

Fargue, founder of experimental river engineering

Fargue, fondateur de la technologie fluviale expérimentale

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ABSTRACT

The founder of experimental river engineering, the Frenchman Louis Fargue (1827–1910) conducted experiments in the last thirty years of the 19th century. His name – not being associated with any formula or any effect – is currently almost forgotten. The purpose of the present work is to highlight French hydraulics of the 19th century in general, and the contribution to its fame by Fargue in particular. His main papers are reviewed from present day knowledge after having given an overview of the environment in which he grew. These results are then discussed and a biography outlines the main stations of Fargue's life.

RÉSUMÉ

Fondateur de la technologie fluviale expérimentale, le Français Louis Fargue (1827–1910) a entrepris des expériences dans les trente dernières années du 19^{ème} siècle. Son nom – n'étant associé à aucune formule ni aucun effet particulier – est actuellement presque oublié. Le but du présent document est de mettre l'accent sur l'hydraulique française du 19^{ème} siècle en général, et la contribution à sa renommée par Fargue en particulier. Ses principales publications sont passées en revue sous l'éclairage des connaissances actuelles après avoir donné une vue d'ensemble de l'environnement de l'époque. Ces résultats sont alors discutés et une biographie souligne les points principaux de la vie de Fargue.

Keywords: Flow; history; hydraulics; open channels; water.

Introduction

Some two hundred years ago, when industrialization started, rivers were mainly used for drinking water supply and waste water disposal, wood transportation and navigation. Then, once railroads became popular, rivers often were corrected, i.e. land previously 'owned' by the river was used for traffic systems, agriculture and growing industries. Accordingly, the developing infrastructure was exposed to floods, a feat that has partially improved by re-naturation only during recent times. Works along a river actually demand often public agreement on the advantages and disadvantages. River engineers envisage still significant problems to predict the consequences of small changes, such as deepening locally a river bed. River engineering is thus still a challenge which is also reflected by intense research activity.

Engineers working with rivers have a long tradition, and several have come to fame. Mention might be made of the Germans Johann Albert Eytelwein (1764–1848), Johann Gottfried Tulla (1770–1828) and Gotthilf Hagen (1797–1884). Yet, until about 1870, nobody thought to model river flows with a hydraulic model, although questions relating for example to weir flow were successfully solved by experimentation. Time was just

not yet mature for such complicated works, and rivers were regulated, modified, improved or even deepened by the advice of experts, resulting in partially excellent results and partially in disasters. France was at the forefront of hydraulic modeling during the second half of the 19th century, with exponents such as André Baumgarten (1808–1859) on Garonne river, Henry Bazin (1829–1917) with his great works on open channel flow, Benoit Fourneyron (1802–1867) known for development of hydraulic turbines, Jean-Victor Poncelet (1788–1867) for weir and orifice experiments with Joseph Aimé Lesbros (1790–1860) at Metz university, and Ferdinand Reech (1805–1880) for experiments in naval architecture including a scaling law actually referred to Froude. Two engineers added fundamental work to river engineering, obviously to establish an additional information on projects to be executed, next to calculations and experience. One was Paul François Du Boys (1847–1924), the other to be highlighted Louis Fargue (1827–1910).

Most French engineers graduated from *Ecole des Ponts et Chaussées* once having passed through basic education at *Ecole Polytechnique*, Paris. They would then normally enter the corps of *Ponts et Chaussées* to start a career in governmental environment. The corps' journal *Annales des Ponts et Chaussées* initiated in 1831 and contained besides papers also a news section

on corps activities. Up to World War I the *Annales* were a leading engineering journal used for publication almost exclusively by corps members. Fargue virtually published all his papers in the *Annales* containing also his obituary. The following introduces the development of Fargue's contributions to river engineering.

