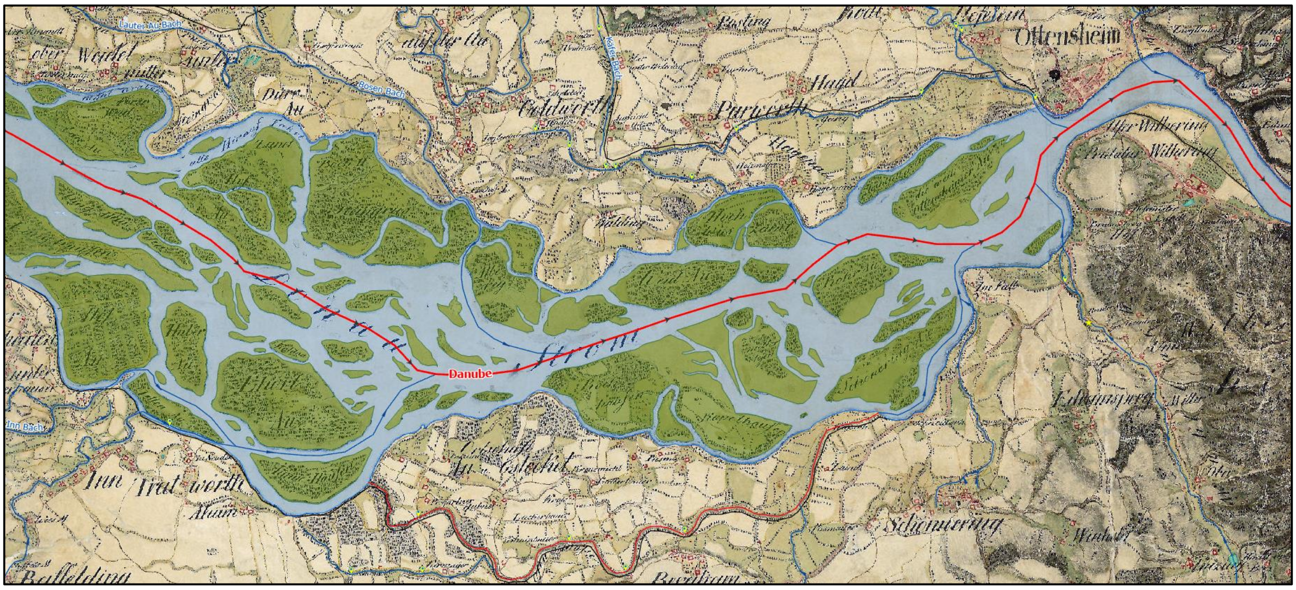

Digitisation of hydrographic features in historical topographic maps

Executive summary

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1. INTRODUCTION

This report describes the activity of identifying and digitising water related data and relevant hydrographic features (*e.g.*: lines of river channels, sand bars, islands, floodplain forest/vegetated area, etc.) from historical topographic maps[1] of Europe. The objective is to develop a **scalable and replicable methodology that can help identify potential restoration sites of floodplains and rivers across Europe** in support of the restoration targets under the EU Biodiversity Strategy for 2030.

The EU's biodiversity strategy for 2030 is a comprehensive, ambitious, and long-term plan to protect nature and reverse the degradation of ecosystems. The strategy aims to put Europe's biodiversity on a path to recovery by 2030 and contains specific actions and commitments [1]. As part of the strategy, the Commission has recently proposed a Nature Restoration Law, which includes as a target **the identification and removal of barriers that prevent the connectivity of surface waters, so that at least 25,000 km of rivers are restored to a free-flowing state by 2030.**

In this context, historical information about previous states of rivers and flood plains becomes very relevant, as it can facilitate river change analysis due to human intervention in rivers and flood plains and facilitate the identification of the location of future restoration activities. To extract this information, previously rasterized and georeferenced **historical topographic maps and surveys** can be used as a basis for describing the configuration of the river environment prior to the construction of man-made features such as dams and barriers or the straightening of its path (*i.e.*: straightened rivers are ecological less valuable, so it is important to be able to identify and measure how much rivers have been straightened).

