THE BEHAVIOR OF IRON IN PEORIA LAKE

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ABSTRACT.—Iron in Peoria Lake can be differentiated into several fractions, of which the great majority was found to be particulate Fe(III). The particulate Fe (III) possess several characteristics. Its concentration is much higher in the upper reaches of the lake than in the downstream sector; it can be correlated with water turbidity; there is a significant correlation between particulate Fe(III), particulate Fe(II), particulate silica, and particulate phosphate. The dissolved Fe(III) concentration is in excess of its solubility, suggesting that it is not in a complete soluble form.

Aqueous solutions of iron have been intensively studied during the past decade. Many investigations have been concerned with the chemical behavior of iron as related to thermodynamic and kinetic models (Hem and Cropper, 1959; Hem, 1960; Stumm and Lee, 1960; Morgan and Stumm, 1964; Ghosh, O'Connor, et. al., 1966; Larson, 1967). Numerous as such studies have been, most of them have dealt with distilled water systems. The results obtained from such systems can not, without modification, be applied to a natural water system. For example most iron studies have been performed under abiotic laboratory conditions. Such studies though informative are not substantive; biological activity does affect the iron behavior in natural water, as suggested by Lee and Hoadley (1967). Furthermore, Morgan and Stumm (1964) have shown, in distilled water studies, that iron most likely plays a role in surface chemical reactions. As natural water contains suspended solid such as detritus, silt, and clay, it is conceivable that the surface phenomenon may be even more important in the natural water system. In an effort to gain some insight into the behavior of iron in a natural water environment the observations presented herein were made, as a part of a limnological study of Peoria Lake.

PROCEDURE

Peoria Lake, is fundamentally a wide basin of the Illinois River (Figure 1). It has been channelized for navigation and is located in one of a series of eight pools extending from the river's confluence with the Mississippi River. At normal pool stage the lake is about 13 miles long and has an average width of 1.5 miles; the maximum depth is 5 meters with a considerable portion of water depth less than 1 meter. During the study period, the residence time within the lake ranged from 2 to 6 days.

Five transects and nine stations were established on the lake (Figure 1). On four of the transects two stations were assigned; one was representative of the channel area and the other the shallower area of the lake. A single station was

