

CROSS-SECTIONAL VARIATION IN THE CHEMISTRY AND SUSPENDED SEDIMENT LOAD OF THE ORINOCO RIVER AT CIUDAD BOLÍVAR

William M. Lewis, Jr. & James F. Saunders, III
University of Colorado,
Boulder, CO 80309.

ABSTRACT

Samples were taken at numerous points across the Orinoco River at Ciudad Bolívar. The samples were collected on three different dates: two during the season of low water (March) and one during the season of high water (September). Total particulates showed strong patterns of distribution both at high and low water. Particulate concentrations in the bottom two-thirds of the central portion of the cross section were as much as two to three times higher than particulate concentrations near the surface or the sides of the river. These were no major patterns in distribution of soluble ions at low water but there was a substantial increase from south to north across the river during high water, even though the nearest major tributary is 170 km upstream. The data show that integrating samplers must be used to characterize the soluble ion chemistry and suspended load of the Orinoco.

VARIACION EN LA COMPOSICION QUIMICA Y MATERIAL SUSPENDIDO A LO ANCHO DE UNA TRANSECCION DEL RIO ORINOCO EN CIUDAD BOLIVAR

RESUMEN

Las muestras provienen de una transecta a lo ancho del Río Orinoco en Ciudad Bolívar. Las muestras fueron colectadas en tres fechas diferentes: dos corresponden al período durante el cual el nivel de agua del río es bajo (Marzo) y la otra cuando el río está crecido (Septiembre). La distribución en la concentración total de partículas presentó patrones muy marcados durante ambos períodos de bajo y alto nivel de agua. La concentración de partículas en el perfil correspondiente a las dos-terceras partes del fondo, en la región central de la transecta, es de dos a tres veces mayor que la concentración de partículas en la superficie o en las márgenes del río. No se encontraron patrones marcados de distribución de iones solubles durante la época de bajo nivel de agua. No obstante, a pesar de que el tributario más cercano se encuentra a 170 km río arriba, se pudo apreciar un incremento en dicha concentración en dirección norte-sur a lo ancho del río. Los resultados indican la necesidad de utilizar muestreos integrales para determinar las características químicas de iones solubles y del material en suspensión del Río Orinoco.

INTRODUCTION

Two kinds of factors can cause major heterogeneity across the current in rivers: 1) the time required for mixing of water

from different sources, and 2) the settling of particulate materials. The degree of variation may be especially important over the cross sections of large rivers. Physical principles dictate that mixing lengths will be very long in large rivers, and the literature provides a number of examples.¹ From the papers of Gessner^{2,3} it is known that the larger tributaries of the Orinoco may retain their identity for many kilometers. The influence of gravity on particulates is also well known in principle but is often assumed negligible.⁴ While this assumption is frequently acceptable for small streams, it is very far from the truth for large rivers. For example, in a recent study of the Amazon; Curtis *et al.*⁵ and Meade *et al.*⁶ showed that sedimentation was responsible for much lower concentrations of particulate materials near the surface than near the bottom of the river and for unequal vertical distribution of particulate size fractions.

As part of a comprehensive chemical and biological study of the Orinoco River, we have studied cross-sectional variation of the river at points near Ciudad Bolívar and Puerto Ayacucho. The cross-sectional profiles at Ciudad Bolívar, to be reported here, provide examples of the amount of variation that can be seen in the river where the opportunity for mixing is maximum, since major tributaries are well upstream of Ciudad Bolívar (Figure 1). The cross-sectional profiles for the vicinity of Puerto Ayacucho will be reported elsewhere (F. H. Weibezahn, in preparation).

