Historical cartographic and topo-bathymetric database on the French Rhône River (17th–20th centuries)

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Abstract

Space and time analyses of channel changes, especially within large rivers subject to high levels of human impact, are critical to address multiple questions about rivers in the Anthropocene era. The reconstruction of long-term (>150 year) evolutionary trajectories permits an understanding of how natural and anthropogenic factors impact hydromorphological and ecological processes in rivers, helps with the design of sustainable management and restoration options, and may also help in the assessment of future changes. However, the reconstruction of channel changes can be challenging: historical data are often scattered across many archives, and the quantity and accuracy of information generally decreases as one goes back in time. This data article provides a historical database of 350 cartographic and topo-bathymetric resources on the French Rhône River (530 km in length) compiled from the 17th to mid-20th century, with a temporal focus prior to extensive river training (1860s). The data were collected in 14 national, regional, and departmental archive services. A table describes the properties of each archived data item and its associated iconographic files. Some of the historical maps are available in a georeferenced format. A GIS layer enables one-click identification of all archive data available for a given reach of the French Rhône River. This database provides substantial new material for deeper analyses of channel changes over a longer time period and at a finer time step compared with previously available data. The database has several potential applications in geomorphology, retrospective hydraulic modelling, historical ecology, and river restoration, as well as permitting comparisons with other ~~large and~~ multi-impacted rivers worldwide. The dataset is available at doi 10.1594/PANGAEA.922437 (Arnaud et al., 2020a). Iconographic extracts of the 350 archived items are available at http://photo.driihm.fr/index.php/category/52.

1 Introduction

30 Characterization of the evolutionary trajectories of the world's rivers and floodplains is crucial for assessment of space-time changes in biogeomorphic processes, the quantification of anthropogenic impacts, and the planning of sustainable management based on conservation and restoration options (Gabrowski et al., 2014; Mould and Fryirs, 2018). The analysis of long-term (>150 year) channel changes provides a holistic understanding of the trajectory of fluvial hydrosystems and their drivers, which helps in defining process-based restoration objectives, rather than determining static reference states (Dufour and Piégay, 2009;

35 Eschbach et al., 2018). It is necessary to extend the timescale of past trajectories to characterize possible shifts in baseline conditions related to climate variability and different degrees of human pressures to help in the assessment of future river changes in the Anthropocene (Pont et al., 2015; Slowik, 2015; Piégay et al., 2020).

The reconstruction of river trajectories requires substantial historical datasets. Series of maps, aerial images, topographic, and bathymetric surveys are generally selected at regular time steps, if available, or before and after major events (i.e. floods, river

40 engineering phases). These are) to assess changes in the river hydromorphological conditions. This set of archival materials is used to extract channel features such as active channel width, bar-island areas (Hohensinner et al., 2004; Michalkova et al., 2011; Scorpio et al., 2015; Lestel et al., 2018; ScorpioHohensinner et al., 20182021), bed degradation/floodplain aggradation rates (Steiger et al., 2001; Downs et al., 2013; Arnaud et al., 2015), riparian vegetation patterns (Cadol et al., 2011; Belletti et al., 2013; Kui et al., 2017; Safran et al., 2017), and landscape unit characteristics (Dufour et al., 2015; Solins et al., 2018;

45 Piégay et al., 2020). Following Roux et al. (1989) and Habersack and Piégay (2008), comparative analyses of large river changes, notably in Europe, have become a critical issue for addressing a series of questions of interest to geographers, historians, engineers, ecologists, geologists, and geochemists. For example, historical maps can help to better contextualize sediment core samples and geophysical surveys when investigating floodplain evolution (Salvador and Berger, 2014) and delta evolution during the Holocene (Vella et al., 2005). Historical cartographic and topo-bathymetric datasets are also of interest

50 to hydrologists analyzing flood frequency based on historical geometries (Billy et al., 2018). They are also key resources in historical ecology, allowing the formulation of hypothesis on fish habitat-species relationships since the industrial revolution, especially given the lack of old quantitative data in terms of species number, abundance, and distributions (Carrel, 2002; Frimpong et al., 2016; Belliard et al., 2018).

A number of historical analyses have been conducted on the Rhône River in Western Europe. Whereas the Rhône washas been

55 a braided and anabranching river in multiples reaches along its 530 km-long French course duringsince the 19th17th century, it has been deeply regulated for 150 years, and is now targeted by large-scale restoration measures aimed at improving morpho-ecological processes (Riquier and Cottet, 2019). On the basis of a map series surveyed in the 1860s at the scale of 1:10 000 by the *Ponts et Chaussées* (Bridges and Roads) public administration, theThe mid-19th century period is usually considered the benchmark for fluvial patterns before extensive river training. Most studies have used this 1860A detailed map series was

60 produced by the *Ponts et Chaussées* (Bridges and Roads) public administration, in the 1860s, at the scale of 1:10 000. It provides data on (i) the morphological pattern of the Rhône and its former branches, (ii) the type of land cover on the floodplain,

and (iii) topo-bathymetric information (Bravard, 2010). Most diachronic studies have used this 1860's map series as a starting point for detecting geomorphic changes, by making comparisons with later maps surveyed at the end of the 19th century and mid-20th century, and aerial images taken since the 1930s (Bravard et al., 1986; Bravard, 2010; Provansal et al., 2014; Bravard and Gaydou, 2015; Parrot, 2015; Dépret et al., 2017; Räpple, 2018; Thorel et al., 2018; Tena et al., 2020). Therefore, the post-1860 planform adjustments are fairly well understood and are combined with vertical adjustments measured on reaches where topo-bathymetric information has been available since the late 19th century. However, little is known about the morphodynamics of the Rhône in the early 19th century and times before this.

This paper presents a historical database of 350 cartographic and topo-bathymetric resources covering the French Rhône River, collected from 14 national, regional, and departmental archive services. The timescale extends from the 17th to the mid-20th centuries, with a pre-1860 focus for cartographic data and a pre-1900 focus for topo-bathymetric data. This database providesThe aim of this paper is to provide substantial new material to extend and detail historical trajectories of the Rhône River for the previously identified purposes,a wide range of research applications including historical hydrology and enableshistorical biogeomorphology, within flood management and river rehabilitation contexts. The compiled database will enable further comparisons with other large braided/anabranching multi-impacted rivers worldwide.

2 Study area

The Rhône is an 812-km long river connecting the French-Swiss Alps with the Mediterranean Sea. Originating at the Furka Glacier, the alpine Rhône drains the Valais region up to Lake Geneva. The lower 534 km of the river course are in France. As a whole, the catchment size is 98 500 km², with 90 500 km² being in France (Olivier et al., in press) (Fig. 1). The river delimits or crosses 11 French administrative departments. The mean annual discharge is 1720 m³ s⁻¹ at its mouth, which makes the Rhône the most important freshwater input into the northwestern Mediterranean Sea (Van Den Broeck and Moutin, 2002). The riverIt drains areas with a wide range of geological, altitudinal, hydro-climatic and land-use conditions, which results in a heterogeneous channel reach characterized by alternating fixed and mobile channel beds, incised valleys, and wide floodplains, and distinct sediment and flow inputs from tributaries (Bravard, 2010; Riquier and Cottet, 2019). The mean bed slopes are 0.9 % on the Swiss river course, 0.1 % on the upper Rhône section (Lake Geneva to Lyon-Saône confluence), 0.05 % on the middle Rhône section (Lyon to Valence-Isère confluence), 0.06 % on the lower Rhône section (Valence to Arles-Gard confluence), and 0.004 % at the delta (Parrot, 2015).

The mean annual discharge is 1720 m³ s⁻¹ at the most downstream gauging station (Beaucaire), which makes the Rhône the most important freshwater input into the northwestern Mediterranean Sea (Van Den Broeck and Moutin, 2002). The 100-year flood is 10 300 m³ s⁻¹. Highest floods since the beginning of daily hydrological measurements, from 1816 at Beaucaire, have occurred in October 1840 (13 000 m³ s⁻¹) and May 1856 (12 500 m³ s⁻¹). These floods are considered as a "reference" for the contemporary period. The mid-19th century corresponds to the end of the Little Ice Age, a period during which flood activity was high: the 1701–1710 period has especially exhibited the highest flood frequency of the Rhône history since the 14th century

(22 months per decade at Arles against 13 months per decade for the 1851–1860 period; Pichard, 1995; Arnaud-Fassetta, 2003).

95 The floods of November 1694 and December 1755 are the highest of their centuries (Pichard and Roucaute, 2014). The flow regime of the Swiss alpine Rhône is snowmelt-dominated, with low flows from November to April and high flows in late spring and summer. The French upper Rhône and the middle Rhône sections are influenced by a wide diversity of tributaries showing several flow patterns, like ice and snowmelt (Isère, Arve rivers) and rainfall (Saône, Ain rivers). On the lower Rhône, the major tributaries (Drôme, Ardèche, and Durance rivers) have a Mediterranean regime with high discharges mostly during

100 spring and autumn and frequent flash floods (Bravard, 2010).

River training was conducted along both the Swiss and French parts of the Rhône. In France, human interventions were developed during three main periods (Thorel et al., 2018; Tena et al., 2020): (1) in the second half of the 19th century, with the construction of longitudinal ~~unsubmersible~~'unsubmersible' dykes to locally protect the population from flooding; (2) from the late 19th to the early 20th century with the systematic construction of groyne fields connected to submersible dykes

105 (infrastructures named ~~"~~'Casiers ~~Girardon"~~Girardon' from the engineer who designed them), created almost continuously from Lyon to Arles, and aimed at concentrating flows into a narrow single-bed channel to improve navigation; and (3) from the 1920s to the 1980s, with the construction of 19 hydro-electric dams and by-passing schemes between Lake Geneva and the Mediterranean Sea by the National Company of the Rhône River (CNR).