Fargue's writings

Traditional approach

The introduction of Fargue's (1908) book reads as follows: 50 years ago, a young engineer occupied with Garonne river reasoned on the improvements to be made for navigation. It was simple for him to obtain information relating to piles, fascines, or riprap. He had only to follow the traditions of the river service, ask the elder colleagues and read the paper by Baumgarten (1848). The courses of *Ecole des Ponts et Chaussées* were related to classic experiments that had no relation to the bottom or even average river velocities, but nothing about the works for improving the stability of banks and river flow depth. Engineers considered as experts had opinions widely different among each other: "Make a straight river axis", said one, "because this is the perfect river shape in landscape, cure river sinuosity!" "Beware making straight rivers", said the other, "because curves seem to be important for river stability. Design circular arcs, because this corresponds to the perfect shape!" "The geometry of the river axis is insignificant", still others commented, "for having a good river, just cut all dead arms, and allow for sufficient cross-section to establish a nearly uniform velocity".

None of these and many other opinions were definite in 1848, and still 60 years later, Fargue confessed: "Do we know so much more today?" In short, there were no design guidelines available. A young engineer thus designed works based on earlier river projects that were considered successful. Fargue yet decided to approach things somewhat different. Starting in 1863, with the first paper in 1868, he was able to demonstrate that in addition to experience and calculations, there existed a third approach to river engineering: Hydraulic modeling (Figure 1). Compared to water flow in a rigid channel, river engineering is complicated by two-phase flow of variable boundary geometry, roughness pattern and discharge characteristics. Fargue admitted that his approach had weak points, as do all models of a prototype, but he introduced a successful alternative. It was that idea rather than the technique for which Fargue deserves credit, therefore.

Fargue as a practicing engineer published a first paper on the temporal change of wood strength in foundations (Fargue, 1857), a second (Fargue, 1864) on an automatic weir construction. Then, in 1868, Fargue came up with his benchmark paper on the correlation between the river plan geometry and flow depth, which was awarded with the Association's Gold Medal. The paper was translated in German by Honsell (1871), known for improvements made on river Rhine close to Karlsruhe.



Figure 1 Model of river meander (Leliavsky, 1961).

1868 Paper

Garonne river upstream of Bordeaux had an average width of 180 m and an average discharge of 700 m³/s. The river bed was constituted by grains of 50 mm in the average, and contained about one third of sand. Along the 22 km long reach, of which Figure 2 shows a portion, Fargue considered 17 meanders and observed both the cross-sectional profiles and the axial bed profile.

By prototype observations of various reaches of Garonne river upstream of Bordeaux Fargue related the average radius of curvature to the maximum flow depth in a river curve, and the reduction of depth downstream close to the point of inflection (Figure 3). In total, six laws for curve parameters of river Garonne were deduced. These have never come into general use, but Fargue demonstrated that fluvial hydraulics is governed by basic physical phenomena. In addition he noted that a straight river does not exist in nature, but that the river plan geometry is composed of a series of sinusoidal curves of variable curvature, that influence significantly a river thalweg profile. As the curvature increases, scour along the outer river side gets larger associated with a trend to an almost triangular cross-sectional profile that is deep along the outer bank and shallow along the inner. Along several meanders, a succession of scour holes downstream of the curvature maximum and 'benches' close to the point of inflection were observed (Figure 3). These posed a problem for navigation because of limited flow depth. Although that paper includes a computational method for river geometry, the essence of Fargue's message was important. Few followed his advice for decades . . . His paper indeed introduced fluvial hydraulics, as stated by the author, and added to the knowledge of loose boundary flow.

1882 Paper

In addition to relations previously established for Garonne river a stability criterion for a river bend was proposed as: The thalweg remains deep and stable between two curves if the almost straight portion at their inflection point has a width smaller than in the curves. The computed ratio between minimum width along the straight river portion and maximum river width in the curve

