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Multi-temporal mapping of the Upper Rhone Valley (Valais, Switzerland): fluvial landscape changes at the end of the Little Ice Age (18th–19th centuries)

Filippo Brandolini ^a, Emmanuel Reynard ^b and Manuela Pelfini ^a

^aDipartimento di Scienze della Terra “Ardito Desio”, Università degli Studi di Milano, Milan, Italy; ^bInstitut de géographie et durabilité et Centre interdisciplinaire de recherche sur la montagne, Université de Lausanne, Lausanne, Switzerland

ABSTRACT

The Upper Rhone Valley (Valais, Switzerland) has been heavily modified over the past 200 years by human activity and natural processes. A qualitative analysis of the morphological and land-use evolution of the Rhone River floodplain since the end of the eighteenth century was carried out using historical maps from 1780 to 1860 processed with Structure-from-Motion (SfM) and Geographical Information System (GIS) tools. This study aims to produce a long-term analysis of river management and land-use change in a stretch of the Upper Rhone Valley around the town of Sion based on a time series of maps, realised in the years 1780–1802, 1820–1845, 1847, 1850s, 1852–1857, 1859–1860. The historical maps were digitised, and for each of the corresponding periods, a map was produced within a GIS. The comparison of the maps was completed by using documentary sources or subsequent studies. With the intention to identify the fluvial landscape changes and past river management, six multitemporal maps were produced. Finally, this research aims to provide helpful diachronic information for planning a future sustainable landscape development in Valais.

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Landscape development; land-use change; fluvial geomorphology; Structure-from-Motion photogrammetry; backdating approach

1. Introduction

The interplay between geomorphological processes, land-use, ecosystems and human influence has always played a special role in the evolution of the fluvial environment since anthropogenic activities started to alter the natural processes (James & Marcus, 2006; Li, Yang, Pu, & Liu, 2017). Land-use change is a dynamic process that links together natural and human systems (Brandolini & Carrer, 2020). Therefore, a historical reconstruction of this process is necessary to evaluate the reciprocal interactions between anthropogenic activities and fluvial environments (Bollati, Reynard, Cagnin, & Pelfini, 2018). Historical maps, when available, represent a valuable resource for understanding the causes, mechanisms and consequences of the human-induced changes in fluvial features and support river management at any scale (Hohensinner et al., 2013; Pătru-Stupariu, Stupariu, Cuculici, & Huzui, 2011). Moreover, the combination of historical data with geoscience data and remote sensing analysis is essential to study the relationship of natural events such as floods and river diversions with human land-use changes through time (Brandolini, Cremaschi, & Pelfini, 2019; Roccati et al., 2018). In regions that are historically affected by flooding and where urbanisation has increased exposure to floods, historical cartography provides valuable indications for planning

more sustainable urbanised alluvial landscapes in the future (Brandolini & Cremaschi, 2018). GIS tools are essential to compare digitised historical maps with more recent ones and to carry out a multi-temporal analysis of landscape dynamics (Lieskovský et al., 2018; Statuto et al., 2017).

The Upper Rhone Valley is located in the Swiss Alps between the Rhone Glacier and Lake Geneva, and it is particularly interesting to study since it represents the largest inner Alpine basin with a size of c. 5244 km². The Rhone River originates from the Furka Glacier (2341 m asl) and, with a total length of 164 km, dissects the western Swiss Alps with a general NE-SW direction upstream of Martigny and SSE-NNW direction downstream (Figure 1).

The Upper Rhone Basin contained some of the thickest Alpine glaciers throughout the Quaternary period (Kelly, Buoncristiani, & Schlüchter, 2004; Schlüchter, 2009), and it was characterised by subsequent advance and retreat phases due to the alternation of glacial-interglacial periods. During the Last Glacial Maximum (LGM), 22.1 ± 4.3 ka BP, the Rhone Glacier filled the Upper Rhone Basin, outflowed onto the foreland and was the main component of the LGM transection glaciers in the western Alps. The deglaciation and retreat from the LGM position started in 21.1 ± 0.9 ka BP and ice collapse already initiated

