RECONNAISSANCE OF SEDIMENT TRANSPORT AND CHANNEL MORPHOLOGY IN THE LOWER RÍO BERMEJO BASIN, ARGENTINA—with a section on reconnaissance of the Lower Río Pilcomayo basin, Argentina and Paraguay

U.S. GEOLOGICAL SURVEY
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By JOHN R. RITTER

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Thomas S. Kleppe, Secretary

GEOLOGICAL SURVEY

V.E. McKelvey, Director

For additional information write to:

Chief Hydrologist
U.S. Geological Survey, WRD
409 National Center
Reston, Virginia 22092

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CONVERSION FACTORS

Factors for converting from the International System of Units (SI) used in this report to English units are given below to three significant figures in some cases. However, when converting from metric to English equivalents, use only the number of significant figures consistent with the values given in metric units.

<u>Metric (SI) units</u>	<u>Multiply by</u>	<u>English equivalents</u>
millimeters (mm)	0.0394	inches (in)
meters (m)	3.28	feet (ft)
kilometers (km)	.62	miles (mi)
square kilometers (km ²)	.386	square miles (mi ²)
cubic meters per second (m ³ /s)	35.3	cubic feet per second (ft ³ /s)
kilograms (kg)	2.2	pounds (lb)
kilograms per cubic meter (kg/m ³)	.0623	pounds per cubic foot (lb/ft ³)
tonnes (t)	1.1	tons, short
tonnes per square kilometer (t/km ²)	2.85	tons per square mile (tons/mi ²)

RECONNAISSANCE OF SEDIMENT TRANSPORT AND CHANNEL MORPHOLOGY IN THE
LOWER RÍO BERMEJO BASIN, ARGENTINA--with a section on reconnaissance
of the Lower Río Pilcomayo basin, Argentina and Paraguay

By John R. Ritter

ABSTRACT

The Lower Río Bermejo in many ways is atypical of most rivers. In general it narrows as it flows downstream; its flow decreases downstream even though the average annual rainfall at its mouth is twice that at its head (1,200 mm vs. 600 mm) but its suspended-sediment discharge increases considerably downstream.

The Lower Río Bermejo begins where the river breaks out of the Andes Mountains. At first it flows over an alluvial fan in a wide braided channel with low banks that are overtopped during floods. Leaving the braided channel the river meanders for the remainder (80 percent) of its length in a narrow channel with high banks that do not seem to have been overtopped recently. The meanders are frequently cutoff, and along the river there are many oxbow lakes. There are also several abandoned stream channels. Old soil horizons, commonly seen in the banks, and terraces indicate the river has downcut. Tectonic movement in the basin probably has had a considerable effect on the river. The overall gradient of the Lower Río Bermejo along the channel is 18 cm/km; the slope of the land surface in the basin parallel to the river is 32 cm/km.

Water discharge and suspended-sediment concentrations have been measured at El Yacaré and El Colorado, both of which are in the meandering part of the river. In 1970-71 the river at El Yacaré, the upstream station, transported about half the suspended sediment transported at El Colorado and less than the Upper Río Bermejo brought into the Lower Río Bermejo. Therefore, between the head of the Lower Río Bermejo and El Yacaré (445 km) there was net deposition and between El Yacaré and El Colorado (575 km) there was net erosion. The river at El Yacaré was narrower, deeper and swifter than at El Colorado.

The Río Pilcomayo is quite different from the Río Bermejo even though they may appear similar on a map. The Río Pilcomayo disappears near Laguna Escalante. The Río Pilcomayo from Villa Montes, Bolivia to the Laguna is called the Río Pilcomayo "Superior" and the river which appears about 160 km downstream is called the Río Pilcomayo "Inferior." The Río Pilcomayo "Superior" commonly overflows its banks and changes its channel. It transports about 100,000,000 tonnes^{1/} of sediment per year and the average-annual concentration of suspended sediment is more than 6 kg/m³. The Río Pilcomayo "Inferior," which seems not to have flooded in several years, is meandering.

^{1/} Metric tons

INTRODUCTION

The Río Bermejo (pl. 1) is one of the largest rivers in northern Argentina. Its basin is divided into two subbasins: the Upper and Lower Río Bermejo basins, the division point of which is near the confluence of the Río Bermejo and its main tributary the Río San Francisco (pl. 1). The two subbasins are quite dissimilar: the upper basin is mountainous with altitudes ranging from 284 to 6,200 meters (m), whereas the lower basin sloping to the southeast is almost topographically featureless with a difference in altitude of only 225 m between Embarcacion and Formosa, a distance of 700 kilometers (km). This report is concerned chiefly with the sediment transport and geomorphology of the Lower Río Bermejo.

Knowledge of sediment transport and channel morphology is important to understanding the suitability of a river for irrigation, hydroelectric power development, and industrial use. Sediment often is considered the main pollutant in a river. It can damage machinery, fill reservoirs, canals and ditches, and create shoaling in harbors. Knowledge of channel morphology is necessary for planning water intakes, diversions, and other river-side structures.

This report is part of a cooperative technical program between the Government of Argentina and the Organization of American States to evaluate the water resources of the Río Bermejo basin and to plan for its development.

Purpose and Scope

The author, at the request of the Organization of American States, was assigned by the U.S. Geological Survey to make a sedimentological and geomorphological reconnaissance of the Río Bermejo and the Río Pilcomayo with emphasis on the Río Bermejo. This was done during August and September 1974. Field trips were made to the Río Bermejo basin during August 11-19 and September 4-7 and to the Río Pilcomayo basin during August 29-September 4.

The principal purpose of this report is to describe the Lower Río Bermejo, its geomorphology and sediment transport from observations and calculations made during the author's reconnaissance of the river. Present sediment problems are emphasized and an attempt is made to suggest other sediment problems that may occur from the future development of the river for hydroelectric power and irrigation.

In addition, rates of sediment transport of the Río Pilcomayo, which rises in Bolivia and flows along the Argentina-Paraguay border, have been calculated and observations of the river are described. Similarities and differences of the Ríos Bermejo and Pilcomayo are discussed and a program for further study of each river is suggested.

Figure 1.--Sketch map of South America showing the general location of the Río Bermejo and Río Pilcomayo basins.

Previous Investigations

Two reports on the Río Bermejo basin have been written by members of the U.S. Geological Survey (USGS) who were assigned to the Organization of American States. Arnow (1971) described the damsites in the Upper Río Bermejo basin, assessed the geology of the area at the damsites and recommended procedures for further evaluation of the damsites. Porterfield (1972) made a reconnaissance of sedimentation in the Upper Río Bermejo basin, which included calculating the rate of sediment transport at several sites. He also briefly described the Lower Río Bermejo and commented on its sediment problems.