This report describes the digitisation exercise carried out in three different areas of interest ("pilot areas") in the Danube River basin, as well as the results of a preliminary analysis of the changes and findings when exploring the historical data and performing a comparison between the historical information and the current river and flood plain configuration in the pilot areas.

2. PILOT AREAS AND HISTORICAL MAPS USED

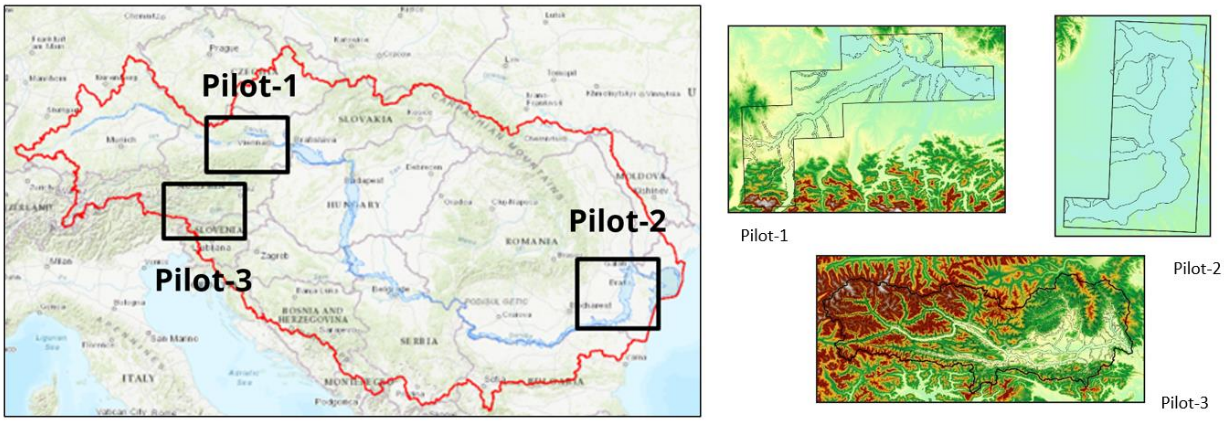
Three areas of interest or pilots were selected within the Danube River basin, see Figure 1. The following table gathers the main characteristics of each of them and the historical maps used. Note that (i) the availability of the legend used and (ii) the accuracy of the historical map covering each pilot were previously assessed in order to ensure an adequate quality of the work. Since all maps corresponded to the Second military survey of the Habsburg Empire (owned by the Austrian State Archive [2] and commercialized by Arcanum [3]), they used the same legend. This legend was available in the Arcanum website [4] [5]. In all cases, the Copernicus Land product Riparian Zones (RZ) layer for the reference year 2018 was used as a mask when digitising [6].

Table 1. Description of the study areas.

Pilot	Location	Area (km^2)	Description	Historical map collections used*	Nº map sheets	Positional accuracy
1	Germany	1,414	From alpine to valley bottom areas	Lower and Upper Austria (1819-1869)	10	Better than 200 meters in most cases [7]
2	Romania	9,245	Mainly valley bottom areas (near the Delta)	Wallachia (1855-1859)	15	
3	Austria (Drava river catchment)	2,325	From alpine to valley bottom areas	Tyrol (1816-1821) Illyria (1829-1835) Styria (1821-1836)	73	

* All of them corresponded to Second military survey of the Habsburg Empire (owned by the Austrian State Archive)

[1] Topographic maps, military surveys at different scales (1:100,000; 1:25,000) from the 19th Century.



Danube River basin extension (in red)

Figure 1. Left: pilots in the Danube River Basin. Right: Pilots in detail, the thin grey line corresponds to RZ mask.

3. HYDROGRAPHIC FEATURE CLASSES

Hydrographic features that could be digitised were defined based on the map legends. The assessment of the map legends was important in order to (i) make sure that hydrographic features were consistently described across maps, and (ii) be able to correctly identify and interpret the different features contained in the maps during the digitisation process. “*Rivers*”, “*Channels*”, “*Islands*”, “*Lakes*”, “*Wetlands*”, “*Floodplains*”, “*Dry ditches*”, “*Bridges*”, “*Watermills*”, “*Riverbanks*”, and “*River source*” features were digitised as polygons, lines and points as necessary. Table 2 describes the hydrographic features defined and detected within each pilot (✓), and their feature classes.