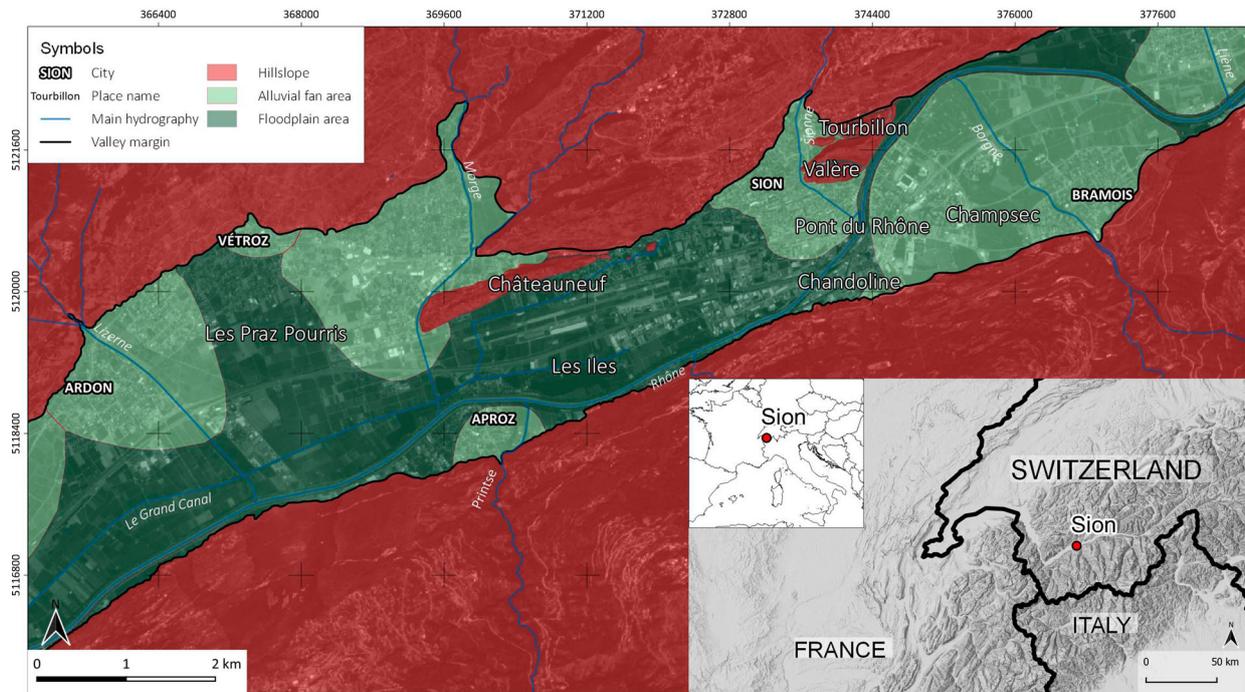


Figure 1. Location of the study area and main units: hillslope, alluvial fan areas and floodplain areas.

between 16.8 and 17.4 ka BP (Schoch A, Henrik, Hoffmann, & Schrott, 2018). The sedimentary succession presents the typical post-glacial Alpine pattern: subglacial stream deposit, lodgement till, ablation till, proglacial lacustrine deposits, glaciolacustrine deposits, bottom-set, foreset and top-set deltaic deposits, alluvial deposits (Stutenbecker et al., 2018). The glacial esaration influenced the mountainsides conformation, but frequently the traces of erosional processes have been covered by alluvial fans. Indeed, the tributaries of the Rhone River developed alluvial fans that influenced its course occupying a vast portion of the plain; two of them (the Illgraben fan near Sierre and the St-Barthélémy fan near Saint-Maurice) had a crucial role in modifying the Rhone River profile. Even though the nineteenth and twentieth-century channelisation profoundly rectified the river course, between Sierre and Martigny, the influence of the alluvial fans developed by the tributaries is still clearly visible on the sinuous pattern of the Rhone River (Reynard, 2009).

The Medieval chroniclers report the occurrence of severe flood events, and during the Little Ice Age (or

LIA, 1350–1850 AD) the Upper Rhone River had certainly a torrential regime as other rivers in the Western Alps (Bravard, 1989). During the second half of the nineteenth century, the anthropogenic activities had a crucial impact on the Rhone basin. The river was channelized twice in the periods of 1863–1894 and 1930–1960 (the so-called ‘Corrections of the Rhone River’, see (Baud, Bussard, & Reynard, 2016; de Torrenté, 1964), which reduced the length of the river (Stutenbecker et al., 2018) and gave to the river the present-day aspect. In the 2000s, after severe flood events, the ‘Third Correction’ began following the ‘Room-for-River’ flood management strategy (Vis, Klijn, De Bruijn, & Van Buuren, 2003) and aims to: (1) widen the river, (2) increase the capacity, (3) secure levees and (4) improve the general environmental quality (Olivier et al., 2009).

Today, the Rhone is a highly regulated Alpine river with an annual mean discharge of 1720 m³/s at its mouth and a flow regime of 17.8 L/s/km² specific discharge (Olivier et al., 2009). The flow regime of the Upper Rhone is characterised by low flows during

Table 1. Main characteristics of the Upper Rhone River Basin (Olivier et al., 2009) and the data registered at the gauging station of Sion (<https://www.hydrodaten.admin.ch/en/2630.html>): A – catchment area upstream of gauging station.