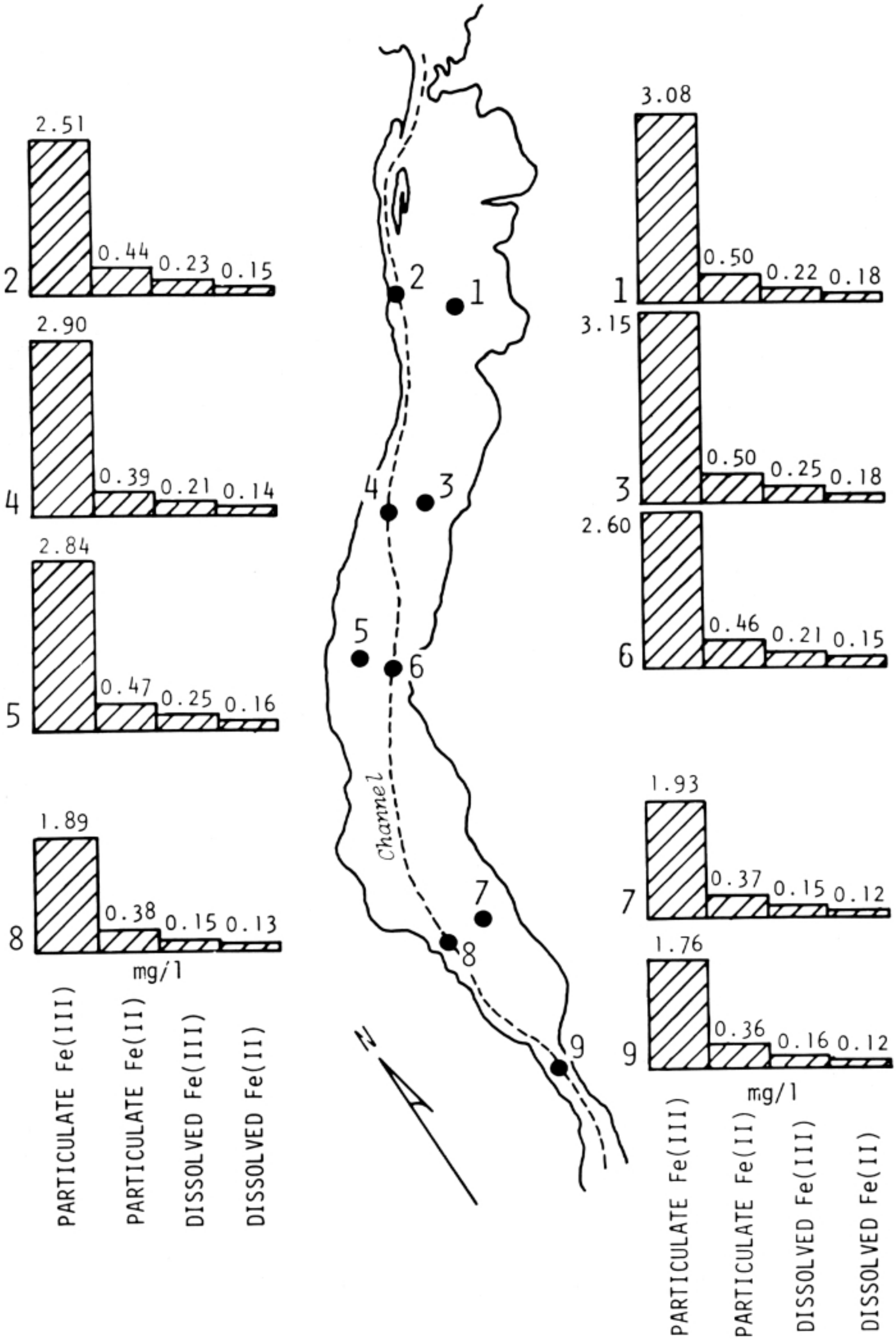

FIGURE 1. Various iron fractions in Peoria Lake.

selected in the "Narrows", the outlet of the lake.

Water samples were collected at the nine stations at a depth of 1 meter using a Kemmerer sampler. Collection was made at one to two weeks intervals. All water samples were transferred to glass bottles which were prewashed with acid.

ANALYTICAL METHODS

The turbidities of all samples were determined immediately upon delivery to the laboratory. The method used closely parallel the Jackson candle method (American Public Health Association, 1965). Also upon delivery a portion of each sample was filtered through an 0.45 micron membrane filter.

The filtrate and unfiltered portions of each sample were separately analyzed for Fe(II) and total iron by using the phenanthroline method (American Public Health Association, 1965). In this manner the concentration of the various fractions of iron were determined, i.e., dissolved Fe(III) and Fe(II) and particulate Fe(III) and Fe(II). All analyses were performed within 48 hours after the collection of samples.

Dissolved oxygen, temperature, and pH were determined in the field. Dissolved oxygen and temperature were determined by an oxygen analyzer manufactured by Precision Sientific Company, and pH was determined by a Beckman model N pH meter.