Acknowledgments

This reconnaissance was made possible by the full cooperation and support of the Organization of American States (OAS) and the Government of Argentina (GOA). The help of Conrado Serrentino, Mission Chief the Río Bermejo Project of the OAS, and Eitel Braun and Nelson da Franca of the OAS was deeply appreciated. Dora Lopez, Alfredo Serra, Mario Nigro and Jorge Manfredi of the GOA accompanied the author on the field trip along the Lower Río Bermejo during August 11-19. They not only were informative and helpful but also made the trip a pleasure when the conditions sometimes were far from pleasant. Pablo Kleiman of the OAS and Thomas Maddock, Jr., of the USGS accompanied the author during the field trip to the Ríos Pilcomayo and Bermejo on August 29-September 6. Their thoughts and suggestions about the morphology and sedimentology of the two rivers are incorporated in this report. The author is grateful to all the above people and to the many others who contributed ideas, time and assistance to preparing this report. A special thanks is given to Agua y Energia Electrica (AyEE) of Argentina for providing unpublished data used in this report and to Dora Lopez for allowing the use of several figures from her unpublished report on the Lower Río Bermejo.

PHYSICAL SETTING OF THE RÍO BERMEJO BASIN

The Río Bermejo basin encompasses an area of about 190,000 km². The upper basin is about 50,000 km²; the lower basin about 140,000 km². The latter figure, however, is a gross estimate because the drainage area of the lower basin is poorly defined due to the flatness of the region and includes the total OAS study area of the Lower Río Bermejo basin shown in plate 1. Some of the study area consists of streams not tributary to the Río Bermejo. The river falls only 245 m between its confluence with the Río San Francisco and its confluence with the Río Paraguay, a distance of about 1,343 km by river; therefore, its average gradient is about 18 centimeters per kilometer (cm/km). Besides the present river channels, the most obvious differences in topography in the lower basin are caused by abandoned river channels and old terraces.

The Lower Río Bermejo flows through three general vegetation zones. From Embarcación to Presidencia Roca (pl. 1) the river passes through the Gran Chaco, an area of dense brush and small trees (monte) intermingled with swamps. Some of this area is used for logging and farming, but generally it is sparsely populated. From Presidencia Roca to about Puerto Velaz the river flows through an area of swamps and grasslands dotted with palm trees. Many farms and ranches are in this area. The area from Puerto Velaz to the mouth of the river is mostly swampy, although the banks of the river are well defined.

West of Presidencia Roca there are few streams, but east of Presidencia Roca there are several small, deeply cut streams with steep, high banks that flow to the Río Paraguay (pl. 1). The area below Presidencia Roca may represent an old delta and the streams may be old mouths of the Río Bermejo.

The Lower Río Bermejo basin is cut by at least 20 known subsurface faults most of which lie approximately perpendicular to the river, and, according to Alfredo Serra (oral communication), two known domes underlie the basin. The tectonic movement in the area probably influences the direction of the course of the river and the deposition and erosion patterns along some reaches of the river. In an area as flat as the Lower Río Bermejo basin, vertical tectonic movements would be readily sensed by the river, which would adjust to such movements. For example, aerial photographs show many abandoned meanders and other evidence of river instability in the stretch above Fortín Lavalle. This area appears to be in a section cut by a horst^{1/}. Although the river is still meandering below the horst, the river seems to be more stable there.

The climate in the Lower Río Bermejo basin is variable. The winters are almost rainless whereas the summers may have considerable rainfall. The precipitation decreases westward, the eastern edge of the basin receiving about 1,200 millimeters (mm) of rain per year; the western edge about 600 mm (Porterfield, 1972). Temperatures in the basin may exceed 50° Celsius (C) in the summer and drop to less than -5°C in the winter.

Because of the flatness of the lower basin and the low banks in its upper reaches, the river may change its channel during floods. Evidently this has happened several times in the past as maps and aerial photographs show several abandoned channels in the basin. For example, the Lower Río Bermejo about 90 years ago abandoned its old channel which is now called the Río Bermejito or Antiguo Cauce del Río Bermejo (the old channel of the Río Bermejo). Its present channel from about El Colgado to Fortín Lavalle is usually referred to on maps as Río Teuco (pl. 1).

^{1/} A horst is an elongate, relatively uplifted, crustal block that is bounded by faults on its long sides (American Geological Institute, 1972, p. 338).

RECONNAISSANCE OF THE RÍO BERMEJO--
AUGUST 12-18, and SEPTEMBER 4-5, 1974

Twelve sites on the Río Bermejo were visited by the writer and his colleagues during August 12-18, 1974, when the river was low (pl. 1). On the way to the Lower Río Bermejo the party travelled between Salta and Oran along highway 34 which parallels the Río San Francisco. Several tributaries of the Río San Francisco were crossed, most within a few kilometers of their mouths. The channels of most of these tributaries were choked with coarse sediment that ranged in size from sand to boulders. Such deposits imply that these sites on the tributaries are parts of an alluvial fan where the tributaries and the Río San Francisco were incapable of further transporting either the sediment load at the rate that it was delivered or the size of the sediment delivered. The deposition seems to have pushed the Río San Francisco eastward.

The Río San Francisco itself (fig. 2) was observed near Yuto, about 55 km above its mouth. Its flow at that time was 29 cubic meters per second (m^3/s) and the recently deposited material along its banks was composed of sand and fines. The banks, about 3 m high, showed evidence of recent erosion. The coarse sediment, being transported and deposited by the tributaries, apparently is not being transported to this reach of the river.

The farthest upstream site on the Río Bermejo that was visited was the damsite at Zanja del Tigre (fig. 3) in the upper basin; the farthest downstream site was about 20 km above its mouth. For comparison, the velocity, width, and bank height of the river at each of the 12 visited sites were visually estimated; thus, they are only gross approximations. The sizes of the bed material, likewise, were estimated, but were lumped into gravel ($> 2 \text{ mm}$), sand ($0.062\text{-}2.0 \text{ mm}$), and fines ($< 0.062 \text{ mm}$), which includes silt and clay. A summary of the observations is given in table 1.

On September 4, 1974, the Río Bermejo from Ingeniero G. N. Juarez to its mouth was observed from an airplane. This flight confirmed that the sites visited on the field trip of August 12-18 were typical of their reaches. Channel deposition, which is more obvious from the air than channel erosion, usually was seen in the areas where it would be expected, such as the inside bends of meanders. Many abandoned meanders, oxbow lakes (fig. 4) and abandoned river channels were seen throughout the landscape, particularly in the reach between Ingeniero G. N. Juarez and El Colorado. The river may be trying to shorten itself as many more areas of recent cut offs and potential cutoff were seen than newly forming meanders. However, the erosion necessary for the formation of new meanders may occur during high flows. The present meanders, as expected, are now eroding on their outer bends. Although deposition seemed to be more prevalent than erosion at low flow, erosion is probably the dominant process over a span of a year. No areas of recent large-scale deposition, such as flood plain deposits, were seen.