Table 2. Hydrographic features identified in Pilots 1, 2 and 3

	River	Channel	Island	Lake	Wetland	Floodplain	River	Coastline	Channel	Dry Ditch	Bridges	Watermill	Riverbank	RiverSource
	Area	Area	Area	Area	Area	Area	Line	Line	Line	Line	point	point	Area	point
Pilot 1	✓	✓	✓	✓	×	✓	✓	×	✓	×	✓	✓	✓	×
Pilot 2	✓	×	✓	✓	✓	×	✓	×	×	✓	✓	✓	×	×
Pilot 3	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓

4. DIGITISATION METHODOLOGY

The digitisation of the hydrographic features was based on-screen manual digitising process using different historical map collections (see Table 1) available through the Arcanum WMTS[2] server. At this point, its automation was discarded mainly due to (i) the low quality observed over some map sheets, and (ii) the lack of continuity observed when representing one feature, *i.e.*, it was observed that the colour of one feature could vary from one map sheet to another, see Figure 2. Furthermore, prior to the automation of a complex process such as this digitisation, the aim was to demonstrate the potential and applicability of the information generated could have.

[2] Web Map Tile Service (https://www.ogc.org/standards/wmts)

The Copernicus Riparian Zones (RZ) layer was as earlier mentioned, used as a mask when digitising. Overview of the specific data sources, and the number of map sheets used for each pilot is visualized in Table 1.

(i) (ii)

Figure 2. Main issues preventing setting up automated process for digitising: There are huge differences in colours and symbology (i), and it can vary between consecutive sheets (ii).

An ESRI geodatabase (.gdb-format) gathering all the hydrographic features defined in section 3 was created for each pilot. Domains were created when needed, in order to facilitate the digitisation process and to avoid typos *e.g.,* different lake types (natural lake, artificial, oxbow lake and watermill pond). The digitisation scale was set on 1:5,000 to 1:10,000 for Pilots 1 and 3, and 1:5,000 to 1:20,000 for Pilot 2 in order to reach the MMU established.

All in all, the approximately digitisation rates were as follow:

- Pilot 1, not uniform due to (i) learning curve and (ii) different complexity observed among different map sheets. Around 30 hours / 1,000 km^2.
- Pilot 2, uniform due to (i) previously learnt lessons and (ii) homogenous area (area near to the Delta, where the wetlands were highlighted). Around 10 hours /1,000km^2.
- Pilot 3, uniform but more complex than Pilot 2 due to characteristics of the digitised area (heterogeneous). Around 15 hours /1,000km^2.

Figure 3 Shows the changes over time in six tiles. Tile (i) visualizes the historical map. Tile (ii) shows the digitised features in blue, green and yellow corresponding to "*River*", "*Islands*" and "*River banks*" respectively; the transparent red color is the RZ layer delineating the area of interest. Tile (iii) shows the digitised features overlaying the current imagery. Tile (iv) is the current imagery and tile (v) shows the RZ river layer overlaying the current imagery. Tile (vi) shows the significant changes in the area visualized by a cross-comparison where the digitised features and the RZ river layer overlay the current imagery. The light green color shows the 'original' river path. The blue color show areas where the RZ river layer and the digitised river overlaps, and the purple color shows the current river path. Furthermore, tile (vi) shows wetland areas have been converted to built-up areas.