RESULTS AND DISCUSSION

Distribution

Some characteristics of Peoria Lake water are shown in Table 1. In general, the water is turbid and rich in the bicarbonates of calcium and magnesium. Nutrient levels

TABLE 1.—Chemical Characteristics of Peoria Lake

	Range	Mean**
Temperature, °C	5.0 — 27.3	19.5
Turbidity, JTU	28.0 — 296.0	115.0
pH	7.57 — 8.69	8.19
Dissolved Oxygen, mg/l	1.4 — 15.3	5.6
Alkalinity*, mg/l	136.0 — 213.0	165.0
Hardness*, mg/l	215.0 — 324.0	268.0
Iron (total), mg/l	0.69 — 13.01	3.21
Ferrous	0.16 — 1.89	0.58
Ferric	0.52 — 11.12	2.63
Fluoride, mg/l	0.17 — 2.06	1.08
Silica (total), mg/l	1.96 — 14.80	6.10
Nitrogen (total), mg/l	3.88 — 14.98	8.85
Nitrate (NO_3–N)	1.65 — 11.12	4.33
Ammonia (NO_3–N)	0 — 5.45	1.15
Organic–N	0.64 — 9.84	3.37
Phosphorus (total), mg/l	0.47 — 3.02	1.13
Orthophosphate–P	0.25 — 2.30	0.84
Polyphosphate–P	0 — 0.67	0.15
Organic Phosphate–P	0 — 0.58	0.14

* expressed as $CaCO_3$
** based on 225 samples

are quite high and upstream wastes discharges are reflected in the relatively low dissolved oxygen content.

The distribution of various iron fractions is shown in Figure 1. Of the four iron fractions, particulate Fe(III) was dominant and constituted over 70 percent of total iron in the lake waters. The next abundant fraction was particulate Fe(II), followed by dissolved Fe(III), and dissolved Fe(II), in that order.

An attempt was made to determine the fluctuation of particulate Fe-(III) from station to station. A two-way analysis of variance was made. The result showed that particulate Fe(III) concentration was significantly different from station to station, i.e., it was not uniformly distributed in the whole lake. Further attempts were made to group the nine stations into three regions; stations 1 and 3, stations 2, 4, 5, and 6, and stations 7, 8, and 9. The analysis of variance was again made in three regions separately. The results showed that there was no longer significant variation of iron concentration within each region. Figure I depicts the results for the three regions.

Particulate Fe(III) was highest at station 1 and 3, ranging from 3.08 to 3.15 mg/l. The intermediate zone was at station 2, 4, 5, and 6, ranging from 2.51 to 2.90 mg/l. The lowest concentrations were at stations 7, 8, and 9, ranging from 1.76 to 1.93 mg/l. This distribution pattern is the same as that observed for turbidity in the lake (Wang and Brabec, 1969).

It should be noted that the percentage of particulate Fe(III), with regard to the total, ranged from 73 to 80. The highest level was at station 2 with a gradual decrease to the lowest level at station 9. This was apparently due to a greater loss of particulate Fe(III) through precipitation along in the water course compared with that of other iron fractions.

If station 2 is considered representative of the inlet and station 9 the outlet of the lake the iron budget can be computed. Figure 2 depicts the results in terms of concentration and load. The positive iron balance indicates that the iron input is greater than the output with the consequence accumulation of iron within the lake.

The observed dissolved Fe(III) concentration averaged 0.20 mg/l which is ten times higher than the solubility of this fraction as cited in the literature (Stumm and Lee, 1960). This suggests that the preponderance of dissolved Fe(III) is not insoluble form but exist possibly as particles of less than 0.45 micron diameter. Shapiro (1964) reported the existence of $Fe(OH)_3$ in the form of a precipitate and peptized sol.

Iron and Turbidity

Since turbidity can be regarded as an index of particulate matter, an attempt was made to correlate particulate iron and turibidty. Figures 3 and 4 show the relationship between turbidity and Fe(III) and turbidity and Fe(II), respectively. Regardless of location within the lake, particulate Fe(III) and Fe-(II) were significantly related with turbidity. A similar analysis with dissolved Fe(III) and Fe(II) did not reveal a similar relationship.