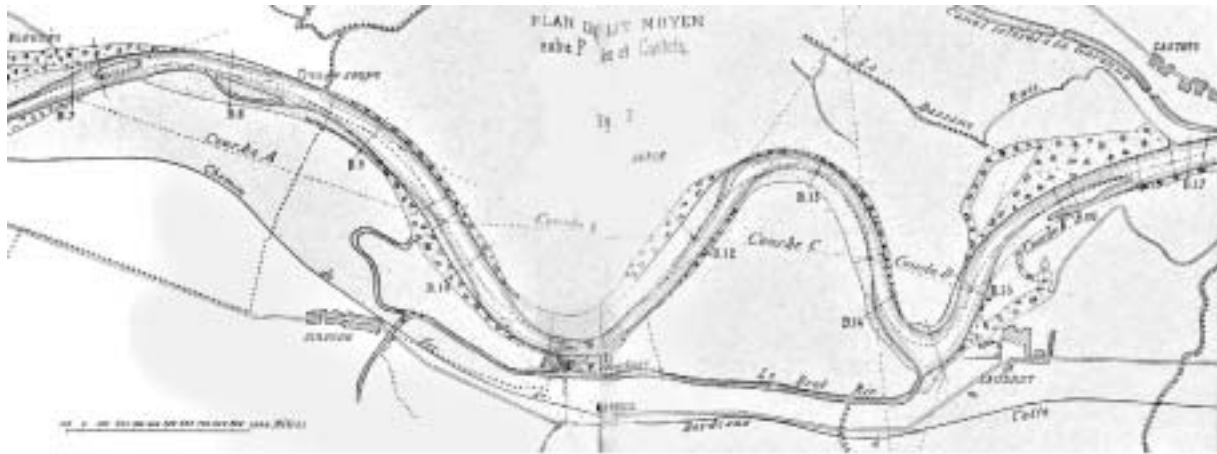


Figure 2 Garonne river upstream of Bordeaux, river reach between Floudès and Castets, flow from right to left.

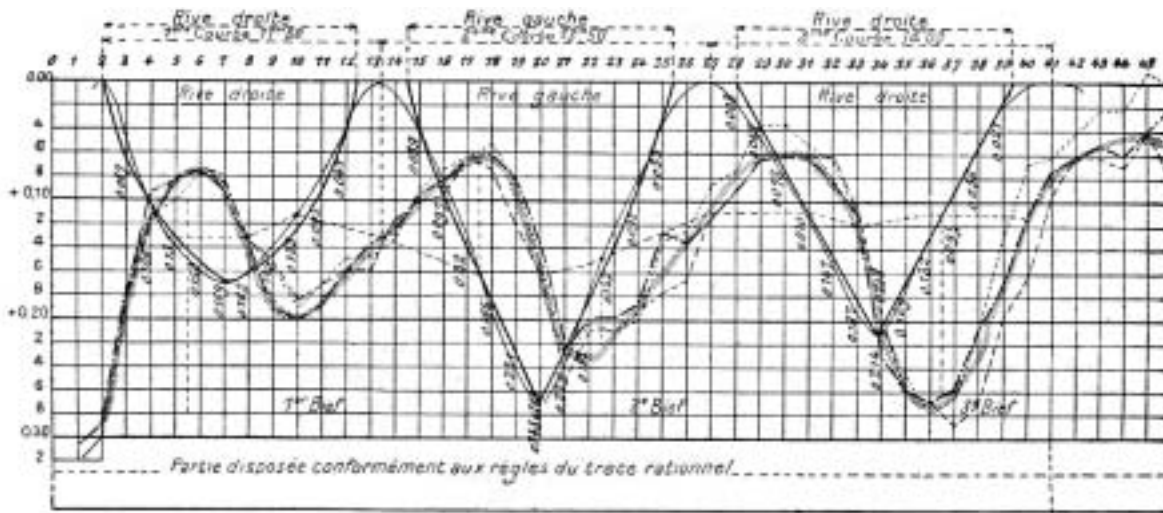


Figure 3 Relation between thalweg profile and plan curvature for three meanders of Garonne river.

was 3/4. This finding may be explained with the deviation of the streamlines from the river axis. As regards sediment transport, Fargue referred to his ‘teacher’ Baumgarten but spent no word on (his rival) Du Boys, who had detracted first relations in 1879 on river Rhone. Fargue then described bend scour, with erosion along the outer and aggradation along the inner bank. Compared to the 1868 paper, few definite additions resulted. The bend geometry was described with transition curves as used in road design in the 1884 paper, without accounting for any hydraulic parameters. A further justification for his findings on curve features may be found in the 1900 paper, obviously based on a contract work for the tidal canal at Antwerp, Belgium (Figure 4).