Channel correction and flow regulation induced major hydromorphological modifications such as incision and armouring,

110 disconnection of secondary channels, floodplain terrestrialization, and subsequent loss of ecological functionalities (Roux et al., 1989; Amoros and Bornette, 2002; Parrot, 2015; Dépret et al., 2017; Tena et al., 2020). A large-scale restoration plan for the French Rhône has been conducted since 1998 to improve ecological conditions in the main channel and floodplain. This plan is based on the combination of two main measures: (i) increasing the minimum flow in by-passed reaches, and (ii) reconnecting abandoned channels (Lamouroux et al., 2015). A second phase of restoration was launched in 2009, and currently

115 consists of enhancing sediment transport processes into by-passed and ~~total~~main channel sections. The measures include riprap removal to reinitiate bank erosion, and ~~artificial~~ reintroduction of gravels dredged from reservoirs and navigable channels or excavated from restored side channels. Monitoring programs are co-constructed between researchers and practitioners, to ~~allow the latter to~~ assess ~~changing scenarios~~restoration success and ~~incorporate them into policy~~provide insights to improve restoration strategies~~.~~ (Lamouroux et al., 2015; Thorel et al., 2018).

120 **3 Material and methods**

3.1 Data collection

This study started with an inventory of historical resources compiled in previous long-term research: the RhônEco program (2001–present), Rhône Sediment Observatory (2009–present), and Rhône Valley Human-Environment Observatory (2011–present). We found one long profile and 15 map series collected between 2009 and 2015 from the CNR, the Regional

125   Directorate for Environment, Development and Housing (DREAL), the National Institute of Geographic and forest information (IGN), and the Departmental Archives of Savoie (AD73), Drôme (AD26), Ardèche (AD07), Isère (AD38), Vaucluse (AD84), and the University of Grenoble (Univ. Grenoble). Most of the maps were scanned and integrated into a GIS interface. Their spatial coverage extends from about 10 km to the entire 530-km length of the French river course. The oldest map series is the Sardinian Maps, consisting of twenty communal maps of the left bank of the upper Rhône surveyed at the scale of 1:2372 (the

130   original scale is in 'trabucs') by the Kingdom of Piedmont-Sardinia in 1728–1738. The most recent map series are the CNR pre-work plans, consisting of 128 sheets surveyed between 1946 and 1983 at the scale of 1:10 000 to plan 19 damming and by-passing schemes on the Rhône River from Injoux-Génissiat to Arles.

    Between 2017 and 2020, we searched archive services that had been only poorly explored previously: the National Archives of Pierrefitte-sur-Seine (AN; 10 days), Bibliothèque nationale de France (BnF; 2 days), and the Departmental Archives of

135   Rhône (AD69; 6 days), Ain (AD01; 2 days), and Gard (AD30; 2 days). The AD Rhône holds the main collection of the *Ponts et Chaussées* administration/Rhône Navigation Service. This consists of numerous maps, plans, and profiles regarding public works and authorizations in the public fluvial domain over the entire river course. We consulted the entire sub-series *S/Public Works (1784-1988)* and *3959 W 1-2030/Rhône-Saône Navigation Service (1807-1994)*. Other relevant references were identified in the AD Rhône numeric catalogue by entering the keywords 'Rhône River' and 'map', notably throughout the

140   *Ancien Régime* (16th–late 18th century). In total, 113 archive boxes were consulted. This research was completed at the National Archives, which also hold the *Ponts et Chaussées* collection. In terms of spatial extent and survey period, the online catalogue contained less information than the AD Rhône one. However, it was possible to identify adequate references with the keyword 'Rhône River' in the sub-series *F/14/Public Works.* Not all resources were described online; thus, the paper registers of the sub-series *F/14/Public Works* and *F/10/Agriculture* were also consulted. The other archive services were similarly searched

145   by keywords, in both numeric catalogues and paper registers. A total of 211 archive boxes were consulted, with each box containing a bundle of documents for either a specific sector at different periods, or a set of surrounding sectors at a given period (Fig. 2). The documents included letters, newspaper extracts, engineer reports, survey tables, cost estimates for further river management, and iconographic resources generally produced to survey flood damage or to plan new infrastructure. We systematically took pictures of iconographic resources, which included maps (Fig. 3.a, b), cross-sections, long profile series

150   (Fig. 3.b), and topo-bathymetric information drawn on maps (Fig. 3.c).

    The series *CP* (Maps and Plans Service) of the National Archives was given special attention. This series contains older, larger and/or fragile maps, field surveys, and engineering structure iconographies, and requires specific authorization for consultation (Fig. 3.b), with the resources having to be consulted one by one. Because of time constraints, we focused on maps covering long river reaches rather than detailed maps of ports and cities, and focused on reaches involved in present river restoration

155   projects, notably those of Péage-de-Roussillon and Donzère-Mondragon. We selected 33 resources amongst the 53 available for consultation in the sub-series *CP/F/14/Streams and Rivers* (6.5 p.). The sub-series *CP/F/14/Canals* had 12 pages dealing with a project for a continuous lateral canal from Lyon to the Mediterranean Sea, which was finally dropped, and 3 pages dealing with the canal from Arles to Port-de-Bouc at the Rhône delta. We selected 39 resources amongst the 113 available for

consultation. The box references consulted in all the archive services are listed in the dataset at doi:10.1594/PANGAEA.922437 (Arnaud et al., 2020a).

All collected data were photographed on a table or on a magnetic board in the case of multiple-sheet and large documents, and were saved in .jpg format. The most interesting data were scanned at high resolution (.JPEG and .TIFF format, up to 3 GB each).

3.2 Database structure

Table 1 describes the properties of the 350 archived data items available in the ~~dataset of~~ Arnaud et al. (2020a~~).~~) dataset. This table has 18 columns that include the following: (1) the type of data: i.e. map, cross-section, long profile, table, topo-bathymetry drawn on the map, (2) the source (archive service) and reference (box number), (3) the original title (in French) and a translated English title, (4) the scale, author, and survey period, (5) the communes covered by the upstream-downstream Kilometric Points (KPs; km 0 is in Lyon, distances upstream from this reference point are negative and distances downstream are positive; the KPs were identified in ArcMap 10.5 using the GIS layer of riverine communes and active channels in 1860, to help in locating the maps with secondary channels). (6) comments on the quality and content of the data, (7) the number of images and their type (on a table or a magnetic board, HD scan, scanned and georeferenced), and (8) the storage file and sub-file.

The iconographic database available in Arnaud et al. (2020a) is 12.7 GB. It contains 3437 images stored in 32 files and 342 sub-files. Thirteen files are named after the engineer who did the surveys. For example, the 'Kleitz (1853-1864)' and 'Bouvier (1785-1848)' files contain 63 and 24 sub-files, respectively. These files describe maps of different reaches, sometimes associated with topo-bathymetry data. The '*Ponts et Chaussées* (1807-1858)' file contains 37 maps surveyed by authors who are unknown or whose names are unreadable. The database also contains 14 files corresponding to a single engineer survey, generally at scales of 1:10 000 or 1:20 000 along a long river course (from 60 to 530 km), e.g. the map by Josserand surveyed in 1845 between Lyon and Donzère (170 km long), or the long profile by the *Ponts et Chaussées* administration surveyed in 1869 from Seyssel to Lyon (151 km long; Fig. 3.c). Three files consist of maps of the three main reaches of the Rhône: the French upper Rhône (16 maps from 1730–1875), the middle-lower Rhône (13 maps from 1642–1857), and the delta (16 maps from the 18th–19th century). Finally, the file 'Topo-Bathy (1799-1882)' contains 19 cross-section and long profile series surveyed by different authors.

The 350 archive resources include 330 maps and 93 topo-bathymetric data items (Fig. 4.a). About forty other documents were also collected, corresponding to plans (<1:1000), information on the Swiss Rhône, and books from the late 19th and early 20th centuries on fish populations (Vingtrinier, 1882; Locard, 1901; Marchis, 1929). Maps and topo-bathymetric data mainly cover the ~~period~~ 1840–1855 period (Fig. 4.b), which corresponds to the beginning of river training after the 100-year flood in October 1840 ~~at Beaucaire (13 000 m³·s⁻¹).~~. This flood was responsible for significant damage, and led to the establishment of the Rhône Special Service within the *Ponts et Chaussées* administration in 1840 (Bravard, 2010). The 1856–1870 period was also well surveyed, ~~after another~~following the other 100-year flood in May 1856 ~~at Beaucaire (12 500 m³·s⁻¹).~~. Nineteen percent

of the database covers the ~~period~~ 1640–1839 period. The oldest resource is a series of 6 maps found in the Chaponnay private archive of AD Rhône, surveyed in 1642–1660, and depicting the 'brotteaux' (grazing areas on recent alluvial deposits) between Pierre-Bénite and Irigny fluvial ports to the south of Lyon (Fig. 5). This map series represents the Rhône River in an artistic manner; however, the distances between villages were checked and were found to be realistic.