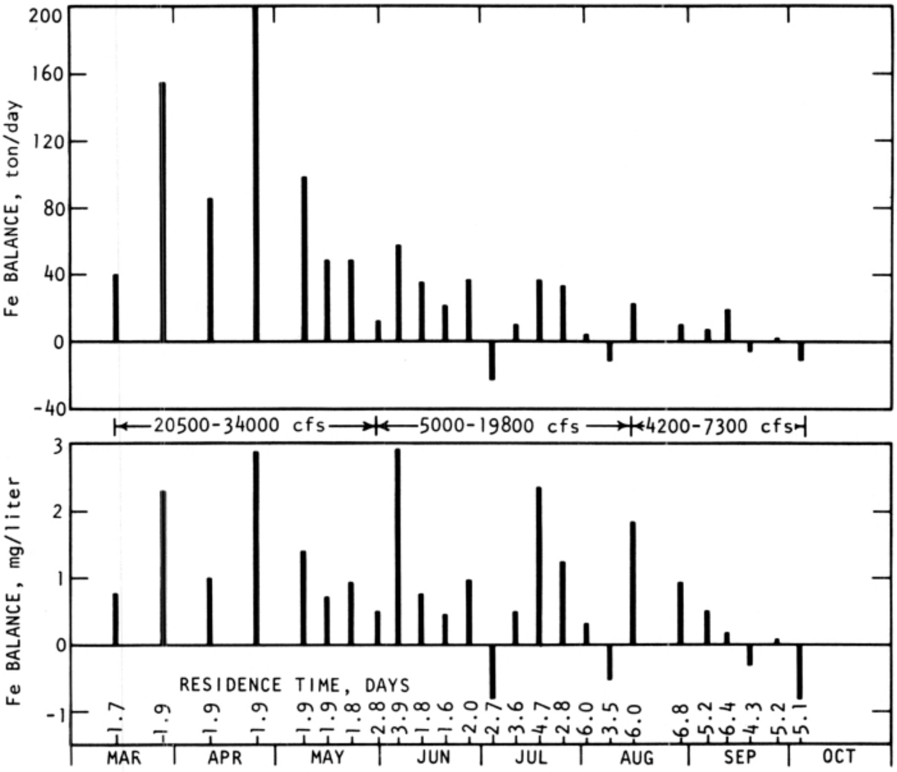

FIGURE 2. Iron budget in Peoria Lake.

The precise structure of particulate iron on the surface of particulate matter is unknown. As previously mentioned it can be in the form of a precipitate granule, film, or peptized sol (Shapiro, 1964). It would seem likely that a strong linkage exist between iron and particulate matter. Iron, being an electrophylic substance, is naturally inclined to attach to clay, a nucleophylic substance, the "backbone" of particulate matter in water.

Dissolved iron, mentioned earlier as not being truly soluble in Peoria Lake may be in the form of neutral salt or an electron-rich form which renders it free from electrostatic attraction to clay minerals or organic detritus.

Iron and Other Elements

A significant relationship between turbidity and particulate iron was observed. A similar relationship between turbidity and particulate silica was also found (Wang and Evans, 1969). It is thus logical to expect that particulate iron is also significantly correlated with particulate silica and phosphate. These relationships are shown in Figures 5 and 6 and summarized in Table 2.