1894 Paper

Together with the 1868 paper, this work may be regarded Fargue’s main addition to loose boundary hydraulics. It is a late description of hydraulic experiments conducted along Garonne river to substantiate the 1868 findings, and obviously the first attempt to use hydraulic modeling in river engineering. Three series A, B, and C of experiments were conducted in an outdoor set-up using the waters of river Estey de Bègles, just upstream where it

runs into Garonne river close to Bordeaux. A 2 m wide and 8 m long intake basin was connected to a 1 m wide channel. Sand of Garonne river was placed almost horizontally after each experiment, for test durations between 45 min and 160 h. In total 21 runs were made in 1875 and 1876 (Figure 5).

For test series A, the channel had a length of 59.50 m, with the river axis formed of four circular arcs of 10 m radius and central angles of 60° each. The two first arcs were directly in contact, whereas the two latter arcs had a linear spacing of 4 m and 8 m, respectively. The 9 experiments of series B were made in a channel 64.80 m long, with variable curve lengths and curve radii. Series C then involved long time observations. The water level was controlled with an end sill of variable height. A significant problem was discharge control, because of fluctuations up to ±50%. Fargue and his collaborators drew the following conclusions (Figure 6):

- Flow concentrates to the outer curve with depositions along the inner bank,
- Thalweg depth varies with river curvature, with minima and maxima following the sign of plan curvature, and
- Transverse river profiles are different at the beginning and the end of a curve for equal relative curvature.

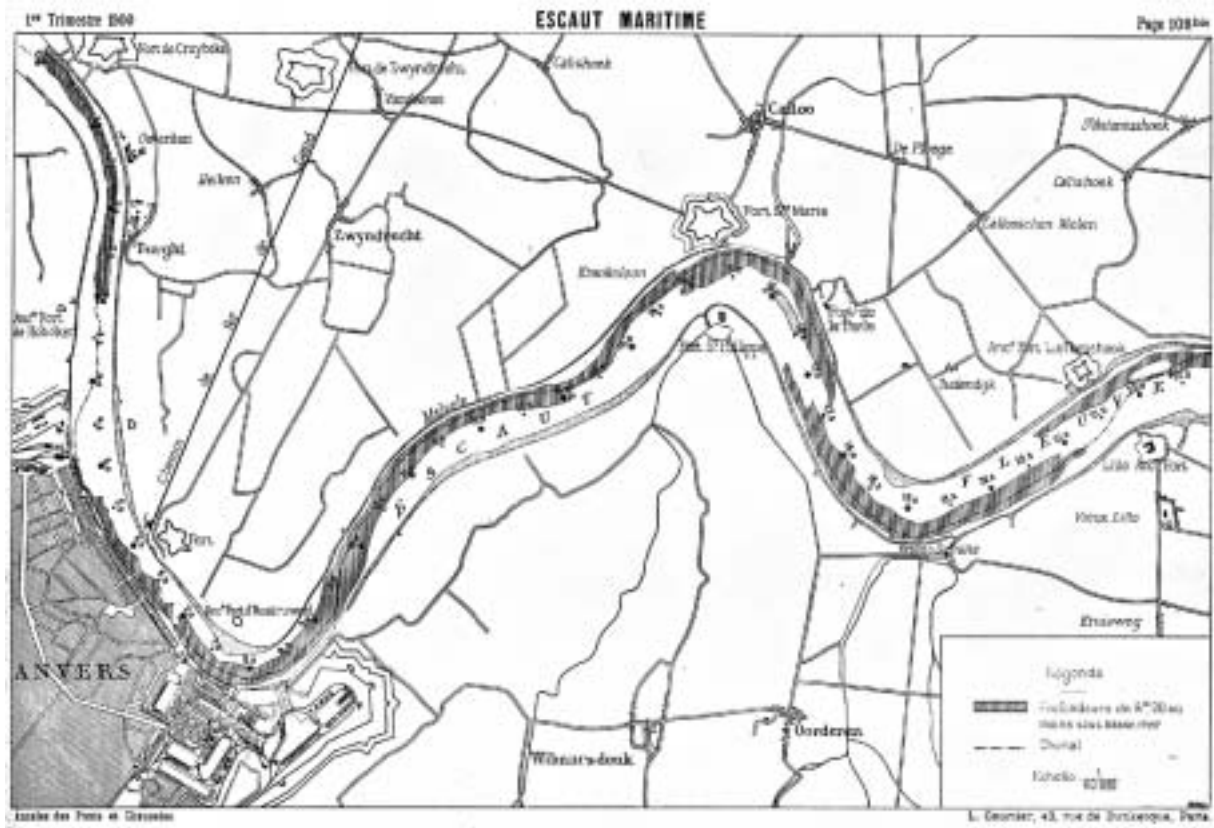


Figure 4 Escaut river at Antwerp, Belgium, which was considered by Fargue (1900).