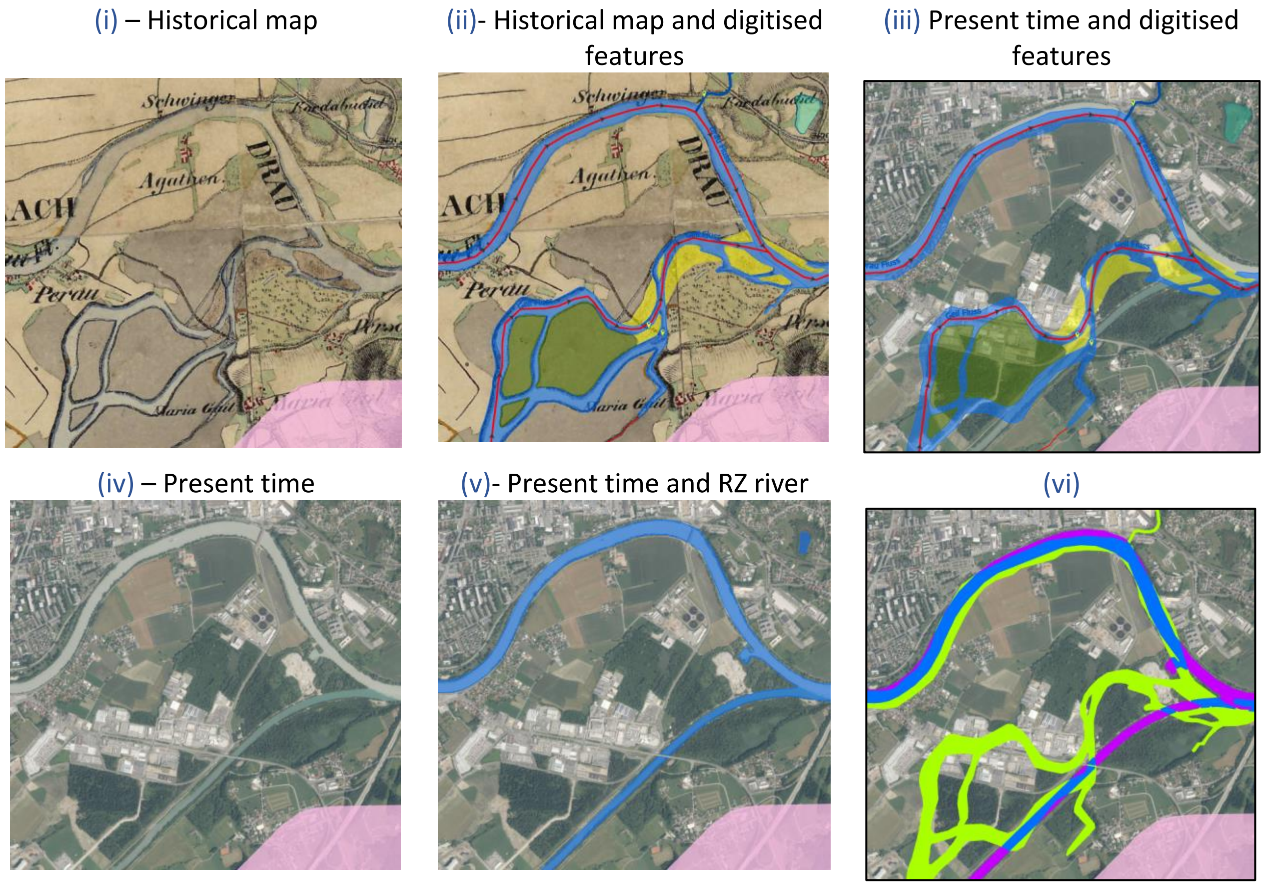


Figure 3. Changes over time. Tile (vi) shows the 'original' river path as green, the blue colours show where the digitised features and the RZ river overlaps, and the purple colour is the current river path.

Map viewers developed to visualize the digitised features:

Pilot 1: https://portal.discomap.eea.europa.eu/arcgis/apps/webappviewer/index.html?id=fc66cb6b4f054344b7ba77e3355ffa8b

Pilot 2: https://portal.discomap.eea.europa.eu/arcgis/apps/webappviewer/index.html?id=a24efd2ad4694e1aa7fba6f10e30e8f9

Pilot 3: https://portal.discomap.eea.europa.eu/arcgis/apps/webappviewer/index.html?id=159f049883564aa2a583af2f6d4c61df

4. RESULTS

As agreed with the EEA thematic experts, the analysis of the digitised river data focuses on extracting relevant statistics on the increase or decrease in water surfaces and in river lengths. Line features were compared with the ones gathered in the Copernicus EU Hydro v012 dataset [8], while the polygon features were compared with Copernicus Riparian Zone (RZ) dataset for reference year 2018 [6].