General characterisation of the Upper Rhone River Basin									
Mean catchment elevation (m)		Catchment area (km ²)		Mean annual flow (km ³)		Mean annual precipitation (cm)		Mean air temperature (°C)	
1655		8018		5.77		162.4		4.3	
Flow regime (in m ³ /s) of the Rhone River at Sion (1916–2003)									
Data Origin	Altitude	A	MQ	SpQ	NQ	HQ	Q2	Q10	Q50
1	484	3349	112	33.4	29	910	461	639	808

Notes: MQ: arithmetic mean annual discharge; SpQ: specific discharge (m³/s/km²); NQ: lowest measured discharge; HQ: highest measured discharge (instantaneous value); Q2: magnitude of a 2-year flood; Q10: magnitude of a 10-year flood; Q50: magnitude of a 50-year flood.

winter while high flows occur in late spring and summer due to snowmelt (see Table 1). Anthropogenic activities such as gravel harvesting and retention in reservoirs have altered the sediment discharge of the river: bedload transport was estimated at 1 Mm³/year at the beginning of the twentieth century, but today it is only 0.2 m³/year (Thureau, Giuliani, Jimenez, & Doutriaux, 2006).

In the last decades several portions of the Upper Rhone River Valley were studied applying a geohistorical approach (Baud et al., 2016; Stäuble, Martin, & Reynard, 2008; Zanini, Zanini, Weber, & Schlaepfer, 2006) and combining historical maps (Reynard, 2009) with geoscience analysis, in particular: between Riddes et Martigny (Baud & Reynard, 2015; Laigre, Reynard, Arnaud-Fassetta, Baron, & Glenz, 2012; Reynard & Baud, 2015); from Viège to Rarogne and Sierre to Sion (Laigre, Arnaud-Fassetta, & Reynard, 2010); and the Conthey area (Stäuble & Reynard, 2005).

This research was conducted in the area around the town of Sion, precisely between Liène and Lizerne rivers (Figure 1). In this portion, the Rhone River presents a sinuous course due to the series of alluvial fans developed by its tributaries Liène, Borgne, Sionne, Printse, Morge and Lizerne (Figure 1). The aim of the study is to produce a long-term analysis of landscape changes in this section of the valley at the end of the LIA, between 1780 and 1860 AD, i.e. before the systematic river training, combining historical maps and GIS analysis. The objective is to create multi-temporal maps to highlight the main modifications due to anthropogenic land and water management activities that occurred in that period.

2. Material and methods

In recent years, historical cartography has increasingly become a fundamental source for the analysis of land-use and environmental changes (Leyk, Boesch, & Weibel, 2006). In this study, the geographical reconstruction of the landscape was carried out over a period of 80 years in six time steps: 1780–1802, 1820–1845, 1847, 1850s, 1852–1857, 1859–1860. The specific historical cartography for each period was examined with the aim to create different base maps to make a comparison in time. The chosen periods were determined by the quality and quantity of historical sources available.

2.1 Historical maps

The principal maps used in the multi-temporal reconstruction of the eighteenth–nineteenth century morphology of the Rhone River floodplain and subsequent changes are listed in Table 2 and include: 16 hand-drawn maps from the *Archives de la Bourgeoisie de Sion* (ABS) stored at the *Archives de l'Etat du Valais* (AEV), one hand-drawn map of the AEV, one topographic map of the *Bibliothèque nationale de France* in Paris and one topographic map from the *Office fédéral de topographie* (Swisstopo).

The ABS hand-drawn maps do not cover the territory of the research area uniformly, but they are extremely useful because they have been realised at a large scale and represent in detail the fluvial landscape appearance. On the contrary, the Swisstopo map covers the whole research area, but their small scale does not allow us to identify valuable particularities about the land-use evolution.

Table 2. List of the historical maps considered in this study. ABS: Archives de la Bourgeoisie de Sion; AEV: Archives de l'Etat du Valais. In bold style, the maps used in the 'backdating approach'.

Period	Historic Map	Date	Source
1780–1802	99/35 Cadastre de Champsec	Started: 1741–1746 Updated: 1761–1772 Last version considered in the research: 1782	AEV, ABS
	99/36 Plan géométrique de la plaine de Champsec/Sion	1782	AEV, ABS
	Napoleonic Map	1802	Bibliothèque nationale de France
1820–1845	97/9 Plan du Rhône depuis le confluent de la Liène jusqu'à Uvrier	1827	AEV, ABS
	97/10 Plan du cours du Rhône depuis le Pont jusqu'à Chandoline	1823	AEV, ABS
	97/17 Plan du Rhône entre Bramois et Uvrier	1827	AEV, ABS
	97/18 Plan du Rhône de Chandoline à Aproz	1827	AEV, ABS
	97/19 Plan du Rhône d'Uvrier à Batassé	1827	AEV, ABS
	97/20 Plan du Rhône de Wissigen au Pont du Rhône	1827	AEV, ABS
	98/5 min du plan du cours du Rhône vers la grande barrière en haut d'Aproz	1825	AEV, ABS
	97/3 Plan du Rhône depuis Praz Bardy jusqu'à la fin du territoire de Sion	1845	AEV, ABS
97/4 Plan du Rhône depuis l'île de l'Evêché jusqu'à Praz Bardy	1845	AEV, ABS	
1847	Dufour Map	1847	Swisstopo
1850	Plan du Chemin de fer (Railway Map)	1850s	AEV, DTP, Plans, Railways, 1
1852–1857	201/7 Plan de propriétés à Aproz	1852	AEV, ABS
	202/1 Plan du Rhône depuis le pont de Sion jusqu'à la Morge	1856	AEV, ABS
	202/11 Plan de dessèchement des marais de la plaine de Sion	1857	AEV, ABS
1859–1860	202/10 Plan de la plaine de Sion pour le dessèchement et le colmatage.	1859	AEV, ABS
	202/12 Plan d'assainissement de la plaine de Sion à Riddes. Avant-projets.	1860	AEV, ABS
> 1860	Siegfried Map (used only for the 'backdating approach' and not considered in the multitemporal maps)	1870–1922	Swisstopo

