	22	0.024	0.104	0.30
	39	”	23	0.017	0.098	—
	40	”	”	0.013	0.057	—
	41	”	”	0.021	0.097	—
	42	Aug.	25	0.031	0.139	0.93
	43	Sept.	8	0.044	0.199	1.02
	44	”	22	0.020	0.092	0.98
	47	Nov.	7	0.024	0.086	0.60
Curve II.	3	Mar.	31, 1952	0.129	0.407	—
	11	April	21	0.032	0.057	—
	12	”	”	0.022	0.059	0.38
	13	”	”	0.024	0.060	0.28
	27	June	6	0.055	0.192	0.48
	28	”	”	0.060	0.215	0.84
	31	”	”	0.086	0.221	0.75
	32	”	”	0.066	0.222	0.81
	33	June	6, 1952	0.078	0.223	0.75
	34	”	”	0.074	0.236	0.81
	35	”	”	0.055	0.209	0.59
	36	”	”	0.050	0.185	0.47
	37	”	”	0.050	0.191	—
	45	Oct.	23	0.084	0.255 ~ 0.249	1.01
	46	”	”	0.091	0.279	—

	No.	Date		m (g/l)	k (1/cm)	v (m/sec.)
Curve III.	6	April	17, 1952	0.160	0.381 ~0.376	1.38
	7	"	"	0.162	0.387	1.18
	8	"	"	0.139	0.382	1.16
	9	"	"	0.140	0.368	—
	10	"	18	0.159	0.338	—
	14	"	21	0.153	0.363 ~0.316	1.58
	16	"	"	0.128	0.364	1.36
	17	"	"	0.141	0.330 ~0.302	1.28
	18	"	"	0.138	0.336	1.10
	19	"	"	0.150	0.330	1.02
	20	"	"	0.161	0.316	1.13
	21	"	"	0.149	0.339	1.63
	22	"	"	0.164	0.374	1.45
	23	"	"	0.152	0.391 ~0.379	1.58
	24	May	2	0.224	0.615	0.48
	25	"	3	0.164	0.436	1.45
Curve IV.	4	April	7, 1952	0.385	0.652 ~0.537	1.03
	5	"	11	0.545	1.036	1.45
	15	"	21	0.202	0.401	1.49
	29	June	"	0.176	0.309	0.78

some for Moiwa along the Tokachi River[1] are added.

It is assumed that the silt particles are opaque spheres and k is proportional to the sum of the sectional area of these particles. The assumption that

$$k \backsim Nd^2 \qquad (d > 10\mu) \qquad \cdots\cdots (2)$$

has been ascertained by Richardson[2], where N is the number of particles of diameter d in a unit volume. If m is the mass of the silt in a unit volume, then

$$m \backsim \frac{4}{3}\pi r^3 N\rho \qquad \cdots\cdots (3)$$

1) The data of the Tokachi River is by courtesy of Mr. Dokoshi of the Department of Agriculture, this university.
2) Richardson, E. G.; J, Sci. Instr. 13, 229 (1936).