195 ~~Fig. 6~~Hydrological information like spatial extent of large floods and the associated water-level at gauging stations is provided on most maps. On the opposite, the discharge of the aquatic channel is rarely given, and we have to assume that the river is represented at its ~~the~~ mean annual discharge, as usual in cartography. Only few maps, like the 'Topographical map of the Rhône River' surveyed in 1857-1876 by the *Ponts et Chaussées* administration indicate in the chart legend that the channel was mapped at the mean annual discharge. Finally, water-level information is systematically provided on topo-bathymetric

200 data, i.e. the water level on the day of the survey, the low-flow level and/or the high flood levels (Fig. 6). Fig. 7 provides a synoptic view of all cartographic data with corresponding spatial scales along the Rhône River. Most items were surveyed between the scales of 1:1000 and 1:20 000, with 1:10 000 being mainly used. This latter scale is suitable for quantitative analysis of morpho-ecological units. Similarly, Fig. ~~7~~8 depicts the longitudinal coverage of topo-bathymetric data.

3.3 GIS integration

205 The longitudinal coverage of each of the 350 data items was positioned along the Rhône River centreline in ArcMap 10.5, according to the upstream and downstream KPs. The individual coverages were then merged into one polyline layer available in the ~~dataset~~ Arnaud et al. (2020a~~).~~) dataset. This layer provides efficient identification, at a single click, of archive resources available for a given reach. For example, dragging a selection box over the Chautagne by-passed reach (KP −146 to −137) displays 24 data items on this reach (Fig. ~~8~~9).

210 The ~~dataset~~ Arnaud et al. (2020a) dataset provides 14 scanned map series, in both raw (.JPEG or .TIFF) and georeferenced (.GeoTIFF) formats (Table 2). They are among the most spatially extensive and accurate maps in terms of the features represented. Half of these maps have been georeferenced in previous works of the Rhône observatories, using a first order polynomial transformation (between 3 and 15 Ground Control Points [GCPs] per image, RMS error up to 50 m). In this study, we tested the spline ~~transformations~~transformation (named Thin Plate Spline transformation in QGIS) based on

215 recommendations of Lestel et al. (2018) for old maps. The spline transformation is a true rubber-sheeting method optimized for local but not global accuracy. It transforms the source GCPs exactly to the target GCPs, with minimal error around the points. The spline transformation is therefore useful when the number of GCPs is important (www.esri.com). The spline transformation was tested on map series of 1760 and 1831 by adding GCPs, and was compared with the ~~first order~~ polynomial ~~transformation~~transformations (Table 2). The positioning on the present orthophotograph was significantly improved, and the

220 spline transformation was therefore applied to the newly collected maps. Raw and georeferenced images are usable in both ArcGIS and QGIS softwares. Among the 316 other maps of the database, most can be georeferenced by using riverine roads,

buildings and dykes as GCPs. When available, land register can also be used. Though, maps surveyed at a too large scale (1:1 000, 1:2 000), or those representing a single bank of the Rhône River, do not have enough GCPs to be georeferenced.

4 Data use and application

225 The type of archive data, either manually photographed or scanned, and in some cases georeferenced, allows the user a qualitative or quantitative analysis, including illustration of the fluvial landscape of a large river at the beginning of the 19th century, evaluation of the main transformations following river regulation, and diachronic GIS extraction of metrics such as channel widths, secondary channel numbers, and gravel bar areas. The scanning and georeferencing of the sources are not exhaustive. The archive references are accurately described in the table of data properties to facilitate easy consultation and

230 scanning of data of interest.

  The dataset depicts heterogeneous information, which depends on the survey date and map objectives. A critical analysis should therefore be carried out before any use of the dataset on a given river reach. As an example, Fig. 910 compiles maps surveyed in the upstream section of the Donzère-Mondragon (DZM) reach, which wasis currently involved in side channel reconnections, riprap removal, and gravel augmentation. The 5-km-long section (KP 171 to 176) embraces the eastern Bayard

235 secondary channel, which was the main course of the river in the late 18th century. Among the 26 maps available prior to 1860, nine have been selected at scales of 1:50005 000–1:10 000. Maps from 1810 to 1842 do not specify the nature of islands. Partial information is given on the 1843 map, with gravel bars drawn in light orange. Symbols are then used on the 1846 map to differentiate gravel bars and vegetated areas. These symbols are also used on the 1852 and 1856 maps: their base map is the 1846 edition superimposed with the new channel pattern and engineering infrastructure, which is a common practice in

240 engineering cartography (Lestel et al., 2018). The 1856 map was edited to report damage to 'unsubmersible' dykes after the flood of May 1856. New islands and gravel bar areas formed after the May 1856 flood arewere drawn in light orange on the 1856 map. Note that the titles of the maps are equivocal: 71 maps of the database have the word 'dyke' in their title and were surveyed to report damages after large floods, rebuild dykes or design new ones. The challenge of map-based historical studies is to use individual sources over time, with sometimes little information on the context in which the map was created, and

245 therefore on its certainty level. The comparison of multiple maps available at close dates (some of them surveyed in the same year by different engineers) allows inconsistencies between individual sources to be resolved while revealing persistent landscape features and patterns (Safran et al., 2017). For example, the coloured map of 1842 from Switzerland to the Mediterranean Sea surveyed by the engineer Arnaud is fairly aesthetic; however, a comparison with other maps highlights the lack of accuracy in the depiction of geomorphic features, notably on the downstream part of the Bayard channel, as well as the

250 non-exhaustive mapping of roads and villages, which limits the number of ground control points available for georeferencing. In addition, when analyzing long-term vegetation changes, it is important to carefully examine vegetated areas representation because vegetation (when available) could be represented in many different ways, either by colors, symbols or annotations (Fig. 10 and 11). In most cases, only vegetated islands and the riparian vegetation close to the channel were mapped (Fig 11a

and 11b). The depiction of vegetation in the entire floodplain was less frequent (Fig. 11c), especially regarding vegetation types (grassland, shrubs, forest, agricultural areas; Fig 11.d). Note that the more recent maps did not have systematically more information than the older ones.

Keeping in mind the preliminary examination of the data accuracy, the large number of historical data items collected in this study should enable deeper analyses of channel shifting, island dynamics, and landscape changes over a longer time period and at a finer time step than those performed in previous studies, and also on many reaches of the Rhône River and tributary confluences for which no historical maps had been collected until now. The archives prior to 1860 provide us with historical benchmarks for process-based river restoration, and permit comparisons with other ~~large~~ rivers with available archives. A potential application could be the detailing of past trajectories of floodplain units, such as that performed by Tena et al. (2020) on three by-passed reaches of the middle and lower Rhône (Fig. ~~10~~12). Similarly, Dépret et al. (2017) combined historical maps and aerial images (1860-2009) to date a series of channel disconnections and study terrestrialization processes. They showed that terrestrialization of naturally cut-off channels was much quicker than that observed on artificially cut-off channels, probably because of much higher bedload transport, which promoted active sediment infilling. The historical dataset is also valuable to explore longer-term ecological succession, such as initiated by Bravard et al. (1986) and Roux et al. (1989) on the ~~work~~upper Rhône section. During the 18th and 19th centuries, the backswamps and the gravel bars of the braided belt were devoted to extensive grazing, and the woody islands were cut every five years for supplying the riverine populations and the town of Lyon with fuel. On the margins of the floodplain, a few hardwood forests of *Fraxinus excelsior*, *Quercus robur* and *Acer pseudoplatanus*, escaped land clearances for pasture, subsistence agriculture and firewood cutting (Roux et al., 1989). More recently, Janssen et al. (2020~~), who~~) showed from aerial images that the critical changes undergone by the riparian forests of the Rhône River under persistent multiple stressors, strongly diverged from near-natural systems ~~under persistent multiple stressors~~ during the ~~past~~20th century ~~(1938–2002).~~.

~~Historical data on fish communities along the Rhône River are available in documents of various types (e.g. Gobin, 1868, the numerous papers and maps from L. Léger and his collaborators, anonymous reports), and comparisons with present datasets allow assessments of changes in fish community assemblages to be made. Combining physical data describing habitat heterogeneity (e.g. channel width, river bank length, diversity and accessibility of different types of floodplain channels; see Hohensinner et al.~~ Historical maps and associated physical data have been used to assess fish-faunistic reference conditions in the framework of European biomonitoring improvement (Wolter et al., 2005; Ramos-Merchante et al., 2021). An~~2004; 2011 for examples on the Danube River) at different periods with data on fish habitat preferences (Lamouroux et al., 1999; Rifflart et al., 2009; Sukhodolov et al., 2009) may be useful to achieve a better understanding of the influence of fluvial landscape transformation over the last few centuries on fish abundance and spatial patterns. Historical maps and associated physical data can thus be used to assess abiotic conditions over time in the framework of biomonitoring methods. For example,~~ historical analysis (from the end of the 19th century) of fish community structure in the Seine River catchment highlighted the major role of river continuity alteration in the decline of migratory species, the importance of introductions of non-native species, and changes in the proportion of rheophilic/eurytopic species in relation to the increase of human population and water pollution

(Belliard et al., 2018). Historical data on fish communities along the Rhône River were discussed by Carrel (2002). In addition to fish data, Léger's maps available in the Arnaud et al. (2020a) dataset provide also morphological information on each river section (mean channel width, mean water depth). Combining physical data describing habitat heterogeneity (channel width, river bank length, diversity and accessibility of floodplain channels; see Hohensinner et al. 2004; 2011 for examples on the Danube River) at different periods with data on fish habitat preferences (Lamouroux et al., ~~densities and water pollution (Belliard et al., 2018).~~1999; Rifflart et al., 2009) may be useful to achieve a better understanding of the influence of fluvial landscape transformation over the last few centuries on fish abundance and spatial patterns. More generally, the combination of biotic and abiotic archival data is important to assess how changes in hydromorphological river conditions influenced on biodiversity.