Figure 2.--Río San Francisco near Yuto. Downstream view.

Figure 3.--Río Bermejo at Zanja del Tigre damsite.

Table 1.--Summary of observations made at 12 sites along the Río Bermejo, August 12-18, 1974

	Site	River pattern	Maximum velocity (m/s)	Channel width (m)	Bank height (m)	Bed material	Comment
Upper basin	Zanja del Tigre	straight	2	120	Left-4 Right-12	gravel sand, fines	
	Embarcación	straight	1.5	200	8	gravel, sand, fines	Less gravel than Zanja del Tigre.
Lower basin	El Espinillo	braided	1?	1,000	Left-1.5	sand, fines	Many islands. Bank interlayered with several laminae of sand and silt, 3 to 50 cm thick. Recent bank deposition.
	El Colgado	braided	2	500	Left-1.5	fine sand	Recent deposition top of bank.
	El Yacaré	meander	1.5	150	Left-6	fine sand	Recent cutoff.
	Las Lomitas	meander	1.5	250	Left-5 Right-8	fine sand, fines	4 levels of old soils in banks.
	Ferry near Fortín Lavalley	meander	2	100	6	fine sand, fines	Channel seems to be changing position.
	Presidencia Roca	meander	1.5	75	Left-6 Right-13	fine sand, fines	3 levels of old soils in right bank
	El Colorado (at gage)	straight	<1	200	Left-13 Right-6	fine sand, fines	3 levels of old soils in banks. Terraces.
	Km 100	straight	1	150	Left-6 Right-15	fine sand, fines	1 level of old soils in banks.
	Puerto Velaz	straight	<1	150	Left-6 Right-8	fine sand, fines	1 level of old soils in banks Banks are vegetated.
	20 km above mouth	meander	<1	250	Left-6	fines

Figure 4.--Oxbow lake in Río Bermejo basin.

On September 5, the river was revisited at Puerto Velaz, Km 100, and El Colorado. The river at those sites had not changed substantially since the August trip. At El Colorado, however, the river at the intake to the city water supply was visited for the first time. The flow there indicated that the streambed had antidunes, the only manifestations of bed movement seen along the river during the August and September field trips.

Discussion of Observations

From table 1 some generalizations of the flow and channel geometry of the river can be drawn, but it is emphasized that the figures in the table are based on visual estimates and thus must be considered gross values. For example, on the field trip the maximum velocity was estimated, not the average velocity, and may be exaggerated. However, it is the relative values that are important. Table 1 shows that as a generalization the Río Bermejo after it joins the Río San Francisco below Embarcacion narrows as it flows toward the Río Paraguay. In a downstream direction the flow velocity decreases, the river banks become higher, and the bed material becomes finer.

The Lower Río Bermejo passes through at least four different phases. Between Embarcacion, where the river leaves its upper basin, and El Colgado the river is wide and braided (fig. 5). There are many islands that would be inundated during high water and the banks are only a little more than a meter high. In this reach the river flows on a steep alluvial fan. From El Colgado to Presidencia Roca the river is narrow and very meandering with high banks (fig. 6). There is evidence of recent erosion and deposition in the channel, and many oxbow lakes and cut-off meanders can be seen. The river here is very unstable. From El Colorado to Puerto Valez, although it still has high banks and is narrow and meandering, the river appears to be more stable and is relatively straighter (fig. 7). Downstream from Puerto Velaz the river again meanders increasingly as it approaches the Río Paraguay (fig. 8). The zones defined above by the four phases of the river's behavior agree in general with the physiographic zones that the river passes through as defined by Eitel Braun (unpublished report OAS).

The banks of the river in its braided reaches are easily eroded and are easily overtopped. Sediment was deposited recently on top of the banks. On the other hand, where the banks are higher and the river pattern no longer is braided, there is no evidence of recent bank overtopping. Many towns and small farms are located along the banks, especially in the reaches below the Gran Chaco. The old soil zones in the banks of river at sites below El Colgado, however, attest to periods of deposition in the past, probably centuries ago. The upper parts of the banks generally are much more erodible than the lower parts (fig. 9), indicating changes in lithology or consolidation.

Figure 5.--Map of Río Bermejo near El Espinillo.

EXPLANATION FOR FIGURES 5 AND 6

Observation site
Terrace scarp
Depression
Terrace
Bank

Drainage line
Line of ancient meander
Point bar
Direction of flow

Figure 6.--Map of Río Bermejo near Las Lomitas.

Figure 7.--Río Bermejo near El Colorado.

Figure 8.--Río Bermejo at its mouth.
Río Paraguay is large river on left.

Figure 9.--Banks of the Río Bremejo near El Yacaré. Note differential erosion of top and bottom.

Sediment is being deposited in the channel as well as on the flood plain in the braided stream section. The flood plain in this section is extensive. Sediment deposition in reaches of the river below the braided section is mostly only along a bank that is opposite an eroding bank. This erosion and deposition pattern is not only prevalent in the meanders but also in the straight reaches such as those near El Colorado (fig. 7). Most of the erosion seems to be bank erosion although the old soil zones and the terraces seen in some reaches indicate that the river has downcut its channel, possibly in response to tectonic uplift.

Most sediments carried by the Lower Río Bermejo must have been eroded from the Upper Río Bermejo basin and from its own channel. There are few tributaries to contribute sediment to the Lower Río Bermejo and there is little evidence of gully and sheet erosion. After the river has passed its confluence with the Río San Francisco (approximately the downstream limit of the Upper Río Bermejo basin), the area is so flat that there is very little drainage area from which sediment can be contributed to the river and addition of sediment to the river must come mostly from channel erosion.

Most sediment transported by the river probably is carried in suspension. Of the sites visited along the river, only at the intake to the municipal water supply at El Colorado was there evidence of bed movement. Most deposited material is finer than medium sand, sizes which could be easily carried in suspension. The width of a river sometimes is indicative of the way it transports sediment. A narrow river is considered to transport its sediment chiefly by suspension; a wide river by bedload transport. Thus in the narrow downstream reaches of the Lower Río Bermejo sediment may move chiefly in suspension. On the other hand in the wide braided upstream reaches of the river much of the sediment may be transported as bedload.