The overall average concentrations

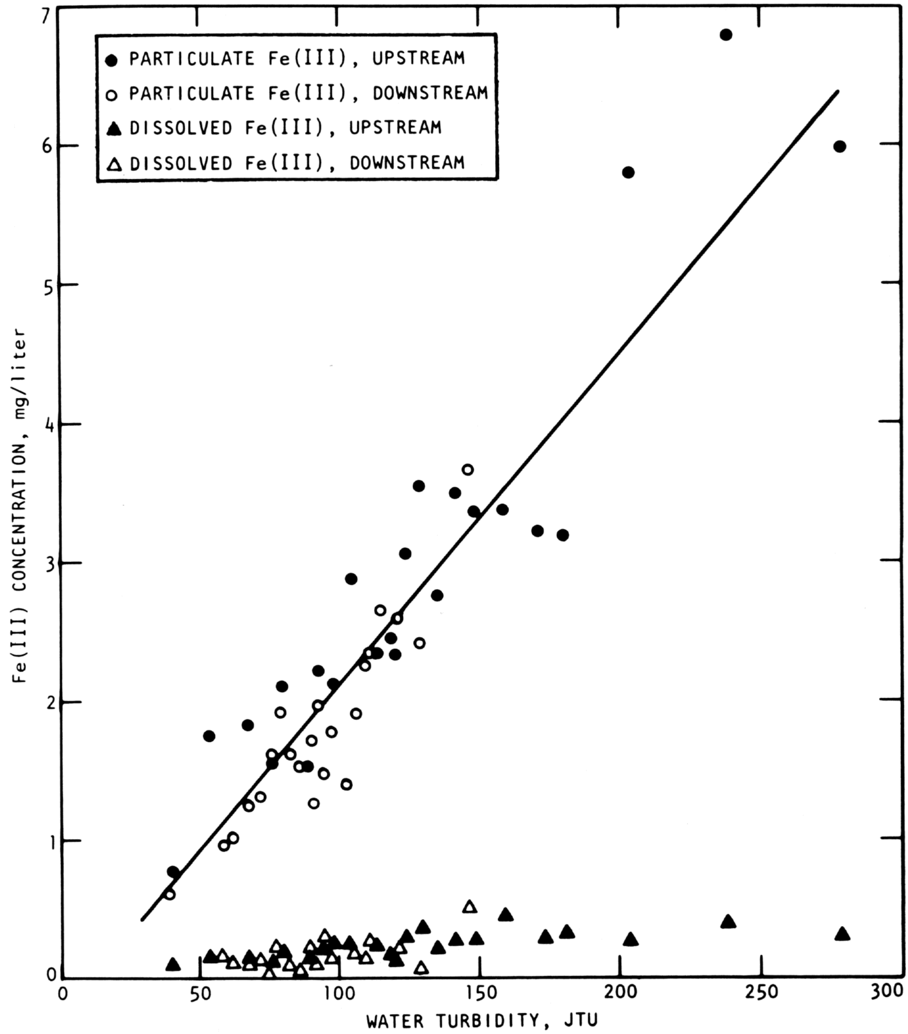

FIGURE 3. Relation between water turbidity and Fe(III) concentration.

