Thesis proposal (2019/2022)

PhD title: Historical reanalysis of Rhône flows at Beaucaire: extreme floods and climatic variability of flows

Research group: Catchment Hydrology research team and River Hydraulics research team, IRSTEA, Lyon-Villeurbanne, France

Supervisors: M. Lang, J. Le Coz, B. Renard

Doctoral affiliation: MEGA (Mécanique Energétique, Génie Civil et Acoustique), Lyon

Profile of the PhD candidate:

- Master 2 research or equivalent
- Good skills in river hydraulics and statistics
- Aptitude for scientific research: rigorous reasoning, scientific writing, fluency in English, willingness to learn French, interest in open questions, creativity.
- Ability and interest in programming. Experience in Fortran and/or R would be appreciated.
- Interest in teamwork and field studies in hydrology

Abstract: *A first step will be related to the analysis of the variability of the Rhône regime during the period 1816-2019, in connection with the climatic variability, hydraulic works on the Rhône river and major changes on the watershed. Then, the reconstitution of the flow and associated uncertainties of the Rhône river at Beaucaire, will be done, using a hydraulic model and historical geometries. It will be based on records of hydro-climatic events from 1300 to today on the lower Rhône from the HISTRHÔNE project. Finally, a flood frequency analysis will be developed, considering a mixed sample issued from a continuous series (1806-2019) and a set of hydrological events (period 1300-1800).*

1. Background and issues

The security of the territory exposed to the floods on the downstream part of the Rhône was considered as worrying since no less than three Territories with significant risk were retained in this sector (Montélimar, Avignon, Rhône Delta), during the first implementation of the Flood European Directive (2010-2015). The major floods of the Rhône, likely to flood all or part of the floodplain, can be a source of major damage. Thus, the total cost of flood-related flood losses from 1 to 4 December 2003 on the lower Rhône is estimated at 1.1 billion euros. This flood, with a return period of about 100 years, remains lower by submersion level than the historic flood of May 1856.

Depending on the nature of the developments in the Rhône Valley (cultivated areas, communication routes, industrial zones, inhabited areas ...), it is customary to reason about more or less important reference floods, and to seek to protect the surrounding areas exposed or at least to define a strategy to mitigate the consequences of floods. The Flood Risk Prevention Plans retain the highest known historical flood, or the centennial flood, whichever is greater. Critical equipment (dams, nuclear power plants) are designed to function properly until the millennial flood or more.

The basin of the lower Rhône is a paradoxical case. It is one of the oldest instrumented basins in France, with first hydrometric staff gauges installed in the first half of the 19th century and a series of daily flows on the Rhône at Beaucaire available on the HYDRO bank only since 1920. It is an equally strategic sector because in a way it integrates all the cumulative effects of the basin. The Rhône River General (EGR) study (SAFEGE -CETTIS, 2000) only exploited a series of floods over 78 years (1920-1997), whereas potentially 200 years of hydrometric observations are available, provided one can convert stage measurements to discharges. Then, the scientific challenge is to be able to include historical information within the statistical study of the water regime of the lower Rhône.

On a larger scale, it is even possible to go back much further than the 19th century on the knowledge of the great floods, droughts and low flows of the Rhône. A thorough investigation through a large amount of data sources (Pichard, 1995, 1999), then the HISTRHÔNE project and the associated database (Pichard and Roucaute, 2014), resulted in a list of nearly 1,500 hydro-climatic events over the 1300-2000 period: 1068 floods and submersions, 234 low-water events, 174 ice episodes (frost or ice transport) and 8 marine submersions. Such past information is complementary to the predictions of climate models for the 21st century, which indicate, for example, that France is experiencing a sharp increase in temperatures (+2 to +4 ° C) and a change in the water regime (Chauveau et al., 2013). In addition, they can contribute to better defining river restoration policies by integrating both the ecological and security issues for property and people. The analysis of the climatic variability of the Rhône regime over several centuries can provide a better understanding of the climate forcing on the Rhône water regime. This will be possible precisely over the 1812-2020 period using continuous daily hydrometric records on the Rhône at Beaucaire, and at a less precise temporal resolution over the 1300-1800 period (focus on extreme events).