The Napoleonic Map was hand-drawn in watercolours by the Napoleon cartographers in 1802. The aim of this map was to plan enhancement of the *Simplon* road that connected Switzerland to Italy for military reasons; close to the road, the cartographers represented precisely any roads, villages, woods, fields and watercourses (Lechevalier, 2005).

The *Dufour* Map was published in the period from 1845 to 1865 using a scale of 1:100,000. It was realised with an equal-area conic projection after direct surveys in the field, and it represents the first official topographic map of Switzerland (Swisstopo). In this study, we used the original version of the plate XVII Vevey – Sion (1847) that shows the Rhone Valley before the integral river training.

The *Plan du Chemin de fer* (hereafter, ‘Railway Map’) was made for the construction of the *Simplon* railway (called *Ligne d’Italie*). Even if not dated with precision, it is probably contemporary to the *Dufour* Map and it, therefore, represents the situation of the Rhone River before the channelisation work that started around 1860.

A multi-temporal cartographic comparison was carried out to reconstruct the original morphology of this portion of the Upper Rhone Valley and to identify the most significant transformations, such as modifications to the river channel, reduction of natural and agricultural areas and urban sprawl.

2.2. Digitising process

All the historical maps considered in this research were either available in georeferenced format or were georeferenced using Ground Control Points (GCPs) identified on current cartographic sources.

The ABS maps were drawn in a different period, scale and style for the upper-middle-class people (*bourgeoisie*) of Sion to map their properties. These large-scale maps represent limited portions of the Rhone River floodplain in detail and served as an invaluable source of information about fluvial landscape changes. On the other hand, perspective projection and geometric foundations of the maps production process are unknown, making the georeferencing procedure in GIS problematic.

The first step of the workflow consisted of digitising the maps to be imported into the GIS software. The Napoleonic Map, the Railway Map and the *Dufour* Map were already digitalised by the Valais administration and Swisstopo that provided a georeferenced copy of these files. Concerning the ABS maps, the scanning would have been challenging because of their size, format and, sometimes, their state of conservation. The large size and format of some historical maps (e.g. ABS 99/36 100 × 150 cm; ABS 202/11 60 × 110 cm) would have required expensive digital scanners to capture the entire map. Moreover, in a few cases, the maps

were very fragile (eg. ABS 202/12) and difficult to handle. To resolve all these issues of size and conservation, each map was digitised using a photogrammetric approach (Brandolini & Patrucco, 2019) with Agisoft PhotoScan. The elaborated TIFF images (96 dpi resolution) were then imported in the open-source desktop software QGIS 3.4.

To perform the georectifying process on the ABS maps, Thin Plate Spline (TPS) and cubic resampling methods (QGIS 3.4) were employed (Baiocchi, Lelo, Milone, & Mormile, 2013). A minimum of three GCPs (Oniga, Breaban, & Statescu, 2018) was detected to scale, rotate and locate each map but the absence of a topographic regular grid in the ABS maps made the georeferencing phase extremely challenging. In particular, the *Pont du Rhône* (Rhone Bridge) was the reference key point in geo-referencing ABS historical maps in association with the historical location of the river dykes and groynes. Other essential reference points were the buildings of towns’ historic centres and the geomorphological features of *Châteauneuf*, *Tourbillon* and *Valère* hills. Moreover, to minimise the spatial inaccuracy of the ABS maps the ‘backdating approach’ was employed (Bednarczyk, Kaim, & Ostafin, 2016; Ferenec, Hazeu, Christensen, & Jaffrain, 2007): it consists in verifying and correcting the positions of the points in older maps according to recent and most accurate maps (Lieskovský et al., 2018). In particular, two georeferenced copies of the historical topographic maps retrieved from Swisstopo have been employed: the *Dufour* Map for the ABS maps dated before the ‘First Correction’ and the *Siegfried* Map (1870–1922) for all the ABS maps made after 1861 (for details on these maps see (Stäuble et al., 2008)). This method cannot resolve all the positional inaccuracies mainly due to scale differences (Kaim et al., 2016) but represents the most reliable approach to georeference ancient historical cartography when other more accurate procedures are not available (Lieskovský et al., 2018).

