



# Continuous Management of the Channel Design to Optimize Navigability in the Middle Paraná River Waterway: “Santa Fe – Confluence”. Argentina

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**Abstract.** This paper exposes how HIDROVIA S.A. (Inland Waterway Concession company) worked in the Middle Paraná River inland waterway “Santa Fe – Confluence” to maintain the navigation channel without dredging works by means of four steps: frequent bathymetric surveys, study of AIS vessels tracks, a special coordination of logistic works in the river with the technical team and buoy tenders crew and effective communication plans with involved stakeholders. This is a stretch of the well-known Paraguay – Paraná Inland Waterway in South America that reaches deep waters in the Río de la Plata. Physical characteristics and depths along this section of Paraná River determine what kind of vessels can sail according to its draught up to 10 ft. With 2 ft. For under keel clearance. From October 2010 to September 2021, dredging works and installation and maintenance of modern aids to navigation system were granted by the concession company. Given the intense morphological dynamics and thalweg migration of the river in this section, the contract stated that it was not suitable to keep a fixed channel design by means of permanent dredging works. It established that dredging works should only be done when and where it is not possible to maintain the channel design by readjustment of its profile with partial changes in the trace and direction of the waterway axis. The Aids to Navigation Department of HIDROVIA S:A. succeeded in doing that by implementing the continuous management of the channel design to optimize sustainable navigation in the Santa Fe – Confluence waterway.

**Keywords:** Middle Paraná River · Thalweg migration · Trace changes · Sustainable waterway

## 1 Introduction

The Middle Paraná River inland waterway “Santa Fe – Confluence” flows entirely through h Argentina country in South America. This is a stretch of the well-known regional Paraguay – Paraná Inland Waterway (from now on HPP, for its acronym in Spanish) which flows through another four countries: Brazil, Bolivia, Paraguay, and Uruguay and finally reaches deep waters in the Río de la Plata next to the open sea (Fig. 1). Average discharge of this stretch of the Parana River is about 15000 m<sup>3</sup>/s (mean waters condition).



**Fig. 1.** The Santa Fe – Confluence waterway. (Modify from Hidrovía SA 2021).

Physical characteristics and depths along this section of Paraná River determine what kind of vessels can navigate and the allowed draught is determined consequently. From Confluence downstream to Santa Fe Port navigation is allowed for vessels loaded up to 10 ft. And fluvial traffic is developed mainly by tug pushing barges convoy and, in some few cases, by self-propelled. Design depth of the waterway also includes additional 2 ft. For under keel clearance.

From October 2010 to September 2021, both dredging works and installation and maintenance of modern aids to navigation system were granted by HIDROVIA S.A. Company. The Aids to Navigation Department was in charge of the installation, maintenance and management of the aids to navigation system that included buoys and beacons according IALA-B guidelines, a network of automatic water level measuring stations and the installation of antennae for the reception of AIS: Automatic Identification System signals. Given the intense morphological dynamics of the river in the Santa Fe – Confluence section, the contract stated that it was no suitable to keep a fixed channel design by means of permanent dredging works. It established that dredging works should only be done when and where it is not possible to maintain the channel design by readjustment of its profile with partial changes in the trace and direction of the waterway axis. That was how HIDROVIA S.A. succeeded in implementing the continuous management of the channel design to optimize navigability in the Santa Fe – Confluence waterway. The purpose of this solution was not only to reduce costs but also to minimize environmental impacts in the river system reaching a sustainable management of the waterway. This requirement could be reached following the river

thalweg migration with the channel axis, but the fluvial activity was so important that it demanded a continuous labor-intensive management to succeed. It required about 50 trace changes of the channel design a year, as an average, that were materialized successfully by HIDROVIA S.A.

This paper exposes the works carried out in the Paraná waterway Santa Fe – Confluence to maintain the designed navigational channel without dredging works by means of four basic steps: frequent bathymetric surveys, study of AIS vessels tracks, an accurate coordination of logistics works in the river with the technical team and buoy tenders crew and effective communication plans with involved stakeholders. Since 2019, the channel design in this waterway has been sustainably guaranteed with no dredging works.