Finally, another potential use of the dataset is the reconstruction of extreme flood events based on historical channel geometries. The Beaucaire-Tarascon station (KP 269.5) records flows of the whole basin, and is the oldest hydrometric station on the Rhône. Daily water level measurements started in 1816, and daily estimates of discharge started in 1920 (Billy et al., 2018). These chronicles are part of the HISTRHONE database, which contains a large volume of archives related to hydro-climatic events in the lower Rhône over a period between the 14th and 20th centuries (Pichard and Roucaute, 2014). Further work by hydrologists will involve exploiting historical topographic data prior to river training to reduce uncertainties in the extrapolation of rating curves of hydraulic modelling based on original channel geometries. The topo-bathymetric data highlighted in this study will be of particular interest (Fig. ~~7~~6 and ~~11~~8).

5 Data availability

The dataset is freely available in Pangaea at doi 10.1594/PANGAEA.922437 (Arnaud et al., 2020a). It contains the iconographic database (12.7 GB), the .csv table describing the properties of the 350 data items (109 KB), the .csv table listing the 281 archive box references (13 KB), and the GIS layer of the longitudinal coverage of the 350 data items (10.8 MB). The dataset is available under the terms of the Creative Commons Attribution-NonCommercial (CC BY-NC) license, which permits use, distribution and reproduction in any medium, provided that the use is not for commercial purposes and that the original work is properly cited. This license was chosen to meet the data reuse policies of the 14 French archive services investigated in this study, 4 of which have a reuse policy equivalent to the CC BY license (National Archives, AD Ain, AD Vaucluse, DREAL, Univ. Grenoble), and 5 have a reuse policy equivalent to the CC BY-NC license (BnF, AD Rhône, AD Drôme, AD Ardèche, AD Gard). Data from AD Isère, AD Savoie, CNR, and IGN, i.e. 10 items among the 350 items in the dataset, are not furnished in the iconographic database. They are indicated as "available on request", because of specific reuse policies of these institutions. The URLs of each institution's reuse policy are given in Pangaea metadata.

Extracts of the 350 data items are available in the public photo gallery of the Rhône Valley Human-Environment Observatory, to enhance data visibility. This photo gallery uses the open source Piwigo software, with images being geolocated on an

interactive map. Map extracts have been oriented according to the flow direction of the Rhône, as long as this did not disturb
320   the toponym reading.

In addition to Pangaea, technical information on the dataset is available in the public metadata catalogue of the Rhône Valley
Human-Environment Observatory. Based on the open source GeoNetwork software, this metadata catalogue is harvested by
the LabEx DRIIHM (international consortium of Human-Environment Observatories) geocatalogue, which is then harvested
by the French geocatalogue and the European INSPIRE Geoportal, so that data discovery is possible at several hierarchical
325   levels (Arnaud et al., 2020b).

6 Conclusions

This study presents a historical database of 350 maps, topo-bathymetric cross-sections, and long profiles compiled on the
French Rhône River over the ~~period~~ 1640–1950 period. Such an inventory of historical data over such a long time period and
long river course (530 km) has never been created before for the Rhône, and has rarely been created for other large rivers. This
330   database will enable further comparisons with other multi-impacted large rivers in Europe, such as the Danube, the Rhine, the
Ebro, and the Po, or even from one continent to another when data are available. The densification of archived time series is
useful to detail and extend past trajectories of geomorphic, hydraulic, and ecological river features, and for conducting
comparative analyses to detect differences and similarities between reaches and between rivers located in different
geographical settings. Recently, ~~restoration~~rehabilitation measures have been extended to other by-passed reaches of the lower
335   Rhône River (Baix-le-Logis-Neuf, Saint-Vallier, Montélimar), and these will also require analyses of channel changes over
the last two centuries to ~~improve~~design restoration ~~strategies~~objectives. Some archive services were consulted in entirety for
the time period and theme of this data article, notably the National Archives and AD Rhône, whereas additional investigations
could be conducted in CNR or other departmental archives in coming years. Possible updates or extensions to the dataset might
therefore happen in the future.

Author contributions

All co-authors actively participated in the project "Collection and visualization of historical biophysical resources on the Rhône
River" (OHM Vallée du Rhône, 2017-2019). Fanny Arnaud and Lalandy Sehen Chanu searched archive services,
photographed historical resources, and prepared the database. Jules Grillot performed GIS treatment of scanned data. Jérémie
Riquier brought his expertise on historical data compiled in previous long-term research on the Rhône River. Fanny Arnaud
345   supervised the project and wrote the paper. Hervé Piégay, Dad Roux-Michollet, Jérémie Riquier, Georges Carrel, and Jean-
Michel Olivier revised the manuscript and provided important contributions in the section "Data use and application".

Competing interests

The authors declare that they have no conflicts of interest in respect to this study.

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List of Tables

Table 1: Extract of the .csv table describing the properties of the 350 archive resources collected in this study. The symbol ~ in the Scale column means that it was not provided in the document, and the scale was therefore estimated by direct measurement of the distance between two benchmarks or by comparison with similar maps.

520

(a)

ID	Type	Source	Ref data	Original title (in French)	Translated title (in English)	Scale	Author(s)	Period
44	Map	AD01	100Fi 67	Plan du cours du Rhône depuis Seyssel jusqu'à Pierre-Châtel sur le territoire de Virignin, ainsi que les communes avoisinantes	Map of the Rhône river from Seyssel to Pierre-Châtel on the territory of Virignin and neighbouring towns	Toises	*NA*	~ 1750
264	Map/Cross section	AN	CP/F/14/10074/1/A/piece25	Projet de halage pour le passage du Pont-St-Esprit	Towing project for the Pont-St-Esprit passage	*~ 1:5000*	Grangent	1812
261	Map	AN	CP/F/14/10074/1/B/piece34	Plan de la partie du cours du Rhône et de la rive gauche de ce fleuve comprise dans le département de la Drôme, entre l'embouchure du ruisseau du Dolon (...) et celle du Lauzon	Plan of the part of the Rhône river and the left bank of this river included in the department of the Drôme, between the Dolon confluence (...) and that of the Lauzon	1:10 000	Grailly	1833
96	Cross section	AN	F/14/6501	Barrage du bras de Lavours	Dam of the Lavours channel	1:1000	O'Brien	1835
255	Map	AN	CP/F/14/10074/1/B/piece35	Plan général de la rive droite du cours du Rhône depuis Limony, jusqu'au pont de Saint-Just. Troisième feuille de Meisse à St-Just	General map of the right bank of the Rhône river from Limony to the St-Just bridge. Third sheet from Meisse to Saint-Just	1:10 000	Ponts & Chaussées	1835
304	Map/Bathy-metry	AD69	S 1434	Amélioration du Rhône devant Beaucaire	Improvement of the Rhône river at Beaucaire	1:10 000	Goux	1851
100	Long profile	AD69	S1356	Nivellement en long sur les deux rives du Rhône	Longitudinal levelling on both banks of the Rhône river	1:10 000	Ponts & Chaussées	1869
10	Map	CNR, AD01	*NA*, 100Fi 69 to 100Fi 114	Plans Branciard	Branciard maps	1:2000, 1:5000	Branciard	1910

525

Sector	Upstr. KP	Downstr. KP	Length (km)	Comment	Nb of images	Image acquisition	Storage file	Sub-file
Seyssel to Virignin	-151	-117	34	This map may have been surveyed after the Sardinian Maps of 1738 and before 1760 because 'lateral lines' from 1760 are not visible everywhere	20	Table	1730-1875_Plans_UpperRhone	1750_NA_Seyssel-Virignin
Pont-St-Esprit	191	193	2	Names of the bridge piers. 3 cross sections	8	Table	1756-1822_Grangent_Plans	PontStEsprit_1812
St Rambert to Pont-St-Esprit	61.5	191.5	130	Map of 12 m long. Name of some islands but not their nature. Left bank only. The Drôme River is visible	25	Table	1833_Grailly_Plan_Dol-Lauz	
Lavours	-131.5		Ponctual data	1 cross section	8	Table	1799-1882_Topo-Bathy	1835_OBrien_Lavours_CS
Meysse to St Just	151	191	40	Not the nature of bars and banks. Right bank only	10	Table	1807-1858_PontsChaussees_Plans	Meysse-StJust_1835
Beaucaire	260	268.5	8.5	2 general maps, 3 detailed maps	3, 6, 3, 3, 4	Magnetic board	1839-1853_Goux_Plans	Beaucaire_1851
Seyssel to Lyon	-150	0	150	Long profile indicating water depth and thalweg elevation	14	Table	1869_PC_LP_Upper Rhone	
Virignin to Caderousse	-116.5	219	335.5	Upstream of Lyon: AD01. Downstream of Lyon: CNR (available on request)	47, 107	HD scan, Georef 1st	1910_Branciard_Plan_Viri-Cad	

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Table 2: Georeferencing information on 14 map series of the database. The BD ORTHO® and PARCELLAIRE® base maps are provided by the IGN.