Thanks to this data processing, it was possible to make all ortho-rectified maps comparable in terms of scale and land-use classification, and it was possible to overlay them, in order to assess landscape changes. The ABS maps represent limited portions of the study area, and they have been realised in different periods with different techniques, scale, fonts and even languages. To overcome the limitations of each singular map, we combined them in mosaics of historical maps with the same chronology/style/scale and representing the same time period. For each map, the land-use changes, water uses and fluvial geomorphological features are indicated. The results consist of 6 multi-temporal maps that reconstruct the landscape evolution of this portion of the Upper Rhone Valley from 1780 to 1860.

Table 3. Main characteristics for each period.

Period	Fluvial Pattern	Water Management	Land-use
1780–1802	Braided	Drainage Canals	Generic agricultural use and woods
1820–1845	Braided/ Wandering	Dykes, Groynes	Generic agricultural use and woods
1847–1850	Braided/ Wandering/ Channelised	Dykes, Groynes	–
1850–1860	Wandering/ Channelised	Dykes, Groynes	Generic agricultural use and woods

3. Results

The characteristics of the historical cartography considered in this research were not suitable for a land-use quantitative procedure (Chiang, Leyk, Honarvar Nazari, Moghaddam, & Tan, 2016; Leyk, Boesch, & Weibel, 2005) but enabled a qualitative interpretation on landscape evolution. The description and the main changes (Table 3) for each period are presented here.

3.1. 1780–1802 (Main Map, Sheet 1/3)

In this period, alternation of braided channels and portions of sinuous unique channel characterises the Rhone River. From the main channel, a series of sub-channels flowed around channel bars especially upstream of the confluence with the Liène River and in the area known in the present-day as *Les Iles* (i.e. The Islands). In the Napoleonic Map (Figure 2(A)), a waterlogged area upstream to the Borgne fan in Bramois is reported. Concerning land-use, few data are available. Napoleon cartographers reported agriculture and wood zones (Figure 2(A)) without indicating any details about the crops cultivated or the arbour species. ABS 99/35 and 99/36 dating back to the second half of the eighteenth century (Table 2) were handy to reconstruct the division of the farmland and the owner of each field on the left side of the Borgne River on the alluvial fan (Figure 3). This portion of the Borgne fan was cultivated at least since 1741 when the cadastre was compiled for the first time, but there is no indication of the specific agriculture use. In this portion of the Borgne fan, an