2. Objectives of the PhD

The objective of the thesis is first to deepen the work on the reconstruction of the flow of the Rhône at Beaucaire using hydraulic modelling based on past geometries, and to evaluate as much as possible the level of uncertainty associated with each flow rate value for the different reconstructed situations. The continuous flow series over the 1816-2020 period will then be used to analyse what is related to "natural" climatic variability and which results from developments on the Rhône river bed and changes in the watershed. In a second step, the entire 1300-2020 period will be analysed through the flood regime. The morphology of the bed of the Rhône being very different before the nineteenth century, with a braided bed and an outlet to the sea through multiple branches, it is likely that the oldest data will be tainted by significant errors on the reconstitution of flows. This being the case, if the past data on the 1300-1800 period (HISTRHÔNE database) makes it possible to position the floods of 1840, 1856 and 2003, not only as the strongest for two centuries but over a much wider period, it is likely that this information modifies our estimate of the flood distribution and associated uncertainties

- **Scientific challenge n°1: Reconstruction of past flows**

Interdisciplinary work will be needed to exploit and interpret the existing sources of information on the past events from the HISTRHÔNE database. It should be remembered that, as it stands, the events were qualitatively distributed into five major categories (Pichard et al., 2017): low water, high-water, overbank flood, severe flood, extreme flood, and distinguishing floods with presence of ice blocks. The objective here is to quantify the peak discharge of floods, with the associated uncertainty. The principle will be to start from the existing 1D MAGE hydraulic model of the Rhône from Lake Geneva to the Mediterranean Sea, developed by Irstea and the Rhône Sediment Observatory (OSR), focusing on the lower Rhône. From a geomorphological analysis of the bed of the Rhône at different times and possible discontinuities in the low-flow stages, geometric data combined with an analysis of the sedimentation in the margins based on the work of the OSR, several past hydraulic models will be established to estimate the stage-discharge relationship, by homogeneous periods. This information will then be incorporated into the BaRatin method (Le Coz et al., 2014), with specific work to include in the Bayesian procedure the calibration of hydraulic model parameters and the calculation of flow rate uncertainties (Westerberg et al., 2019).

- **Scientific challenge n°2: Fine analysis of the variability of the lower Rhône regime over two centuries (1816-2020 period)**

The continuous series of flows from 1816 to 2020 will first be crossed with the known history of developments on the bed of the Rhône and the watershed. We will study the morphogenic floods that shape the bed of the Rhône, and we will examine the extent to which the Girardon structures (transverse spur dikes made at the end of the 19th century to fix the bed of the Rhône) modified the upstream-downstream transfer conditions, and ultimately the flow regime of the lower Rhône. In a second step, the 1816-2020 series will be crossed with the reconstructions of historical low flows resulting from the PhD thesis of Caillouet (2016) on the 1871-2012 period (SCOPE-Climate model), the analysis of a century of hydro-climatic variability in the Durance basin (Kuentz's PhD thesis, 2013), and the work of Brönnimann et al. (2019) on the frequency of floods in Central Europe in the nineteenth century. We will try to distinguish between "natural" and "anthropogenic" variability (hydraulic structures, land use).

Scientific challenge n°3: Large-scale seven-century analysis of the Rhône flood regime and interest of historical information in estimating extreme floods

At the end of the first stage, the longest hydrometric time series reconstructed in France will be available (see challenge No. 1), with quantification of the uncertainties associated with each value. We will focus on the climatic variability of the Rhône regime for seven centuries and its relationship with climate "proxies" available elsewhere (Bhend et al., 2012, Brönnimann, 2015). Then a specific work will be done to integrate the previous flood events of the 1300-1800 period. The statistical analysis will have to be adapted accordingly (see likelihood function used in the frequency model as well as the error model) to make it possible to treat a mixed sample composed of a continuous series (recent 1816-2020 period) and of a censored collection of data (remote 1300-1800 period). We can then compare the estimates of reference flood flows from different periods, show precisely the gain provided by a broader chronological length (in terms of reduction of the final uncertainty) and specify the limits of using old data (in case the final uncertainty increases). The hypothesis of climatic stationarity will be discussed as well as the possibilities to get rid of it for statistical analysis via the introduction of climatic co-variables.

3.3. Insertion of the thesis topic into the UR's scientific project

3.1 Consistency with the activities of the research teams

The PhD subject mobilizes the skills of the "Catchment Hydrology" team in statistical hydrology, uncertainty analysis and hydroclimatology, and the "River Hydraulics" team in hydraulic modelling and sediment transport analysis. It is in the continuity of existing works of both teams:

• Analysis of uncertainties in hydrometry: Alliau et al. (2015), Horner et al. (2018), Kiang et al. (2018), Le Coz et al. (2014) ; Mansanarez et al. (2016), McMillan et al. (2017), Renard et al. (2006);

• Flood frequency analysis with historical information: Benito et al. (2004), Kjeldsen et al. (2010), Lang et al. (2010), Neppel et al. (2010), Naulet et al. (2005);

• Hydro-climatic reconstitution: Caillouet et al. (2016, 2017).