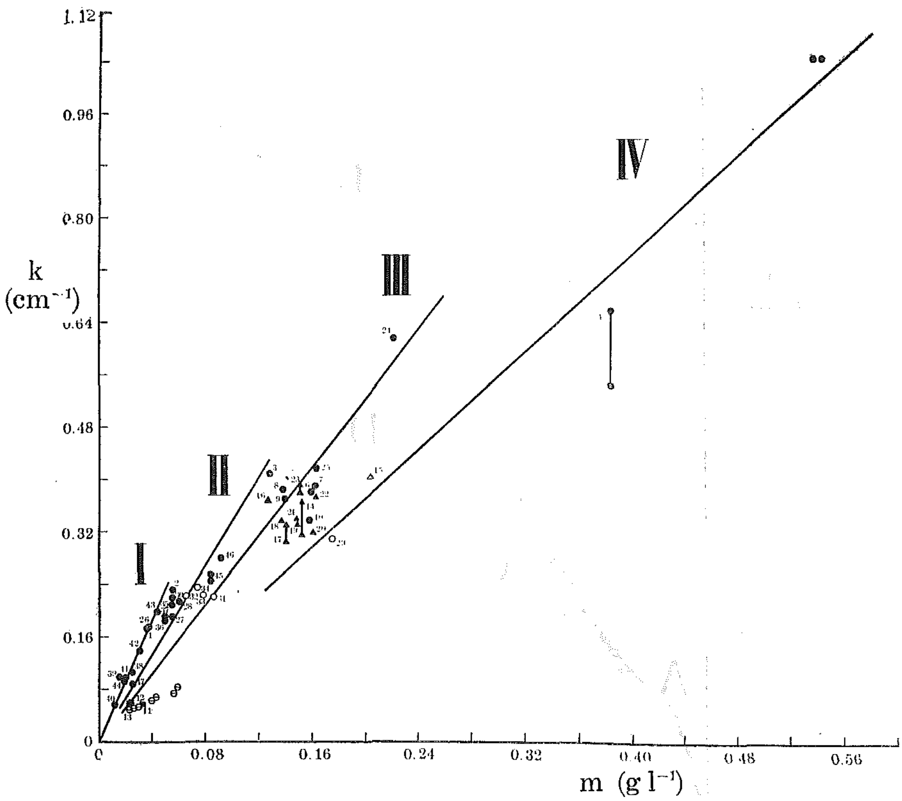


Fig. 4.

● …… Ishikari (surface) ▲ …… Ebetsu (surface)
○ …… Ishikari (near the bed) △ …… Ebetsu (near the bed)
⊖ …… Moiwa (surface)

where ρ is the density of a particle of radius r.

In the case of dilution, N was reduced step by step and r is constant, so from (2) and (3)

$$k \propto m \quad \cdots\cdots\cdots\cdots \quad (4)$$

i.e. k-m curve is a straight line through origin. k and m in the diluting experiments are plotted in Fig. 5. They can almost be regarded to be on straight lines. Slight deviations of their extrapolation from the origin are supposed to be due to the errors of volume measurement which accumulated with the successive dilutions. In the case of $m=$ constant, we obtain

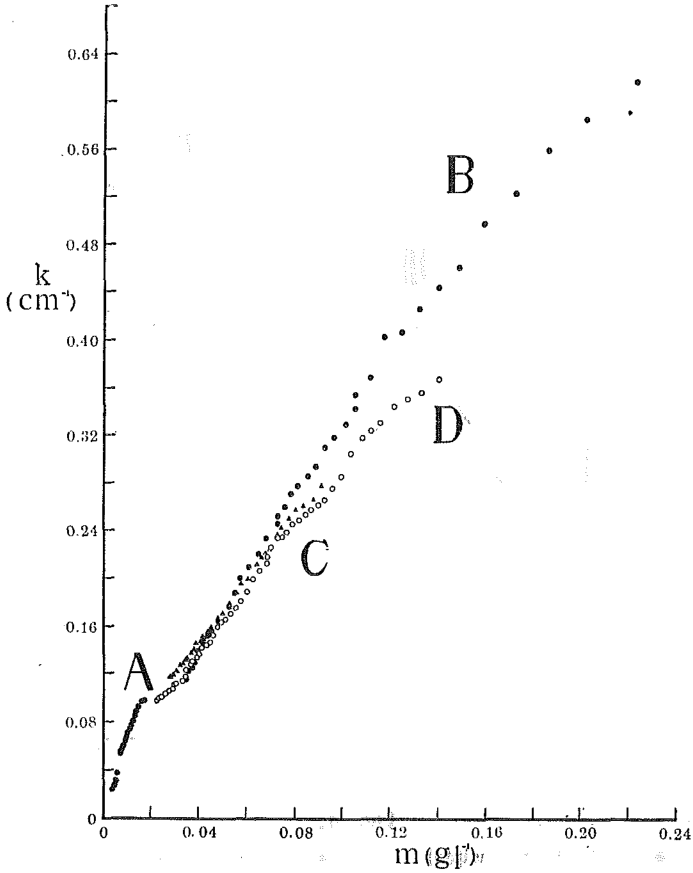


Fig. 5.