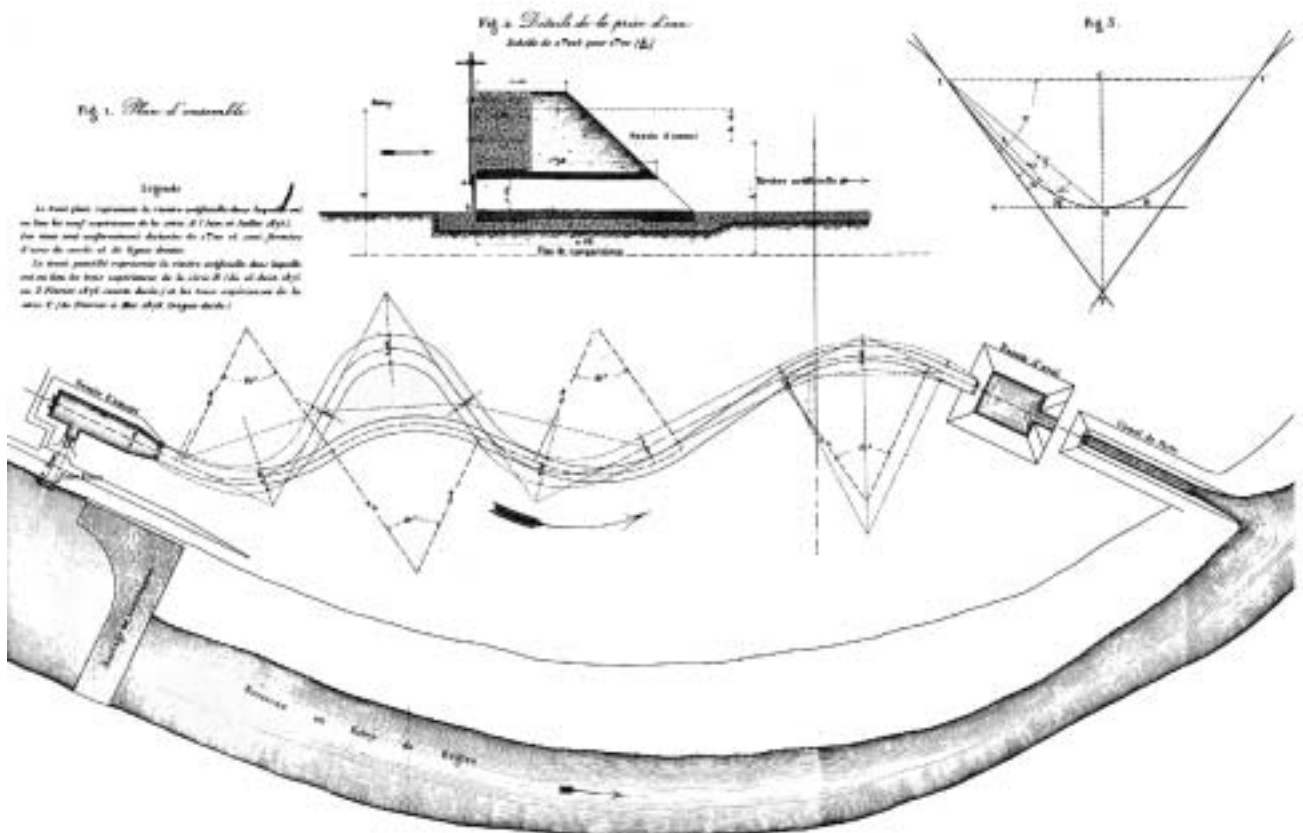


Figure 5 Test arrangement of Fargue (1894) for experiments on river meandering in 1875/76.