METHODS

The studies to be reported here were all made on the Orinoco River near Ciudad Bolívar, 0.5 kilometers above the Puente de Angostura. Cross sections were made both at high water and at low water. A high-water cross section was taken on 21 September 1982 when the maximum channel depth was 48 m, and low-water cross-sections were taken on 30 and 31 March 1982, when the maximum channel depth was 37 m. The two consecutive cross-sections taken in March provide documentation on the amount of stability that can be expected in cross-sectional patterns from one day to the next. One each date, several stations across the breadth of the river were selected as sampling sites (six stations in September and five in March). At each station, a series of samples was taken from the top to the bottom of the water column (3-m intervals in September, 5-m intervals in March). Each sample was taken with a 2.1-liter Van Dorn grab sampler attached to a 15-kg weight. Since the Van Dorn sampler is open at the top and at the bottom, it does not allow sedimentation to occur within the sampling chamber until the chamber is closed for collection of the sample.

The samples were filtered in the boat immediately after collection through Whatman GF/C glass-fiber paper (effective pore size, ca. 2 μ m) that had been dried and weighed. The filters were then dried at 65°C and reweighed. The amount of particulate material on the filter, expressed as mg/l, provides the estimate of total particulates to be reported here.

The filtrate was treated with cesium chloride and lanthanum oxide dissolved in sufficient hydrochloric acid to reduce the pH of the sample below 2. The filtrate was then analyzed

by atomic absorption for calcium, magnesium, sodium, and potassium. The samples were all analyzed together in random order so that slight deviations in the instruments or handling procedures would not influence the interpretation of patterns

in the river. The analyses included standards and standard spikes. The recovery of standard spikes averaged above 90 %.

RESULTS

Table I shows the mean value for total particulates and for the four major cations on each of the three sampling dates. The table also includes the standard deviations and the coefficients of variation ($100 \cdot s/\bar{x}$), which is an indication of relative variability. As expected, the total particulate concentrations were lower in March than in September. On both dates there was considerable variation, but both absolute and relative variation were highest at high water. In contrast to particulates, soluble cations were present in larger concentrations at low water than at high water. The heterogeneity of concentrations was always much lower for cations than for particulates. Relative variation (s/\bar{x}) was not noticeably higher at high water than at low water for all four cations.

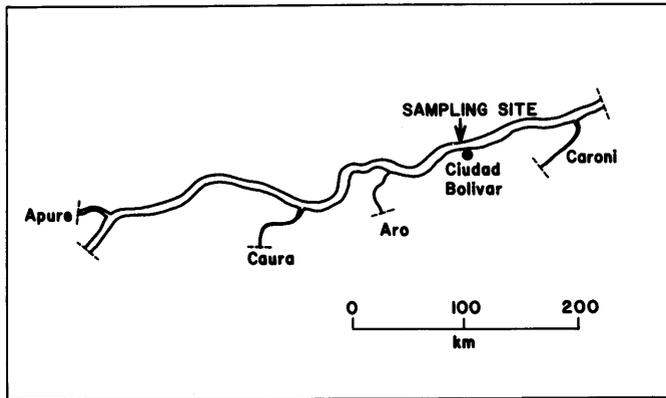


Figure 1. Sketch map of a portion of the Orinoco where the samples were taken.