FLOW IN THE LOWER RÍO BERMEJO

Much of the data and information in this section was furnished by the Río Bermejo Mission of the Organization of American States in Buenos Aires. The quantity of sediment transported by a river is, of course, related to flow. Flow duration, maximum flow, daily flow, and the parameters used to measure flow (velocity, width and depth) are important to understanding the processes of sediment transport. Most of the annual flow of the Río Bermejo occurs from January through April.

Comparisons of the flows of the Río Bermejo at El Yacaré and El Colorado for the 1970-73 water years^{1/} are shown in table 2. The flow data for the 1973 water year at El Yacaré are incomplete as the station was discontinued after March 22, 1973. These comparisons show that the maximum flows and mean daily flows for each year were higher at El Yacaré, the upstream station, than at El Colorado, which is 575 river kilometers downstream. The differences in the mean daily flows for each year, although consistently less at the downstream station, are within the limits of accuracy of measurement.

^{1/} A water year is a year beginning September 1 and ending August 31 and is designated by the calendar year in which it ends.

Table 2.--Comparisons of flow of the Río Bermejo at
El Yacaré and El Colorado

Site	Water Year	Discharge, in cubic meters per second			
		Maximum instantaneous	Maximum daily mean	Minimum daily mean	Mean (a)
El Yacaré	<u>b/</u> 1973	--	2,158	12.0	--
El Colorado	1973	1,600	1,585	18.5	415
El Yacaré	1972	1,400	1,392	22.3	230
El Colorado	1972	--	1,134	21.6	213
El Yacaré	1971	1,540	1,522	10.0	298
El Colorado	1971	--	1,134	13.3	283
El Yacaré	1970	1,296	1,281	18.5	291
El Colorado	1970	1,096	1,083	17.6	283

a/ The mean daily discharge at the confluence of the Río Bermejo and Río San Francisco is: 1973-435 m³/s, 1972-266 m³/s, 1971-327 m³/s, and 1970-327 m³/s.

b/ September 1, 1972, to March 22, 1973.

The comparisons of the mean daily flows at El Yacaré and those for the Río Bermejo at its confluence with the Río San Francisco, 445 river kilometers upstream, also indicate a loss of water in a downstream direction (table 2). The peak flows at the confluence were much higher than at El Yacaré, too. Thus, peak discharges are attenuated as the flow proceeds downstream. The apparent loss of water may be attributed to over-bank flow between the confluence and El Yacaré, evaporation, transpiration or infiltration. Undoubtedly, all four, to some degree, are responsible for the water loss and each one may be the main cause at a given time and at a given place.

Although on a daily hydrograph the peak runoff periods of Río Bermejo at all three sites often have the same duration, the high flows sometimes continue for longer periods at the downstream sites. The effects of reduced peak flows and reduced mean flows on sediment transport cannot be evaluated at this time, but peak flows often carry most of the sediment transported annually by a river; thus, a reduction in peak flow, if there is also a loss in velocity, might be one reason for the loss of suspended sediment in the reach between the confluence with the Río San Francisco, and El Yacaré.

The flow-duration curves for the Río Bermejo at El Yacaré and El Colorado (fig. 10) show that during the 1970-71 water years the cumulative distribution of the flows at each site were fairly similar. The main difference noted in the graph is that the flows equalled or exceeded 10 percent of the time were higher at El Yacaré than at El Colorado. This graph, therefore, is another indication of the attenuation of peak flows as the river moves downstream.

The downstream reduction of the annual mean flow seems contradictory because the average annual rainfall increases in a downstream direction (600 mm/yr near Embarcacion; 1,200 mm/yr near the mouth of the Río Bermejo). A possible explanation is that little runoff from the rainfall gets into the lower reaches of the river because of the flatness of the land. Instead the rain seems to pond in shallow depressions that become swamps. The ponded water and infiltration from the Río Bermejo may provide ground water that feeds the numerous small streams that parallel the Río Bermejo near its mouth, although the swamps in the basin suggest that the percolation of water into the subsurface formations is very slow. The few small tributaries to the Lower Río Bermejo do not seem to contribute enough runoff to the river to replace water that has been lost along the way.

In summary, the Río Bermejo seems to lose water as it flows downstream from its confluence with the Río San Francisco. This loss may be due to several causes, and the small surface-water inflow to the river (because of the few tributaries and flat drainage area) and the amount of ground water inflow are insufficient to make up for the water loss.

Figure 10.--Flow-duration curves, Río Bermejo at El Yacaré and El Colorado, 1970-71 water years.

SEDIMENT TRANSPORT

The rates of sediment transport at the two stations (El Yacaré and El Colorado) on the Lower Río Bermejo were calculated by using flow-duration curves (fig. 10) and the relations between instantaneous discharge and instantaneous concentrations of suspended sediment (fig. 11) from data provided by the Río Bermejo Mission of the Organization of American States in Buenos Aires. It was assumed that the instantaneous relations would be about the same as the mean-daily relations.

Two periods of flow duration were used: a 2-year period, 1970-71 and a 4-year period, 1970-73. The latter represented the total flow duration that was available for each station; however, because the flow data at El Yacaré were incomplete for the 1973 water year (data were not collected after March 22) the suspended-sediment discharge calculated for the 4-year period at that station would be low because high flows occurred through the remainder of March and through April. Therefore, the 2-year period (1970-71) was used to check the relation of suspended-sediment discharge between the two stations. That 2-year period also coincided with the period used for the relationship between flow and suspended-sediment concentration.

The average quantity of suspended sediment discharged at El Yacaré was about 41,000,000 tonnes per year during 1970-73 and 31,500,000 tonnes per year during 1970-71; at El Colorado the average annual discharge was 82,000,000 tonnes and 60,000,000 tonnes respectively, for those same periods. Therefore, the calculations for the two periods indicate that the average quantity of suspended sediment passing El Colorado each year is about twice that passing the upstream station, El Yacaré.

The average quantity of suspended sediment transported at the confluence of the Río Bermejo and Río San Francisco was estimated to be 48,000,000 tonnes per year for 1970-71. For this 2-year period the average annual transport at Zanja del Tigre was estimated to be 34,000,000 tonnes, far below the average annual rate of 57,100,000 tonnes for the period of 1946 through 1967 at that site (Porterfield, 1972). Thus the values, given above for 1970-71 and 1970-73 should not be used for long-term estimates as those values are probably much lower than the long-term average discharge and therefore not representative.

Figure 11.--Suspended-sediment transport curves, Río Bermejo at El Yacaré and El Colorado, 1970-71 water years.

