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The more dikes the higher the floods: Vienna and its Danube floods, c. 1700 to 1918

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Contents

Abstract

Vienna, residence of Holy Roman emperors in early modern times and capital of the Austrian and later the Austro-Hungarian monarchy until the end of WW I, has been threatened by Danube floods for centuries. Early plans for flood protection elaborated by Venice's famous "cosmographer" Vincenzo Coronelli date back to 1717. Unfortunately, his and other early plans were unfeasible mainly due to technical constraints. Gaining control over Danube floods in Vienna would have meant controlling a powerful alpine river with a highly fluctuating discharge and sediment regime.

From 1768 onwards, the frequency and intensity of floods significantly increased, probably due to climate change, volcanic eruptions and land use changes in the Danube basin. This resulted in frequent inundations of Vienna's suburbs, which had already spread out onto the floodplain. Starting in the 1770s, an 18-km-long levee system was constructed; it was partly

destroyed already in 1787 by a disastrous spate. Contemporaries discussed whether the new hydraulic structures had reduced the flow capacity and thus even worsened the disaster.

The 19th century continuously brought new and higher dikes to protect the fast-growing metropolis. Every new dike reduced the flood retention area and heightened the flood stage. Viennese had kicked off a risk spiral. After a severe ice jam flood in 1862, new plans for a radical solution became concrete. To solve the problem once and for all, the whole Viennese Danube section was channelized between 1870 and 1875. This total control of the river turned out to be illusion.

1. Introduction

Among larger medieval cities of Europe, Vienna stands out as situated along a swiftly flowing alpine river rather than being near a river mouth or on the coast. Alluvial rivers such as the Viennese Danube can show unpredictable floods and channel changes, and humans inhabiting the river corridor must repeatedly cope with alterations of their physical environment. This was specifically the case in the late 18th century, when the Viennese were confronted with a grave danger: the Danube's flood activity intensified both in frequency and severity. At that time Vienna, the stable residence of the Holy Roman Empire due to the Habsburgs holding the crown, had already began to expand over the floodplain close to the historical city center. Vienna was becoming ever more prominent, being home to and hosting important authorities.

Vienna's historical city center, the former Roman legionary camp Vindobona, was created in the first century CE at the margins of the floodplain on a Pleistocene terrace above the river. Only few, lower-lying areas of the city were affected by severe Danube floods, but infrequently. In the early 14th century, first settlements were founded on the more stable islands near the city center. No major urban expansion into the fluvial landscape was considered until 1683, when the second siege by Ottoman troops failed and the constant military threat by the other Danubian superpower ceased. Since the late 17th century the Danube floodplain gained a new role as an important land resource for the growing capital (Haidvogl et al., in press). Nonetheless, channel changes and increasing flood activity of the Danube severely affected the further development of the city. Numerous ice jams and summer floods not only inundated the settlements in the floodplain but also damaged the bridges and roads crossing the Danube almost every year.

In this paper we reconstruct how the Viennese coped with the increasing threats posed by Danube floods over 200 years. We show how changing societal strategies for flood protection reduced risks in some cases, but also led to new, amplified floods in Vienna.

We focus on the long-term legacies of past human interventions and ask how hydraulic and technical measures in the past influenced and continue to affect the urban development and the morphology of the city even up to the present. The paper is based on the GIS reconstruction of the Danube river landscape at 11 points in time between 1529 and 2010 that was conducted in the framework of the research project ENVIEDAN (Winiwarter et al., in press; Hohensinner et al., in press a, in press b).[1] The research presented in this paper is the outcome of a joint effort of an interdisciplinary research team comprising environmental historians and river morphologists. The history of rivers, floods and droughts is a hybrid: it is the common history of nature and society, it is a socio-natural history. Accordingly, this kind of historical research requires both bodies of expertise, that of natural scientists and that of historians.

2. The Viennese Danube

For a sound understanding of the challenges that the Viennese had to face, we must first take a closer look at the Danube itself. Around 1700, the Viennese Danube and its floodplain were by no means pristine anymore; this landscape already featured human influences, above all the local use of riparian forests and probably also large-scale land use changes in the upper catchment. Though Vienna is situated more than 900 km downstream from the Danube's sources in southern Germany, the river still shows a mountainous character with a highly variable flow regime, frequent floods and almost annual ice jams (Liepolt, 1965). For the Viennese Danube section in particular, the regime of the major alpine tributaries Inn, Traun and Enns is essential. Prior to systematic regulation in the 19th century, the Viennese Danube must be referred to as an "anabranched river" (according to Nanson & Knighton, 1996). Such a river system does not behave like a single river channel that can be easily trained; in fact it acts like several rivers in a common floodplain. Most of the time, one or two sinuous main arms existed that were split by large gravel bars and smaller islands (Hohensinner et al., 2008). Moreover, numerous side arms were typical; they could develop courses that were largely independent from the other arms. Separated by large vegetated islands, they featured a straight, braided, sinuous or even meandering course (Figure 2). One of those side arms was the Donaukanal (in historical times called the "Wiener Arm", Viennese branch). This may have been a former main arm until the high Middle Ages. It was an essential transport route at least from late medieval times through the whole early modern period and until the 19th century. It formed the lifeline of the city on which material and energy (wood) was brought to the city on water. The floodplain between the arms consisted of different zones showing distinct morphological dynamics.

[1] FWF project "Environmental history of the Viennese Danube 1500-1890: Understanding long-term dynamics, patterns and side-effects of colonization of rivers", FWF grant no. P 22.265-G18

More stable islands close to the city center were used for early colonization. A good share of the river landscape, however, was characterized by smaller and larger, more or less dynamic islands. Historical sources indicate that the Danube repeatedly developed distinct river bends or even meander loops towards south to the historical city. When the sinuosity of the river bend exceeded a certain threshold inherent to the river type, the Danube cut off the bend and formed a new, straighter channel further north, which then once again started to shift towards the city. In Vienna, the Danube needed 100-130 years for such a single river bend/meander life-time cycle (Hohensinner et al., in press b). Form a long-term perspective, covering centuries or even millennia, it becomes clear that the Vienna's relationship to its highly dynamic Danube was a walk on a thin line. The city needed a nearby river for navigation, as part of its fortification system, as a source of kinetic energy in ship mills, and for the provision of a protein-rich diet based on fish. At the same time, a river too close to the city was a barrier for urban expansion and a permanent threat because of floods. For centuries, urban society tried to balance this dilemma, working hard to manipulate the flow of water and sediment of this powerful river. Up to the late 19th century, however, humans mainly dealt with and reacted to the river's own morphological dynamics and to the unintended effects of their own, earlier interventions.

Vienna was threatened by the Danube's floods probably from the very beginning of its existence – in particular the rather young (i.e. late medieval) settlements on the floodplain in front of the city walls. Summer floods after heavy rainfalls and thaw floods in spring were not the greatest challenge. The greatest threats came in winter, when ice jam floods frequently severely damaged the populated areas of Vienna. Smaller flood events inundated the low-lying floodplain areas almost annually. Higher floods as well as severe catastrophic floods inundated the floodplain settlements several meters high every few years. Sometimes, two or more catastrophic floods occurred within a single year (Bergenstamm, 1812; HZB, 1908). Floods caused by ice jams in winter were a typical phenomenon along the Viennese Danube: the numerous branches of the river favored the formation of such jams (Pasetti, 1859; HZB, 1908). Moreover, floods from smaller tributaries like the river Vienna ("Wienfluss"), Ottakringerbach and Alserbach – all three located close to the city center – could cause severe damage. In some cases, after heavy rainfalls, floods brought by the Danube coincided with those of the tributaries, leading to widespread inundations even on the higher terrace of the historical city.