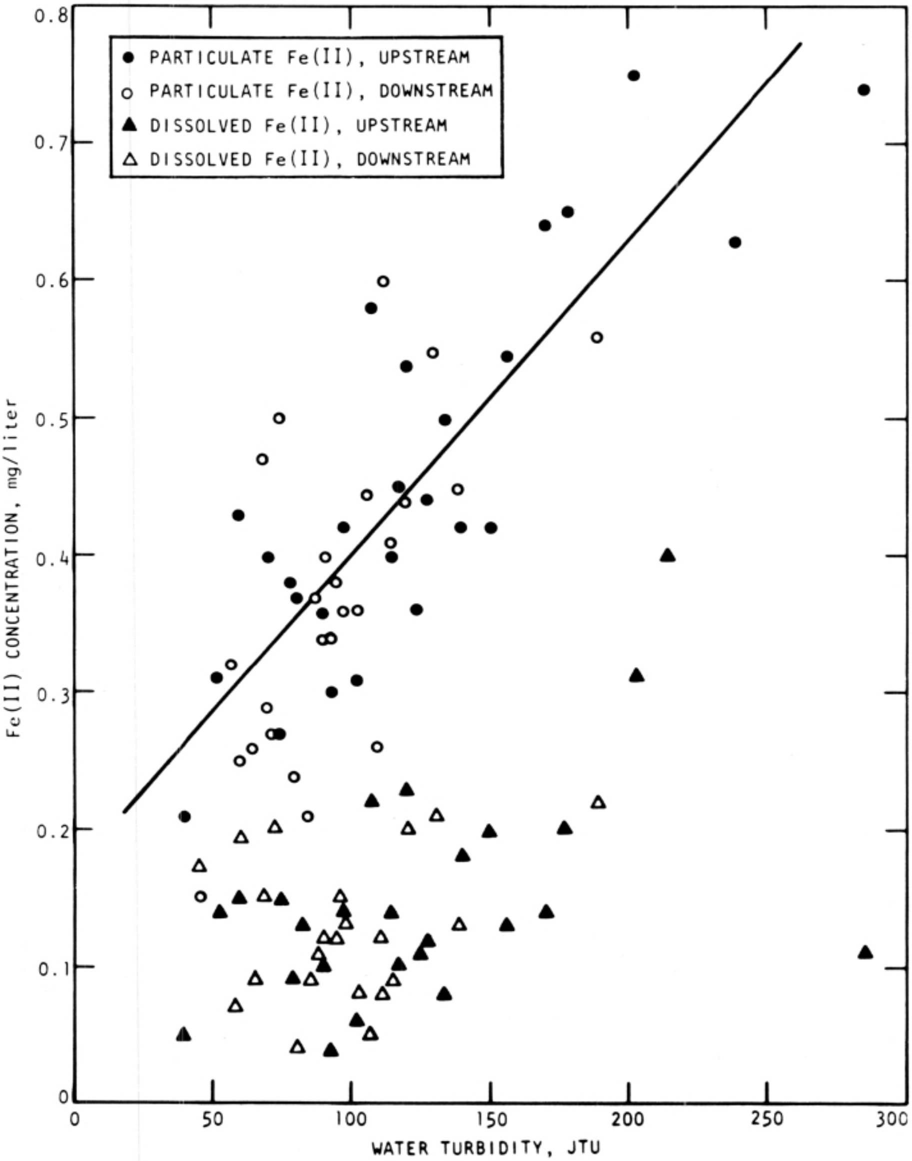

FIGURE 4. Relation between water turbidity and Fe(II) concentration.

TABLE 2.—Correlation Coefficients of Various Parameters in Peoria Lake

	Part. Fe(III)	Part. Fe(II)	Part. SiO_4	Part. PO_4	Turbidity
Part. Fe(III)	....	0.587**	0.704**	0.850**	0.854**
Part. Fe(II)	0.587**	....	0.218	0.257	0.751**
Part. SiO_4	0.704**	0.218	....	0.444*	0.454*
Part. PO_4	0.850**	0.257	0.444*	....	0.648**
Turbidity	0.859**	0.751**	0.454*	0.648**	....

* = 95% significance level
** = 99% significance level

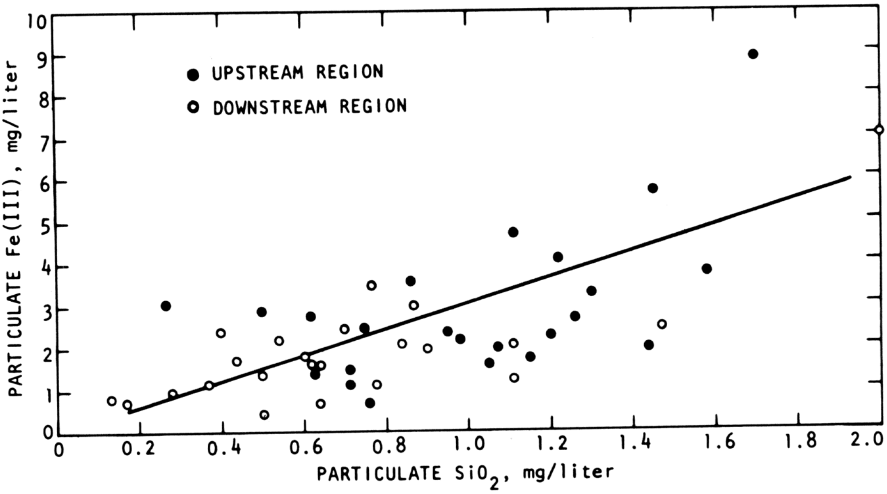

FIGURE 5. Relation between particulate silica and particulate Fe(III).

of particulate iron, silica, and phosphorus were 2.48, 1.80, and 0.42 mg/l, respectively. These values represent a molar ratio of 3.15, 2.15 and 1 in the same order. In other words, on particulate matter the computed sum of silica and phosphorus molecules was exactly same as the iron molecules. The result suggests a stoichiometric relationship among these three constituents.