4.1.1. STRAIGHTENED RIVERS

The lengths of the main rivers digitised (the largest and widest located in the studied areas) were compared with EU Hydro in order to obtain the percentage of change (increase or decrease) presented in Table 3.

Table 3. Change rate (%) of the main rivers for Pilots 1, 2 and 3.

PILOT 1			
River	Digitised (1819-1869) (km)	EU Hydro* (km)	Change rate (%)
Danube	111.59	99.93	**10.45**
Traun	106.10	105.88	**0.20**
Ager	51.65	50.69	**1.86**
Enns	20.24	19.57	**3.34**
Krems	15.26	12.59	**17.54**

PILOT 2			
River	Digitised (1855-1859) (km)	EU Hydro* (km)	Change rate (%)
Danube	363.09	357.27	**1.60**
DanVekie	145.78	136.00	**6.71**
Borcia	147.82	140.77	**4.77**
Ialomitza	115.05	90.76	**21.11**
Siretu	73.04	75.82	**3.82**

PILOT 3			
River	Digitised (1816-1836) (km)	EU Hydro* (km)	Change rate (%)
Drava	248.96	237.39	**4.65**
Gurk	140.67	137.82	**2.03**
Geil	114.22	102.16	**10.55**
Möll	76.56	75.59	**1.27**
Lavant	63.83	56.89	**10.87**
Lieser	27.15	27.22	**0.27**

*Temporal extent: 2006-2012 / Date of publication: Nov, 2019 / Revision date: Nov, 2020

Among the 16 rivers assessed, five presented a length reduction rate exceeding 10%. While analyses conducted over the entire lengths of the rivers did provide some general trends, they were not sufficient to represent the high degree of spatial heterogeneity of observed river alterations. A more in-depth analysis was therefore conducted by splitting rivers into different sections defined on topographical features derived from a DEM [9]. The numbering of sections (1 to 5) in Pilot 1 and 3 is representative of the transition from mountainous areas (upstream) to valley bottom areas (downstream). For Pilot 2, these sections are also ordered from upstream to downstream, all located in a valley bottom area, see Figure 1 and Table 4.

Table 4. Percentage of change of the main rivers of each pilot when analysing by different sections.

Main river	Overall change rate (%)	Change rate (%)				
		Section 1	Section 2	Section 3	Section 4	Section 5
Danube (Pilot 1)	**10.45**	5.43	2.79	9.50	**18.22**	-
Danube (Pilot 2)	**1.60**	2.40	1.62	2.64	0.79	-
Drava (Pilot 3)	**4.65**	4.01	2.57	4.24	**8.06**	2.89

Since the sections of Danube (Pilot 2) are located over a similar type of terrain (valley bottom area), the change rates are also very similar. On the other hand, for the Danube (Pilot 1) and the Drava river (Pilot 3), in general, higher decreases were observed over wider areas located in the valley bottom areas or downstream, where reduction rates greatly exceeded the average reduction rates computed for the whole river length (indicated in bold).

4.1.2. CHANGES IN WATER SURFACES

In order to analyse the changes in water surfaces, (*i.e.,* “*Rivers*”, “*Lakes*” and “*Wetlands*”), a comparison with the relevant RZ layers, and the rate of change (increase or decrease) was estimated, see Table 5.

Table 5. Statistics of the reduction observed for each hydrographic feature.

	PILOT 1			PILOT 2			PILOT 3		
	Digitised (km^2)	RZ* (km^2)	Change rate (%)	Digitised (km^2)	RZ* (km^2)	Change rate (%)	Digitised (km^2)	RZ* (km^2)	Change rate (%)
River	135.39	79.92	**40.97**	637.10	546.82	**14.17**	56.84	47.26	**16.85**
Lake	65.01	77.25	**18.83**	547.99	194.84	**64.44**	60.20	67.40	**11.96**
Wetland	-	0.96	-	3,369.59	123.44	**96.33**	15.89	6.80	**57.21**

*Temporal extent: 2017-2018 / Date of publication: Dec, 2021 / Revision date: Dec, 2021

A general reduction in water surfaces was observed. Lakes in Pilots 1 and 3 were an exception as their surfaces increased between 10-20%. This increase could be related to the building of dams and the retreat of glaciers, which created new lakes.