Nevertheless, despite such numerous threats the Danube also provided valuable resources that promoted the city's economic growth: timber from the riparian woods, fish from different types of water bodies and habitats, pastures in the floodplain and, finally, the attractive possibilities of water-borne transportation along the river.

3. Struggling with the floods

3.1 The long way to the first flood protection measures

Geomorphologic investigations into Vienna's ground shed light on early flood events that affected Vienna's urban development in premodern, medieval and even ancient Roman times: In the third century CE a large part of the Roman settlement on the Pleistocene terrace was eroded by the river during one or several major floods (Gietl et al., 2004; Grupe & Jawecki, 2004). Since then, all subsequently constructed fortifications and the spatial expansion of the city had been constrained by that eroded bank until the city wall was removed around 1860.

The oldest archival sources for floods in Vienna from 1012 CE onwards are found in the monastery Klosterneuburg, a few kilometres upstream from Vienna (Bergenstamm, 1812). Our analysis of historically documented floods shows that a first phase of significantly amplified flood activity can be identified in the 1560s and 1570s (Figure 1). This period coincides with the onset of the so-called "Grindelwald Fluctuation", the first extreme phase of the Little Ice Age (LIA) between the 1560s and 1620s (Pfister, 1980, 2007; Behringer, 1999). At that time, however, all available financial and material resources were spent on river engineering measures aimed at preventing further channel changes that severely impacted Vienna's economic growth (Hohensinner et al., in press b). Between the 1580s and around 1700, the flood regime of the Danube apparently fluctuated on a lower level (Figure 1). Towards the end of the "Maunder Minimum" (1645-1715; Eddy, 1976), our data point to a first increase in the flood activity of the Viennese Danube. The increasing threats by floods probably gave rise to the first plans for systematic flood protection measures developed by Vicenzo Coronelli in 1717.[2] Until then, flood protection was primarily based on passive practices, but in some specific places also on the erection of local flood levees. Flooding was considered to be a regular component of the riverscape, and the practices aimed at adapting the spatial location of buildings to the inundation risk and at mitigating the negative impacts (Haidvogl et al., in press). Coronelli, the famous Venetian "cosmographer"[3], worked out an ambitious plan not only for a large-scale flood protection scheme that for the first time included the rapidly prospering suburb Leopoldstadt, but also for training the Danube in order to secure the vital waterway on the Viennese branch (Donaukanal) to the city (Mohilla &

[2] Maps: "Il Danubio Moderato Dalle Proposta segnate di Rosso del Padre Coronelli.", V.M. Coronelli, 1717, British Library, London, Sloane MS 3603 ff.; "Il Danubio moderato: dalle proposte segnate di Rosso", V.M. Coronelli, 1717, reproduction, Austrian National Library, KS K I 99.900; "Mali del Danubio: proposte per Rimediarli", V.M. Coronelli, 1717, reproduction, Austrian National Library, KS K I 99.899; report of the regulation plans: "Rifflessioni del P. Coronelli Sopra il Danubio", 1717, Wiener Stadtbibliothek, Handschriftensammlung, Jb 55 748, I.N. 4879, and British Library, London, Sloane MS 3603 ff.

[3] For Coronelli and his role in the emerging European network of hydraulic experts around 1700 see: Appuhn (2006), i.p. 91-92.

Michlmayr, 1996).[4] These plans were probably initiated by Emperor Charles VI, who requested his imperial authorities to elaborate a comprehensive proposal to solve the unsatisfactory situation in 1717 (Thiel, 1906). However, the ambitious plans were unfeasible, mainly due to the high costs and technical constraints. Gaining control over Danube floods in Vienna would have meant controlling a powerful alpine river with a highly fluctuating discharge and sediment regime.

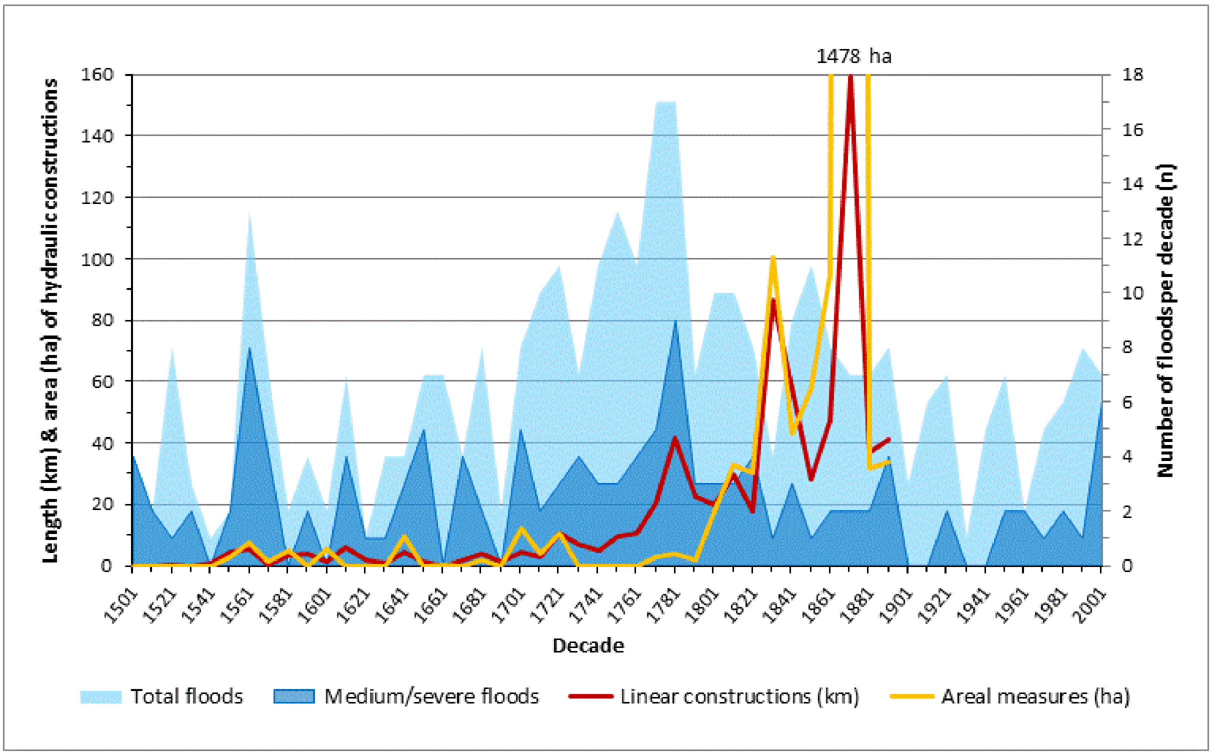

Figure 1: Historically documented linear hydraulic constructions (km/decade), areal river engineering measures (ha/decade) and number of floods per decade (light blue: total documented floods, dark blue: medium and severe floods). The values for the hydraulic constructions do not include measures at the Viennese Danube tributaries (so far no data are available for the 20th century; modified according to Hohensinner et al., in press b).

The major problem in the discussion of appropriate river management strategies was that several interests vital for the city and for the various stakeholders opposed each other (Thiel, 1906).[5] A systematic flood protection scheme would have been technically and financially feasible if the Viennese branch (Donaukanal) would have been cut off from the main Danube arm (compare Figures 3-6). This rather small side arm, however, was the essential supply

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[4] As a basis for the planning, around 1715, Coronelli conducted the first detailed and geographically coherent survey of a longer Danube section at Vienna ("Mappa Des Donau Stroms Sambt denen von selben ausgehenden Armen Und darinen befindlichen Häuffen wie auch der Tiefen des Stroms Und von zeit zu zeit in selben Gemachten beschlächten und Geführten Canal Sambt denen angränzenden Orthen und ...", Joseph Haas reproduced the map in 1752, a copy of the reproduction from 1862 can be found in the archive of the monastery Klosterneuburg, SP 404).