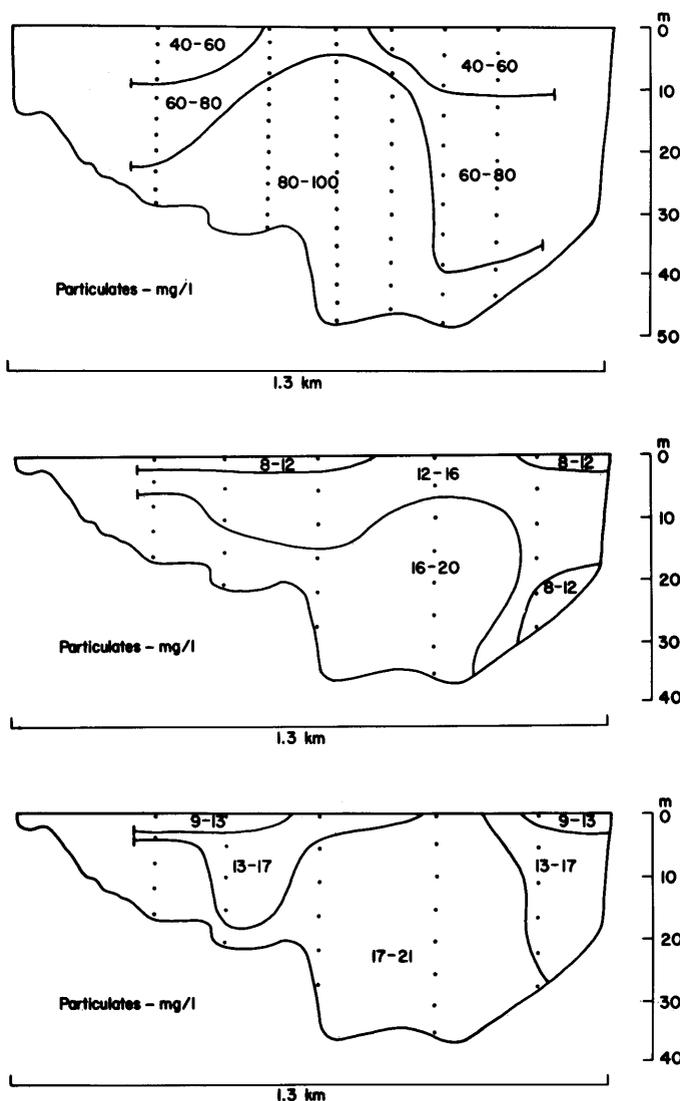


Figure 2. Contour diagrams of particulate concentrations (mg/l) on 21 September (top), 30 March (center), and 31 March (bottom) 1982 (mg/l).

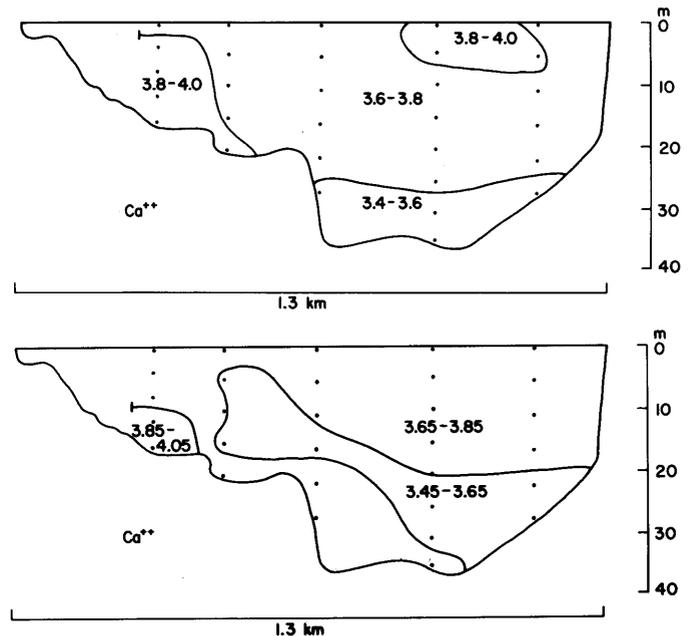


Figure 3. Contour diagrams for Ca^{++} on 30 (top) and 31 (bottom) March, 1982 (mg/l).

Table I also shows that there was a change in the particulate load and in the concentration of sodium in the Orinoco between March 30 and March 31. The change was surprisingly large considering the short amount of time (24 hours) that elapsed between the two samples series.

Figure 2 summarizes by means of contour diagrams the particulate concentrations in the cross sections of the Orinoco River for March and September. The pattern for all three sample sets is very similar. A core of high concentrations is found in the center of the river, particularly over the bottom two-thirds of the water column. In general, concentrations increased from the sides toward the center and from the top toward the bottom.

Both of the low-water sample sets (March) showed very high homogeneity in soluble cations. No pattern whatever could be discerned in the data for sodium, potassium, or magnesium. A very slight heterogeneity, which is depicted in Figure 3, was observed for calcium.