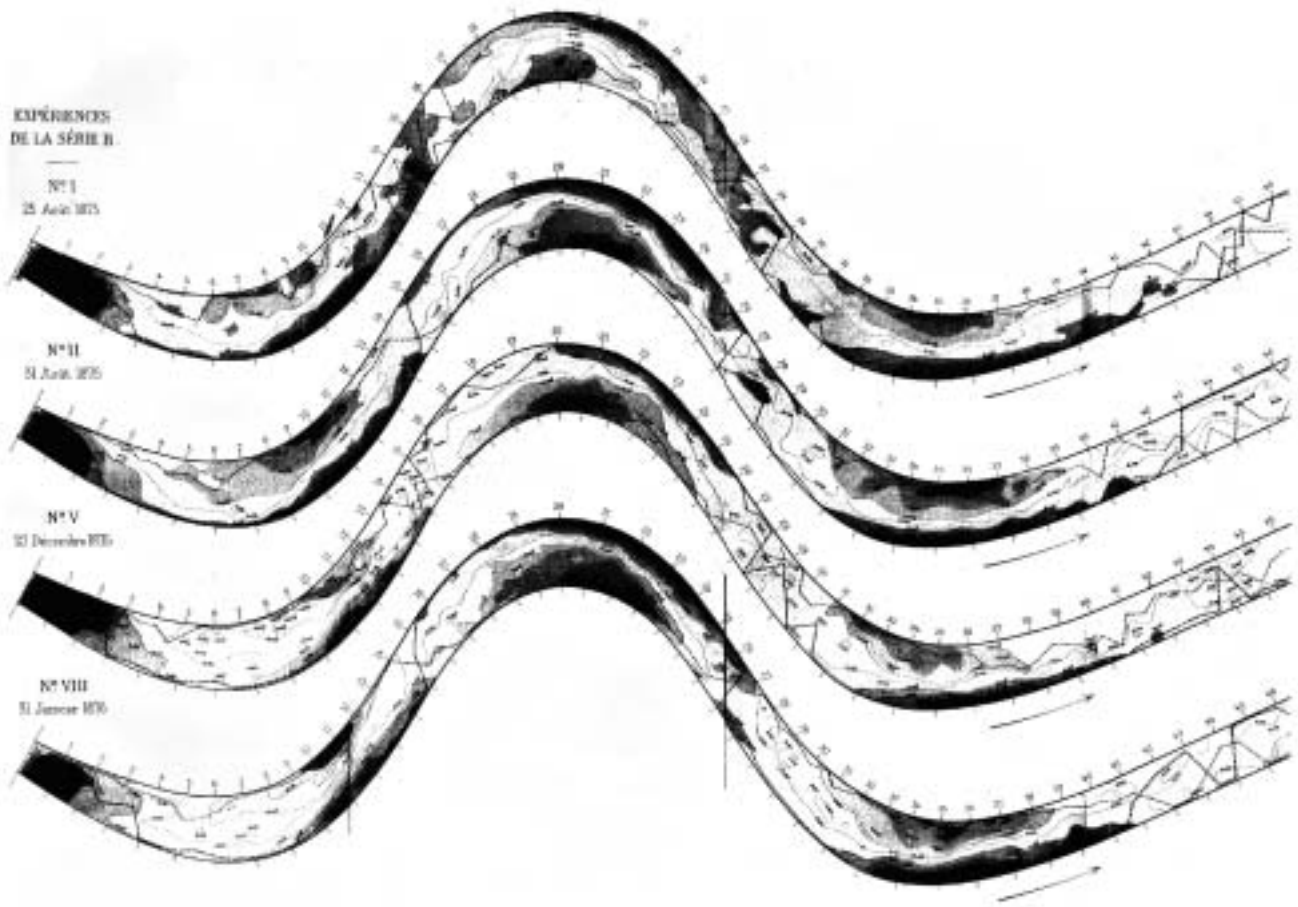


Figure 6 Observations of Fargue (1894) relating to series B for average surface velocities between 0.29 and 0.69 m/s and discharges between 67 and 209 l/s.