[5] According to a contemporary comment made by Hofbaurat Ignaz Edler v. Mitis in 1846, the history of Vienna's river management was that of an "ununterbrochenen, offenen und versteckten Kampfes der verschiedenen Interessen" (continuous, forthright and hidden conflict of different interests; in: Thiel, 1906).

line to provision the city and dispose waste water (Gierlinger et al., in press). As the efforts to improve the flood protection with a longer dike system were unsuccessful, new proposals aimed at lowering the highest flood levels by cut-offs instead of levees (Mohilla & Michlmayr, 1996). In 1760, Ritter v. Spal(l)art created a new regulation plan for the Viennese Danube that should mitigate the ongoing threats by floods and improve navigation on the Danube and the Donaukanal (Thiel, 1906). Amongst several smaller measures, his plan envisaged excavating a huge cut-off channel between two major river arms to improve the Danube’s flow capacity during floods (compare Figure 2).[6] In the following years, only some smaller measures proposed by Spal(l)art, mostly repairs of existing hydraulic constructions, were carried out. No comprehensive river engineering project could be initiated before the end of the Seven Year’s War, in which Austria was involved between 1756 and 1763 (Thiel, 1906). In the meantime, Viennese had to face increasing threats by Danube floods. The suburbs in the floodplain were hit by major spates every two to three years, which not only affected Vienna’s economy but also urban sanitary conditions.

Figure 2: Regulation plan designed by Ritter v. Spal(l)art in 1760; the proposed cut-off channel between two major river arms to improve the Danube’s flood conveyance is depicted in the middle of the plan (see footnote 6).

[6] Map “Carte Topographique d'une partie des environs de la Ville de Vienne et du Cours du Danube devant cette ville avec ce qu'on y propose pour le fixer et empecher ses variation Continuelles.“ and manuscript “Mémoire sur les visites et observations du cours du Danube devant la ville de Vienne, tel qu'il se trouvoit pendant le mois d'Octobre 1760 que les eaux ont été basses et une récapitulation des ouvrages qu'on croit convenables dans les différentes branches du Danube pour y fixer le cours des eaux et pour arreter leus variations continuelles par R. Spalart.“, Ritter v. Spal(l)art, 1760, Austrian State Archives, Haus- Hof- u. Staatsarchiv, Handschriften, Weiß 713, Böhm. Katalog, Fol. 69a, Kodex 397; manuscript: Sign. U/II/1/4.

In 1767, the hydraulic engineer Fremaut from Trieste, was called to Vienna in order to elaborate a new regulation plan. As soon as the preparation for the costly project (650 000 Gulden) was completed, Empress Maria Theresia perceived the necessary expenses as too high and commissioned several advisors of the court to reassess the project. After heavy disputes between the involved experts and after Fremaut had died in 1768, a new hydraulic expert, the Hungarian engineer Johann Sigismund Hubert, was entrusted with revising Fremaut's regulation plan. Hubert produced an adapted regulation program for the Danube and the Donaukanal one year later in 1769.[7] His regulation program proposed the construction of a several-kilometres-long dike system upstream from Vienna at the northern bank in order to protect the villages in the northern Marchfeld plain (based on Fremaut's original plan). The Danube should be straightened and laterally constrained by hydraulic structures and the navigability of the Donaukanal improved by several smaller regulation measures. Hubert's proposal provoked new disputes amongst the called experts of the court's commission (Thiel, 1906). Finally, the commission decided first to test the effectiveness of some of the proposed measures on a smaller scale in the following years. The problems of the Danube remained unsolved. Even worse, they dramatically amplified in the following years.

3.2 Race against the floods

While disputes raged about the different regulation plans, the frequency and intensity of floods once again severely increased from the late 1760s onwards. Between 1768 and 1789, a total of 36 floods were documented, 7 of these being very severe (Figure 1; Hohensinner et al., in press b). The increased fluvial activity most probably reflected the climate change towards the end of the Little Ice Age in combination with large-scale land use change in the drainage basin and volcanic eruptions in Iceland in 1783/84. The latter promoted the adverse weather conditions in Western and Central Europe (Bork et al., 1998; Vasold, 2004; Pfister & Brazdil, 2006). Flooding culminated in 1786, when several very severe floods occurred, and finally in 1787 with the probably second highest flood within the last 500 years, the so-called "Allerheiligengieß" on 1st of November (Pasetti et al., 1850; HZB, 1908). The dramatic culmination of the inundations, together with ongoing channel shifting towards the suburb Leopoldstadt and an island named Brigittenau close to the city, called for urgent hydraulic measures.

[7] "Plan von dem Lauff der Donau von Tuttenhoff bis an die große Brücken worauf die zum Regulirungs-Systeme erforderliche Däme und Sporren mit rather farbe angemerkt sind.", J.S. Hubert, 1769, Austrian States Archives, Hofkammerarchiv, F 3/1; "Plan über den Lauff der Donau von Kloster Neuburg bis in dem Bratter.", J.S. Hubert, 1769, depicted by E. d'Irigoyen, Austrian State Archives, Hofkammerarchiv, F 329