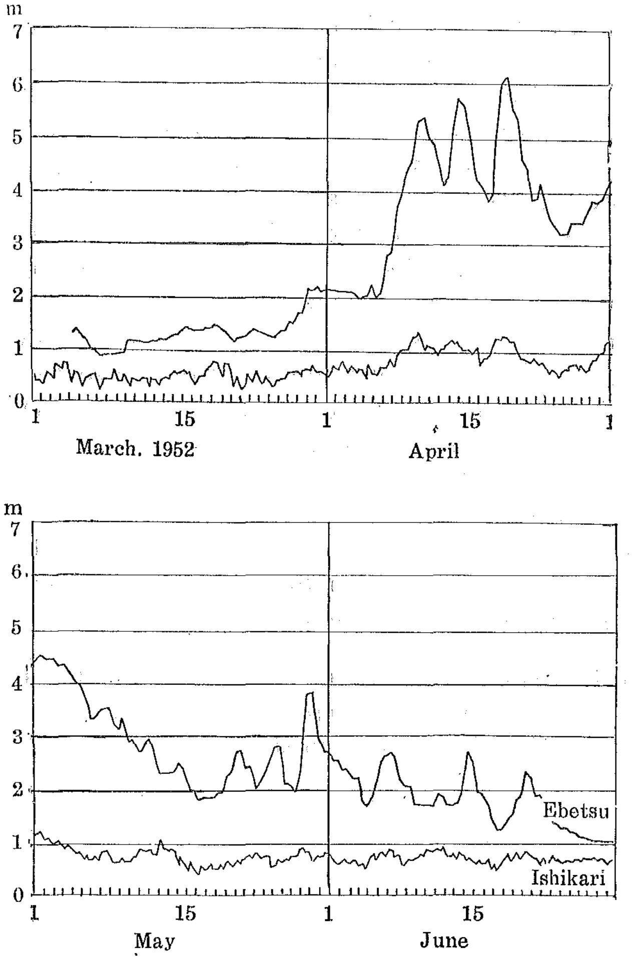
A ······ Data of July 23, 1952
B ······ Data of May 2, 1952
C ······ Data of October 23, 1952
D ······ Data of April 17, 1952

$$k \backsim \frac{1}{r} \qquad \cdots\cdots\cdots\cdots \qquad (5)$$

Formula (5) means that the radii of the particles contained in each samples of the same concentration, are inversely proportional to the extinction coefficient.

In Fig. 4, it is found that these points are classified into four groups which are represented by four straight lines respectively. The grouping is tabulated as in Table 1.

Fig. 6.



The daily variation of the water stages observed at Ishikari and Ebetsu are shown in Fig. 6, to see the characteristics of these groups.

Twelve observations which belong to group I are with a few exceptions, those of low-water in summer and before spring flood. The particle size is small and velocity is also slow. The observations represented by curve III are those of maximum elevation at the time of the spring flood due to snow thawing. The velocity is high and the particles are very large. Curve II represents the intermediate group between I and III. These observations were carried out in the front or the later part of the flood wave. The results obtained above are all in good agreement with the theoretical expectation. Lastly the points of group IV, which has the largest size of particles, are those of April 7, and of April 11, when the spring flood was progressing day by day. The silt concentration and the velocity of flow are greater than those of maximum time of the flood. Points No. 15 and No. 29 are not those obtained at the time of flood, but are values of the depth of 5 meters. It has been supposed that the water at depths immediately above the bed has relatively heavy silt concentrations due to the saltation load. These observations showed that in this case the suspended materials should contain many coarse particles.

Strictly speaking, the assumption that the size of particles is uniform is not true, but if each size distribution curve has a maximum at one value of radius, interpretations of *k-m* relations above mentioned would approximately be recognized.

From the data of the Tokachi River, as plotted in Fig. 4, it is shown that the silt particles are quite different in size and concentration from those of the Ishikari River, So it is expected that to obtain the *k-m* curve for the various rivers would be very interesting and valuable in the study of erosion and sedimentation.

We wish to express our thanks to Prof. Yoshiro Ikeda for his interest and encouragement. Thanks are also due to Mr. Tetsuzo Sasakawa for his able collaboration in the course of these experiments.