Again, these observations involve no hydraulic parameters. It remains unclear why Fargue did not publish his results earlier, possibly being urged by the 1895 paper of Osborne Reynolds on the model of tidal river Mersey near Liverpool in 1885.

1903 and 1907 papers

The purpose of the 1903 paper was to compare observations with a computational approach by Poisson (1902). He essentially adopted a 1-D approach and used the Bernoulli and the continuity differential equations. His formulation included equations in the radial and the tangential directions with coordinates σ and s . If the velocity across a river curve is assumed essentially constant, the governing system of equations was demonstrated to be

$$\frac{dz}{ds} + \frac{F(U)}{h} = 0 \quad (1)$$

$$\frac{dz}{d\sigma} = 0 \quad (2)$$

Here, z is the free surface elevation, $F(U)$ a function of average cross-sectional velocity U , and h is flow depth. To simplify boundary conditions, vertical side-walls were considered and the flow depth was assumed as $h(y) = (ay + b)^{-1}$, with a and b constant for a certain curve. As a first result, Poisson observed that

the flow depth is inversely proportional to streamline curvature, a result in agreement with Fargue's observations. He then demonstrated the existence of an axis of flow, in which the complicated curve flux may be concentrated as a stream tube. At the inflection point between two curves, a horizontal bed profile was deduced, whereas the largest transverse slope occurs at the point of maximum axial curvature. The latter may be represented by elliptic functions as the solution of the governing differential equation, yet Poisson's simplified approach involves the sine function, with the solution similar to Gerstner's trochoidal wave profile.

In a second approach, (2) was expanded by adding the centrifugal acceleration term. The effect of friction slope was demonstrated to be small. The rules of Fargue for river curves were then verified. To apply the results of Poisson's theory, the flow axis should initially be in equilibrium, that is the friction slope should be equal to the (average) bottom slope. Once the average velocity is known, the bed profile, the local average flow depth may be determined, and the river banks can be computed from purely geometrical conditions. It should be noted that Poisson's approach is essentially one-dimensional, thus not accounting for secondary currents responsible for river meandering. His approach may be regarded a very first attempt to model complicated river flows. Fargue (1903) also considered a stream tube and assumed a sine function as plan meander geometry. Further, Fargue related the average bed profile to the river profile in

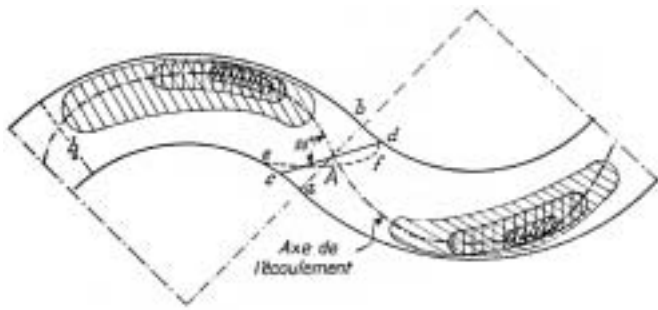


Figure 7 Streamtube approach for a river meander with *Axe de l'écoulement* = flow axis (Leliavsky, 1961).

plan, to confirm observations over the past 50 years. He proposed a design for stable river curves, yet still neglecting any hydraulic parameters. Figure 7 shows a typical river reach, with the river axis crossing the stream tube axis at the points of inflection, and the river width then being a minimum.

Fargue's (1907) last attempt to set down an analytical description of river bends involved sine curves for *both* the plan and the determining bed profiles having equal length but are out of phase by one fourth of the wave length (Figure 2). From all observations published in 1868 and 1894, one typical curve was retained to define the parameters of the governing profile, including the angle at the inflection point. The difference between the maximum bed elevation and the scour depth increases with that angle. Fargue (1907) finally questioned: "How then should banks of a stable canal for navigation be designed? This question has not yet been answered in a rigorous way", he continued. "The present note would like to suggest a rational method based on observations and correct interpretations. One would start with the profiles of plan curvature and streamwise axial flow depth close to the river portion to retain the characteristic river features. Then, these should be applied to the river portion to be improved, by accounting for the preceding observations. First applied to scale models and then to large rivers, this method provides satisfactory results, with the question of stable river flow being advanced significantly."