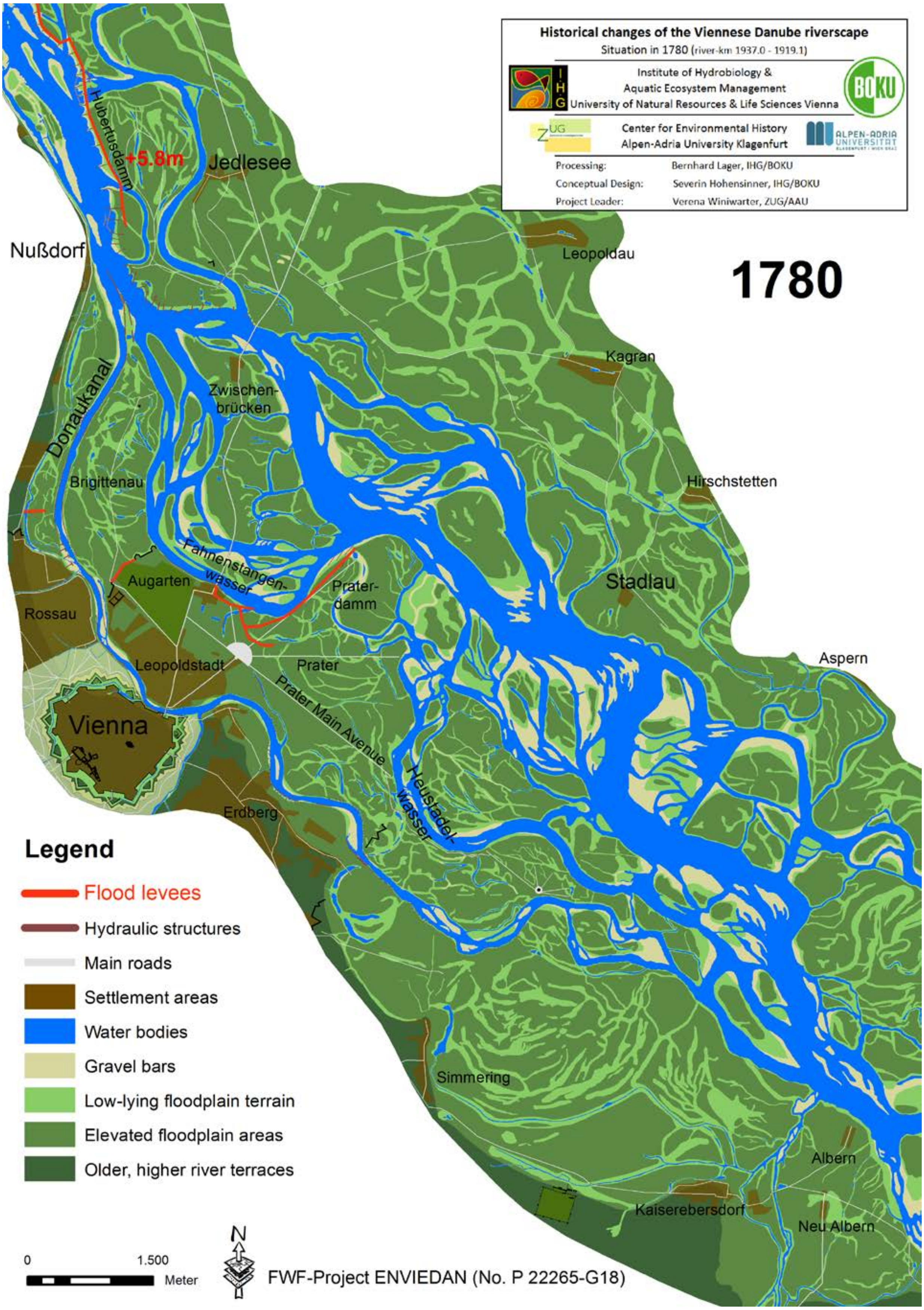

Figure 3: Viennese Danube river landscape in 1780 (red lines: flood protection dikes; red number in the figure: height of the dike in relation to the zero point of gauge/approximately mean annual low water level).

Despite a lengthier dispute between the newly established imperial “Navigationsdirection” and other administrative institutions about the project design, Empress Maria Theresia finally entrusted Hubert with the construction of the first systematic levee system in 1776/77 (Thiel, 1906). As part of a larger protection scheme, it was designed to protect Vienna from floods and to improve navigability upstream of the capital. The late absolutistic state had discovered that its rivers improved economy and trade and created a common territory.

The “Navigationsdirection” established in the 1770s under Maria Theresia was responsible for improving navigability along the whole then Austrian Danube section from Bavaria to Zemun (today a suburb of the Serbian capital Belgrade) and of the Danube’s major tributaries, in particular in Hungary and on the Balkans. In Vienna, an almost 7-km-long levee system (later called “Hubertusdamm”) was largely erected along the northern river bank from Langenzersdorf to opposite Nußdorf by 1784; final modifications of the dikes lasted until 1786 (Figure 3).

The height of the dike, which was 5.8 m above zero point of gauge/approx. mean annual low water level, was designed to cope with then largest Danube floods. At the same time, along the Danube branch “Fahnenstangenwasser”, another 1200-m-long dike (known as Leopoldstädter Damm) was constructed to protect Leopoldstadt; this dike was extended by 1700 m into the Prater in 1780/81 (named Praterdamm; Figures 3-4). Additional levees were set up in the early 1780s to protect the new “Augarten Park” in Leopoldstadt and some parks and gardens along the Donaukanal. But luck was not on Vienna’s side with these large-scale projects: The Hubertusdamm was partly destroyed soon after completion by the catastrophic “Allerheiligengießˮ in 1787, prompting a public discussion in which Emperor Joseph II was personally involved. The issue was whether the new dikes might have even increased the flood risk (Thiel, 1906). The Viennese argued that Hubert’s constructions (in modern terms) constrained the flow capacity at higher floods, potentially artificially elevating the water levels. The dike was not rebuilt until 1849, more than 50 years later.

After the “Allerheiligengieß”, due to the continuing threats of floods, dike construction concentrated at areas closer to the historical center. Additional several-kilometres-long levees, 5 m above zero point of gauge high, were constructed along the Fahnenstangenwasser in the Brigittenau. By 1793, all urban areas adjacent to the Fahnenstangenwasser were protected by dikes (Figure 4). The flood threat posed by the Donaukanal remained, however. The increasing efforts of the Viennese to counteract the tremendous floods are reflected in Figure 1. It shows a significant boost of the linear hydraulic constructions (dikes, spur dikes, embankments, guiding walls, etc.) going hand in hand with the flood peak in the 1780s. The work load then gradually decreased up until 1800.

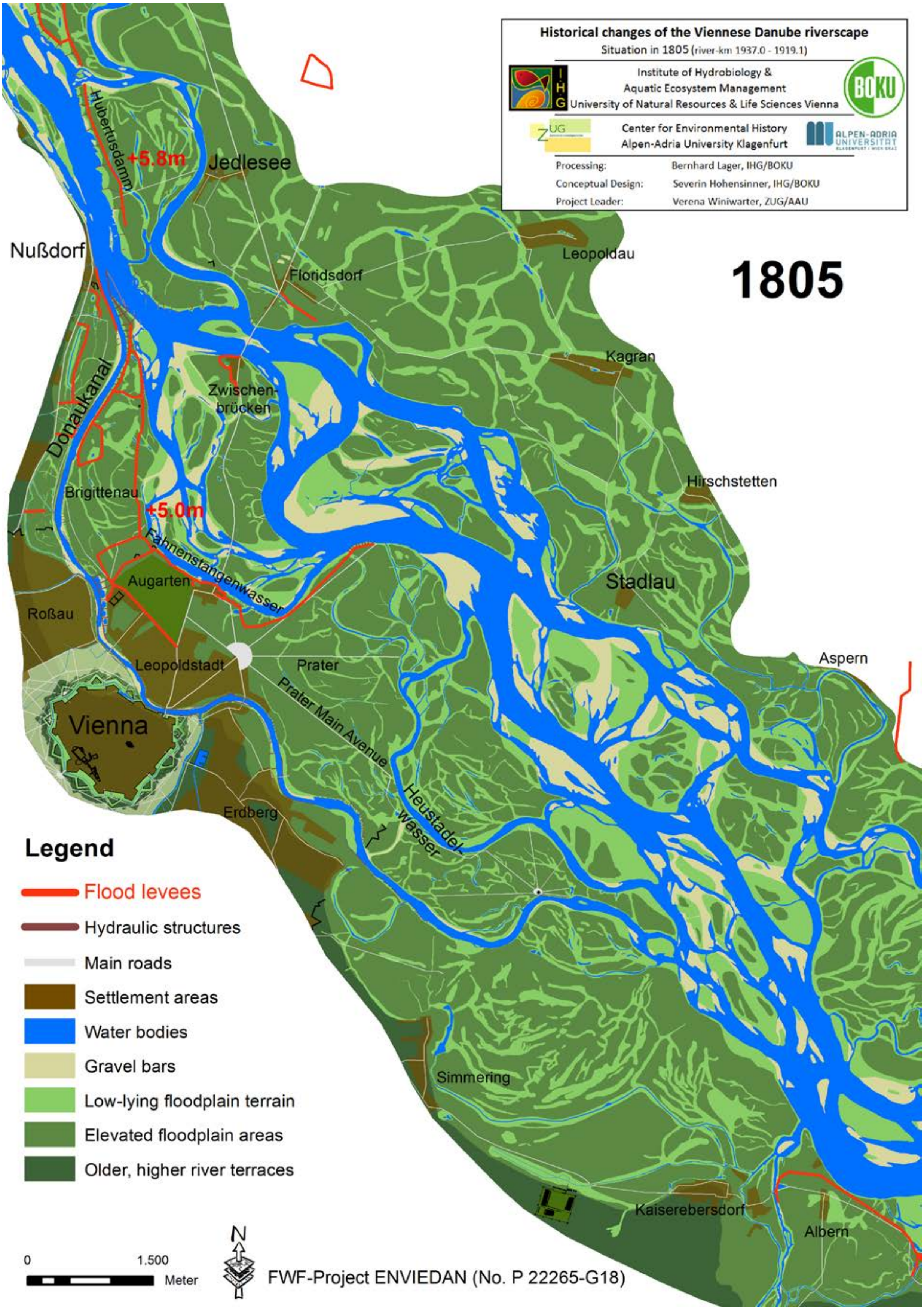

Figure 4: Viennese Danube river landscape in 1805 (red lines: flood protection dikes; red numbers in the figure: height of the dikes in relation to the zero point of gauge/approximately mean annual low water level).