Nevertheless, in comparing those values for 1970-71:

<u>Suspended-sediment discharge (tonnes/year)</u>	<u>Site</u>
48,000,000	- Confluence with Río San Francisco
31,500,000	- El Yacaré
60,000,000	- El Colorado

it is apparent that suspended sediment was deposited between the Río San Francisco confluence and El Yacaré, and that suspended sediment was picked up between El Yacaré and El Colorado. Furthermore, a comparison of the sediment-transport curves (fig. 11), indicates that at low flows the river carried more sediment at El Yacaré than at El Colorado, at medium flows it carried about the same quantity of sediment at both sites and at high flows it carried much more sediment at El Colorado than at El Yacaré. This suggests that at low flows more sediment was deposited than eroded between the two stations, at medium flows erosion and deposition were about in balance, and at high flows more sediment was eroded than deposited. Most of the erosion probably took place in the river channel; some of the sediment deposited at lower flows was scoured and the channel banks were eroded. Most of the channel from El Yacaré to El Colorado has banks composed of material that is relatively resistant to erosion near their bottoms and material that is more easily eroded near their tops (fig. 9). Because of the resistant bottom layer, low flows would not undercut the toe of the bank and produce bank erosion or sloughing, whereas high flows may undercut the bottom of the erodible layer. Because of the differences in resistance to erosion between the sediment composing the bottom part of the bank and that composing the top part, the high flows should cause the major erosion of the bank. Of course, during high water much more area of the bank is available for erosion than at low water. The higher velocities also increase erosion and sediment transport.

Most sediment carried at the confluence of the Río Bermejo and San Francisco probably is deposited before it reaches El Yacaré. The braided section of the river below the confluence is an area where sediment is deposited on the flood plain and in the channel. Much of the sediment transported at El Yacaré may be eroded from the channel between there and El Colgado.

The average concentration of suspended sediment carried by the river during 1970-71 was about 3.8 kilograms per cubic meter (kg/m^3) at El Yacaré and 7.3 kg/m^3 at El Colorado.

Suspended sediment sizes at El Colorado were measured 14 times from September through December 1973. Those data (from Dr. Guillermo Scartascini of AyEE) show that the average percentages of clay, silt, and sand carried in suspension were 16, 42, and 43, respectively. The median size ranged from 33 to 54 microns (μ) and averaged 42 μ . About 90 percent of the sediment was finer than medium sand ($< 250\mu$).

The above discussion of sediment transport is based on data obtained during a period of 4 years or less during which the flow probably was lower than average. A year of very high flows could show other relations than those discussed and could have an effect on sediment transport that would be far more important on the river system than the period considered in this report. Thus, the values and interpretation given above should be used with caution until a period of high flows is observed and interpreted.

CHANNEL PATTERNS AND HYDRAULIC GEOMETRY

The channel patterns and hydraulic geometry of a river are responsive to the flow regimen of the river and the physical characteristics of its setting. The pattern varies with the quantity of sediment transported by the river, with the size of the sediment, and with the changes in flow and channel morphology. Morisawa (1968) revised an equation of grade by Rubey (1933) to read:

$$n \text{ SFP} = \frac{kL^a D^b}{Q^c}$$

where n is the channel roughness, S is the slope, F is the form ratio which has the greatest capacity for tractive load, P is the channel pattern, L is the quantity of sediment discharge, D is the average diameter of the bedload, Q is discharge and k is a constant. Pattern is, therefore, related to and determined by several environmental factors, a change in any one of which could effect a change in the pattern. Pattern is controlled also by geologic features.

The overall channel pattern of the Lower Río Bermejo is sinuous. If the sinuosity ratio proposed by Schumm (1963) is used:

$$\frac{\text{stream length}}{\text{valley length}} = \frac{1,343 \text{ km}}{730 \text{ km}} = 1.84,$$

it is readily seen that the stream length is almost twice that of the valley length and can be considered very sinuous. If the section of the river below El Colgado is used, the sinuosity ratio is more than 2.0.

The Lower Río Bermejo has two chief patterns: A braided pattern in the upper one-fifth of its length and a meandering pattern for most of the remainder. Between El Colorado and Puerto Velaz, however, the river is relatively straight.

The slope of a river is an important river parameter. The slopes of the Río Bermejo downstream from Zanja del Tigre, shown in table 3, are from the most recent (1974) profile. There are discrepancies between it and much older profiles and there is some question regarding its accuracy. However, the overall slope between the confluence with the Río San Francisco (Juntos de San Francisco) and the Río Paraguay (18 cm/km) seems to be correct.

Table 3.--Slopes of the Río Bermejo¹

Site	Elevation (meters)	Distance above mouth (kilometers)	Slope (centimeters per kilometer)
Río Paraguay	35	0	12
Pt. Pigo	41	50	9
Pt. Expedición	47	117	16
Pt. Zapallar (El Colorado)	60	196	14
Presidencia Roca	68	254	9
Tartagal	76	341	28
Confluencia	93	402	9
Colonia Km 503	102	503	20
Km 642	122	600	15
El Pintado (El Yacaré)	146	758	16
La Florencia	174	936	18
Las Llaves	196	1,060	19
Desemboque	234	1,255	50
Juntos de San Francisco	278	1,343	17
Manuel Elordi	281	1,361	73
Zanja del Tigre	311	1,420	

^{1/} From a profile made by Ing. J. Cacciolo, August 31, 1974.

Braided channels have been shown by Leopold and Wolman (1957) to be associated with a steeper gradient than meandering channels. As seen in table 3, the steepest slope in the Lower Río Bermejo is between the confluence with the Río San Francisco and Desemboque, which is in the braided section of the river. Braiding also usually is associated with easily erodible banks and with high bedload and sometimes occurs in a section where the stream cannot transport either the quantity or size of sediment supplied to it as bedload (Morisawa, 1968). Highly erodible banks were observed in the field along the braided section of the river. The amount of bedload carried by the river was not determined, but a wide river is usually considered to have a high bedload and the braided section of the Lower Río Bermejo is 4 km wide in places.

If the Lower Río Bermejo drops most of the bedload that it transports out of the mountains, in the braided section, its meandering downstream may be a means of dissipating energy no longer needed to transport bedload. Schumm (1963) has noted that the meandering reaches of rivers of the Great Plains in the United States have large amounts of silt and clay in the banks and beds and narrow and deep channels. This is also true of the meandering reach of the Lower Río Bermejo. The wide, shallow reaches of the Great Plains streams observed by Schumm tend to be relatively straight. As will be shown later, the straight reach of the Río Bermejo at El Colorado, is wider and shallower than the meandering reach at El Yacaré.

Meander wave length is related to drainage area, to bankfull flow (Dury, 1963), to the amount of silt-clay in the channels (Schumm, 1968) and to the channel width (Blench, 1971). Only the relation of meander wave length to channel width could be checked in this reconnaissance. At least 17 meander wave lengths and 10 channel widths were measured from aerial photographs of five areas to calculate averages for each area. The results are shown below in downstream order.