Translated title (in English)	Scale	Author(s)	Period	Sector	Length (km)	Nb img	Georeferencing transformation	Nb GCPs / img	RMS error (m)	Base map
Map of part of the Rhône river from Cordon to Hyenne (…)	1:30 000	*NA*	18th c.	Yenne to Cordon	25	2	Spline	12-24	10⁻⁵	BD ORTHO® & PARCELLAIRE®, OpenStreetMap©
Geometrical map of part of the Rhône river from Geneva to the Guyer confluence (…)	1:28 246	De Bourcet	1760	Genève to St-Genix	107	7	1st Order Polynomial & Spline	13-25 & 20-26	34-44 & 10⁻⁵	BD ORTHO® & PARCELLAIRE®, OpenStreetMap©
Map of the marshes and the plain from Beaucaire to Aiguemortes (…)	*~ 1:100 000*	Delisle	Late 18th c.	Beaucaire to the sea	57	1	Spline	31	10⁻⁵	BD ORTHO® & PARCELLAIRE®, OpenStreetMap©
Napoleonic land register	1:10 000	Napoleon I	1810-1832	St-Maurice to Piolenc	63.5	16	1st Order Polynomial	*NA*	*NA*	BD ORTHO® & PARCELLAIRE®
The Rhône river-: border between the Kingdom of France and the Duchy of Savoy	1:14 400	Corefa	1831	Cressin to St-Genix	30	1	1st Order Polynomial & Spline	23 & 38	59 & 10⁻⁵	BD ORTHO® & PARCELLAIRE®, OpenStreetMap©
General plan and project for the dyke to be built against the highest floods of the Rhône (…)	1:10 000	Dignoscyo	1837	Jons to Pierre-Bénite	31	2	Spline	50-85	10⁻⁵	BD ORTHO® & PARCELLAIRE®, OpenStreetMap©
Map of the Rhône river between Donzère and Arles	1:10 000	Ponts & Chaussées	1846	Donzère to Arles	116	12	Spline	19-52	10⁻⁵	BD ORTHO® & PARCELLAIRE®, OpenStreetMap©
NA	1:10 000	*NA*	1854	Anglefort to Massignieux	23	5	Spline	10-14	10⁻⁵	BD ORTHO® & PARCELLAIRE®, OpenStreetMap©
Topographical map of the Rhône river	1:10 000	Ponts & Chaussées	1857-1876	Surjoux to the sea	489	58	1st Order Polynomial	~ 15. Improvement of 9 images: 10-17	< 50. Improvement of 9 images: 4.6-12.8	BD ORTHO®
Completion and first maintenance works	1:10 000	Girardon	1891	Lyon to Donzère	169.5	55	1st Order Polynomial	6-15	3.0-9.5	BD ORTHO®
Bathymetric maps of the Rhône river	1:10 000	Ponts & Chaussées	1897-1908	Lyon to the sea	307	66	1st Order Polynomial	4-12	0.6-20.5	BD ORTHO®
Branciard maps	1:2000, 1:5000	Branciard	1910	Virignin to Caderousse	170	107	1st Order Polynomial	3-15	0.3-11.3	BD ORTHO® & PARCELLAIRE®
General staff maps	1:20 000-1:80 000	Etat-Major	1832-1941	Genève to the sea	535	162	1st Order Polynomial	4-6	0.8-26.3	BD ORTHO®
Pre-work plans	1:10 000	CNR	1946-1983	Anglefort to Caderousse	162	128	1st Order Polynomial	4	*NA*	BD ORTHO®

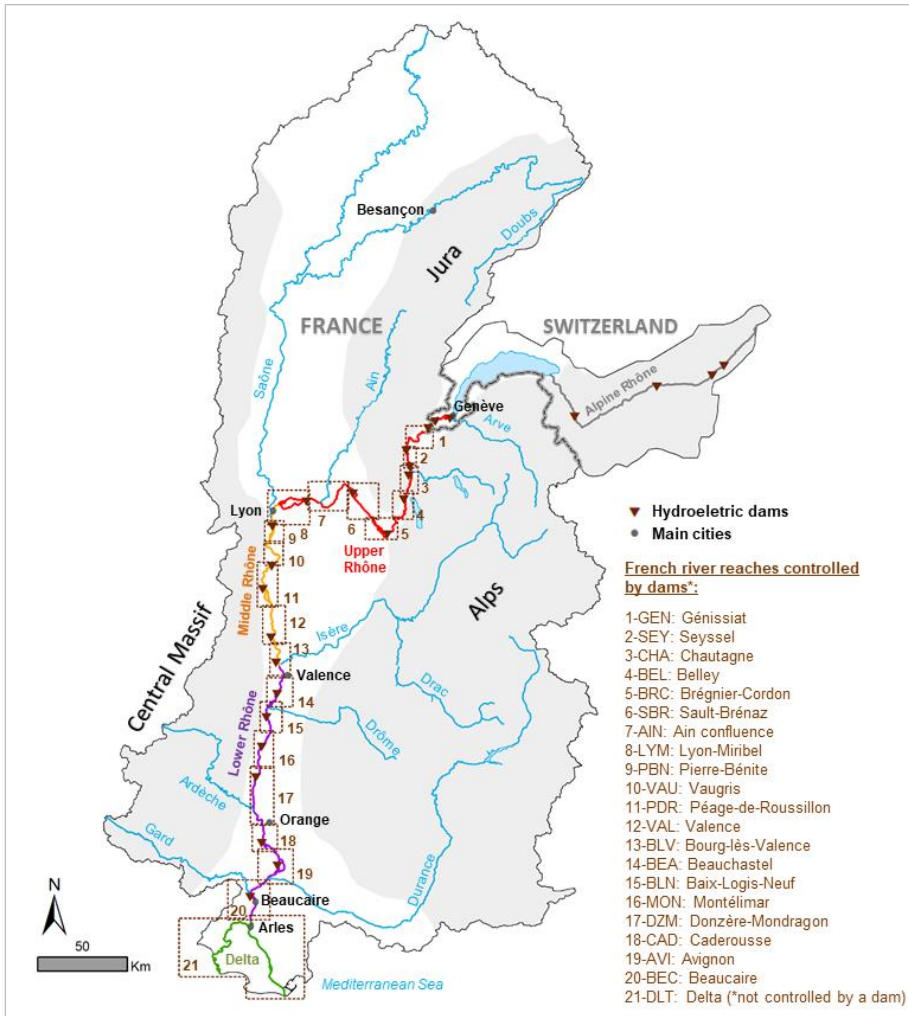



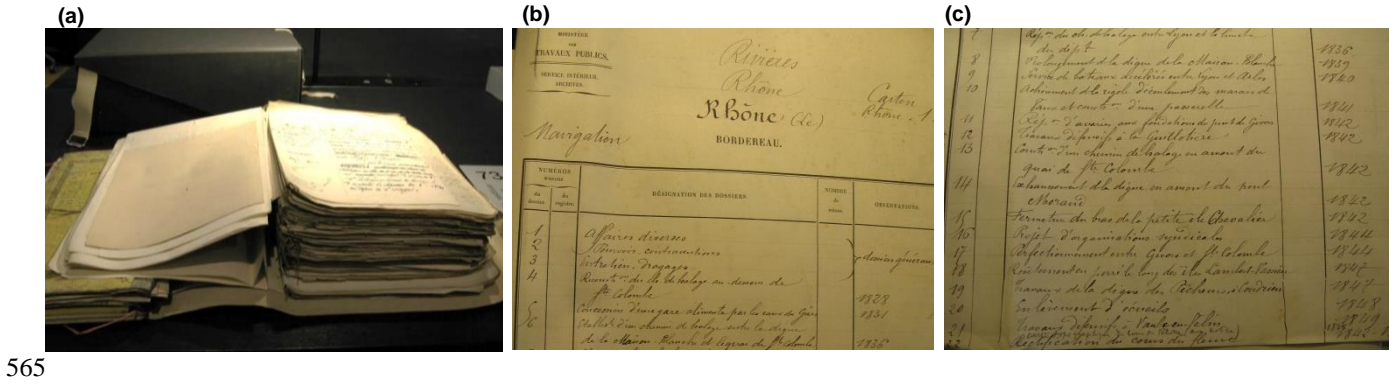
Figure 1: The Rhône River corridor in the French-Swiss basin.