3.3 The more dikes the higher the floods

Though the Danube's flood activity receded after 1789, flood frequency remained high in the early 19th century compared to the period prior to 1700 (Figure 1). The Viennese authorities were aware of the unsatisfactory situation with the annually inundated roads through the floodplain. They therefore concentrated on improving the transport infrastructure crossing the still highly dynamic fluvial landscape. Between 1805 and 1817 several important roads connecting the imperial capital with the northern provinces were upgraded and transformed to causeways in order to elevate them above the mean annual flood level. Simultaneously different local communities constructed several smaller dike systems (Figure 5). While the latter had only little influence on the floods, the causeways in particular even heightened the flood threat. Causeways almost perpendicular to the flow direction of the Danube constrained the flood conveyance of the river, and those located along the northern river banks severely truncated the flood retention capacity of the riverscape. Both together contributed to the threat of floods, which was additionally exacerbated by other hydraulic constructions at the bifurcation of the Donaukanal and the main arm near the village Nußdorf upstream of the capital.

As in previous centuries, the navigability of the Donaukanal was still severely affected by ongoing siltation processes. For navigation, Viennese needed water in this side arm. Since late medieval times, river engineering concentrated on this task. With the water, however, came the sediment, and the Donaukanal silted up, making it an obstacle for navigation. In order to prevent further siltation, several guiding walls were constructed in the Danube at Nußdorf between 1816 and 1825 (Figure 5). The goal was to direct as much water as possible from the Danube into the Donaukanal. Both guiding walls constricted the flow profile of the Danube to only 150 m and led to a human-caused uplift of the Danube's water level (Wex, 1876).

A new era in Vienna's urban history started in 1830, when a catastrophic flood caused by a massive ice jam overtopped almost all levees and inundated most urban areas within the floodplain (Wex, 1876). A cholera epidemic in the same year made the situation even more dramatic. A new regulation program was tackled. Between 1831 and 1833 the existing dikes were fortified and heightened to 6.3 m above zero point of gauge, and new dikes with the same height were constructed in Nußdorf and north of the Danube near Floridsdorf. Because some areas close to the city center were repeatedly inundated due to ice jams in the downstream section of the Donaukanal, in 1832/33 a cut-off canal 2500 m long was excavated at the Donaukanal's confluence with the Danube to reduce the danger of ice jam floods (Pasetti, 1859; Figure 6).

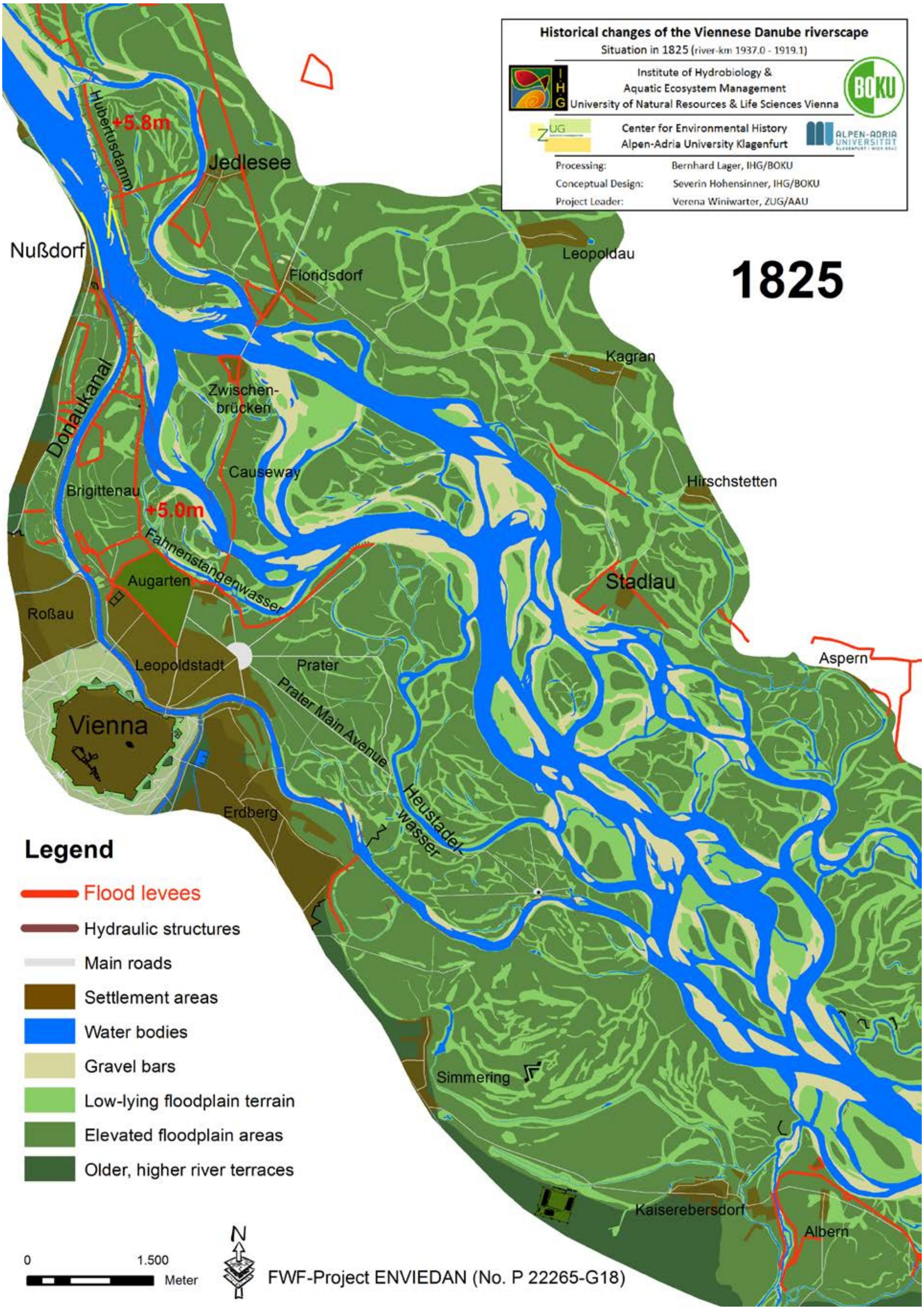

Figure 5: Viennese Danube river landscape in 1825 (red lines: flood protection dikes; red numbers in the figure: height of the dikes in relation to the zero point of gauge/approximately mean annual low water level; yellow structures in the Danube near Nußdorf: guiding walls constructed 1816-1825).