## 2 Santa Fe – Confluence Waterway

The Paraná River section of HPP is in one of the most populated and industrialized area of South America. It is a strategic link to facilitate trade between the south of Brazil, Bolivia and Paraguay and Rosario city (Argentina) from where it can connect to deep draught vessels with the Atlantic Ocean. It is considered the most important integration way of MERCOSUR since it is one of the most important transport routes needed to facilitate physical integration for the five countries. Its commercial area of direct influence (hinterland) is estimated at about 720.000 km<sup>2</sup> and about 3.500.000 km<sup>2</sup> of indirect influence with a population of more than 40 million inhabitants (Escalante 2015). Santa Fe – Confluence waterway is 650 km long.

### 2.1 Commerce

Main cargo for this route is iron ore and grains with some share of containers and fuel. Important to highlight is that two countries, both Paraguay and Bolivia have this waterway as the only international trade connection due to their condition of land-locked countries. The hinterland of the waterway has a very big agriculture potential as well as reserves of iron ore and manganese that have of worldwide importance. Soybean and by-products, iron ore and fuels gather at least 88% of total freight (*Op. Cit.* 2015). Table 1 shows tonnage passed through the waterway in: 2015–2019 (Hidrovia SA. 2021).

**Table 1.** Cargo tons in the Santa Fe - Confluence waterway. 2015–2019.

Products	Total cargoes [tons]				
	2015	2016	2017	2018	2019
Soybeans	7.721.289	8.322.094	9.034.433	9.837.442	8.106.063
Other grains	4.214.646	633.464	1.318.628	887.298	1.766.175
Iron ore	4.126.000	3.564.751	3.807.790	3.574.748	3.792.662
Liquid cargo	4.064.111	3.679.247	3.599.026	4.402.984	3.939.994
General cargo	1.460.559	1.075.810	994.310	1.253.193	1.379.994
Total	21.586.605	17.275.366	18.754.188	19.955.665	18.984.772

The volume of transported cargo along the stretch Santa Fe – Confluence has been growing up since 3,7 million tons in 1996 up to 22 million tons in 2019. In 2019 there were more than 11.300 travels, and in 2021 about 12.300 trips (Marpegan and Pérez, 2020).

## 2.2 Navigation Along the Waterway

The Santa Fe–Confluence waterway allows both domestic and international commercial river traffic to and from Argentina, Uruguay, Paraguay, Bolivia and south of Brazil. Cargo is transported by a fleet composed mainly by barges and pushers and some self-propelled vessels. These barges are arranged in convoys of different sizes pushed by tugs of adequate power (Escalante 2015). Usual arrays applied to carry bulk cargo, are convoys from 16 to 30 barges:  $4 \times 4$ ;  $4 \times 5$ ;  $5 \times 5$  and  $5 \times 6$  all of them with a tug pusher and the biggest convoy with a pusher of more than 7,000 HP (*Op. Cit.* 2015; Hidrovía SA. 2021). Physical dimensions are shown in Table 2 considering Mississippi type barges 60 m long and a tug pusher length of 50 m (Hidrovía S.A. 2021). The longer ones have maneuvering restrictions along straight areas and or where the river turns in curves of the channel.