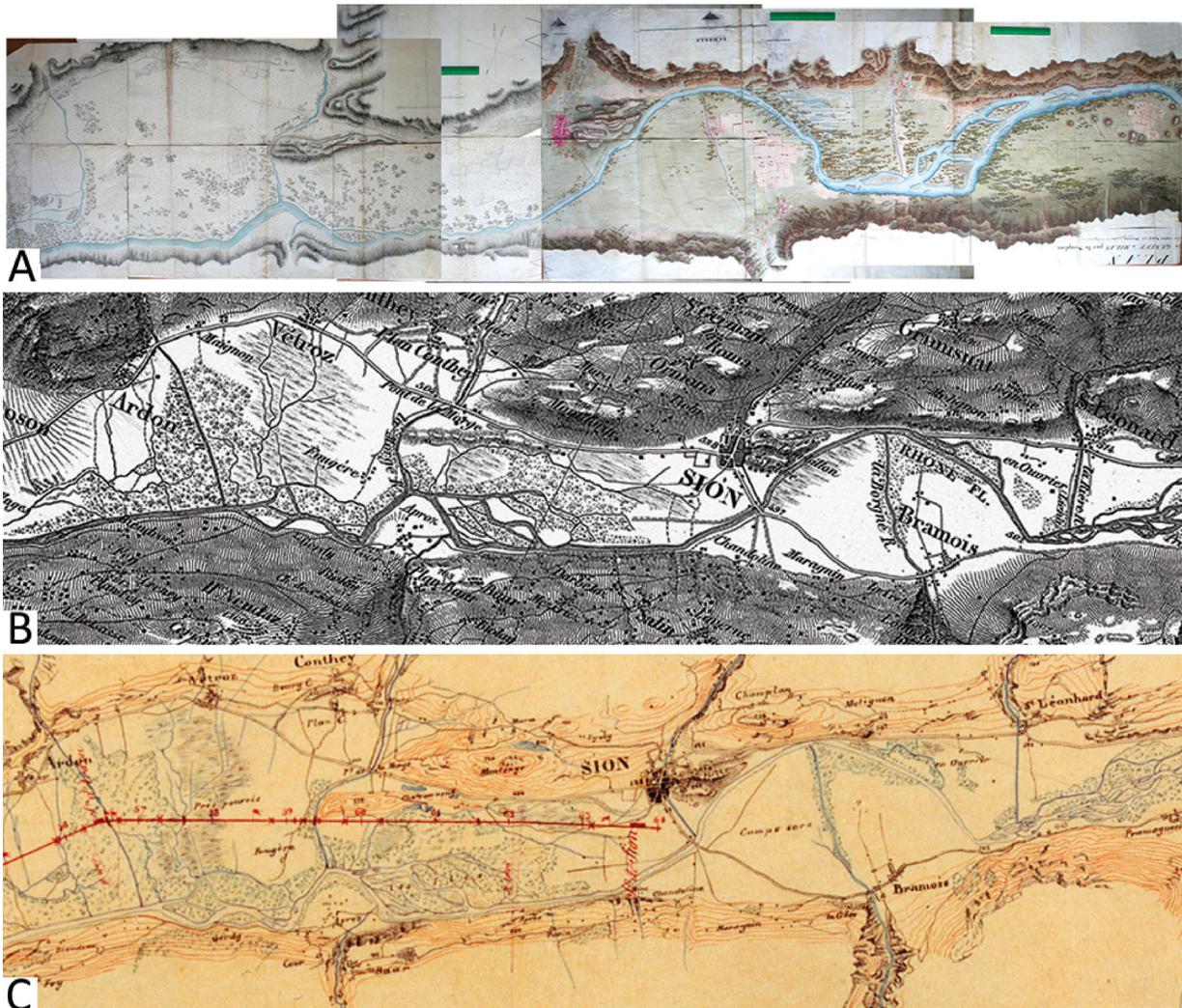


Figure 2. The study area as it is represented in the Napoleonic Plan (A), the Dufour Map (B) and the Railway Map (C). (Courtesy of ©Archives de l'Etat du Valais, AEV and Swisstopo).



Figure 3. 'Plan géométrique de la plaine de Champsec/Sion' digitalised with Agisoft Photoscan (Brandolini & Patrucco, 2019) (Courtesy of ©Archives de l'Etat du Valais, AEV, ABS 99/36). The map is oriented with South at the top of the map.

irrigation system was active, and few channels are still active in the present day. Downstream of the *Pont du Rhône* woodland is common but not homogenous. This woodland fragmentation might be evidence of parallel secondary land-use probably represented by extensive pasturelands. Regarding the hydrographic elements represented in the Napoleonic Map, the Morge River and Lizerne River flowed in the Rhone River following their natural watercourses bordered by forests.

3.2. 1820–1845 (Main Map, Sheet 1/3)

The study of this interval is based on 9 historical maps with the same style and scale, dated between 1823 and 1845 (Table 2). The Rhone River is still partly braided with channel bars and sub-channels. The historical maps of this interval are much more detailed than the Napoleonic Map, so it was possible to reconstruct with more precision the bars features and the braided channels. Moreover, on both sides of the Rhone River dykes and groynes (Figure 4) testify anthropogenic activities on the river in that period. The aim was to manage the fluvial sediments to reclaim waterlogged areas and to rectify the river watercourse. The groynes, indeed, keeping the fluvial sediments, reduced the number of the sub-channels and filled the floodplain wetlands progressively. Very few indications about land-use are available for this time interval, and

historical maps report only woods and meadows along the Rhone River banks.

The *Les Iles* zone represents the most interesting area to understand the river pattern evolution through the nineteenth century (see 'Les Iles detail' box in Multitemporal Maps, Sheets 1/3). Here the place name still indicates the presence of former fluvial bars, depicted in the Napoleonic Map and then represented in the ABS maps with more precision. Furthermore, dykes and groynes seem to have deactivated many sub-channels with the Rhone River fluvial sediments, but the presence of woods only in the centre of the channel-bars suggests that the former braided channels were probably still active occasionally. Therefore, the Rhone River in this period seems to have been characterised by a single-thread sinuous and wandering channel pattern (Fryirs & Brierley, 2018). Moreover, plans to build further dykes and groynes in the area are reported. The historical maps for this time interval report some particulars about the land-use along the Rhone River banks: fields, orchards or meadows are indicated even though the cultivations are unknown. The presence of orchards south of the river in the area between the *Pont du Rhône* and Aproz seems to indicate that the protection by the dykes was sufficient to allow, quite close to the Rhone River, land-uses more sensible to floods than meadows or forests.