The centrally planned systematic protection measures were accompanied by numerous smaller dikes constructed by local communities. By 1849, a network of such piecemeal dikes existed in the floodplain north of the Danube. The increased river engineering measures after the 1830 flood are clearly illustrated by the significant peak of both the linear hydraulic constructions and the areal constructions (cut-offs, channel fillings, terrestrialization measures, etc.) in Figure 1.

The comprehensive efforts seem to have mitigated the flood threat for only a few years. A new problem arose when the first (Northern) railway was constructed in 1837/38. In Vienna the era of the railway started directly in the middle of a still highly dynamic riverine landscape. In order to prevent the railway lines from being flooded, they were constructed on a 7.6-m-high dike that crossed the whole riverscape (Pasetti, 1859; Figure 6). This dike was 1.3 m higher than those already in place to protect the suburbs. The flood in 1843 showed that the new railway dikes significantly affected the flood conveyance of the Danube and increased the probability of floods in the suburbs. Not only was the new key transport technology of the 19th century, the railway, still affected by river morphology, but in Vienna it also had an effect on the river and its behavior. With the dense network of new infrastructures for the fast-growing metropolises of 19th century Europe, the relationship between the city and the river became even more complex. The new transport infrastructures in the fluvial landscape even increased Vienna's vulnerability to the river.

Further works to mitigate that problem involved constructing a new dike upstream of that of the railway in order to protect Brigittenau and Leopoldstadt in 1848 (Brigittenauer Ergänzungsdamm). This dike had to be further heightened to 7.6 m above zero point of gauge between 1851 and 1854 in order to reach the same height as the directly downstream dike of the Northern Railway (Höften, 1856; Pasetti, 1859). Nonetheless, this dike could not solve the underlying problem caused by the causeway and the railway traversing the floodplain: the floods in 1849 and 1850 revealed that both constricted the Danube's flow during floods and artificially heightened water levels. As a solution, in each of the two obstacles, two culverts – each 38 m wide – were installed in 1850 to improve the flood conveyance (Pasetti et al., 1850).

Between 1848 and 1850, numerous other hydraulic measures were conducted in the course of the so-called "Notstandsbauten", a work program for the needy Viennese workforce designed to prevent further social turmoil (Thiel, 1906). In fact, these "Erdarbeiter" ("earthworkers") from the "Prater" were among the first that started violent protests in the spring of 1848, the year that brought a series of bloody conflicts and an atmosphere of anarchy not only to the Austrian but several European capitals. In autumn the Viennese revolution was violently suppressed and a neo-absolutistic political regime was established.

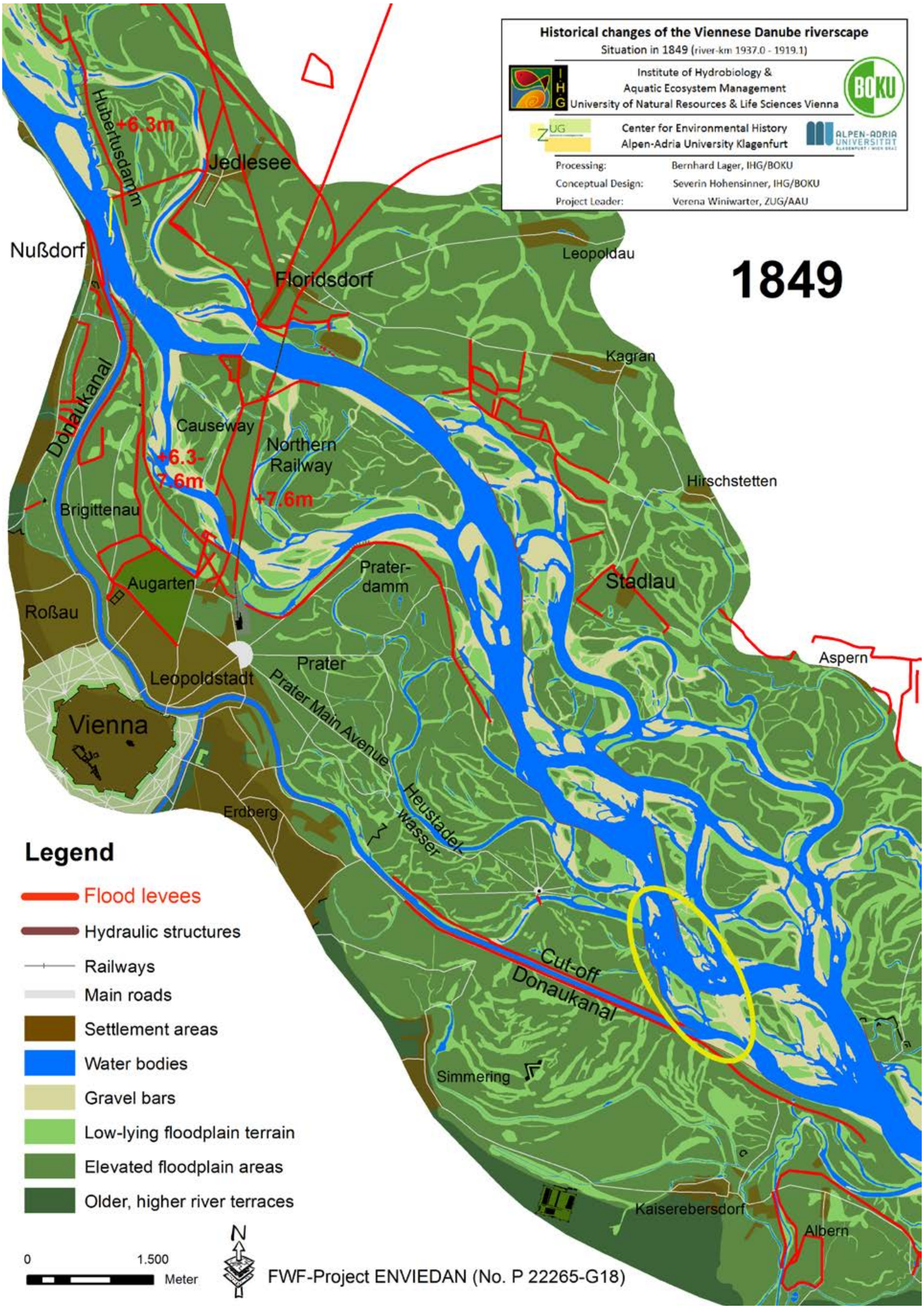

Figure 6: Viennese Danube river landscape in 1849 (red lines: flood protection dikes; red numbers in the figure: height of the dikes in relation to the zero point of gauge; yellow: location of the main river arm that was deflected to the outflow of the Donaukanal in 1849/50, later harbor Freudenau; modified according to Hohensinner et al., in press b).

This episode of 1848 is remarkable in its political context and in its consequences for river engineering projects in the first phase of the industrial revolution. Political authorities attempted to contain social upheavals with projects to manipulate water (this is, of course, a much longer and not only an Austrian story). In Vienna in 1848, however, such projects concentrated the hopeless and the poor in the urban space. Precisely this spatial concentration laid the ground for the outbreak of violent conflicts.

A major project in that period focused once more on the outflow of the Donaukanal. The newly excavated bed of the lower Donaukanal (1832/33) did not mitigate inundations in the city because sediment accretion directly downstream from the outflow of the Donaukanal in the Danube fostered the formation of ice jams. Therefore the main arm of the Danube was deflected to the outflow of the Donaukanal in 1849/50. The idea was to erode the aggraded material to prevent future ice jams at that location (Pasetti, 1859). Except for the lengthening of the Praterdamm, no further major measures were executed. Instead, the existing hydraulic structures were repaired, fortified and partly heightened. A case in point is the Hubertusdamm upstream from Vienna, which was inoperable since the “Allerheiligengieß” in 1787.