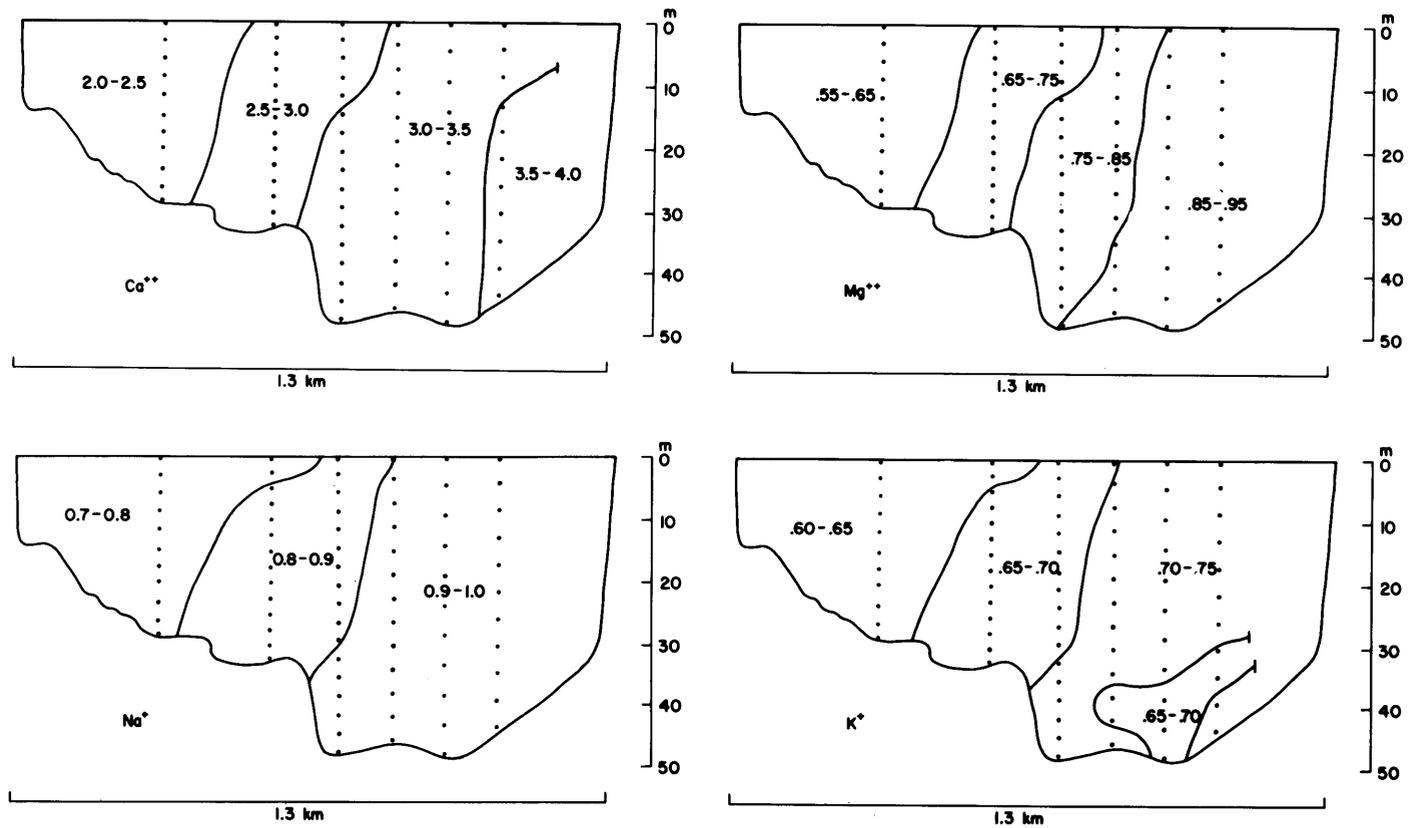


Figure 4. Contour diagrams for the four major cations on 21 September, 1982.