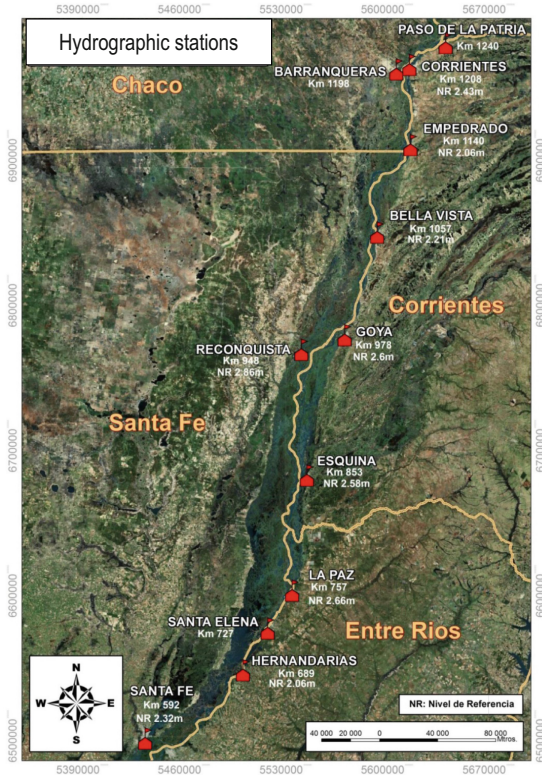
**Table 2.** Dimensions of convoys usually used in the Santa Fe - Confluence waterway.

Vessel type	Barges [units]	Length [m]	Breath [m]
General Cargo	1	139/200	18
Convoy $4 \times 4$	16	290	44
Convoy $4 \times 5$	20	290	55
Convoy $5 \times 5$	25	350	55
Convoy $5 \times 6$	30	350	66

## 3 Technical and Sustainable Channel Management

The required waterway management must keep safe navigation conditions, for all kind of vessels along the Santa Fe – Confluence channel for 24 h all day of the year in any fluvial and hydrometric condition: high, mean or low waters. The contract demanded a level service higher than 97% that meant a permanent coordinated work, in agreement with authorities (Subsecretary of Ports, Waterways and Merchant Marine, Naval Hydrographic Service, Argentine Naval Prefecture) and users (Captains, boat skippers and shipowners). This also requires planned regular services campaigns in the river to attend each buoy and beacon, a permanent availability of technical and human resources, analysis of recent bathymetric surveys and the study of convoys or ships tracks up and downriver.

To succeed in offering proper response for each necessary change or adjustment in any buoy or beacon, two operational bases were installed in both ends of this waterway, downstream in Santa Fe port and at the upper end in Barranqueras port (Fig. 2). Between these two stations, other strategic locations were Goya, Reconquista, La Paz and Paraná ports.



**Fig. 2.** Hydrographic stations and Hidrovía SA operational bases in The Santa Fe – Confluence waterway. (Hidrovía SA 2021b).

### 3.1 Bathymetric Surveys

Bathymetric surveys were regularly done for different purposes with hydrographic boats. Surveys were carried out along the channel axis and its edges with high density of profiles (each 200 m) where it is difficult to sail the river (shallow and stretch waters) in the “Pasos”; along the channel axis and less density of cross sections (each 1000 m) between subsequent Pasos (in what is called “Entrepasos”) and along secondary branches of the river. The annual survey reached a total profiles length of 9250 km in the Santa Fe – Confluence waterway.

Pasos and Entrepasos are stretches of the Middle Paraná River where the contract requires to keep 3,66- and 4,00-meters depth respectively. Pasos are the places where a strong sedimentation takes place close to the channel and there is adjacent intense activity of sandbanks and dunes. Entrepasos are the more stable hydro sedimentological parts of the waterway. The Pasos are about 43 % of the Santa Fe – Confluence waterway length and have hold 65 % of channel axis changes up to September 2020 (Marpegan and Pérez, 2020).

### 3.2 Channel Axis Changes

With the bathymetric surveys, the trace of the channel can be monitored to detect when a change in direction is necessary. The fluvial movements of sandbanks and dunes of the Middle Paraná River change the river morphology almost in a continuous way so that secondary branches of the river and some areas of its principal course that were initially unfit to commercial navigation turn to be deep o wide enough to allow development of this activity safely in agreement with technical contract conditions.

Table 3 shows how much changes in channel axis were done annually from 2011 to July 2020 in Pasos, Entrepasos and in areas combined by Pasos and Entrepasos. 413 changes were carried out in that period.