Fargue's impact

Fargue (1908) stated relating to his 1868 paper: "It was pure coincidence that the results agreed so well with what happened afterwards with the river". A first success occurred during the 8th International Congress of Navigation held at Paris in 1900. A final acceptance – as Fargue noted – was a review of his method in the best hydraulics book of that time by Flamant (1891) and two other books exclusively on river engineering, obviously the first to appear worldwide (De Mas, 1898; Lechallas, 1884). Two years before passing away, Fargue added the third book to the profession, and stated as the primary rules of river engineering:

- (1) With sinuous river courses navigation experiences much less problems than in straight rivers
- (2) Water flow in a mobile bed is imperatively dictated by meanders, with the straight portion being just a transition between two consecutive curves. If the river sides had the same plan,

the cross-sectional shape would be kept constant and thus offering the least hydraulic losses

- (3) Because no theory exists so far for river flows, question nature for the optimum solution!

Fargue's book (1908) as most of his papers is hard to read because of no systematic approach and a difficult writing. He also would hardly compare results with others, except for Baumgarten. Accordingly, it is much easier to follow Flamant, a master of technical writing and presentation of technical ideas.

Eydoux (1921), another authority of hydraulics, summarized the six design guidelines of Fargue as:

- (1) River curvature is related to the maximum flow depth along its thalweg,
- (2) Maximum river depth is located always downstream of the center of a curve,
- (3) Maximum scour depth increases with the angular deviation from the upstream to the downstream river tangents,
- (4) For a continuous change of thalweg depth, a curve should neither be too long nor too short,
- (5) Each abrupt change of any curve parameter results in an abrupt change of thalweg elevation, and
- (6) The thalweg slope is directly related to the change of curvature along a river bend.

These six rules were established partly with model observations and verified on Garonne river. The equations derived by Fargue have never come into general use, however, although Fargue was the first to present relations between the plan and the longitudinal bend profiles. None of these depends on hydraulic parameters such as discharge, density or Froude number.

Fargue's biography

A complete biography on Fargue illustrated with two portraits by Paul (1987) is mainly based on Clavel (1910). Other notes were presented by Minier (1882), Feret (1889), Estaunié (1932) and St. Le Tourneur (1975). Louis Jérôme Fargue was born on May 20, 1827, at Verdun, France. He entered Ecole Polytechnique in 1847, and was accepted by the Corps des Ponts et Chaussées in 1849, after the tumultuous events of the 1848 revolution (Figure 8). He was named engineer of the corps in 1852 and sent to river Garonne in Southern France. First with the navigation service, he collaborated for railroad projects between Bordeaux and Toulouse, from 1864 to 1868. Upon returning to the river service until 1875, he was stationed at Bordeaux as a member of the maritime service of Garonne river. His contribution to river improvement brought him the distinction *Chevalier de la Légion d'Honneur* in 1869. After having been active in the German-French war 1870/71 as a colonel, and for river engineering at Bordeaux, he was promoted to chief engineer in 1875, and then transferred for four years to Gap, in the French alps. Back to Bordeaux in 1879, he occupied the position of chief engineer of the maritime service for river *Gironde*, and was then responsible for port construction and improvements of the tidal river reach downstream of the city. After promotion to General



(a) (b)
Figure 8 Fargue (a) as a student at Ecole Polytechnique in 1847 and (b) when retired around 1900.

inspector of the *Ponts et Chaussées* corps, he moved to Paris in 1885, also because his large canal project close to Bordeaux was not accepted. There, he directed the French canal department and particularly improved navigation conditions of Seine river. From 1887 to 1901 he served in addition as a member of the agricultural hydraulics commission.

Fargue was appointed member of Bordeaux *Académie des sciences* in 1882, and was transferred to non-resident member from 1886 to 1897, the year he retired. Since 1887, he was *Inspecteur général* of first class, and thus a member of the general council of *Ponts and Chaussées*. He was a governmental expert for works on the rivers Nile and Maas, Belgium. He died at *Tiremont* close to *Nérac* on February 24, 1910, where his beloved river had fascinated him for almost 50 years.

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