Meander wave length <u>(meters)</u>	Channel width <u>(meters)</u>
3,700	330
2,100	210
2,400	210
1,500	150
1,600	160

The ratio of meander wave length to channel width was thus about 10 to 1, which is the same ratio shown by Blench (1971) for other rivers.

The hydraulic geometry of the Lower Río Bermejo at El Yacaré and El Colorado was related to discharge (fig. 12) by a method described by Leopold and Maddock (1953). The flow velocities at the two sites increased at about the same rate for an increase in discharge, but the velocity for a specific discharge at El Yacaré is slightly more than that at El Colorado (fig. 12, table 4). The river at a given discharge at El Yacaré was much deeper than at El Colorado and average depth increased at a faster rate. On the other hand, the river at El Yacaré at a given discharge was narrower than at El Colorado, even though the width at El Colorado did not change much at discharges greater than $180 \text{ m}^3/\text{s}$. Table 4 shows that the river at the shallower but wider site, El Colorado, carried more suspended sediment at a given discharge than at the deeper but narrower site, El Yacaré, even though the velocities were slightly higher at the upstream station. This is not typical of many rivers. For example, Leopold and Maddock (1953, p. 24) have stated, "a wide river having a particular velocity is observed to carry a smaller suspended load than a narrower river having the same velocity and discharge." A wide, shallow channel commonly is associated with a decrease in suspended-sediment discharge and an increase in bedload.

The same interpretation can be made if flow-duration data are used instead of specific discharges. In table 5, however, it can be seen that the velocity at El Yacaré, at a discharge that is equalled or exceeded 1 percent of the time, is higher than that at El Colorado. Otherwise, the velocities are within 10 percent of each other.

Leopold and Maddock (1953, p. 26) stated "the rate of increase of suspended-sediment load with discharge is a function of the ratio:

$$\frac{\text{rate of increase of velocity with discharge}}{\text{rate of increase of depth with discharge}} //$$

The data for El Yacaré and El Colorado support the statement above. The ratio at El Yacaré was 0.67, and the rate of increase in concentration was 0.28 kg/m^3 for each increase in discharge of $100 \text{ m}^3/\text{s}$. The ratio at El Colorado was 0.83 and the rate of increase in concentration was 14 kg/m^3 for each increase in discharge of $100 \text{ m}^3/\text{s}$. These computations were made from data for discharges between 500 and $1,000 \text{ m}^3/\text{s}$ (table 4).

POSSIBLE EFFECTS OF DAMS ON THE REGIMEN OF THE LOWER RÍO BERMEJO

Several dams have been proposed for the Upper Río Bermejo (Arnow, 1971) the farthest downstream of which are on the Río Bermejo at Zanja del Tigre and on the Río San Francisco near Yuto. Dams and reservoirs regulate flow downstream and reduce the quantity of sediment being transported by the river. By doing so, they affect the channel downstream.

Figure 12.--Relations of width, depth, and velocity to discharge, Río Bermejo at El Yacaré and El Colorado.

Table 4.--Comparison of hydraulic geometry and concentration of suspended sediment at specific flows for the Río Bermejo at El Yacaré and El Colorado, 1970-71 water years

Site	Water discharge (m ³ /s)	Average velocity (m/s)	Width (m)	Average depth (m)	Average concentration of suspended sediment (kg/m ³)	Average suspended- sediment discharge (kg/s)
El Yacaré	1,000	1.9	140	4.0	4.6	4,600
El Colorado	1,000	1.7	217	2.7	12.8	12,800
El Yacaré	500	1.3	125	3.1	3.2	1,600
El Colorado	500	1.2	205	2.1	5.8	2,900
El Yacaré	100	.63	94	1.7	.75	75
El Colorado	100	.60	150	1.2	.89	89
El Yacaré	50	.54	70	1.3	.30	15
El Colorado	50	.50	105	.97	.40	20

Table 5.--Comparison of flow, hydraulic geometry, and concentration of suspended sediment
at specific flow durations for the Río Bermejo at El Yacaré and El Colorado,
1970-71 water years

Site	Percent time discharge equalled or exceeded	Water discharge (m ³ /s)	Average velocity (m ³ /s)	Width (m)	Average depth (m)	Average concentration of suspended sediment (kg/m ³)	Average suspended- sediment discharge (kg/s)
El Yacaré	1.0	1,420	2.2	150	4.6	5.6	8,000
El Colorado		1,080	1.7	215	2.8	14.0	15,000
El Yacaré	10	860	1.7	140	3.7	4.3	3,700
El Colorado		780	1.5	210	2.4	9.6	7,000
El Yacaré	50	115	.68	98	1.7	.90	100
El Colorado		120	.62	160	1.3	1.1	130
El Yacaré	90	27	.48	55	1.0	.13	3.5
El Colorado		27	.42	76	.8	.21	5.7

Prediction of the effects of dams on the downstream river is difficult. As Schumm (1968) stated "It is unfortunate for the student of rivers that neither water (Q_w) nor sediment (Q_s) discharge will change alone...The fact that channel depths will change directly with Q_w but inversely with Q_s and that gradient will decrease with an increase in Q_w but will increase with an increase in Q_s further complicates any attempt to predict the manner in which a river will adjust..."

Channel changes below some dams have been studied. For example, Leopold and Maddock (1953) noted that the channel of the Colorado River at Yuma, Ariz., about 560 km below Hoover Dam, was changed considerably after the construction of the dam. They concluded that the channel had degraded because of the reduction in suspended load and had become narrower because of the cessation of large floods. The mean velocity of the Colorado River at Yuma had decreased considerably due to an increase in roughness. Slope remained essentially constant.

If the conclusions just given apply to the Río Bermejo, the following are some effects that may be expected from reservoir development. The braided section of the river, which is close to the dams, would become deeper and narrower, which may imply that the river would change from a bedload-transporting channel into a channel transporting mostly suspended sediment. Channel deepening would imply that the material eroded from the bottom of the channel would be moved downstream. Moreover, if the slope remains relatively constant and the bankfull flow is reduced, the channel may try to change its form from a braided pattern to a meandering one, in accordance with the slope-discharge relationship shown by Leopold and Wolman (1957) for braided and meandering patterns.

The changes in the width of stream created by a dam sometimes are followed by rapid growth of vegetation along the new channel. Such growth helps to stabilize the banks and keeps the width stable at bankfull stages.

In a study of the adjustment of channel capacity downstream from a reservoir in the River Tone basin, southwestern England, Gregory and Park (1974) reported that the reduction of channel capacity downstream from the reservoir persisted to a point where the drainage area contributing to the river was at least four times that of the area draining to the reservoir. If that finding applies to the Lower Río Bermejo, the channel capacity of the entire lower river would be affected.