Despite the comprehensive efforts at improving Vienna’s flood protection, a general problem became increasingly apparent: all the measures were carried out in a piecemeal manner, without an underlying master plan. As soon as a dike segment was reconstructed and fortified, new troubles arose at other locations during the subsequent floods. Moreover, the various unsystematic hydraulic constructions in the river bed and in the floodplain even worsened the flood threats. According to calculations of Ritter v. Wex, the construction supervisor of the Viennese Danube regulation program from 1870-1875, the various hydraulic structures led to an additional human-caused heightening of the water level by 1.3 m (Wex, 1876). A major problem was that Vienna’s waterscape did not behave like one river, but rather as several rivers, each potentially showing a more or less independent flood regime. For example, the suburbs Leopoldstadt and Brigittenau were protected against inundations involving the main river arm in the northeast. However, an ice jam in the Donaukanal could provoke a severe flood in the southwest and thus inundate large areas of the suburbs. Floods of the larger tributaries Wienfluss and Ottakringerbach could additionally cause severe inundations independently from the Danube. Generally, dikes are constructed to prevent inundations from one side only. A flood coming from the other side can cause unintended effects. In such cases, dikes can even exacerbate the inundation, thereby preventing water from leaving the area behind the dike. Such problems became apparent during the floods in 1849 and 1850, when the Viennese authorities and local residents were forced to break away short sections of some dikes to enable a run-off (Pasetti et al., 1850; Donau-Regulirungs-Commission, 1868).

After the extreme ice jam flood in 1862, which once again inundated large areas of Vienna, new plans for an all-embracing Danube regulation program were discussed.

3.4 The radical transformation of the riverscape

The discussion of an all-embracing regulation program to solve all the Danube-related threats once and for all started in the early 1820s, a few years after the Congress of Vienna (1814-1815) had drawn a new political map of Europe in the aftermath of the Napoleonic Wars. The protracted discussion of the 1820s failed to produce a feasible regulation plan. In 1850, another attempt was made to solve the ongoing Danube question: a "Danube Regulation Commission" was established and charged with elaborating comprehensive planning principles and evaluating the different regulation options. The further expansion of the city had by that time become conceivable, forcing planning to take this into account (Pasetti et al., 1850; Donau-Regulirungs-Commission, 1868). In fact, Vienna's population grew by a factor of ten during the 19th century, from about 250 000 in 1800 to more than 2 million around 1910. This demographic explosion was not unique to Vienna among European capitals, but in Vienna the urban crisis could only be solved spatially by better controlling the dynamics of the Danube. Nevertheless, it took another 20 years until a final regulation project could be tackled. Between 1870 and 1875, large parts of the Viennese riverscape were transformed into new areas ready for urban expansion.

The Danube's main arm was straightened in order to prevent future ice jams. For this purpose, two cut-offs (6.6 km and 2.8 km long) were excavated (Donau-Regulierungs-Commission, 1898). Parallel to the new bed, a low-lying 470-m-wide inundation area was excavated to improve the flow capacity during floods. New flood protection levees at both sides of the new Danube between 5.7 and 6.3 m high (Inundationsdamm or Marchfeld-Schutzdamm) were constructed to spare the whole city from inundations once and for all. The material from the excavated cut-offs was used to fill up most of the former side arms (compare Figures 6 and 7). Large parts of today's districts of Brigittenau and Kaisermühlen were later erected on this material. During the excavation works, about 163 000 m^3 of older hydraulic structures, thousands of wooden piles and 18 400 running meters of sills and ties were removed (Lederer, 1876; Prokesch, 1876). The removal of the old hydraulic structures and the excavation of the new bed lowered the Danube's water level by ca. 1.3 m (Wex, 1876). This work was carried out by a thousand workers under miserable conditions and by fossil-fuel-driven machines brought to Vienna by French companies from the freshly completed Suez Canal. After this effort was largely terminated in 1875, the Viennese thought that the centuries-old threats of Danube floods had been finally solved.

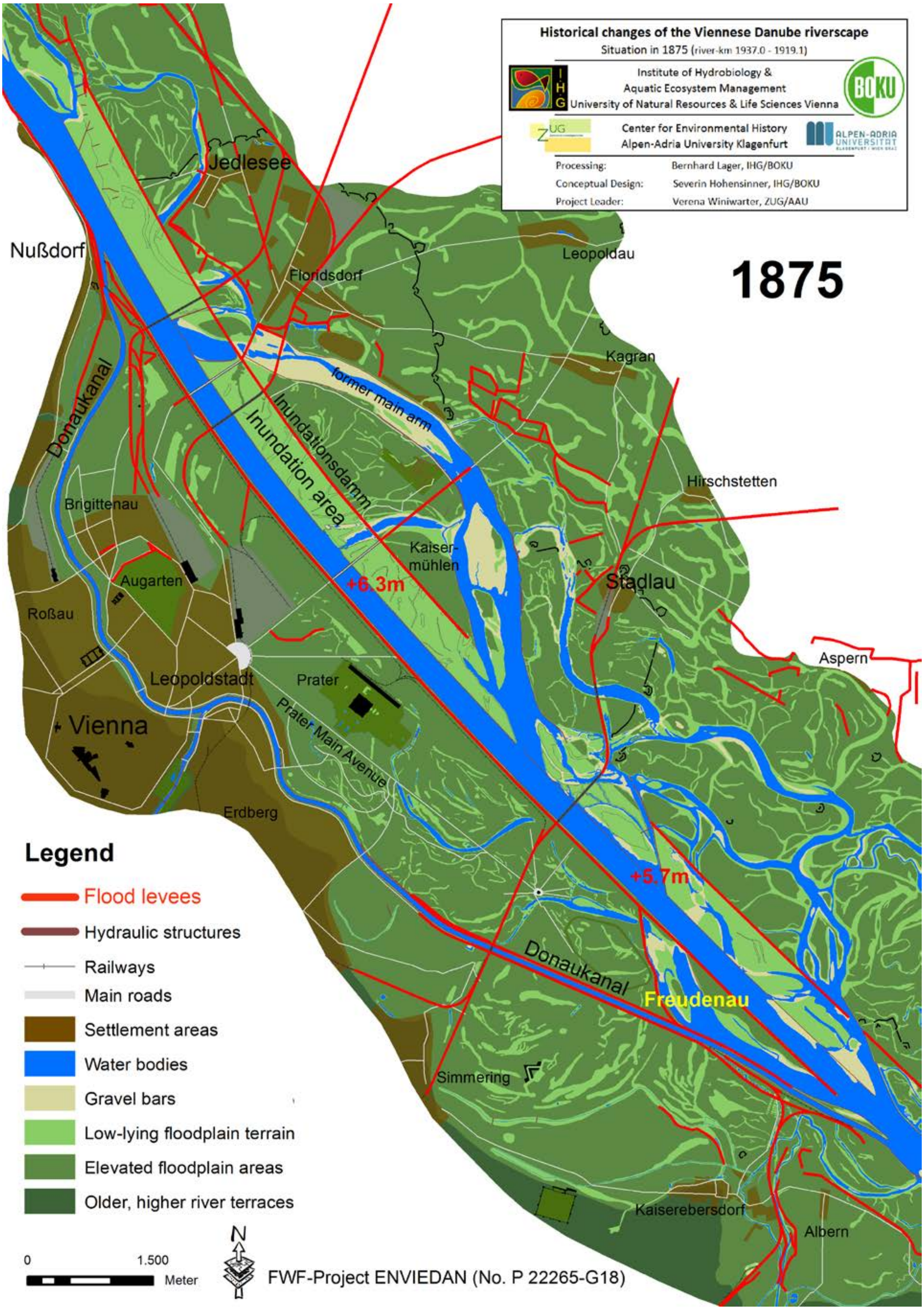

Figure 7: Viennese Danube river landscape in 1875. The reconstruction shows the transformation from the former piecemeal flood protection scheme to the new systematic dike system (red lines: flood levees; yellow: location of the former main arm that was deflected to the outflow of the Donaukanal in 1849/50, later harbor Freudenau; modified according to Hohensinner et al., in press b).

