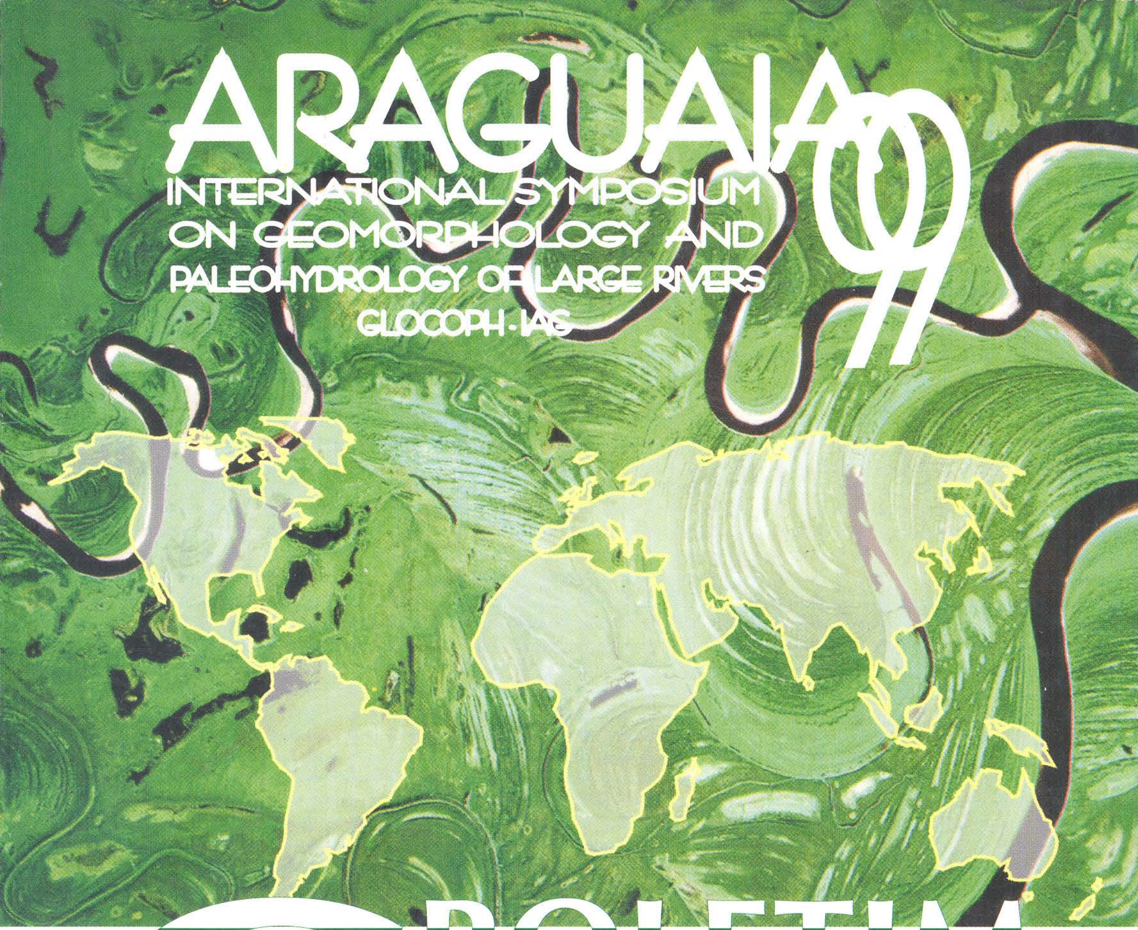

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SHIFTING MODES OF THE PARANÁ RIVER THALWEG IN ITS "BRAIDED" MIDDLE-LOWER REACHES

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The Paraná River is the sixth river in the world and the third in South America as measured by discharge. Along 1,000 km between the confluence of its last important tributary (the Paraguay River, at 27° 18' S - 58° 36' W) and the apex of its delta on the Río de la Plata estuary (33° 48' S – 59° 16' W), the main channel has a mean discharge ranging between 21,000 m^3/sec and ca. 16,000 m^3/sec, with the lower values resulting of the flow diverted to 10 to 170 km-long anabranches, and other minor streams flowing in its wide alluvial plain.

Downstream from the Paraguay River confluence, the Paraná main channel pattern is a succession of enlargements followed by narrower, shorter and deeper reaches. In a 400 km-long reach around Pueblo Brugo (31° 24' S - 60° 06' W), for example, the mean effective widths (i.e., without island widths) and the mean depths of the main channel are 2,000 m and 1,000 m, and 5-8 m and more than 12 m, at both, enlargements and narrow reaches, respectively. In the same area, the mean lengths of the two typical reaches are 11,600 m and 1,900 m. The water surface slope is in the order of 10^{-5} (smaller at narrower zones), and the bed sediments are medium size sands along the whole length (Drago & Amsler, 1998).