3.2 Scientific profile of the doctoral student at the end of his thesis

The PhD must have a Master 2 Research or equivalent. It must have a solid basis in river hydraulics and statistical hydrology. The transversal nature of the thesis subject, in connection with hydrometry, river hydraulics, geomorphology, statistical hydrology and hydro-climatology, should provide several avenues for the PhD student. It will be able to consider a deepening on one of the themes treated while pursuing in the field of the research, or to value its knowledge and know-how in consultancy or in operational service.

3.3 Scientific and technical valorisation of the thesis

The interest of the approach developed during the thesis is to develop a probabilistic framework which integrates the uncertainties and to be able to appreciate the contribution and the limits of past data for the study of the regime of the rivers. As such, this methodology can be exploited and transferred to other major French rivers (Loire, Garonne, Seine, Rhine…) or international rivers (Danube, Yangtze...) for which we have qualitative information over several centuries.

Moreover, as pointed out by the IPCC (2012, p111): "*Many weather and extreme climate are the result of natural climate variability, which provides the backdrop for anthropogenic climate change*". The latest IPCC report (2014, Fig. 5.14) mentions the existence of climate variability-oscillations in Europe over several decades, which shows the difficulty of inferring climate characteristics from short series.

The long series of reconstructed flows - with uncertainties - on the Rhône over the 1300-2020 period can be shared within the international network PAGES (http://www.pages-igbp.org), made up of around 5000 scientists from 125 countries. This network is interested in the study of the past climate, based on historical and paleo-climatic data. This series could be the subject of case studies for hydrology courses (ENTPE, University of Lyon) or a summer school on climate (International PAGES network, H20'Lyon University School).

From an operational point of view, the elements produced during the thesis may be useful for the estimation of extreme floods, and cross-referenced with the reference values currently used in the lower Rhône, for spatial planning and human safety (dikes, dams, nuclear power plants).

4.Feasibility of the thesis

4.1 Partnership

Exploratory contacts were made with the following partners:

• Georges Pichard (Aix-Marseille University): cf. challenge No. 1 (agreement in principle to jointly analyze data from the HISTRHÔNE database for the period 1300-2000);

• Hervé Piégay (ENS Lyon, UMR5600) and J. F. Berger, B. Mourier, T. Winiarski (scientists involved in the Rhône Sediment Observatory): cf. challenge No. 2 (agreement in principle to be associated with the geomorphological analysis of the bed of the Rhône at different times);

• Jean-Philippe Vidal (Irstea Lyon): cf. challenge No. 2 (agreement in principle to cross the results obtained during the thesis with the 20CR climatic reanalysis, 1871-2016 period).

In addition, other people will be asked for the steering committee: Robin Naulet (CNR Lyon), Pascal Billy (DREAL ARA), Thibaut Mallet (Symadrem), Vazken Andréassian (Irstea Antony), Stefan Brönnimann (Univ Bern, Switzerland).

4.2 Funding of the thesis

This thesis has a scholarship from the University School of Research of Water Sciences and Hydrosystems, EUR H2O'Lyon. It is a continuation of a first study (Bard and Lang, 2017) commissioned by the DREAL Auvergne-Rhône-Alpes for the update of the general study of Rhône floods (Safege Cettis, 2000) and exploratory investigations conducted at Péage-de-Roussillon under the OSR.