Several years later, however, it became clear that even this radical rearrangement of the fluvial landscape had not solved all problems. The dikes were apparently too low for very large floods. In the following decades, further improvement measures were undertaken. These included partially heightening the dikes and constructing a new weir at the new inflow of the Donaukanal between 1894 and 1899 (Thiel, 1906). The 30-years-flood in 1897 and in particular the 100-years-flood in 1899 showed that additional efforts had to be made to ultimately protect the city (Waldvogel, 1910/11). Up until 1908, certain sections of the flood levees were once again repaired and heightened.

After the fall of the Habsburg Monarchy in 1918, which left Vienna as the oversized capital of the small first Republic of Austria, the maintenance of the city's flood protection facilities remained a major concern. Between 1933 and 1935, some sections of the Inundationsdamm/Marchfeld-Schutzdamm had to be once again be fortified and heightened (Baumann, 1951). After World War II, a new 21-km-long flood bypass called "Neue Donau" was created within the inundation area that was excavated between 1870 and 1875. In more recent years, dikes were heightened, and flood protection gates for harbors and the outflow of the Donaukanal were constructed (Figure 8). Today, uncertainty remains as to whether these measures will be sufficient to protect Vienna under future, altered climatic conditions. There is never an end to regulation.

4. Conclusions

Studied from an interdisciplinary perspective combining natural sciences and history, the case of Vienna and the Danube shows that the centuries-long efforts to mitigate floods locally without considering implications on a larger scale always had unintended and unwanted consequences. All the endeavors could not mitigate the continuing threats: the Viennese had triggered a risk spiral that could not be stopped (Müller-Herold & Sieferle, 1997). This insight still holds true today for various human interventions in fluvial systems.

The systematic transformation of the Viennese riverscape to urban areas was finally accomplished by the great Danube regulation program 1870-1875. The comprehensive river engineering measures in the 19th century established the future development potential of Vienna for centuries.

One illustrative example is today's harbor Freudenau at the eastern outskirts of Vienna (compare Figures 6-8). The location and the spatial extension of this still important facility is a result of the deflection of the main Danube arm towards the outflow of the Donaukanal in 1849/50. This required erecting massive guiding walls in the river bed (see subchapter 3.3). That guiding wall was not removed, nor was the Danube bed originating from 1849/50 filled in during the Danube regulation in the 1870s.

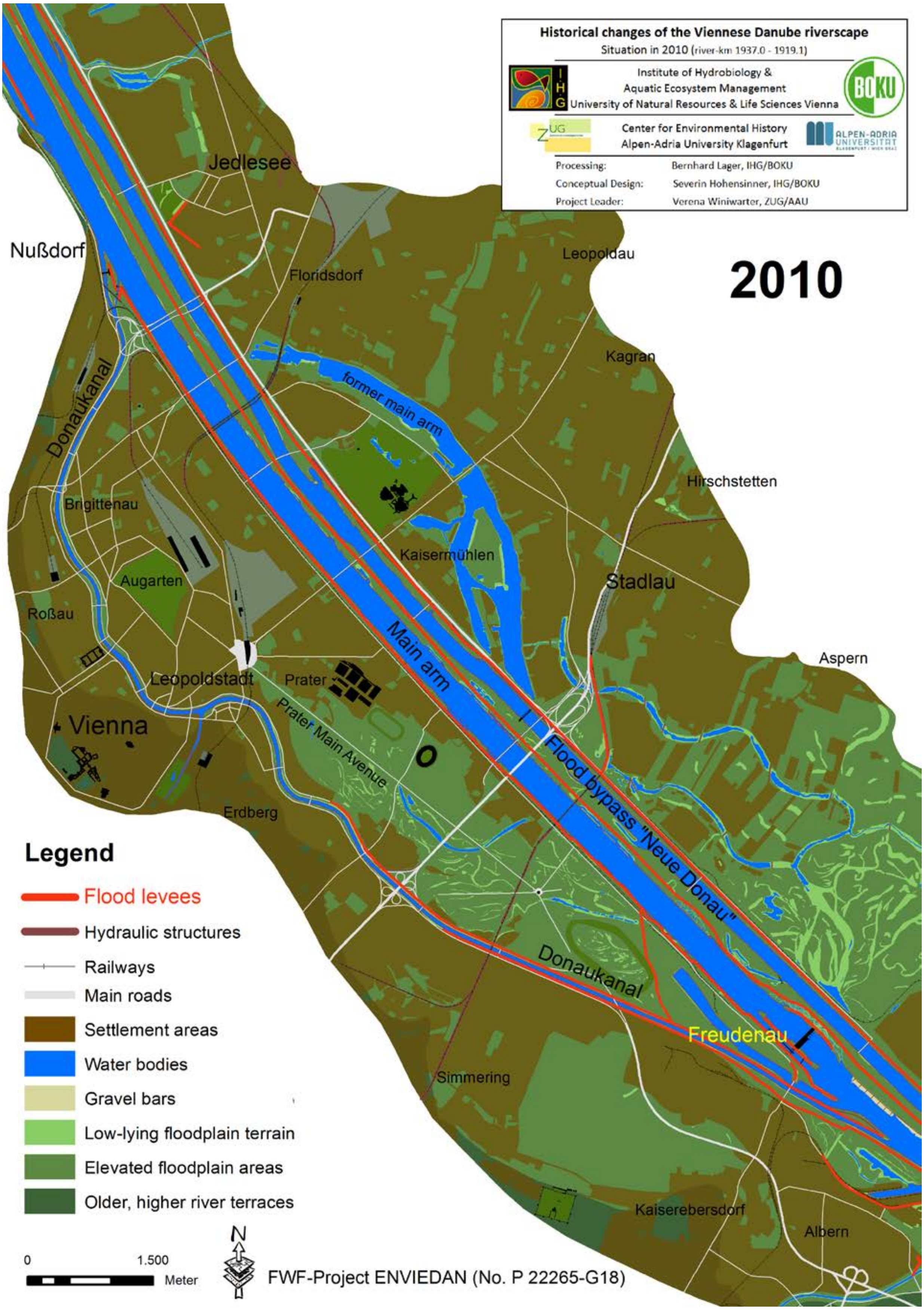

Figure 8: Viennese Danube river landscape in 2010 (red lines: flood protection dikes; yellow: harbor Freudenau).

The decision was to use those structures for a new harbor, which was finally constructed between 1899 and 1902 (Donau-Regulierungs-Kommission, 1902). The harbor was integrated into the city's transport infrastructure by new railways and roads. During subsequent decades the harbor gained importance due to several trading companies and additional urban infrastructure in its environs. Today, the harbor Freudenau is the largest port on the Danube in eastern Austria, and its diverse logistical capabilities and capacities continue to be enlarged. Flood protection of this port was improved with a new, massive gate (Hafentor) only in 2010.

Although flood protection practices changed again in the late 20th century, the arrangements from the period of promoterism still have to be maintained and adapted by cities all over the industrialized world. The fluvial arrangements we have inherited from our ancestors determine our present scope of options when dealing with rivers and their floods.

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