Channel sand bars and islands concentrate at enlargements resembling a braided channel pattern, as was classified by some authors (e.g., Iriondo, 1988; Drago, 1990). Nevertheless, a conspicuous difference with a typical braided river exists because of the importance that the Paraná River thalweg has, at any cross section of the channel. In fact, the thalweg concentrates up to 70 % of the discharge flowing in a section, and its bottom level is currently placed 4 to 10 m below the more-frequent-depths of the bed river at enlargements, and more than 15 m (up to 55 m) below the same level at the narrower zones. This geomorphic feature of the river, i.e., the existence of "a major single stream (the thalweg belt) flowing within the limits of a wider one (the channel itself)", was observed by fluvial engineers as early as the beginning of this century (e.g., Reposini, 1913). Later on, some non-geomorphologic reports have suggested that the morphology and mobility of the entire river depend on the hydrosedimentological dynamics and shifting properties of the thalweg (e.g., Cabral, 1973; Parodi & Estruco, 1975). These first and rather qualitatively conclusions, began to be systematically studied during the last three years in the frame of the project: "Characterization of the thalweg shiftings in the Paraná River", and in some related applied studies (FICH, 1997, 1998; Amsler et al., 1998; Toniolo et al., 1999). These analysis were developed on the basis of detailed bathymetric records of the entire river bed, performed in the 400 km-long reach already mentioned, from 1905 to nowadays. Hydrologic, hydraulic, sedimentological and planform morphological (from air views) data and measurements of river below the Paraguay River confluence, complemented the records information.

As a result of these studies, the channel pattern classification in the middle-lower reaches, was reviewed. It is believed that *braided with sinuous (or meandering) thalweg* pattern (pattern-type 4 of Schumm, 1985), describes better the planform characteristics and *morphological processes* observed at this stream. In fact, the lateral displacements of the Paraná River thalweg can be done in continuous or discontinuous ways, resembling the meandering streams. The recorded typical mode of continuous shift was that of a meander (or wave) enlargement (i.e., the growth of the thalweg wave amplitude in a reach, without changes in its wave length). By this mechanism the erosion rates at "concave" banks (near to the thalweg wave apex) may range over 100 m/year, while the opposite banks remain without major changes by riparian erosion or sedimentation.

Downstream displacement of the thalweg waves apexes was also observed, with not measurable variations in the wave lengths. Nevertheless, the related downstream bank movements appear to be unimportant compared with the amplitude changes.

Additionally, chute cut-offs of the thalweg waves have been recorded. They may be "subaerial" (the new channel is cut down on the alluvial plain), as well as "subaqueous" cut-offs (the new thalweg is developed on the river bed at a place previously occupied by middle or side bars). In the case of the subaqueous chute cut-offs, an erosive-very-deep-and-very-narrow channel (it will be subsequently the new thalweg), begins to scour the river bed from a deep point downstream of a channel enlargement. With time, the erosive channel progresses upstream without changes in its morphological aspect, through a mechanism that resembles the backward motion in the headwater of a gully. The erosive channel captures an increasing water discharge becoming finally the new thalweg over a sector or the entire length of the channel enlargement. This last mechanism of thalweg formation as part of several geomorphic processes observed in the Paraná main channel, was not reported previously. Moreover, it seems that the chute cut-offs phenomena are not always a direct consequence of a channel slope reduction, as occurs after a progressive increase of the thalweg wave amplitude.

Both, subaerial and subaqueous thalweg cut-offs, may be completed in five or up-to-fifty years, from the beginning and later development of the erosive channel to the obliteration by silting (sometimes, absolute) of the former thalweg. The consequences of a chute cut-off process are as important as the thalweg wave enlargement. At a single enlargement, for example, thalweg chute cut-offs implying lateral displacements up to 4,000 meters were measured. On the other hand, in a 60 km-long train of thalweg meanders downstream Port Diamante (32° 04' S – 60° 39' W), the 1936-to-1943-completed cut-off of a single wave, reduced the thalweg sinuosity from 1.38 to 1.27, implying a shortening of 8 % in the sailing route. An "extreme" (but not uncommon) case, was the thalweg sinuosity reduction from 1.47 to 1.15, measured in front of Paraná city (31° 42' S - 60° 30' W) between 1908 and 1913. Here, the channel sedimentation of saturated sands accelerated by the thalweg cut-off in a 14 km-long reach, was 50 Hm^3 in 20 years (the channel volume decreased nearly 30% according to measurements reported by Drago, 1990), with a concave bank migration to the new thalweg position, at rates of up to 180 m/year.

The knowledge gained about the shifting modes of the Paraná River thalweg and the better classification of its channel pattern, have some implications on the studies concerning this large alluvial river both, basic and applied. In fluvial engineering, for example, some near bank structures, such as bridges, ports, roads (or the special case of the Subfluvial Tunnel near Paraná city), are exposed to risks associated with the thalweg shifting dynamics. The most vulnerable structures (at short and medium terms), are those near the thalweg wave apex at channel enlargements. The adequate maintenance of the navigation route by dredging, is another example where the new knowledge also apply principally during the time span along which a cut-off process is in progress. The bed dredging works should be planned keeping in mind the natural thalweg wave enlargements, or subaqueous cut offs characteristics, presented here.

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