TABLE I

STATISTICAL SUMMARY OF THE CROSS-SECTIONAL DATA ON THE SAMPLING DATES. ALL CONCENTRATIONS ARE mg/l

	March 30			March 31			September 21		
	\bar{x}	s	C.V.*	\bar{x}	s	C.V.*	\bar{x}	s	C.V.*
Particulates	15.18	2.76	18.18	17.09	2.48	14.51	76.08	16.62	21.85
Ca ⁺⁺	3.74	0.77	4.55	3.69	0.09	2.44	3.05	0.37	12.13
Mg ⁺⁺	0.88	0.04	4.55	0.89	0.01	1.12	0.79	0.09	11.39
Na ⁺	1.95	0.07	3.59	2.44	0.04	1.64	0.89	0.07	7.87
K ⁺	0.73	0.07	9.59	0.78	0.04	5.13	0.69	0.05	7.25

* Coefficient of variation, % (100 · s/ \bar{x}).

The high-water sample series (21 September), unlike the low-water series, showed a definite pattern in cation concentrations over the cross-section. Figure 4 shows the contour patterns for all four major cations. The concentrations increased steadily from south to north across the river (right to left looking downstream). The increase was roughly 50% for all cations from the low side to the high side.

DISCUSSION

Patterns in distribution of particulate materials are reminiscent of those documented for the Amazon.^{5,6} The higher particulate levels deep in the water column reflect the sedimentation of particles from the upper water column. The tendency

of particulate concentrations to increase from the sides toward the center is explained by the higher velocity of the river near its core. It is clear that surface samples from the river would be potentially very misleading with respect to the concentration of particulates in the river. A sample taken halfway across the river and one-third down the current profile would produce an estimate very close to the velocity-weighted average of the entire profile, but could still be misrepresentative of particulate size and composition. It is evident from these results that use of a discharge-integrating sampler such as the type recommended by Meade *et al.*⁶ is best suited for representational sampling of the Orinoco River.

The Orinoco River does not receive any major tributaries in the immediate vicinity of Ciudad Bolívar. The Caura, which is very small in proportion to the Orinoco, brings in water

from the Guayana Shield about 170 km above Ciudad Bolívar. The Meta, carrying water from the Llanos, enters approximately 340 km above Ciudad Bolívar. Thus the Orinoco at Ciudad Bolívar has had maximum opportunity for mixing. Nevertheless, dissolved constituents show very significant lack of homogeneity at high water. The water from the south side of the drainage originates from the Guayana Shield, and this may explain the steady increase in concentration from south to north (right to left) across the profile of the river. The failure of this large river to homogenize, even many kilometers below the nearest major source of inflowing water, illustrates the necessity of integrated sampling, even for soluble materials.

ACKNOWLEDGMENTS

This work is a contribution to a collaborative Venezuelan-North American research effort on the Orinoco. We are grateful for logistical support by the Venezuelan Ministerio del Ambiente y Recursos Naturales Renovables and to the U.S. National Science Foundation (Grant DEB 8116725) for financial support. We thank Dr. T. Swain, Mr. M. Benson, Mr. S. Hamilton, Ms. Suzanne Sippel, and Ms. Mary Jo Surbrugg for doing the field and lab work.

REFERENCES

1. Hynes, H. B. N.: *The Ecology of Running Waters*. Univ. Toronto Press, Toronto. 555 p., 1970.
 2. Gessner, F.: *Limnologische Untersuchungen am Zusammenfluss des Rio Negro und des Amazonas (Solimoes)*. Internat. Rev. ges. Hydrobiol. 45: 55-79, 1960.
 3. Gessner, F.: *Zur Limnologie des unteren Orinoco*. Internat. Rev. ges. Hydrobiol. 50: 305-333, 1965.
 4. Beaumont, P.: Hydrology. p. 1-38 in *River Ecology* (B. A. Whitton, ed.) Blackwell, London, 1975.
 5. Curtis, W. F., Meade, R. H., Nordin, C. F. Jr., Price, N. B., and Sholkovitz, E. R.: *Non-uniform vertical distribution of fine sediment in the Amazon River*. Nature 280: 381-383, 1979.
 6. Meade, R. H., Nordin, C. F. Jr., and Curtis, W. F.: *Sediment in Rio Amazonas and some of its principal tributaries during the high-water seasons of 1976 and 1977*. Simposio Brasileiro de Hidrologia Vol. 2, p. 472-485, 1979.
-