**Table 3.** Annual changes in direction of the channel axis in the Santa Fe - Confluence waterway (Marpegan and Pérez, 2020).

Year	Pasos	Entrepasos	Combination sites: Pasos + Entrepasos	Total
2011	12	0	7	19
2012	33	9	9	51
2013	23	16	1	40
2014	33	16	3	52
2015	34	16	14	64
2016	28	17	4	49
2017	47	9	2	58
2018	29	16	1	46
2019	2	11	1	14
To June 2020	6	4	10	20
Total:	247	114	52	413

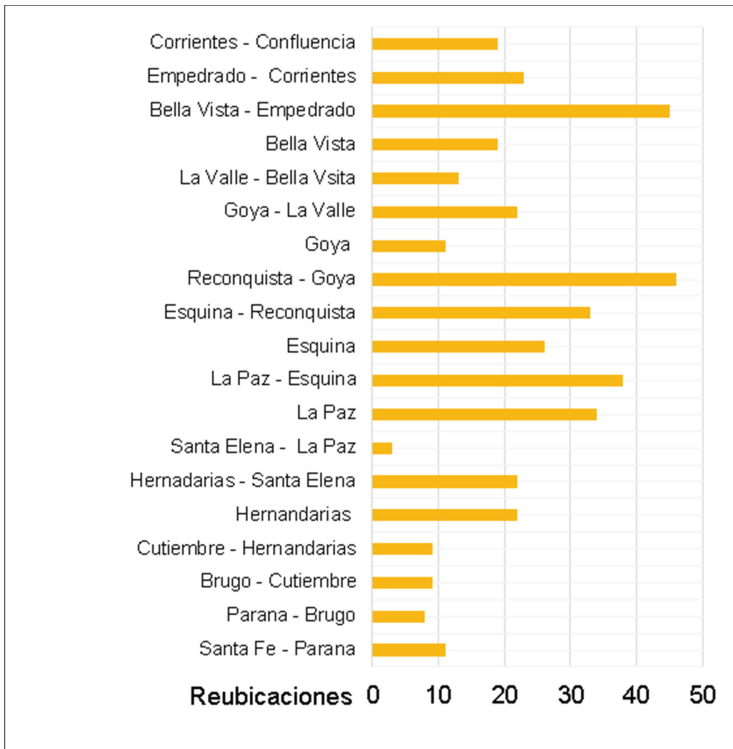
Figure 3 shows the changes done in the Santa Fe – Confluence waterway along the river, from upriver in 1230 km at Confluence to 584 km in Santa Fe port where 3 sections with different morphological activity can be identify. From the lower end: Santa Fe – Santa Elena stretch with low activity, Santa Elena – Goya section is the critical zone with the most frequent talweg migration and Goya – Confluence section with moderate activity. These characteristics of each stretch determine the number of changes in the channel axis that are necessarily made to comply with the contract of keeping safe navigation conditions with less o no dredging works.