In Pilot 2, the extent of wetlands decreased by 96% and the surfaces occupied by lakes decreased by (64.44%). These numbers are consistent with previously published work [10], estimating that since 1900, 64% of the wetlands on our planet have disappeared victims of urban, agricultural and industrial development, overexploitation of water resources, pollution and the construction of dams.

River surfaces have suffered a less pronounced reduction (from 14 to 17%) in Pilots 2 and 3, and 41% in Pilot 1. Part of these reductions could be attributed to river straightening and also to the loss of lateral branches, see Figure 4.

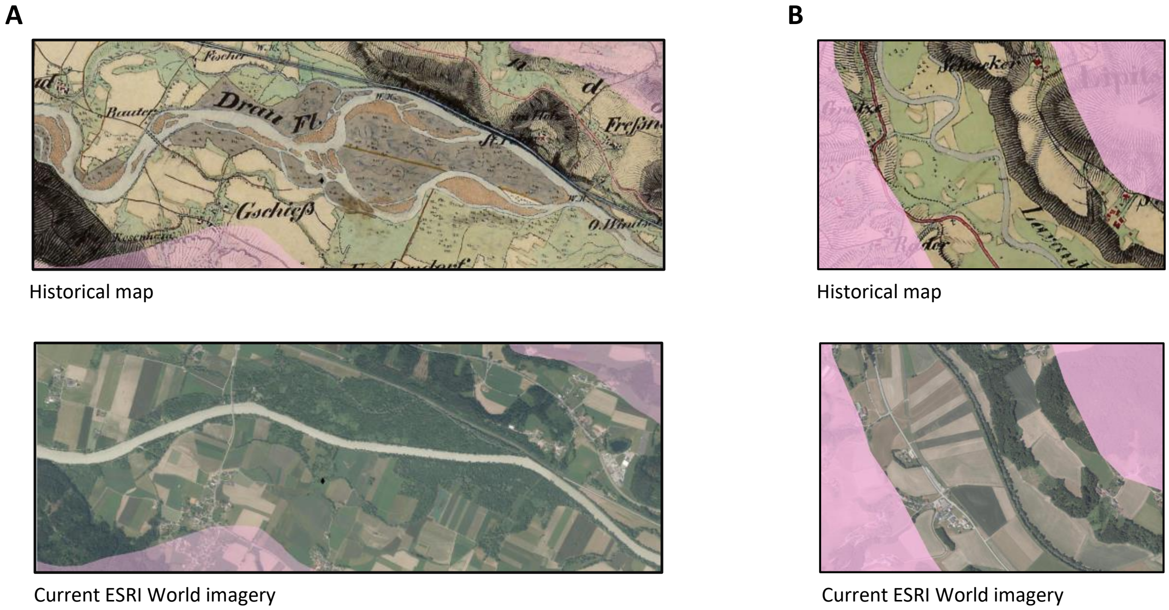


Figure 4. Examples of straightened rivers and loss of the lateral connectivity.

Finally, although the river banks do not contain water, they turned out to be an interesting feature, in particular in fluvial geography, as this information could be used to identify the potential future risk for flooding areas. Its changes over time appear to be related to dam construction, glacial retreat, and/or human impacts such as the railway construction and agricultural development.

It is obvious that the construction of dams affects surrounding areas, so, it was found interesting to take them into account when developing this study. In this work, two dam geolocation data sources were used, AMBER [11] and GRanD [12], and the first one turned out to be the most complete.

5. CONCLUSIONS

Historical maps are valuable data sources and are probably the closest one can ever get to the original path of rivers and wetland areas. The historical maps can be used to learn about previous configurations of river and flood plains. This information can be compared with the current state, facilitating the extraction of useful indicators of change and the identification of potential locations for restoration.