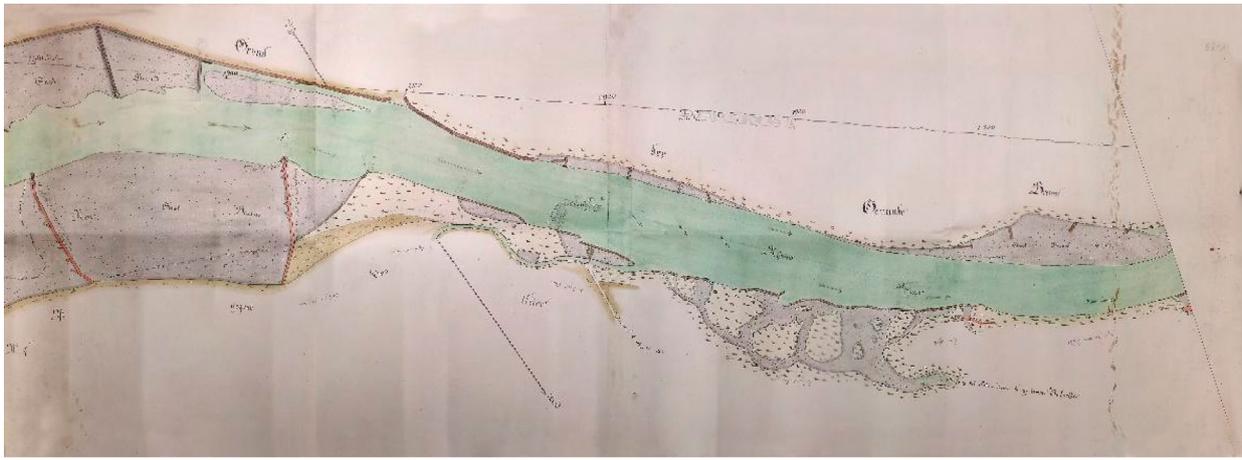


Figure 4. ‘Plan du Rhône entre Bramois et Uvrier’ digitalised with Agisoft Photoscan (Brandolini & Patrucco, 2019). (Courtesy of ©Archives de l’Etat du Valais, AEV, ABS 97/17).

3.3. 1847 and 1850s (Main Map, Sheet 2/3)

Two maps (see Main Map, 2/3) have been considered for this interval: the Dufour Map (Figure 2(B)) and the Railway Map (Figure 2(C)). Both these maps are extremely useful to have a general view of the Rhone River pattern in this period because they cover the whole research area. Besides that, these maps have a too small scale and present no particular details about water management or land-use. The Dufour Map reports woods and wetland areas in *Praz–Pourris* and around *Châteauneuf* and the *Lizerne* River appears rectified and channelised. In the Railway Map, the *Praz – Pourris* wetlands occupy less area than in the Dufour Map and probably depends on the period of the year when the *Plan du Chemin de fer* was made. In both maps, the Rhone River seems characterised by a single-thread sinuous pattern except: (1) upstream the of *Liène* River and between *Aproz* and *Ardon* (braided pattern) (2) in the *Les Iles* area (wandering pattern) (Fryirs & Brierley, 2018).

3.4. 1852–1857 and 1859 – 1860 (Main Map, Sheet 3/3)

The historical maps considered in Main Map Sheet 3/3 show the Rhone River right before the ‘First Correction’ that occurred in the 1860s (Figure 5). Compared with the previous periods, the dykes and groynes system seems to have been developed mainly in *Les Iles* zone (see ‘Les Iles detail’ box in Multitemporal Maps, Sheets 3/3). Fields, orchards, woods are indicated generically and without any particular detail while the Rhone River seems almost completely channelised with only a locally wandering pattern.

4. Discussion and conclusions

This study enabled us to understand the evolution of the Rhone River in the Sion area between the *Liène* and *Lizerne* rivers in the final phases of the LIA. As reported in other portions of the Rhone Valley as in the *Saillon* area (Laigre et al., 2012), at the turn between the eighteenth and nineteenth century the braided