### 3.3 Tracs from Automatic Identification System: AIS

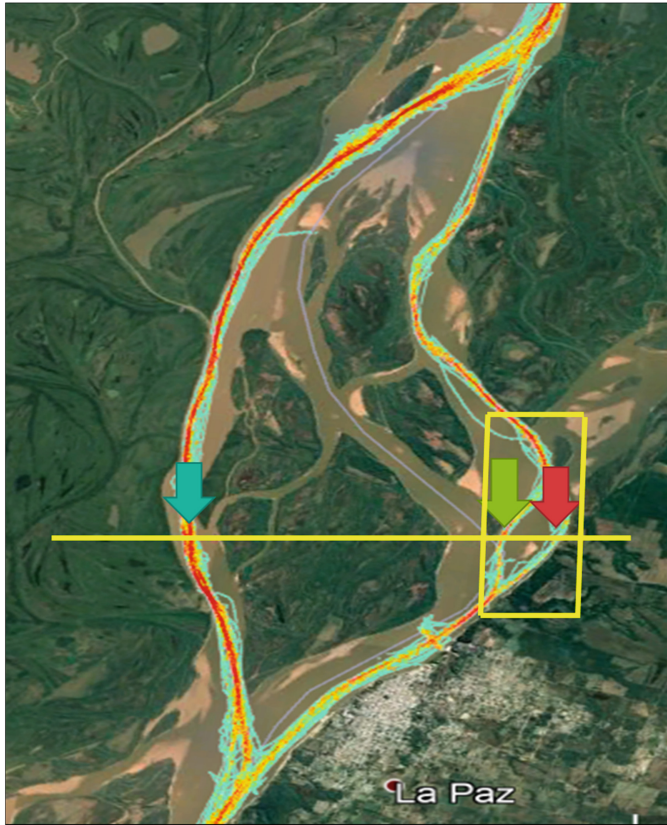
Information about fluvial traffic in the Santa Fe – Confluence waterway get from AIS records was studied and correlated with the vessel type, the direction of each trip, stretch of the river, local hydrometric levels and type and amount of transported cargo. This analysis was particularly meaningful in sections where the Paraná River offers

alternative branches as in Paso *Raigones* – *San Juan* Branch shown in Fig. 4 and consequently allowed to:

- Make a real time monitoring of navigation in the waterway
- Supervise and oversee the boats in charge of bathymetric surveys and technical assistance to the buoying system.
- Generates warm maps of different traffic densities
- Know how the convoys and vessels use the channel and identify collisions between vessels and or with buoys.
- Validate actual channel design and installed aids to navigation quality of service.



**Fig. 3.** Spatial distribution of channel axis changes in Santa Fe – Confluence waterway. Period: 2012 – July 2020



**Fig. 4.** Traffic nautical density. Paso Raigones/San Juan Branch case. Santa Fe – Confluence waterway.

### 3.4 Interaction with Users and Stakeholders

Since the beginning of the concession in 2011, Hidrovía S.A established and kept a frequent interaction with stakeholders, users and interested public by means not only of available official tools but also implementing new ones in order that user of the channel always access and know technical information about the in the Santa Fe – Confluence waterway status. For example:

- List of signals installed
- List of signals with any fault or malfunction and its type
- Minimum depth in each Paso
- Planed area for the survey campaigns
- Preliminary design of channel axis changes to be proposed to the authorities
- Other interested and related topics.



#### 4 Case Study: Paso Raigones and San Juan Branch

18% of the 413 axis changes carried out between 2011–2020 were in the area where the fluvial morphology and thalweg migration are more active. It is close to La Paz port in Santa Fe – Confluence waterway between 740 km and 785 km including 4 Pasos: *Cortada Arroyo Seco*, *Riacho Raigones*, *Curuzú Chali* and *Garibaldi* and additionally the Entrepasos between them (Fig. 5). This area is about 50 km long and 765 km was the most critical place where more thalweg migration was registered.

In 783 km the Middle Paraná River opens its principal course into 3 other ones, like a “trifurcation” that gives place to *San Juan* and *San Juancito* branches and additionally subsequent Pasos *Raigones* and *Curuzú Chali* (Fig. 5). The morphologic intense activity in this area demands almost permanent bathymetric surveys that were done by Hidrovia S. A, to verify and or rectify navigational channel axis trace and the visual aids to navigation installed to maintain safe nautical conditions. It could be statistically reported that the interval between successive changes was 70 days as an average.



Fig. 5. Middle Paraná River close to La Paz Port.