Important conclusions following the analysis and digitising of hydrographic features from the historical maps performed in this study are:

- This type of maps contains very detailed information, having a huge potential for extracting data with relevant environmental value, especially in the context of nature restoration.
- The accuracy of the historical maps is good enough for the purpose of this study (better than 200 meters in most cases).
- The complexity and quality of the different historical map sheets is however variable, which has an impact on the digitalisation process. The complexity depends on the type of landforms presented in the

area covered by the map, *e.g.,* presence of single versus branched rivers, mountainous versus valley bottom areas, etc. while the quality refers to how well the map is preserved. The greater the landscape complexity was, the longer the digitisation procedure took. Digitisation was also slower for maps that were less well preserved.

- The digitisation rate depended on the characteristics of the digitised area. In general, digitisation is a time-consuming process.

In terms of the results of the analysis, and although the positional errors of the historical maps themselves may have over- or underestimated the results in absolute terms, **the study clearly reveals the large number of changes that have occurred on hydrographic features over time. These areas could correspond to areas of interest where measures could be taken within the context of nature restoration activities under the Biodiversity Strategy 2030.**

In all cases, the main changes correspond to the straightening of rivers, also coupled with the loss of lateral connectivity and the reduction of water surfaces.

When estimating the change rate (%) of the straightened rivers, an analysis conducted by splitting rivers into different sections is suggested in order to represent the high degree of spatial heterogeneity of observed river alterations. The **largest reductions were generally observed over wider areas located in the valley bottom areas or downstream**. Splitting rivers into different sections is also recommended when developing hydrographic studies on the constructions of dams and the potential effects on surrounding areas.

In areas that have been drained for agricultural use, the reduction observed for wetlands and lakes is very significant, *e.g.*, in the case of an area near the Danube Delta, reductions up to 96% and 64% respectively were observed.

The riverbanks information could be used to identify potential future risk for flooding areas. They are of particular interest in fluvial geography, which studies the processes associated with rivers and streams and the deposits and landforms created by them.

The **Riparian Zones layer proved to be very valuable as a mask when digitising**. Although slight differences were observed when comparing with the Potential Flood Prone layer, it was observed that the historical river surfaces are better covered by the RZ layer and in particular branched rivers.

Proposals for potential future steps to bring the project further:

- It would be interesting to design a **process that could automatically identify areas of interest** from the point of view of the Biodiversity Strategy (*i.e.,* areas where lateral connectivity has been lost).
- In case it was feasible to easily identify these AOIs, the next step could be to research if it is possible to **automatically extract (within the AOI) those hydrographic features** that are considered the most interesting ones (*i.e.,* rivers, riverbanks, lakes, wetlands).
- As last consideration, we identified that historical maps also contained information regarding **glaciers**. This information could be used to assess their retreat. Its study was out of the scope of this project, but it could be assessed in the future.

[1] https://ec.europa.eu/environment/strategy/biodiversity-strategy-2030_en
[2] https://www.statearchives.gv.at/
[3] https://www.arcanum.com/en/
[4] https://www.arcanum.com/media/uploads/mapire/legend/secondsurvey1.pdf
[5] https://www.arcanum.com/media/uploads/mapire/legend/secondsurvey2.pdf
[6] https://land.copernicus.eu/local/riparian-zones/riparian-zones-2018
[7] Timár, Gábor & Biszak, Sándor & Székely, Balázs & Molnár, Gábor. (2011). Digitized Maps of the Habsburg Military Surveys – Overview of the Project of ARCANUM Ltd. (Hungary). DOI: 10.1007/978-3-642-12733-5_14.
[8] https://land.copernicus.eu/imagery-in-situ/eu-hydro/eu-hydro-river-network-database
[9] https://www.eea.europa.eu/data-and-maps/data/eu-dem
[10] https://www.wwf.es/nuestro_trabajo/agua/humedales/
[11] https://portal.amber.international/ or https://www.eea.europa.eu/data-and-maps/data/external/the-amber-barrier-atlas
[12] https://globaldamwatch.org/grand/