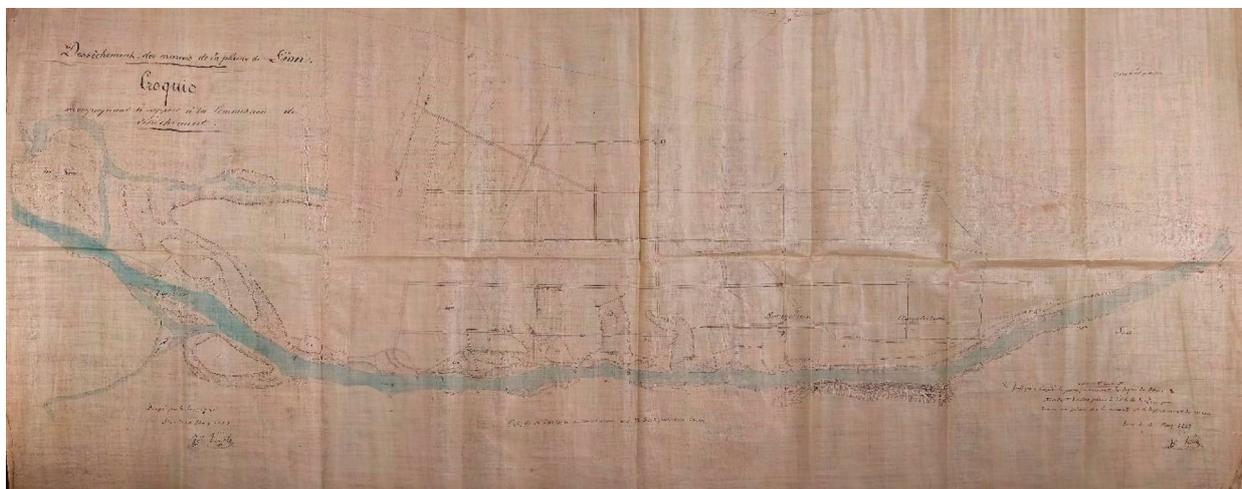


Figure 5. ‘Plan de dessèchement des marais de la plaine de Sion (1857)’ digitalised with Agisoft Photoscan (Brandolini & Patrucco, 2019) (Courtesy of ©Archives de l’Etat du Valais, AEV, ABS 202/11).

pattern of the Rhone River seems to be limited to some specific parts such as the confluence with torrential tributaries such as the Sionne or the Printse rivers, as well as particularly flat portions of the floodplain upstream of large alluvial fans such as the sector situated just upstream of the Borgne river alluvial fan. In the other sectors, the river presents a sinuous natural pattern.

The land-use was interpreted manually, which might have resulted in human-induced errors, but excluded any misclassification problems present in automatic procedures (Leyk et al., 2005). Also, comparison of the land-use based on diverse cartographic sources may be influenced by the differences in definitions and map purposes (Lieskovský et al., 2018) for these reasons all the maps considered in this study have been analysed with the support of local historians.

The instability of the watercourse may explain the large presence of woods downstream of Sion and upstream of the Borgne alluvial fan. Nevertheless, large sectors of the plain are cultivated on alluvial fans, such as the Borgne River fan, and also in the Rhone River plain itself. Swamps have limited extension in the area. All these indices corroborate the conclusion (Évéquoz-Dayen, 2009) that at the turn of the nineteenth century, the Rhone River plain was far from being unexploited and covered with swamps, as described by foreign travellers (Reichler & Ruffieux 1998).

From the end of the eighteenth century, the anthropogenic activities modified the natural evolution of the Rhone River, affecting the fluvial dynamics. First of all, the construction of dykes and groynes had the effect of keeping the fluvial sediments reclaiming flood-prone areas. This process took several decades and right before the first river training project (1860s) *Les Iles* area was still characterised by a wandering channel pattern (Fryirs & Brierley, 2012). Nevertheless, the presence of orchards closed to the main channel of the Rhone River in the 1840s certainly indicates that the impacts of flooding were becoming less important, partly because of the construction of various dykes in the previous years.

The use of the large-scale ABS historical maps gave us the opportunity to highlight new details about the evolution of the Upper Rhone Valley landscape at a local scale and to understand the impact of human-induced changing on the Rhone River. The main learning concerns the fact that quite systematic building of dykes and groynes happened almost 40 years before the first Rhone correction. The objective was to reduce the lateral extension of the Rhone River by building longitudinal dykes and to concentrate flows by the construction of submersible groynes. This technique that has then been used systematically during the general river training since the 1860s, not only had the

objective to concentrate flow but also wanted to provoke artificial sedimentation of the spaces comprised between the dykes and groynes.

To conclude, the information about the land-use change remains limited to few indications about the occurrence of woods, fields, orchards and meadows along the river banks, but no details about the agriculture activities are available. Concerning the fluvial landscape changes, this research highlighted the impact of past flood management on the natural development of the Rhone River. Since the 2000s, local authorities have been proposing sustainable solutions to deal with climate change impacts in the Upper Rhone Basin (Clarvis et al., 2014). Therefore, the ‘Third Correction’ was planned to mitigate flood hazard, e.g. restoring flooding areas on selected stretches upstream of Lake Geneva (Kremer et al., 2015): with this aim the results of the research here proposed might serve as an indication to restore the historical appearance of the Rhone River before the ‘First Correction’. In general, multitemporal maps could represent valuable tools not only to understand the past evolution of a region but also to plan future sustainable landscape management projects.

Software

The ABS historical maps have been digitalised using the software Agisoft PhotoScan 1.4.4. Data processing and map design were performed with open-source GIS QGIS 3.4 Madeira (2018 QGIS Development Team).

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ORCID

Filippo Brandolini  <http://orcid.org/0000-0001-7970-8578>

Emmanuel Reynard  <http://orcid.org/0000-0001-5980-9902>

Manuela Pelfini  <http://orcid.org/0000-0002-3258-1511>

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