The particulate matter in Peoria Lake is believed to be mainly silt and clay particles. These particles carry negative charges principally due to isomorphous substitution. In a water environment, these particles may associate with various elements through physico-chemical forces. Of the three constituents — particulate Fe(III), silica and phosphorus — particulate Fe(III) is the most likely one to attach to particulate matter. Silica and phosphorus may then link with particulate matter through the iron "bridge", a propounded mechanism in soil chemistry (Evans and Russell, 1959).

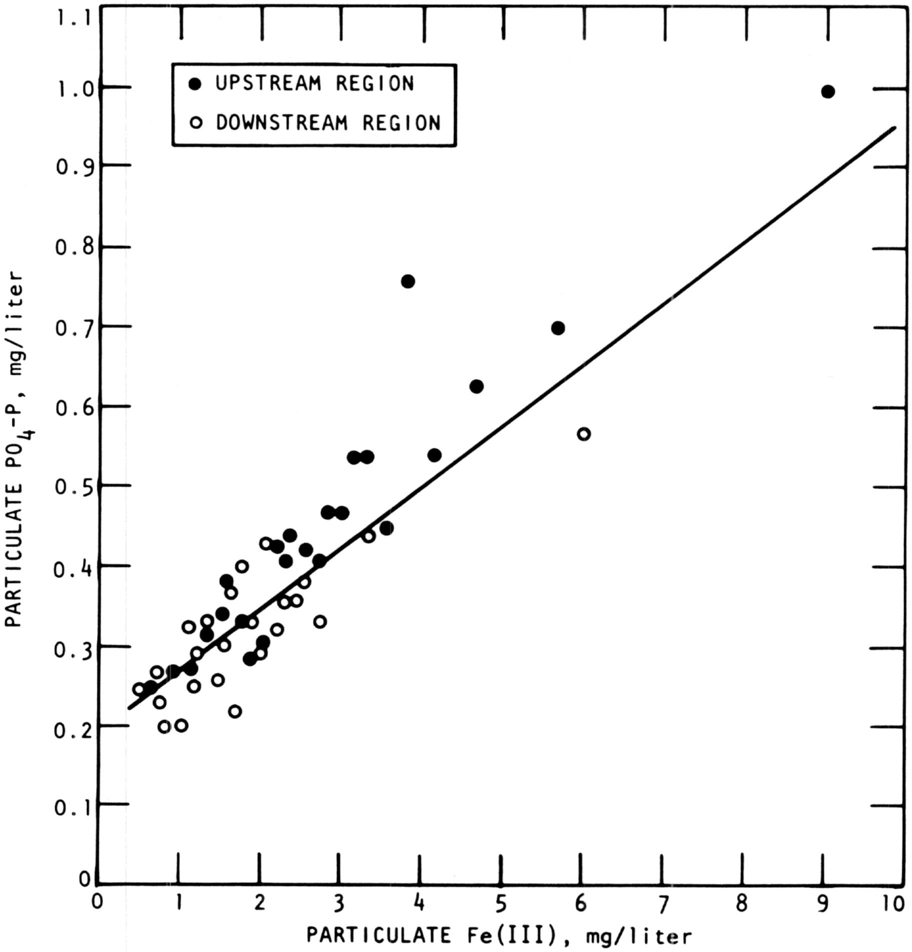

FIGURE 6. Relation between particulate Fe (III) and particulate PO_4-P.

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