In the previous section, it was shown that the ratio of meander wave length to width in the Lower Río Bermejo was about 10 to 1. If the width of the channel is changed by the dams and the above ratio remains constant, the meander wave length would be changed, creating new erosion and deposition.

The suggestions of possible adjustment of the Lower Río Bermejo to upstream dams, mentioned in the foregoing paragraphs, are drawn from situations that may not apply to the Río Bermejo. Therefore, they should be considered only possibilities until more data are collected. Data collected before the dams are constructed can be used to help make predictions, and, combined with data collected after dam construction can provide relations that may have transfer value to other rivers such as the Río Pilcomayo.

RECOMMENDATIONS FOR FURTHER STUDY OF SEDIMENT TRANSPORT AND HYDRAULIC GEOMETRY OF THE LOWER RÍO BERMEJO

More information is needed to determine a sediment budget for the Lower Río Bermejo. The necessary data include flow parameters (velocity, width, and depth), slope, suspended-sediment concentration and discharge, grain-size analyses of suspended sediment and bed material, bedload, bed roughness, and water temperature. Most of these characteristics must be measured in the field; bedload, however, can be estimated indirectly from equations based on the other characteristics, if it cannot be measured directly. Only at El Colorado are some of the above characteristics now being measured on the Lower Río Bermejo. The station at El Yacaré has been discontinued.

The required data should be obtained at as many sites as possible, and over a wide range of flows although those at high water would be the most important. In addition to the active El Colorado station, stations for measuring daily sediment discharge are recommended: 1. Below the confluence of the Río Bermejo and Río San Francisco, to measure the quantity of sediment transported to the Lower Río Bermejo from the Upper Río Bermejo. 2. Below El Colgado to determine the net quantity of sediment depositing or eroding in the braided section of the river. 3. Near El Yacaré to make use of the data already collected in this area for correlations with conditions elsewhere, and 4. Near Puerto Velaz to determine the quantity of sediment passing through the river into the Río Paraguay. A station near Fortín Lavalle (Colonia Perin) might also be important because this location is near a change in physiography and vegetation. Except for El Colgado and El Yacaré all the above sites should be accessible during all times of the year. Measurements at other sites 100-200 km (river distance) apart could be made 3 to 6 times a year over several years.

Changes in the river pattern are now being studied by Srta. Dora Lopez from historical aerial photographs. If there are significant changes in physical features such as meander wave length and radius, channel width and river length, perhaps they can be related to hydrologic changes. Historical changes in the channel are a measure of the relative stability of the channel along its length and possibly can be used to determine volumes of erosion and deposition.

An accurate profile of the river should be made. This would be invaluable because several important equations and relations in hydraulics and sediment transport incorporate slope or gradient as a parameter.

The tectonics of the region probably have a profound effect on the Lower Río Bermejo as the river may be structurally controlled. Vertical movements, either by tectonic activity or gradual uplift, would be important to the regimen of a river in an area as flat as the Lower Río Bermejo basin. Possible recent tectonic movements are implied from the apparent offsets of the river, from terraces and old soil zones, and from the mapped faults and subsurface structural domes. A program to determine the rates of vertical and horizontal tectonic movements in the basin should be started.

RECONNAISSANCE OF LOWER RÍO PILCOMAYO BASIN

The Lower Río Pilcomayo (pl. 1) is different from the Lower Río Bermejo even though they parallel each other, are in adjacent basins, and flow over adjacent alluvial fans. The Río Pilcomayo forms the boundary between Argentina and Paraguay and has its headwaters in Bolivia. Southeast of Laguna Escalante the Río Pilcomayo disappears for about 160 km. The reach of the Río Pilcomayo from about the Bolivian border to its point of disappearance is referred to as the Río Pilcomayo "Superior"; the reach from its point of reappearance to its mouth is referred to as the Río Pilcomayo "Inferior."

The Río Pilcomayo "Superior," often overtops its banks and evidence of flooding and flood deposits are seen in many places. This flooding may account for the difference in vegetation in the Gran Chaco north of the Río Pilcomayo and that in the Gran Chaco along the Río Bermejo which seldom seems to flood in that area. According to Hugo Benito of the Proyecto Pilcomayo of the OAS, Asuncion, Paraguay (oral communication, Sept. 1974), during a recent flood most of the water of the Río Pilcomayo spilled over its flood plain and entered the Río Verde which joins the Río Paraguay near Concepcion, about 300 km north of the mouth of the Río Pilcomayo "Inferior." The flooding often causes the river to form or pick a new channel. For example, in September 1974 the river flowed into the Laguna Escalante and not south of it as shown in plate 1.

The author observed the Río Pilcomayo from the air from Mision San Andres (Argentina) to its mouth and observed it from the ground at Mision San Andres, at several sites near Laguna Escalante (Paraguay) and at several sites near its mouth during August 29-September 3, 1974. This seemed to be a time of fairly low flow. Visual estimates of width, velocity, bank heights, and size of bed material were made.

The Río Pilcomayo at Mision San Andres (fig. 13) had a channel about 100 m wide and banks about 6 m high. The flow velocity was about 0.7 m/s, and the bed material there was mostly silt. As the river flowed downstream toward Laguna Escalante it became narrower, meandered more and in places was braided.

Figure 13.--Río Pilcomayo "Superior" at Mision San Andres.

The river entered Laguna Escalante through several channels incised in a delta. This was a new section of the river. According to local residents the Laguna Escalante a year ago was 7 km north of the river. The outlet from the Laguna Escalante also was composed of several small channels (fig. 14), each headed by a knickpoint or small waterfall about 0.5 m high. Those knickpoints had been moving upstream and reducing the size of Laguna Escalante. At Padilla about 1 km downstream from Laguna Escalante the river (fig. 15) had a width of about 28 m, a depth of about 1.2 m and a velocity of about 0.1 m/s or about one-seventh that at the outlet. The banks stood about 1.5 m above the water surface.

Farther downstream (perhaps about 4 km) the river entered a laguna or banado called Laguna Tres Palmas which apparently was created when the river changed its course. At Ramoncito (fig. 16) about 0.5 km above the banado the river had a width of about 30 m, a depth of about 5 m, a velocity of about 0.1 m/s and banks about 1 m above the water surface. As the river entered the banado the river had widened to 50 m, the banks were almost non-existent, and the depth was about 1.5 m. The bed material was silt and clay.