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Figure 2: Example of the box F/14/6706 in the National Archives (online catalogue information: 'Rhône River, Files 1-22, 1828-1849'): (a) bundle of documents; (b) and (c) content description.
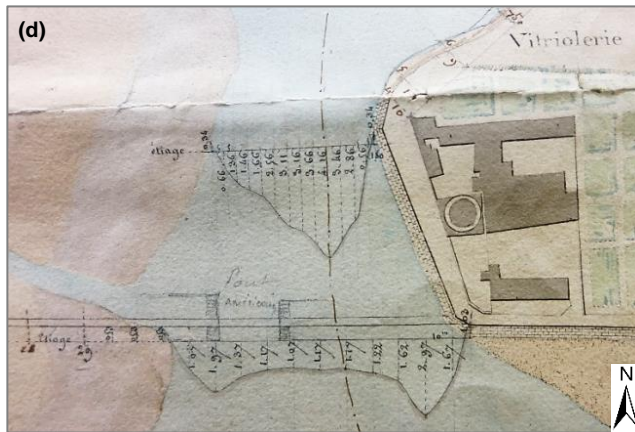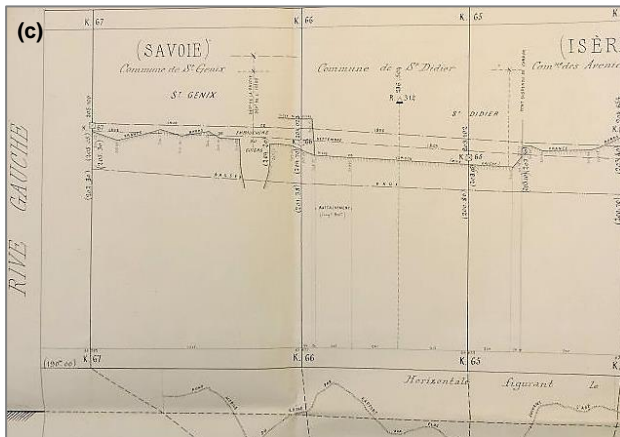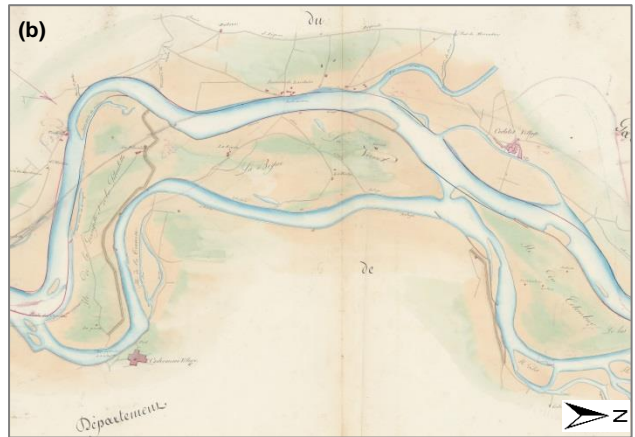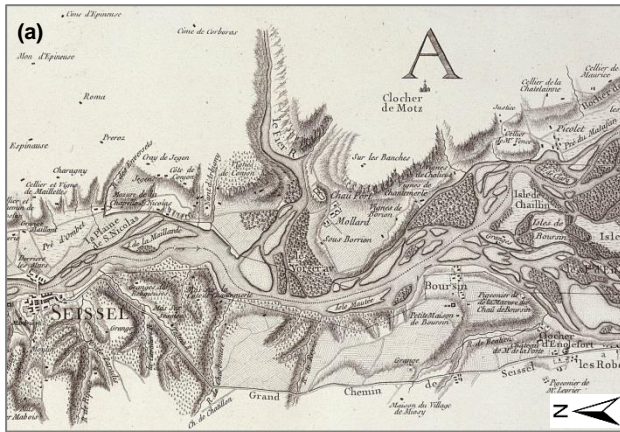
Figure 3: Examples of the archive resources collected in this study: (a) map series at 1:28 246 between Geneva and the Guiers confluence, 1760. Extract of sheet n°3/7 (source: De Bourcet, AD Savoie, 1Fi S52-53); (b) bathymetric information on a map at 1:2000 in Lyon, 1833 (source: Garella, AD Rhône, S 1361); (c) long profile of the left bank and the thalweg of the upper Rhône, 1869. Extract of the sheet n°6/6 (source: *Ponts et Chaussées*, AD Rhône, S 1356); (d) map series at 1:10 000 from Geneva to the Mediterranean Sea, 1842. Extract of the sheet n°20/25 (source: Arnaud, National Archives, CP/F/14/10074/2/Piece 8).
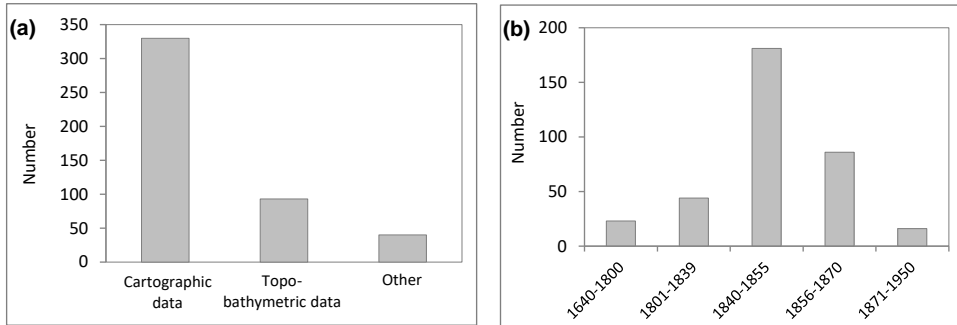
Figure 4: (a) Number of archive data items compiled in this study. "Other" corresponds to plans <1:1000, long profiles of the Swiss Rhône, and books. (b) Temporal extent of cartographic and topo-bathymetric data.

Figure 5: Map at ~1:10 000 between Pierre-Bénite and Irigny, 1644 (source: Maupin, AD Rhône, 44 J 336).