4.3 Forecast timetable of the thesis

Year 1: Mastery of statistical tools / Collection and analysis of old data / Reconstruction of past flows	Handling of the BaRatin method and the chain of propagation of uncertainties up to the estimation of the flow distribution (see tools developed at Irstea Lyon)
	Handling of the existing 1D MAGE hydraulic model, from the Rhône from Lake Geneva to the sea, developed by Irstea and the OSR, focusing on the lower Rhône
	Collection and analysis of old data (Rhône bed topography, flood ratings) in connection with the work of the University of Aix-Montpellier (see HISTRHÔNE database) and the UMR5600 EVS and the OSR
	Establishment of "past" hydraulic models for the reconstruction of flows in Beaucaire over several centuries, with the estimation of the associated uncertainties (specific work on the coupling of BaRatin with a hydraulic model). The identification of any segmentation between successive rating curves will be based on information on the past morphology of the Rhône and discontinuities in the low-water stages. A complete time series of flows has been reconstructed on the Rhône at Beaucaire since 1812. It will be completed with an estimation of flows on the significant events of the period 1300-1800
Year 2: Fine analysis of the 1816-2016 period	Definition of small floods (so-called morphogenic) that shape the bed of the Rhône. Analysis of the evolution of their occurrence and their characteristics (duration, rise vs. flood ...), which may be partly related to the morphological evolution of the bed. One of the hypotheses is that the Girardon works carried out at the end of the 19th century deeply modified bed geometry (disconnection of secondary arms, incision of the bed, increase of the grain size of the beds) leading to a reduction in transfer time and retention to modify the downstream hydrographs. This is the most important morphological change on the Lyon - Arles continuum.
	Evidence of climatic variability in the Rhône regime in Beaucaire during the last two

	centuries. Crossing of the series of discharges over the period 1816-2016 with the reconstruction of historical low-flows from Caillouet's thesis work (2016) over the 1871-2012 period (SCOPE-Climat model), the analysis of a century of hydro-climatic variability in the Durance basin (Kuentz's thesis, 2013), and the climatic reanalysis on the upstream Rhône (Brönnimann et al., 2019). Investigation of causalities on changes in the Rhône regime, for example in terms of seasonality or occurrence and characteristics of small floods, to be linked with major changes in the basin or on the Rhône continuum (dams, embankment, glacier cover , vegetation cover ...) or climatic variability.
Year 3: Study of the variability of the regime of the Rhône over seven centuries and study of extreme floods	Analysis of the climatic variability of the Rhône regime for seven centuries and possible relationship with climate "proxies" available elsewhere.
	Adaptation of the chain of propagation of uncertainties (stage, flow, flow distribution) to the case of censored data.
	Comparison of the estimate of the flood distribution with different datasets (period of the data series, threshold of perception of the past data, probability distribution). Regional consistency of flood quantile estimates will be carried out over a wider area (Sea-Beaucaire-Avignon-Montélimar) from the hydrometric series available on the lower Rhône.
	Scientific publication via 3 articles: Uncertainties propagation chain for the frequency analysis of long hydrometric series // Impact of the adjustments made on the bed of the Rhône in the 19th century on the flood regime // Climatic variability of the Rhône regime over the 1300-2020 period.

5. Supervision of the thesis

The PhD supervisor will be Michel Lang (Accreditation to supervise research in Statistical Hydrology, 2000), with two co-supervisors: Jérôme Le Coz (Accreditation to supervise research in Hydrometry and Hydraulic Modeling, 2017) and Benjamin Renard (Research Fellow in Statistical Hydrology, uncertainties specialist). Benjamin Renard has been awarded a Marie-Curie Fellowship for a 2-year mobility in Australia (Adelaide University), starting in May 2019. He will be associated remotely with the supervision of the thesis, in particular on the challenge N ° 3.

Researcher	Thesis supervising	Thesis co supervising
M. Lang	M. Darienzo (2017-2020)	/
J. Le Coz	/	L. Gond (2018-2021), M. Darienzo (2017-2020), G. Dramais (2016-2020), S. Pouchoulin (2016-2019)
B. Renard	/	M. Darienzo (2017-2020)

6. Practical information

The doctoral student is bound to IRSTEA by a fixed-term contract giving rise to the social protection of common law. The duration of the contract is three years. The monthly remuneration (January 2019) is € 1,874.41 gross (€ 1506.46 net).

The candidate must have graduated as Master (or equivalent) during the constitution of recruitment file.

Applications should be sent to michel.lang@irstea.fr and to jerome.lecoz@irstea.fr before June 30, 2019. The application must include the following documents:

• Application form attached (4 pages): Civil status, Training, Internships, Jobs, Languages, other information

• CV;

• Photocopies of the identity card or residence card;

• Electronic version of an internship report or Master's thesis or article ... which gives an idea of the work already done by the candidate;

• Thesis project in 2-3 pages.

An interview will be held in the first week of July for candidates who have been selected after reviewing the file. The final decision will be communicated by mid-July.

References of Irstea Lyon researchers on the thesis topic

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Renard B. *et al.*, 2006. An application of Bayesian analysis and Markov chain Monte Carlo methods to the estimation of a regional trend in annual maxima. *Water Resources Research*, 42:W12422, doi: 10.1029/2005WR004591

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