#### 4.1 AIS Data

AIS data allow an offline analysis to understand and follow the trace evolution. As a result of that, the company was able to (Fig. 6):

- Study temporal deviation from vessels path from the designed channel
- Identify areas for bathymetric surveys
- Evaluate use and frequency of change for the existing alternatives
- Report about navigation habits along shallower areas (kind of vessels)

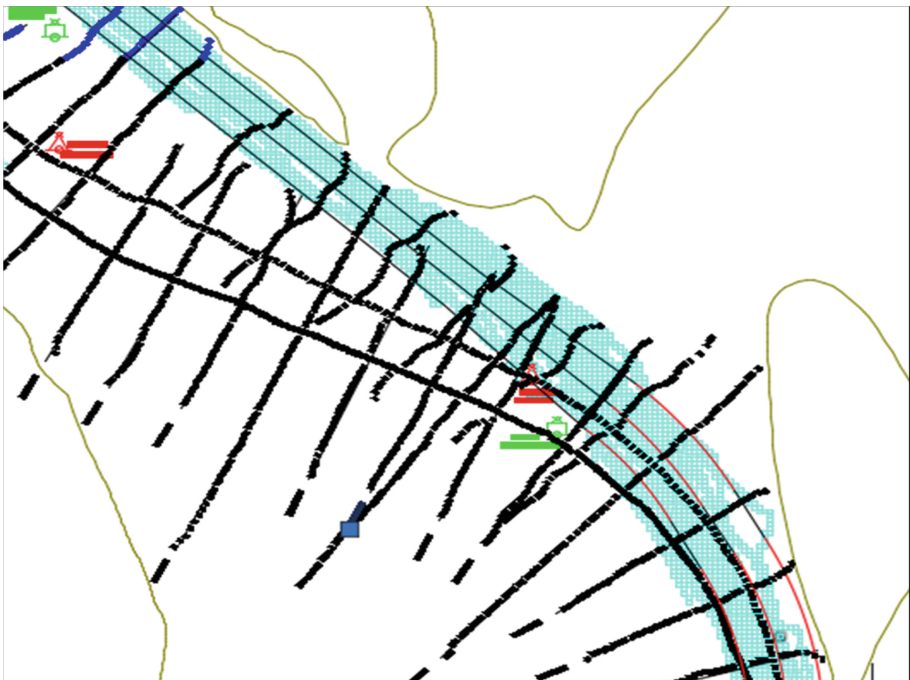


Fig. 6. Channel shift to left margin.

#### 4.2 Bathymetric Surveys and Alternatives Analysis

For this example, bathymetric surveys along *Paso Riacho Raigones* were done to look for bigger depths that could justify a new axis change. Some other surveys were also carried out along secondary branches *San Juan* and *San Juancito*. In all of them the

navigability conditions were observed and analyzed, and the critical depth were identified. It allowed to keep Paso *Riacho Raigones* as the deepest option for the channel.

The final design was then validated with traffic density analysis got from all the vessels tracks in the area and additionally where also new aids to navigation designs were determined.

## 5 Conclusions

The intense morphological activity of the Middle Paraná River with continuous bed forms and dunes migration is a strong characteristic of the fluvial system that determines how the navigational channel can be defined along its course. This was considered in the contract that required a channel design maintenance with reduced or no dredging works, tracing continuous thalweg migration with the axis changes.

The work done by Hidrovía S.A. in the Santa Fe – Confluence waterway between 2011 and June 2020, shows clearly that no unique channel design is possible, it cannot be fixed in time and demands a permanent adequation.

That fluvial complex scenery is complemented by maneuvering restrictions to barges convoys that sail this waterway, specially the longer ones. Sometimes the best nautical option (or a shorter straight path) for the channel axis does not match the proper morphological option (the deepest). Different ships and barges convoys have its own preferred alternative.

It is important to promote stakeholders, authorities and users participation in the channel and the aids to navigation design process that is necessary not only to optimize the waterway facilities but also to improve navigation safety avoiding groundings and collisions between vessels or against the buoys. This collective work also leads to continuous improvement methodology for the intervention in Santa Fe – Confluence waterway.

The work carried out to follow natural migration of the river thalweg moving the channel axis was a heavy task for Hidrovía S.A., and the achieved success shows that sustainable navigation is possible with soft intervention in the river and minimum or no dredging works.

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