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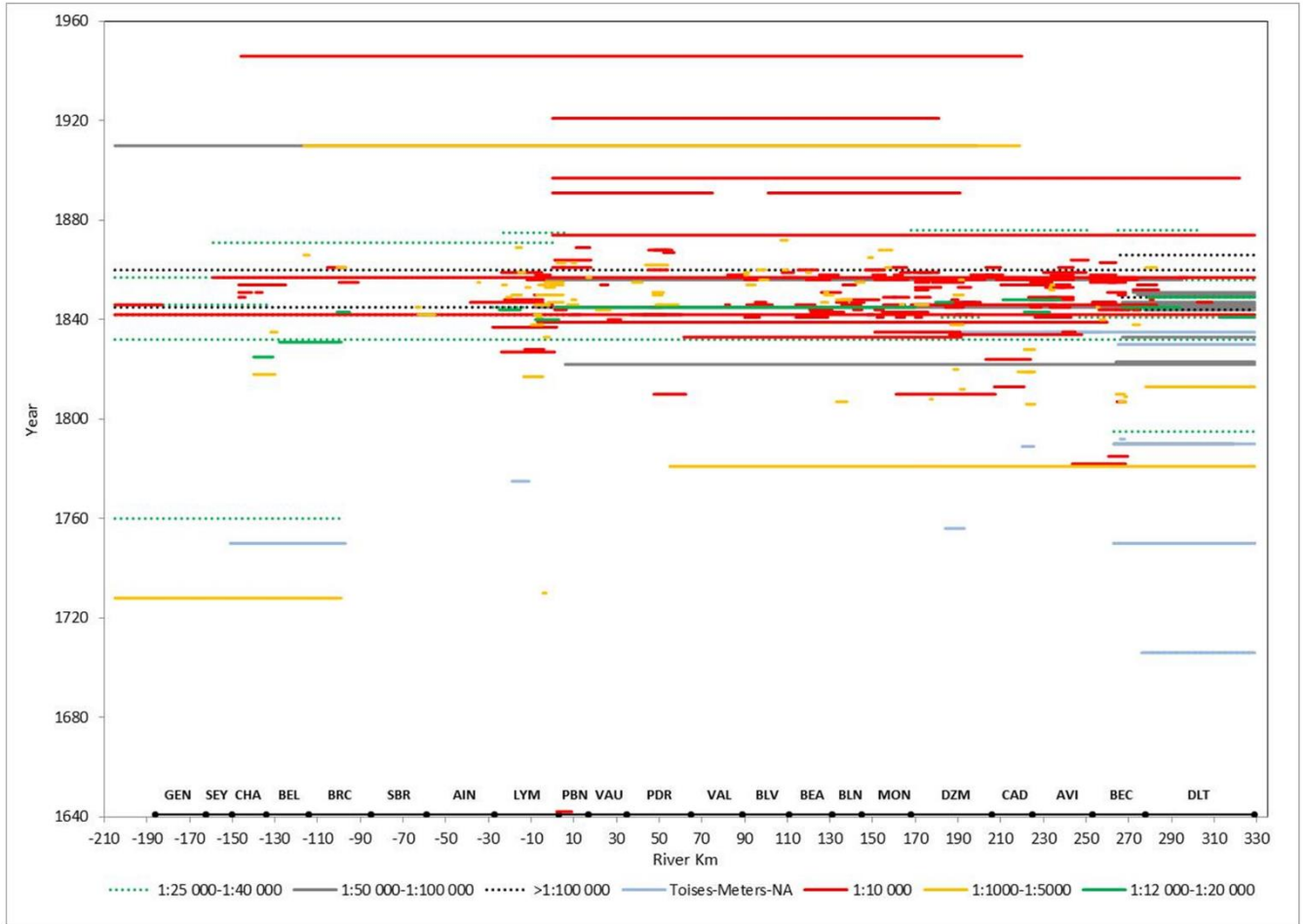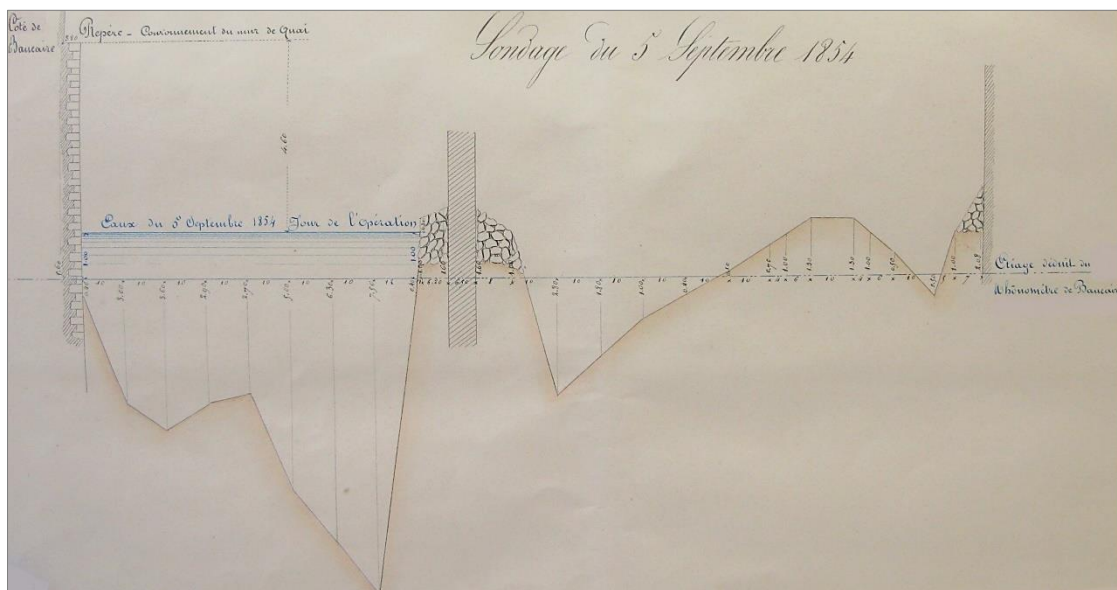
Figure 6: Cross-section at the suspension bridge of Beaucaire-Tarascon. The low-flow water level deducted from the Beaucaire gauging station and the water level on the day of the survey (September 5, 1854) are indicated in blue (source: Aymard, AD Rhône, S 1434).
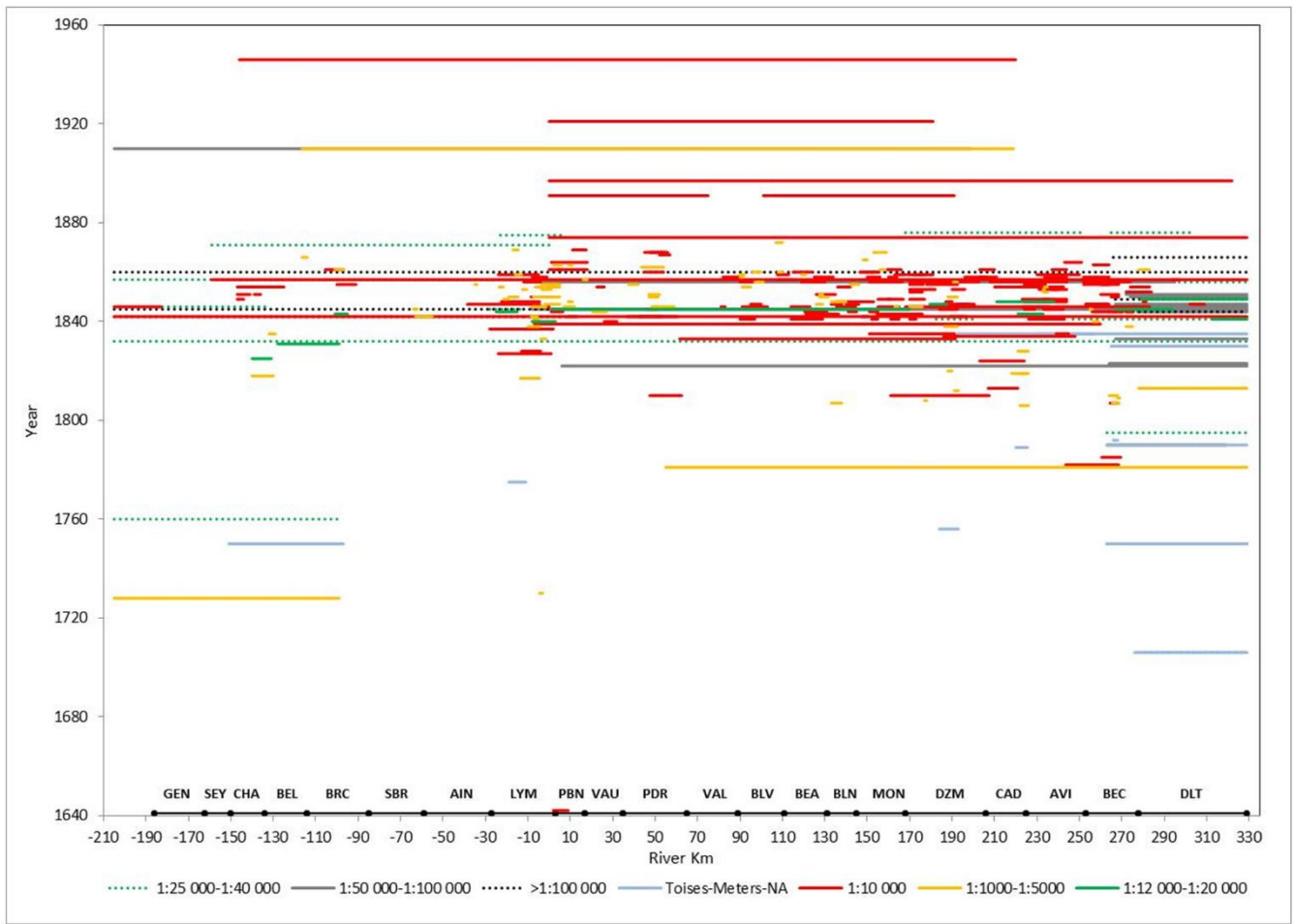
Figure 7: Longitudinal coverage and spatial scales of the cartographic dataset. The spatial extent of present river reaches is superimposed on the x-axis (see Fig. 1 for acronyms).
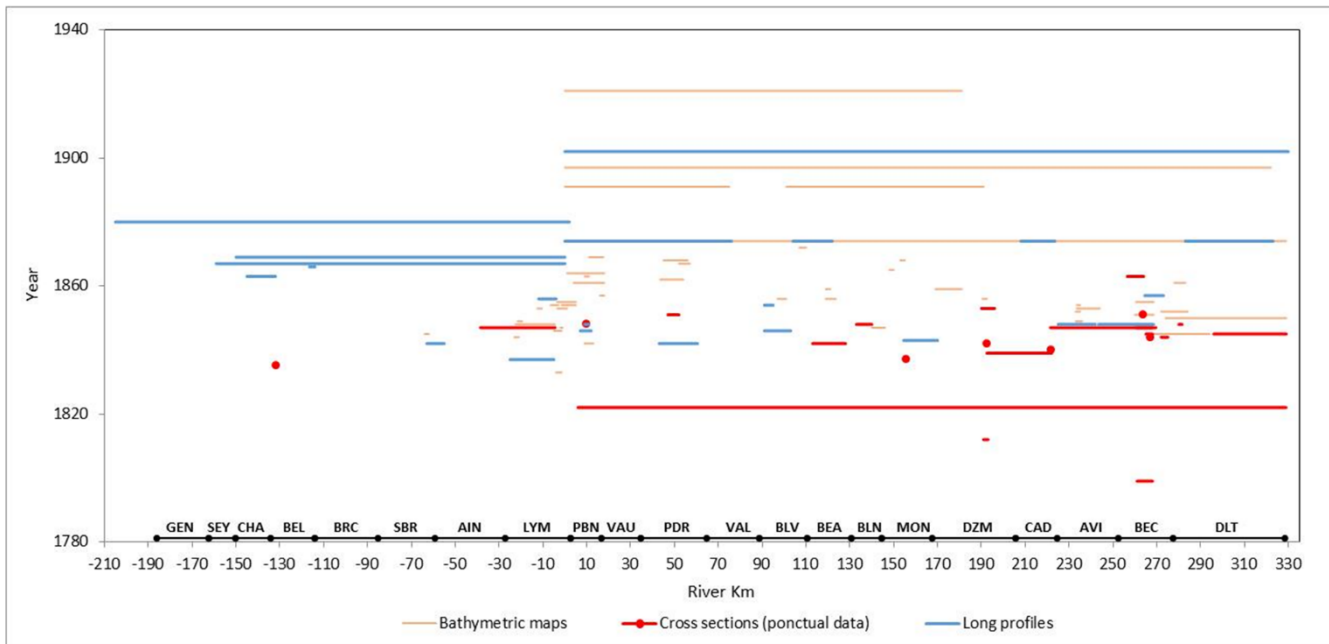
Figure ~~7~~8: Longitudinal coverage of the topo-bathymetric dataset. The spatial extent of present river reaches is superimposed on the x-axis (see Fig. 1 for acronyms).

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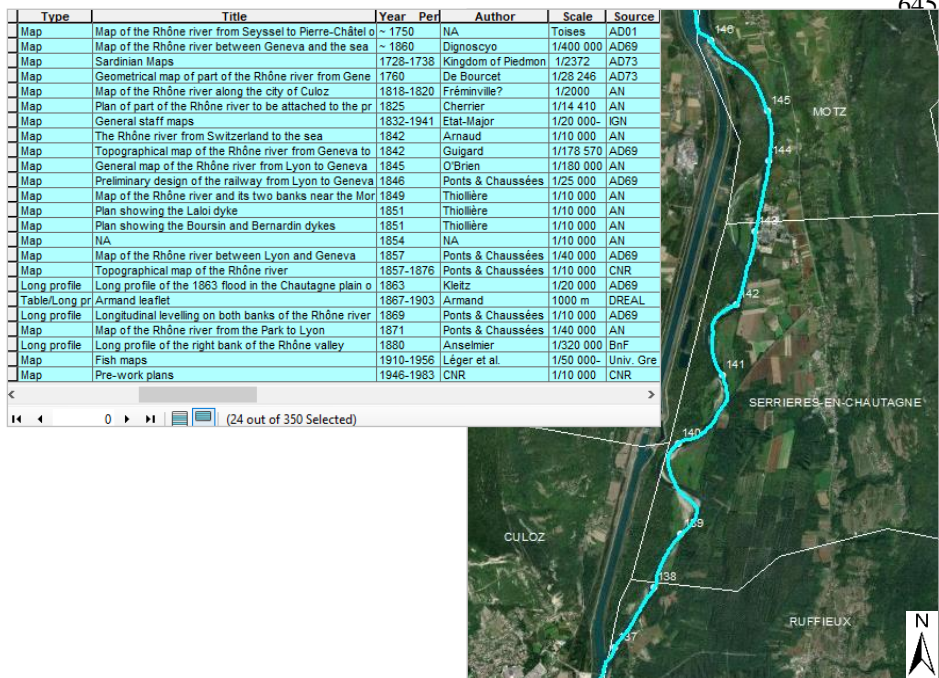