About 5 km below Laguna Tres Palmas the river flowed into another banado called Elisetché-Cue. Several kilometers (downstream) from there the Río Pilcomayo "Superior" disappeared. About 160 km southeast of the point of disappearance is a stream designated the Río Pilcomayo "Inferior" which now has no obvious connection with the Río Pilcomayo "Superior." This stream and several others that parallel it (any of which could have been named Río Pilcomayo) flow into the Río Paraguay. The Río Pilcomayo "Inferior" near its mouth has many meanders, and banks covered with vegetation, some of which extended into the river (fig. 17). The several sites visited within 25 km upstream from the mouth had about the same dimensions--a width of 30-40 m, a bank height of 6-10 m, and velocities of about 0.1 m/s. This seemed to be an area of steady flow with little erosion or deposition. Ground-water discharge may be its chief source. There was no evidence of recent floods.

The rate of suspended-sediment transport has been calculated for the Río Pilcomayo "Superior" at two sites in Argentina, La Paz and Fortín Nuevo Pilcomayo (table 6). The average annual rate for the La Paz station was estimated for the 1968-69 and 1972 water years from its flow duration for that period and its sediment-transport curve derived from unpublished data of Agua y Energía Eléctrica (AyEE) of Argentina. The average annual rate for the Fortín Nuevo Pilcomayo station is published by AyEE (1970) for the 1953-67 water years. The station at Fortín Nuevo Pilcomayo was discontinued in 1968 because the river stopped flowing at that site. Because of the different time periods used in the summary given in table 6 the sediment transport at each station should not be compared, except to generalize that the quantity of suspended sediment transported yearly at La Paz was probably greater than that transported at Fortín Nuevo Pilcomayo, the downstream station. A comparison of the average annual discharge at each station from 1961 to 1967 shows that each year the discharge at Fortín Nuevo Pilcomayo was about 80 percent of that at La Paz except for 1961 when the discharge at the downstream station was 20 percent greater than that at the upstream station.

Figure 14.--Outlet of Río Pilcomayo "Superior" from Laguna Escalante

Figure 15.--Río Pilcomayo "Superior" at Padilla, about 1 km below Laguna Escalante.

Figure 16.--Río Pilcomayo "Superior" at Ramoncita, about 0.5 km above Laguna Tres Palmas.

Figure 17.--Río Pilcomayo "Inferior" near its mouth showing vegetation along its banks.

Table 6.--Summary of average-annual suspended-sediment discharge of the
Río Pilcomayo at La Paz and Fortín Nuevo Pilcomayo, Argentina

Station	Period (water years)	Drainage area (km ²)	Average annual suspended-sediment discharge (tonnes)	Average annual suspended-sediment yield (tonnes/km ²)
La Paz	1968-69, 1972	96,000	100,000,000	1,000
Fortín Nuevo Pilcomayo	1953-67	130,000	60,850,000	<u>a/</u> 470

a/ Agua y Energía Eléctrica (1970). If the years 1953 and 1963, for
for which the records do not cover the entire year, are not used,
the average annual suspended-sediment discharge for 13 years is
about 68,500,000 tonnes and the yields is about 530 tonnes/km².

The average concentration of suspended sediment at La Paz (1968-69, 1972) was 19 kg/m^3 . The average-annual concentration at Fortín Nuevo Pilcomayo ranged from 6.4 to 19.0 kg/m^3 for the years of full record; the maximum daily concentration for each year ranged from 17.33 to 204 kg/m^3 and the minimum daily for each year from 0.036 to 0.48 kg/m^3 (AyEE, 1970).

Unpublished flow and concentration data were available for the station at Fortín Nuevo Pilcomayo from September 1, 1967 to April 20, 1968. After April 20 there was no flow in the river at the station. For that period of 233 days, the quantity of suspended sediment transported by the river was estimated from flow-duration and sediment-transport curves to be 44,000,000 tonnes. The average concentration was 16 kg/m^3 . Figure 18 shows the sediment-transport curve for the 20 days in April and for the period September 1967-March 1968. It is interesting to note that as the discharge dropped from 115 to $0 \text{ m}^3/\text{s}$ in April the quantity of sediment carried by the stream at a given discharge was several times higher than the average quantity transported at that discharge (fig. 18). An explanation for this increase cannot be made at this time. The Río Pilcomayo at La Paz during this same period (September 1-April 20) carried 160,000,000 tonnes, about $3\text{-}1/2$ times that at Fortín Nuevo Pilcomayo. The average concentration at La Paz then was 25 kg/m^3 .

The high concentrations of suspended sediment carried by the Río Pilcomayo may be at least part of the reason that the Río Pilcomayo floods regularly and changes its channel or course. A large load deposited during high water because of a change in hydraulic conditions might raise the bed of the stream high enough for the river to overtop its banks. The fact that the Río Bermejo carried lower concentrations and less sediment than the Pilcomayo may explain why that river has not changed its course significantly in the last 90 years.

SUMMARY AND CONCLUSIONS

Two field trips were made to the Lower Río Bermejo and available hydrologic data were analyzed. The observations made on the field trips indicated that in general, as the river flows downstream, its channel narrows, its banks increase in height, the velocity decreases and the bed material becomes finer. The braided reach of the river between Embarcacion and El Colgado (some 170 km northwest of El Yacaré) was observed as an area of deposition. The downstream reaches are probably areas of erosion, although deposition was also seen. These reaches are downcutting and meandering.

The water discharge decreases in a downstream direction. The suspended sediment discharge seems to decrease between the point where the river breaks out of the mountains and El Yacaré, whereas the suspended sediment discharge seems to increase between El Yacaré and El Colorado.

Figure 18.--Suspended-sediment transport curves--Río Pilcomayo at Fortín Nuevo Pilcomayo, September 1, 1967-March 30, 1968, and April 1-20, 1968.

The above mentioned decrease and increase in suspended sediment discharge confirm net deposition in the braided upper reach and net erosion in the lower meandering reach. Erosion, meandering and shifting of the river channel in response to present conditions and to future damming may cause problems for future river development.

Thus, before the Lower Río Bermejo is developed for irrigation and other projects, present hydrologic conditions and the consequences of dams in the upper basin need to be studied. More data on channel geometry, flow, and sediment transport need to be obtained in such studies. The effects of possible tectonic movement also need to be considered.

Although the Río Pilcomayo "Superior" is also very meandering in parts, the river is unlike the Lower Río Bermejo. In many places the Río Pilcomayo "Superior" has poorly defined banks, often floods much of its basin and often changes channels. Moreover, southeast of Laguna Escalante the river disappears for about 160 kilometers. The flow and suspended sediment discharge at La Paz were higher than those at Fortín Nuevo Pilcomayo, some 250 km downstream. The concentrations of suspended sediment and suspended loads carried by the river are extremely high and probably partly explain the frequent flooding and changing of channels.

In contrast, the Río Pilcomayo "Inferior" does not seem to flood very often and seems to carry small suspended-sediment loads.

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