665 **Figure ~~8~~9: GIS layer of the longitudinal coverage of data collected in this study. Example of the 24 available data items on the Chautagne river reach (KP −146 to −137). Basemap: Esri.**

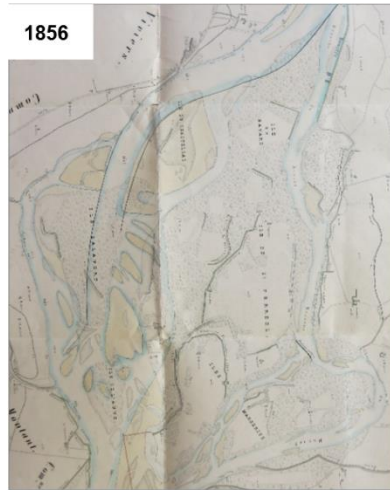
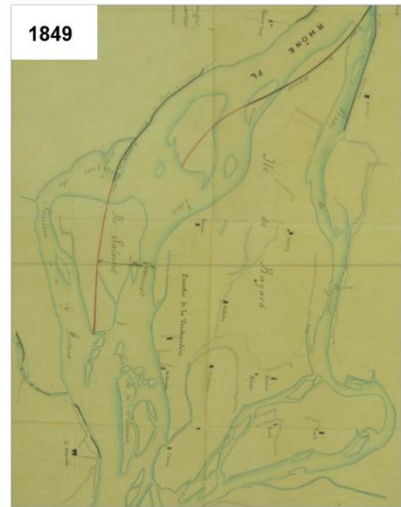
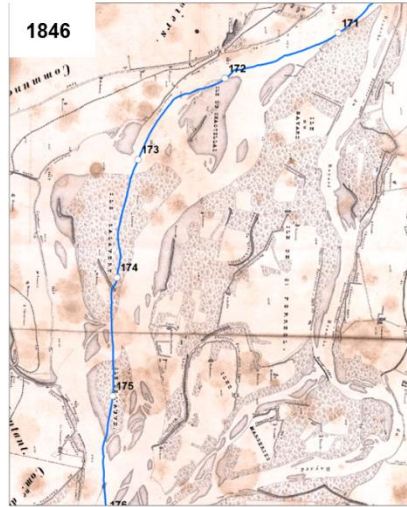
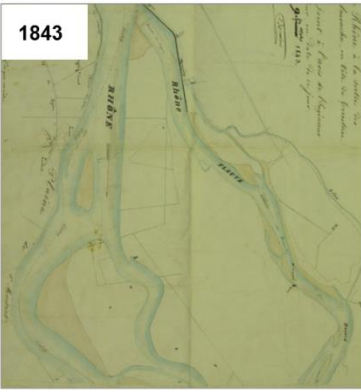



Figure 9̶10: Examples of maps surveyed on the upstream section of the Donzère-Mondragon reach, 1810–1860. The present Rhône centreline ~~and Kilometric Points (KPs) are~~is superimposed on the 1810 ~~and~~, 1846 **and "1860-2020"** georeferenced maps. **The scale is given by the spacing between the Kilometric Points (KPs) on these maps.** The "1860-2020" map shows the present orthophotograph, on which the delineations of aquatic channels in 1860 were superimposed (Source: 1810: Napoleonic Land Register; 1835, 1846, 1856 and 1860: *Ponts et Chaussées*; 1842: Arnaud; 1843: Bouvier; 1849 and 1852: Goux; 2020: Esri).

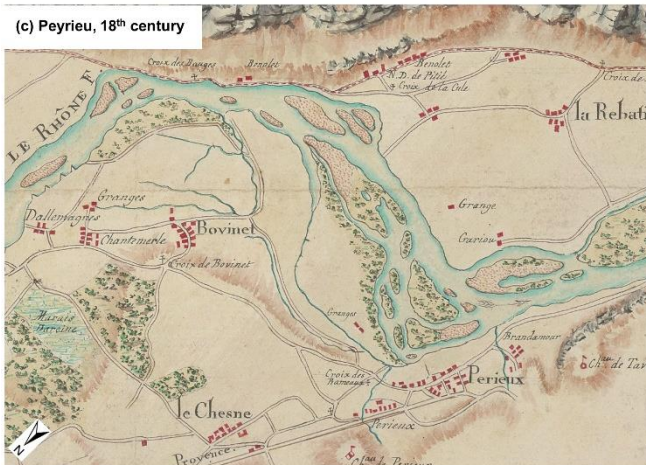
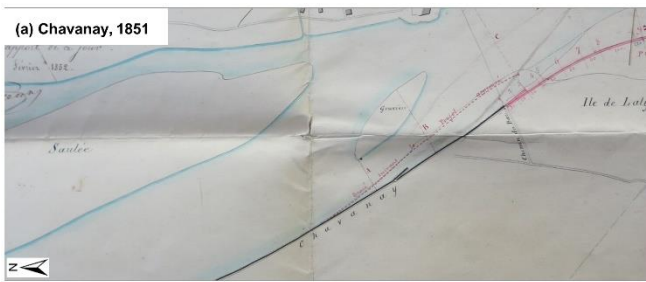
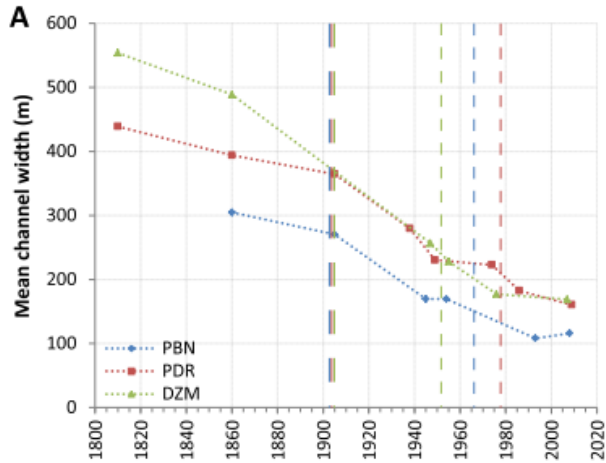



Figure 1̶0̶Figure 11: Examples of vegetation representation, from the simplest to the most detailed: (a) island annotation: 'saulée' in French means 'willows', 'gravier' means 'gravel' (source: Goux, 1851, AD Rhône, S 1393); (b) riparian vegetation close to the

channel (source: Kleitz, 1856, AD Rhône, S 1397); (c) depiction of vegetation in the floodplain (source: unknown author, 18th century, National Archives, CP/F14/10074/1/A/Piece3); (d) differentiation between vegetation types (source: Bouvier, 1844, National Archives, F/14/6583).

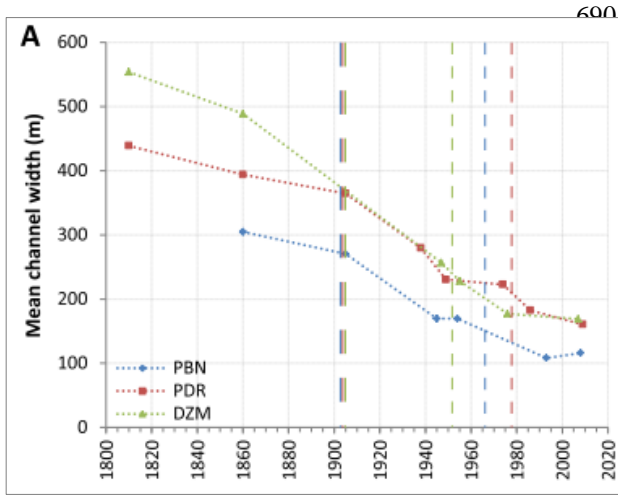
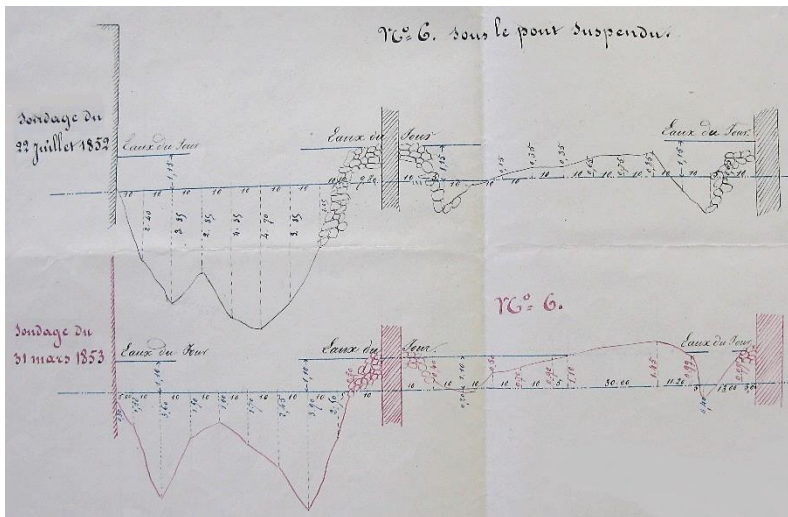



Figure 12: **Temporal variation in the mean active channel width of three reaches of the Rhône between 1810 and 2009. Long dashed lines correspond to the Girardon training phase and short dashed lines correspond to the channel by-passing for each reach (Tena et al., 2020).**

~~Figure 11: Cross-sections under the suspension bridge of Beaucaire-Tarascon with water level and channel bottom surveyed on July 22, 1852, and March 31, 1853 (source: Aymard, AD Rhône, S 1434).~~